SCIENCE AND SOCIETY

Protecting crop genetic diversity for food security: political, ethical and technical challenges

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Abstract | Crop genetic diversity — which is crucial for feeding humanity, for the environment and for sustainable development — is being lost at an alarming rate. Given the enormous interdependence of countries and generations on this genetic diversity, this loss raises critical socio-economic, ethical and political questions. The recent ratification of a binding international treaty, and the development of powerful new technologies to conserve and use resources more effectively, have raised expectations that must now be fulfilled.

Hunger and malnutrition are the everyday reality for more than 800 million people, and 15 million people, mostly children, die as a consequence each year. With the world population expected to reach 8.3 billion by 2030, the Earth will have to feed an extra 2 billion people, of whom 90% will live in developing countries[1]. It is therefore crucial to ensure not only that enough food can be produced reliably to feed this expanding population, but also that it is accessible to all.

Food production and security depend on the wise use and conservation of agricultural biodiversity and genetic resources. Crops and their wild relatives comprise what I refer here to as plant genetic resources for food and agriculture (PGRFA) — the genetic variability that provides the raw material for breeding new crop varieties, through classical breeding and biotechnological techniques, in response to environmental and demographic changes. However, many of these genetic resources are currently under-used or at risk.

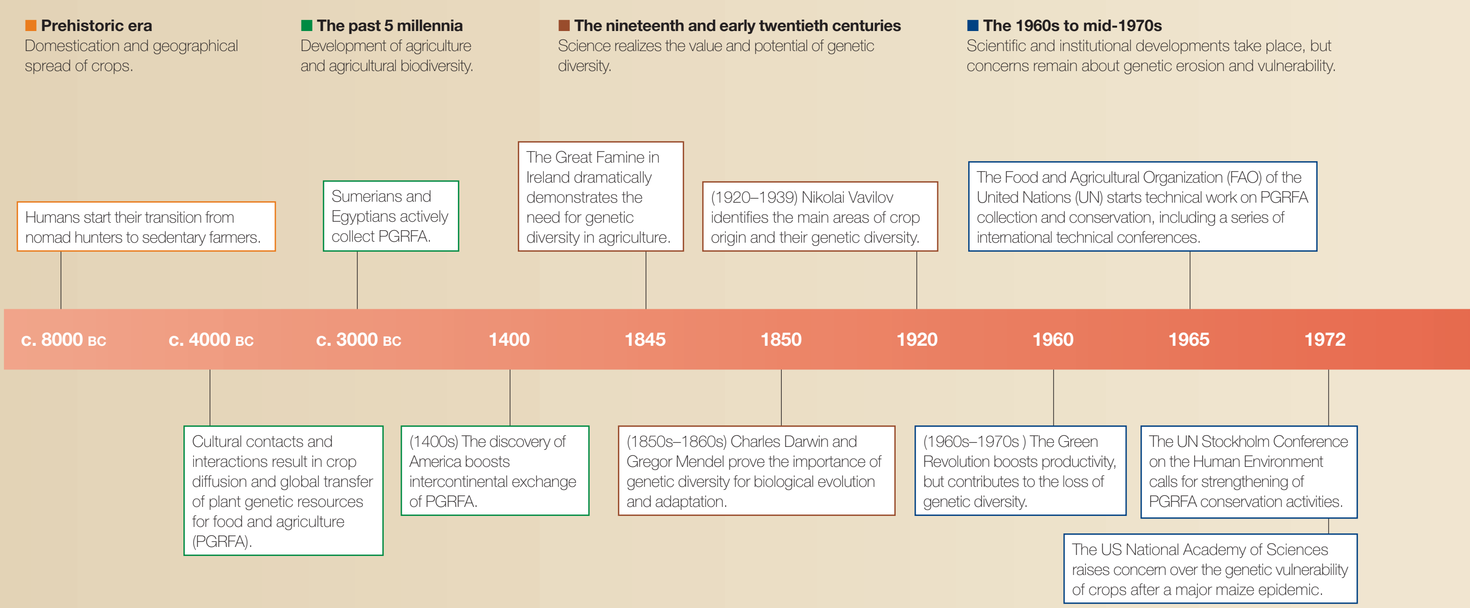
The protection of PGRFA is not just a technical and scientific challenge; the management, use and exchange of these resources are imbued with socio-economic, legal, political and ethical implications. As most countries are reliant on genetic resources from elsewhere, it is essential that the international community develops fair rules to ensure management, access and benefit-sharing.

Here I describe the origin and diversification of crop genetic resources, their loss in modern times and the risks that this raises. I then analyse the actions that are needed to conserve crop genetic diversity, identifying important political, socio-economic and ethical issues. This is followed by a discussion of what has been achieved so far, with special emphasis on the development of an agreed international legal framework, the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA)[2], which entered into force in 2004. Finally, I discuss future challenges for the conservation and use of crop genetic diversity.

Origins of crop genetic resources

Since life appeared on Earth about 3 billion years ago, the number of species has generally increased through a process of continuous diversification. This storehouse of genetic diversity has allowed the effective use of the Earth's energy resources and provides a vast capacity for adaptation, conferring stability and balance within the biosphere. Crucially, it also provides us with the genetic resources that we use to meet our nutritional and other livelihood needs.

Timeline | **A history of the development and exchange of plant genetic resources**



The appearance of agriculture roughly 10,000 years ago (TIMELINE) disrupted the ecological balance of numerous systems. Fortunately, the process of domesticating plants and animals and the spread of agriculture were slow enough to allow a new equilibrium to emerge. In this process, of the more than 300,000 flowering plants that have been described, man is estimated to have used more than 7,000 species to satisfy basic human needs[3]. Mutual adaptation took place between humans and the plants they grew, and between these plants and their environment. Soil and climate conditions, as well as the cultural features of local civilizations, were major factors in determining this process of adaptation. Genetic diversity was maintained, and even increased, during this long period; the heterogeneous varieties developed by farmers in each location became well-adapted to varying local conditions.

Although crop productivity might not have been high, the vast portfolio of genetic diversity managed by farming communities increased the likelihood of a reasonable level of production, which is a highly desirable trait for the kind of local subsistence agriculture that was practised then, and still is in many areas of the developing world. This stability is due to the coexistence of an array of plants, each with different characteristics: some resistant to specific diseases, some tolerant to cold and others to heat, and so on. So, although the production of different components of the agricultural system varied with weather and disease conditions, a minimum yearly yield was likely. Another stabilizing characteristic during this period was the slow growth of the human population.

Loss of diversity in modern times

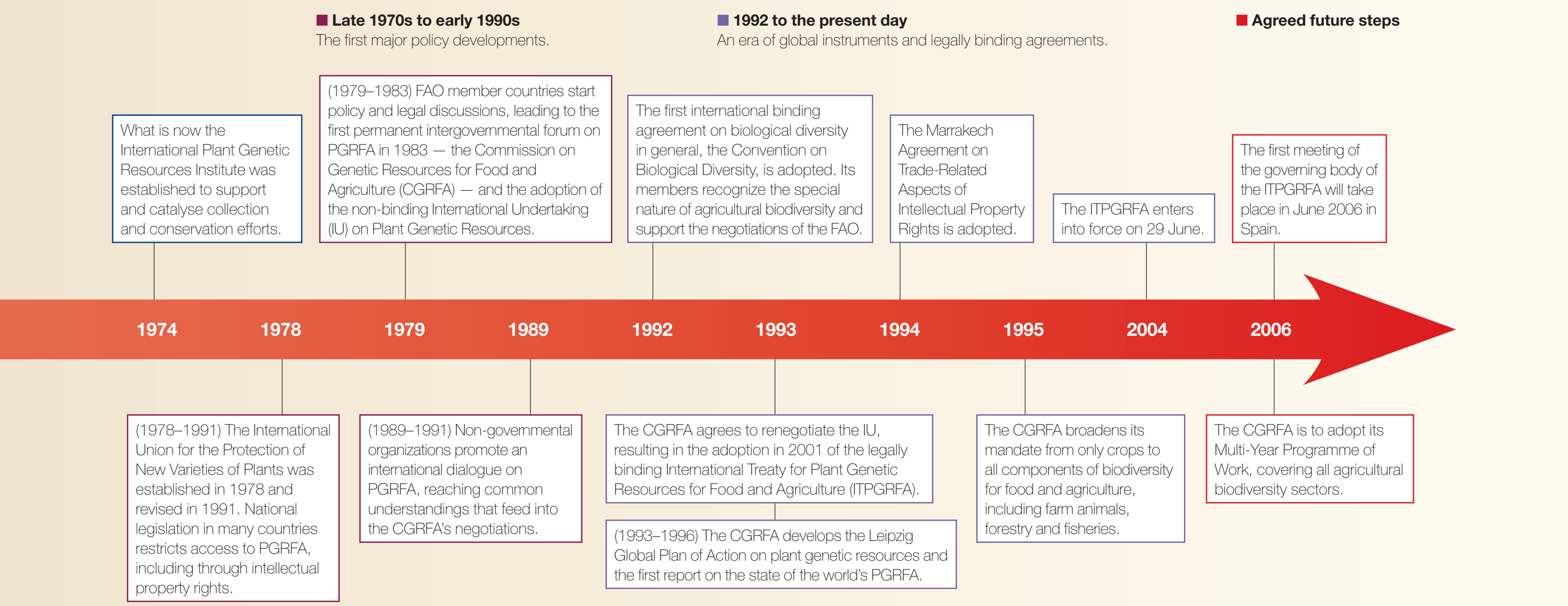
Interactions between civilizations and ethnic groups have generated a fusion of customs and lifestyles, with an important effect on crop genetic diversity. Since the Industrial Revolution, rapid changes in population size, ecological degradation and globalization have led to a dramatic reduction in crop genetic diversity. Barely more than 150 species are now cultivated; most of mankind now lives off no more than 12 plant species[3,4].

The concentration of populations in urban areas and the rising demand for food has created a situation in which high production, which is based on uniform crops, has been given priority over more reliable, diversified production. The introduction of modern farm machinery, marketing and transport methods that require uniform crop characteristics have required the introduction of standard, homogeneous plants. Through the joint efforts of plant breeders and public and private organizations, the demand for productivity and homogeneity has been met. Among the main crop species, a limited number of standard, high-yielding varieties has been developed. This trend, which peaked during the so-called 'Green Revolution', has made it possible to boost food production (see supplementary information S1 (table)). However, this has been at a high price: the loss of innumerable heterogeneous traditional farmers' varieties.

The dangers of genetic erosion

The loss of local species and varieties usually results in irreversible loss of the genetic diversity they contain, known as genetic erosion. This has dangerously shrunk the genetic pool that is available for natural selection, and for selection by farmers and plant breeders, and has consequently increased the vulnerability of agricultural crops to sudden changes in climate, and to the appearance of new pests and diseases.

History has provided some important demonstrations of these dangers. For example, in the United States in 1970, the fungus *Helminthosporium maydis* destroyed more than half the standing maize crop in the southern part of the country. The crop had been grown from seeds that have a narrow genetic base and are susceptible to this disease[5]. In this case and others, the problem was resolved by breeding resistant varieties using genetic resources that were obtained from other parts of the world. Several comparable events in recent years



have endangered the social and economic stability of various countries.

Following the *H. maydis* outbreak, the US National Academy of Sciences formed a committee to examine the genetic vulnerability of important crops. Many of these were found to have a dangerously narrow genetic base. For example, 96% of peas grown in the United States originated from just 9 varieties[6]. This phenomenon can be extrapolated to numerous crops and countries, and the most recent data show a worsening trend[3].

No one can deny the importance of improving crop varieties and increasing production. However, in our eagerness to do this we might be robbing nature of genetic diversity — a safety mechanism that took millions of years to build up. Through classical plant breeding and modern biotechnologies we can improve crop varieties by using genes that are responsible for desired characters. These genes are first identified among existing genetic resources, and then transferred to target varieties. The maize example given above, and those covered in BOX 1, demonstrate the enormous importance and value of plant genetic diversity in improving agricultural production. To provide adaptability to unpredictable environmental and climatic changes, maintain resilience in the face of variation in production systems, and meet the needs of the expanding human population, all countries rely on crop genetic diversity from all over the world. Both local farmers' varieties, now in the process of being replaced, and endangered wild relatives of crop plants need to be conserved for possible future use.

Box 1 | The importance of conserving and using plant genetic resources

The value of both traditional farmers' varieties and wild relatives of cultivated plants in crop improvement and agricultural development cannot be overemphasized. There are many examples of this, highlighted below by a few examples.

Traditional farmers' varieties have provided many individual traits that have been introduced into existing, improved breeding lines:

- **One local variety of wheat that is found in Turkey, collected by J. R. Harlan in 1948, was ignored for many years because of its many negative agricultural characteristics. But in the 1980s it was discovered that the variety carries genes that are resistant to many disease-causing fungi. It has since been used as a source of resistance to a range of diseases[3,57].**
- **The primitive Japanese dwarf wheat variety, Norin 10, introduced into America in 1946, had a key role in the genetic improvement of wheat during the so-called 'Green Revolution'. It was used as a donor of the genes that are responsible for dwarfism, which allow increased nitrogen uptake and therefore increased production in intensive farming systems[58].**

Wild relatives of current crop plants, although agronomically undesirable, might also have acquired many desirable characteristics as a result of their long exposure to natural selection, and can therefore make very useful contributions to crop improvement:

- **An outstanding example is the genus *Lycopersicon*, in which many wild species can be crossed with the cultivated tomato *L. esculentum* and have been successfully used as donors of fungus-resistant genes (*L. hirsutum* and *L. peruvianum*), nematode-resistant genes (*L. peruvianum*), insect-resistant genes (*L. hirsutum*), genes for quality improvement (*L. chmielewskii*), and genes for adaptation to adverse environments (*L. cheesmaniae*). Similar examples could be cited for most crops[59].**
- **Wild forms of *Beta* collected in the 1920s were used in the 1980s in California as a source of resistance to rhizomania, a devastating sugar-beet root disease. Meanwhile, it was found that the collections also show *Erwinia* root-rot resistance, sugar-beet root maggot tolerance, and moderate leaf-spot resistance[60].**

These examples show that genetic material that once seemed to be of no particular value has proved to be crucial in crop improvement. The concept of 'usefulness' is a relative one, which might vary according to the needs and the information available.

What needs to be done?

The conservation and sustainable use of genetic resources goes far beyond avoiding the extinction of species. The objective must be to conserve and use as much diversity as possible within each species. Plant genetic resources can be conserved *ex situ*, for example in gene banks (facilities that store samples (accessions) of crop genetic diversity, usually as seed and vegetative material) or *in situ*, either on-farm for farmers' varieties, or in natural reserves or protected areas for wild plants. These methods should be considered complementary, and the development of appropriate national and international strategies is required for their effective use.

Ex situ conservation in gene banks is mainly used for cultivated plants that are propagated through seeds. This tends to be cheaper than *in situ* conservation, requires little space and resources are easily accessible to plant breeders[6–8]. The main drawback, however, is that a genetic resource ceases to evolve as the natural processes of selection and adaptation are halted. In addition, only a small amount of the genetic diversity present in a given population is usually represented in the collected sample. This is further reduced every time the resource is regenerated, owing to genetic drift and natural selective pressures under different environmental conditions. Furthermore, many gene banks do not meet appropriate standards of storage and regeneration, resulting in poor seed viability[3,9–12].

Nevertheless, *ex situ* collections have a crucial role in the conservation of many varieties, particularly those that have already disappeared from the field. More than 6 million accessions are currently maintained in long-term collections[3]. However, many accessions are inadvertently duplicated[12,13] and minor crops and wild relatives of crops are poorly represented[14,15]. The lack of reliable information on accessions in gene banks significantly reduces their value to farmers and breeders, and hinders the identification of duplications[14,16,17].

In situ conservation involves the protection of the areas, ecosystems and habitats in which plants of interest have developed their distinctive characteristics, and is achieved through legislative measures and the use of incentives. This is the preferred technique for wild plants; the great advantage is that the evolutionary dynamics of the species are maintained. The principal drawbacks are the costs that are associated with incentives and law enforcement, and the social and political difficulties that occasionally arise, especially for on-farm management. This method might be economical, however, if the aim is to conserve all species within a specific area, rather than just one[18–24].

An increasing number of *in situ* conservation areas, including conservation on-farm in traditional agricultural systems, are protected at the national level[3], but conservation areas that are specific to PGRFA are still rare[14,25]. An integrated approach to *in situ* conservation is taken by the Globally Important Agricultural Heritage Systems Initiative, which aims to promote the conservation and sustainable management of the world's most important indigenous and traditional agricultural systems, and their associated biological and cultural diversity[26].

Despite the benefits of these strategies, conservation alone is not enough. Proper characterization, evaluation, documentation and cataloguing of crop genetic resources are needed to allow their effective use. Last, but not least, access to PGRFA is an essential condition for their use in research, plant breeding and agricultural development.

Politics, economics and ethics

International interdependence. Access to plant genetic resources and their conservation and sustainable use have socio-economic, political, legal and ethical implications, which are often associated with problems that threaten the economies of the countries concerned. The genetic diversity that saved maize in the United States in the twentieth century, as well as most of the useful diversity that is referred to in the examples provided in BOX 1, came from developing countries, where its existence was not accidental. It was the result of the work of generations of traditional small-holder and peasant farmers who — in a world in which they are often ignored or seen as a burden — are the true guardians of most of the world's remaining agricultural biodiversity in the field. These are the people who continue to develop and conserve the raw material that is needed to deal with changing environmental conditions and unpredictable human needs, and who make this material available to other farmers, professional breeders and biotechnologists.

Rapid globalization and economic integration are increasing interdependence among countries. No country is self-sufficient for crop genetic resources: the average degree of genetic interdependence among countries for their most important crops is around 70% (REFS 27,28) (see supplementary information S2 (table)). Early in the twentieth century, the Russian geneticist and plant breeder N. I. Vavilov identified the areas with the greatest genetic wealth of cultivated plants and wild relatives. These were in Mexico and Central America, the Andean area, the Mediterranean basin, Central Asia, the Near East, China, Ethiopia, India and the Indo-Malaysian region. Paradoxically, many countries that are poor economically, and generally located in tropical or subtropical zones, are rich in terms of genetic diversity[29–31].

All countries are both donors and recipients of plant genetic resources and related information, and the production of new varieties often uses genetic material from many countries[32]. Most of the efforts that are necessary to manage plant genetic resources can therefore only be carried out through international cooperation[14,33].

Intellectual property and other restrictions on access. Recent years have seen an acknowledgement of the growing value of PGRFA, owing to both the development of new powerful technologies to realize their potential and the knowledge that they are not an unlimited resource. As a consequence, questions that are related to access and benefit-sharing, the security of the material and the ownership of collections are the subject of continuing debate[34]. National laws that restrict access and use of PGRFA have emerged in many countries, and the introduction of intellectual property rights (IPRs) for new varieties and their genetic components in developed countries has been followed by application of national sovereignty and restrictions on access to PGRFA in developing countries[14,35–37].

The continuing availability of plant genetic resources for scientific purposes must be ensured through equitable and binding agreements and regulations. Ethical solutions to the problems described above must be found and implemented within an overall political framework that ensures food security and sustainable agriculture for future generations and allows the equitable sharing of benefits. For this task, the United Nations, as a universal inter-governmental forum, has a fundamental role — to facilitate the necessary inter-governmental negotiations[38].

What has been achieved so far?

Early achievements. Several international efforts have been made to identify, protect and use PGRFA. Initially, these were mainly of a technical nature. In 1967, 1973 and 1981 the Food and Agriculture Organization (FAO) hosted three international technical conferences, which led to the publication of books that summarize technical advances[39–41]. In addition, the non-governmental international agricultural research centres (IARCs), in particular the International Plant Genetic Resources Institute (established in 1974), have promoted and facilitated international technical cooperation. The IARCs conserve more than 600,000 accessions *ex situ* in 11 gene banks, which according to some estimates might represent as much as 40% of the diversity that is maintained *ex situ* for the main crops[3].

In 1983 the FAO established an intergovernmental Commission on Genetic Resources for Food and Agriculture (CGRFA). This was in response to the political, socio-economical and ethical issues that have been discussed above, as well as the need to reduce the duplication of efforts and foster cooperation and complementarity at the global level. The CGRFA provided the first permanent international forum for the negotiation, development and monitoring of international agreements and regulations in this field. Its current membership of 167 countries makes it widely inclusive. Relevant technical assistance agencies, inter-governmental organizations, development banks, non-governmental organizations, and private foundations also participate in the meetings of the CGRFA. The commission aims to reach consensus on areas of global interest, and compromise on areas of disagreement.

The CGRFA has developed a comprehensive global system on PGRFA, which aims to ensure international cooperation and avoid duplication of efforts[42]. It includes a Global Plan of Action for the Conservation and the Sustainable Utilization of PGRFA, through which countries have negotiated and agreed on 20 essential priority activities[43] and a World Information and Early Warning System, and a database that functions as a clearing house to allow the collection and maintenance of worldwide information on these resources[44]. It also produces a periodic report on the state of the world's plant genetic resources for food and agriculture[3], and has established international networks to facilitate cooperation among stakeholders[45]. In addition, the CGRFA has negotiated and developed several international agreements, voluntary undertakings and codes of conduct, to promote and facilitate good management and access to PGRFA. They include the ITPGRFA[2] and the International Code of Conduct for Plant Germplasm Collecting and Transfer[46]. A Code of Conduct on Biotechnology as it Relates to Genetic Resources for Food and Agriculture is currently in preparation[47].

An international treaty for plant genetic resources. In 1992 the UN Environment Programme adopted the Convention on Biological Diversity (CBD)[48] — the first binding international agreement of its kind. The CBD provided a legal framework for the conservation and sustainable use of all biological diversity. However, it does not provide specific solutions for the unique features and problems that are related to agricultural biodiversity[49]. Consequently, the countries decided that the CGRFA should negotiate a legally binding international agreement that is specific to PGRFA, in harmony with the CBD. In November 2001 the FAO conference reached a decision, which was deemed historic by many, when it adopted the ITPGRFA[2]. The treaty

Box 2 | The ITPGRFA

The International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA) encompasses all plant genetic resources for food and agriculture (PGRFA). Through the treaty, countries agree to promote the development of national integrated approaches to the exploration, collection, characterization, evaluation, conservation and documentation of their PGRFA, including the development of national surveys and inventories. They also agree to develop and maintain appropriate policies and legal measures to promote the sustainable use of these resources, including on-farm management, strengthening research, promoting plant-breeding efforts, broadening the genetic bases of crops and expanding the use of locally adapted crops and varieties, and under-used species. These actions would be supported, as appropriate, by international cooperation provided for in the treaty.

The most important and creative part of the ITPGRFA is the establishment of the Multilateral System (MS) of Access and Benefit-Sharing. The MS applies to 64 genera, including the major crops and forages, which were agreed on the basis of two criteria: importance for food security[37] and level of interdependence among countries[61]. At the global level, these crops provide about 80% of the food we derive from plants.

Through the MS, sovereign nations have agreed to share resources and benefits. The genetic resources of the MS will be made available for research, breeding and training, and their recipients should not claim any intellectual property or other rights that limit access on these resources, or their genetic parts or components, in the form received from the MS. The "benefits arising from the use, including commercial, of plant genetic resources for food and agriculture under the Multilateral System shall be shared fairly and equitably through the following mechanisms: the exchange of information, access to and transfer of technology, capacity-building, and the sharing of the benefits arising from commercialization, taking into account the priority activity areas in the rolling Global Plan of Action, under the guidance of the Governing Body." It establishes the payment, which is in certain cases mandatory, of an equitable part of the monetary benefits that are derived from the use of PGRFA into the funding strategy of the treaty.

The treaty establishes a funding strategy to mobilize funds for activities, plans and programmes to support the implementation of the treaty, in particular in developing countries and in line with the priorities that have been identified in the Global Plan of Action. The funding strategy includes the monetary benefits that are paid in accordance with the MS, as well as the Global Crop Diversity Trust, which is described in the main text. The governing body of the international treaty will periodically establish a target for the funding strategy.

Another innovative element of the treaty is the development of farmers' rights. They recognize the enormous contribution that the local and indigenous communities and farmers of all regions of the world have made and will continue to make for the conservation and development of plant genetic resources. The treaty makes governments responsible for the realization of farmers' rights, including the protection of relevant traditional knowledge; provision for farmers to participate equitably in sharing benefits; and farmers' participation in national policy decision-making.

provides a bridge between agriculture, commerce and the preservation of the environment, and is the result of 23 years of debate, including 7 years of formal negotiations, between more than 160 member nations within the CGRFA. This process also involved participation by representatives from non-governmental institutions and the private sector.

The treaty came into force on 29 June 2004. Its objectives are the conservation and sustainable use of plant genetic resources for food and agriculture and the fair and equitable sharing of benefits that arise from their use. The core of the treaty is its innovative Multilateral System of Access and Benefit-Sharing, which ensures continuous availability of important genetic resources for research and plant breeding, while providing for the equitable sharing of benefits, including monetary benefits that are derived from commercialization. Another innovative feature is its provisions for farmers' rights. The ITPGRFA relies on several supporting components that were previously developed by the CGRFA, in particular the Global Plan of Action, the Global Information System, international networks, and terms and conditions for the conservation of and access to *ex situ* collections that are maintained by the IARCs. Other features of the treaty are discussed in BOX 2.

The first meeting of the governing body of the treaty is planned for June 2006. Meanwhile, what will be an essential element for its funding strategy has already been developed: the Global Crop Diversity Trust[50]. This was established under international law as an independent organization in October 2004. It was constructed largely as an endowment fund, with a target of US$260,000,000. As of July 2005, it had received $56,000,000 in firm commitments, and a further $50,000,000 was under discussion, with contributions coming from both public and private sources. The trust will be used to ensure financial sustainability for the conservation of the world's most important crop diversity *ex situ* collections, as a 'genetic pantry' for mankind.

Society will benefit from the treaty in different ways: consumers will benefit because of a greater variety of foods and agricultural products, as well as increased food security; the scientific community will benefit through access to the plant genetic resources that are crucial for research and plant breeding; IARCs will benefit because their collections will be put on a safe and long-term legal footing by the treaty; and both the public and private sectors will benefit because they are assured access to a wide range of genetic diversity for agricultural development.

Challenges for the future

Technical and scientific challenges. Powerful new technologies have increased the value of PGRFA, especially for wild species, as potential donors of useful agricultural traits. Molecular genetics, genomics, proteomics, cryopreservation and ecogeographical remote-sensing techniques (using satellites and aircraft) have greatly expanded the technological basis for the location, conservation and management of genetic resources. Advances in informatics and communication techniques have also markedly increased our capacity to use, analyse and communicate related data and information.

There is now a need for an integrated strategy for the conservation and management of plant genetic diversity and the organization of related information at several levels. At the highest level, this is necessary for entire agro-ecosystems. It also applies to the gene pools of individual crops at the interspecies level (each crop and its wild relatives), and at the intervarietal amd intravarietal levels (the last of these accounts for the adaptive capacities of the many varieties that are grown by traditional farmers). Adequate information about the genetic material that is conserved, whether *ex situ* or *in situ*, should allow users to locate the desired material. For each crop and region, this strategy would allow for different forms and degrees of conservation, taking into account different national needs, as well as the economic, technical and human resources available.

The conservation of PGRFA is not enough; their appropriate usage is essential. Many accessions in gene banks are considered to be under-used[3,14], other than for disease-resistance screening[51]. The potential for greater use of genetic resources clearly exists, especially given the new molecular technologies that can be used to identify and transfer genes that control valuable traits[52]. A major new initiative to address these is the Generation Challenge Programme, which is a consortium of international and national research institutes[53].

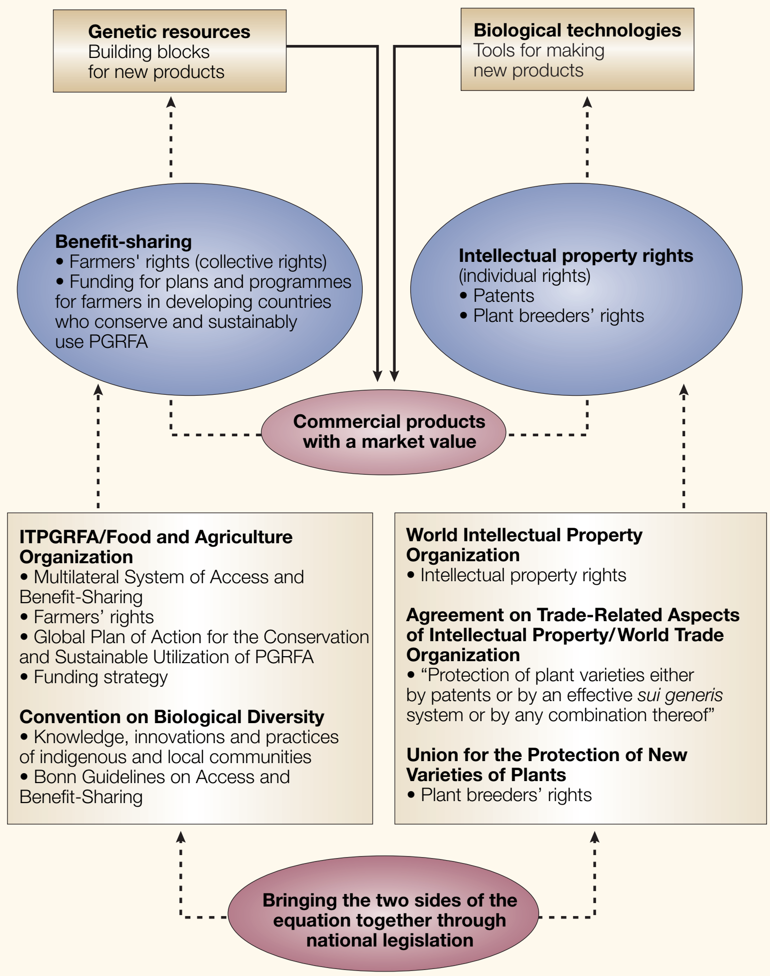
Social challenges. To ensure that the benefits derived from plant genetic resources reach all those who need them, public-sector research is needed in areas in which the private sector does not invest. Most commercial crop varieties are not adapted to the needs of poorer farmers who have limited or no access to irrigation, fertilizers and pesticides. A new environmentally friendly, socially acceptable and ethically sound agricultural model is needed to meet their needs. This could be achieved by using publicly supported programmes to breed crops that are able to withstand adverse conditions, including drought, high salinity and poor soil fertility and structure, and that provide resistance to local pests and diseases. Such programmes are likely to build on farmers' existing varieties, which often contain these traits. There are encouraging examples of this kind of research, which needs to be supported.

The entry into force of the ITPGRFA provides hope for fighting hunger and malnutrition, including at the local level. Its provisions on sustainable use, farmers' rights and benefit-sharing allow for cooperation between farmers and breeders in genetic improvement at the level of traditional farmers' varieties, rather than just seeking uniform 'universal genotypes'.

Economic challenges. The cost of conserving plant genetic diversity is high, but the cost of not taking action is much higher. Economic resources for the conservation and sustainable use of agricultural genetic resources are well below adequate levels. This problem is especially serious in the case of the *in situ* conservation of traditional farmers' varieties and, increasingly, of wild relatives of cultivated plants, which are largely found in developing countries. The scarcity of economic resources in these countries is not only an obstacle to the protection of wild species, but also a major cause of genetic erosion, as people search for fuel-wood or convert virgin areas into farmland. The protection of these areas for *in situ* conservation would benefit all countries, and there should therefore be international participation in efforts to safeguard them. The establishment of the Global Crop Diversity Trust, as an important element of the funding strategy of the ITPGRFA, is a step in the right direction. However, this fund is specifically for *ex situ* conservation. Financial strategies are needed to support the other aims of the treaty.

Box 3 | **Balancing the value of PGRFA and the biological technologies that use them**

Plant genetic resources for food and agriculture (PGRFA) provide the building blocks that allow classical plant breeders and biotechnologists to develop new commercial varieties and other biological products. Although they are undeniably important, neither genetic resources, nor the biological technologies that apply to them, have an appropriate market value by themselves. However, there often is a clear market value for the commercial products that are obtained through their use. Since the 1960s several international bodies and agreements (for example, the Union for the Protection of New Varieties of Plants, the World Intellectual Property Organization, and the Agreement on Trade-Related Aspects of Intellectual Property Rights) have addressed this. In doing so, provisions have been introduced that confer on the developers of biological technologies individual rights (intellectual property rights such as plant-breeders' rights and patents) that allow the rights-holders to appropriate profits from commercial products that might result from the use of those technologies. Since the 1990s other international agreements, especially the International Treaty for Plant Genetic Resources for Food and Agriculture (ITPGRFA), have recognized collective rights (farmer's rights and benefit-sharing) of the providers of the genetic resources. This might contribute to a more symmetrical and balanced system of incentives, which promotes the development and application of new biotechnologies, but also ensures the continued conservation, development and availability of the genetic resources to which these technologies apply (see figure). It is now up to national governments to implement these provisions. This should include the development, as appropriate for each country, of national legislation that takes into account the two sides of the system that are represented in the figure, thereby promoting harmony and synergy in the implementation of the various binding international agreements.



From a macroeconomic perspective, PGRFA have been treated as an unlimited source of continuing benefits. They are in fact a limited resource to be used by all generations to come. The full value of such resources for the future continues not to be reflected in market prices. A sustainable economic solution to the problem is the internalization of the conservation cost of the resource into the production cost of the product. For example, when buying an apple, we could pay not only the cost of production, but also the costs of maintaining genetic resources that will allow future generations to continue eating apples. The ITPGRFA provisions concerning benefit-sharing, including the sharing of monetary benefits that are derived from commercialization, represent a first step in this direction.

Legal and political challenges. The entry into force of the ITPGRFA marks a milestone for international agricultural cooperation. However, some of its provisions need to be further developed at the first meeting of the governing body in June 2006. These include a standard material transfer agreement for plant genetic resources to regulate access and determine the level, form and manner of monetary payments on commercialization. Mechanisms to promote compliance need to be developed, as does the funding strategy of the treaty. Once it is operating smoothly and the benefits are being realized, future meetings might be able to reach consensus in other controversial and challenging issues, such as increasing the number of crops that are covered by the Multilateral System of Access and Benefit-Sharing.

After a country's ratification, the provisions of the ITPGRFA need to be fully implemented at the national level, which will require the development of national measures. In some cases legislation will also be needed to prevent genetic erosion, promote the conservation, characterization and documentation of indigenous genetic resources, implement farmers' rights, facilitate access to genetic resources for research and plant breeding, and promote benefit-sharing. The rapid rate at which countries are ratifying the treaty in their national parliaments is encouraging.

The treaty cannot be seen in isolation from other relevant national and international legislation on biodiversity and related technologies[44,54] (BOX 3). Access to genetic resources and related biotechnologies is increasingly threatened by the proliferation of IPRs and the expansion of their scope, as well as by the increasing number of national laws that restrict access to and use of PGRFA. The effectiveness of the ITPGRFA in halting or reversing the current tendency towards restriction will depend on how its provisions are interpreted and implemented by individual countries and the international community.

Public awareness. Finally, scientific, political and economic support for the conservation of, access to and sustainable use of plant genetic resources for food and agriculture urgently needs to be mobilized. The political will that has been demonstrated by the speed of ratification of the treaty needs to be translated into action. The first meeting of the governing body will be an excellent opportunity to promote this. However, raising public awareness of the importance of genetic diversity and the dangers of its loss are other important goals: no system of legal provisions is likely to succeed without public understanding and consensus. Encouragingly, some grass-roots level initiatives have already been successful in raising public awareness of and involvement in the conservation and use of PGRFA[55,56].

It should not be forgotten that genetic erosion is just one consequence of mankind's exploitation of the planet's natural resources. The fundamental problem is a lack of respect for nature, and any lasting solution will have to involve establishing a new relationship with our planet and an understanding of its limitations and fragility. If mankind is to have a future, it is imperative that children learn this at school, and that adults make it part of their life.

Conclusion

Never have we had such powerful tools to control our future, and yet never has so much been at risk. For agricultural development to be sustainable, and for some harmful processes to be reversible, it is necessary to preserve the natural resources on which development is based. The achievement of a world without hunger or poverty is the responsibility of all of us, which must not be avoided or left to chance.

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Competing interests statement
The author declares no competing financial interests.

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Action Group on Erosion, Technology and Concentration web site: http://www.etcgroup.org
Biological Diversity in Food and Agriculture: http://www.fao.org/biodiversity/index.asp
Commission on Genetic Resources for Food and Agriculture: http://www.fao.org/ag/cgrfa/default.htm
Ethics in Food and Agriculture: http://www.fao.org/ethics/index_en.htm
Generation Challenge Programme web site: http://www.generationcp.org/index.php
Globally Important Ingenious Agricultural Heritage Systems: http://www.fao.org/landandwater/agll/giahs/default.stm
International Union for the Protection of New Varieties of Plants web site: http://www.upov.int
The Convention on Biological Diversity: http://www.biodiv.org/default.shtml
The Global Crop Diversity Trust — Start with a Seed: http://www.startwithaseed.org/items/homepage.php
The International Agricultural Research Centers: http://www.cgiar.org
The Seed Savers Network: http://www.seedsavers.net
The Slow Food web site: http://www.slowfood.com
The State of the World's Plant Genetic Resources for Food and Agriculture: http://www.fao.org/ag/AGP/AGPS/Pgrfa/wrlmap_e.htm
Trade-Related Aspects of Intellectual Property Rights: http://www.wto.org/english/tratop_e/trips_e/trips_e.htm
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