
Biotechnology in the Maintenance and Use of Crop Genetic Diversity

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INTRODUCTION

Recent years have seen an explosive growth in our understanding of heredity and in the tools we have to manipulate it to meet human needs and aspirations. Yet we live in an age in which more than 800 million people go hungry and species are becoming extinct at a faster rate than at any other time in human history. This paper attempts to explore some of the issues involved in the interrelationship between biotechnology, biodiversity, and sustainable agricultural production. It concentrates, in particular, on the implications of new biotechnologies for plant breeding and crop genetic diversity and indicates ways we can use the tools of biotechnology to help alleviate poverty, increase food security, and conserve the world's biological heritage.

CROP IMPROVEMENT AND BIOTECHNOLOGY

Ever since the first crops were domesticated, some ten thousand years ago, farmers throughout the world have brought new species into cultivation and selected from them the plants best suited to their needs and circumstances. Down the millenia, as needs have changed and as human populations have moved to new environments, continued selection has given rise to an enormous diversity of planting materials. Even today, farmers in many parts of the world continue to adapt their crops to meet new needs, adding to the pool of genetic diversity.

Our understanding of biological processes has grown rapidly in this century, not least in the field of genetics. As a result, it has become increasingly possible to base crop breeding efforts on scientific principles, adding enormously to the speed and precision with which improved varieties can be produced. Our comparatively recent, but growing, ability to manipulate DNA provides plant breeders with an extremely powerful range of tools that have enormous significance for the future of agriculture.

The new DNA-based techniques have enabled us to understand and, hence, better manage and use the genetic diversity of cultivated plants and their nondomesticated relatives. DNA markers, linked to traits of agricultural, economic, or social importance, have enabled breeders substantially to improve the efficiency with which they can select parents and progeny. In addition, our growing ability to transfer genes between completely unrelated species or even to produce “designer genes” and to promote their expression in a new host’s genetic background has opened up possibilities for introducing novel characteristics that are not presently found within the gene pool of the crop concerned.

It is this latter tool of biotechnology, often referred to as “genetic engineering,” that provides us with perhaps the greatest opportunities for tailoring our crops to meet future needs. Yet this same set of techniques are cause for the greatest religious, ethical, social, and environmental concerns. Leaving aside religious objections to “tampering with life,” if we are fully to realize the potential that these new technologies offer, society as a whole must weigh their pros and cons and put in place the necessary checks and balances to ensure that they support societal objectives and do not impose unacceptable risks or costs.

Many of the optimistic expectations, as well as the concerns, over the impact of genetically engineered crops are the same as those for conventional plant breeding, and they may or may not be amplified by the application of gene transformation techniques. Some concerns, however, uniquely relate to the introduction of alien genetic material into our crops, food, and the environment.

In many cases, a trait introduced by genetic engineering can have a positive impact on environmental and human health and lead to sustainable increases in food production with fewer external inputs. For example, genes for resistance or tolerance to insects and diseases and to abiotic stresses such as cold, heat, drought, or salinity enable large and stable yields to be produced with a minimum input of agrochemicals. A good example is the case of black sigatoka, a devastating disease that affects bananas and plantains. Currently, plantation growers commonly spray their crops with forty or more applications of fungicide in any one season to control this disease. The majority of growers, however, are smallholders who cannot afford to spray and who suffer large reductions in yield and income as a consequence. Bananas and plantains are

extremely difficult and expensive to breed by conventional means, and genetic engineering offers a major opportunity for developing varieties that are resistant to black sigatoka. The result will be higher yields and increased food security for smallholders, as well as a reduction in health risks to plantation workers and the environment.

Nevertheless, genetic engineering is still regarded by many with suspicion. In spite of its positive potential for agriculture, it remains controversial. Widely held concerns include the following:

- Much of the leading edge expertise in biotechnology lies in private sector companies that are interested in using the new techniques to develop products that will return a profit on their research investment. Thus high-value crops and major crops that are grown on large areas and that have wide rather than local adaptation generally receive far greater attention from private for-profit companies than “minor” crop species of more local importance. Yet the latter are often grown by poor farmers living in marginal and diverse agricultural areas and who may have few production alternatives. Although the increasing application of biotechnology in crop improvement and the related strengthening of intellectual property rights regimes are only one set of factors in the growing privatization of plant breeding, concerns have been voiced that the concomitant reduction in publicly sponsored breeding will have negative consequences for these farmers. Unlike the private sector, public plant breeding can, and frequently does, address social objectives, and continued public support for crop improvement is widely regarded as critical in situations of market failure, that is, when there is no possibility of capturing an adequate economic return on investment.
- In many parts of the world, plant breeding has resulted in large areas being sown to genetically uniform varieties. Even where a choice of varieties exists, they are often closely related. Although these varieties are often more productive than the local types they replace, increasing the genetic uniformity of crops can have consequences for long-term agricultural sustainability. The deployment of a few additional genes in such varieties through genetic engineering might reduce susceptibility to a particular pathogen or stress but do little to reduce overall vulnerability. The tendency to shift breeding efforts from conventional hybridization and selection techniques to a greater use of genetic engineering is likely to exacerbate the situation further, as breeders increasingly come to rely on the addition of one or two new genes to an elite, widely grown variety. Integrated approaches, which use both conventional breeding methods to help broaden the genetic base and more targeted gene transformations, could help reduce such vulnerability. Additional measures to promote the use of a larger

number of genetically dissimilar varieties would also help to reduce genetic vulnerability.

- Many of the early releases of genetically engineered varieties have incorporated genes for resistance to herbicides — especially glyphosate. In some cases, the varieties are sold as part of a package that obliges the farmer to use a particular brand of herbicide. There are concerns about the potential negative effects of the increased herbicide use that such varieties are likely to provoke and about the tendency for agrochemical companies to get involved in plant breeding for the purpose of developing and promoting such packages. It is undoubtedly true that farmers will adopt a packaged variety only if it is to their economic advantage to do so. Nevertheless, the growing practice of packaging raises a more fundamental question: to what extent do improved economic returns for farmers and the production of cheaper food justify the potential long-term consequences of such practices for human and environmental health?
- The potential risks associated with the release of genetically modified organisms (GMOs) into the environment have been widely publicized, and several countries have adopted national biosafety regulations. The parties to the Convention on Biological Diversity are currently negotiating an international biosafety protocol to the convention. But many countries still lack appropriate regulations, and there is evidence that the field testing of genetically engineered organisms has, on occasion, taken place in these countries specifically to avoid the more restrictive regulations elsewhere. In this regard, the research centers of the Consultative Group on International Agricultural Research (CGIAR) have taken the stance that they will field test GMOs only in countries where national regulations exist.

THE CONSERVATION OF GENETIC DIVERSITY

Genetic diversity provides the basis for all plant breeding efforts. Traditionally, plant breeding has relied on landraces and improved varieties and, to a lesser extent, on cross-fertile undomesticated ancestral forms as sources of genes for desired traits. More recently, particularly with the development of tissue culture methods such as embryo rescue techniques, it has become possible to use species that are less closely related to the domesticated crop as gene sources. Once regarded as a leading-edge tool of biotechnology, such techniques for interspecific hybridization have now become almost routine and in many circumstances have been superseded by the more powerful and targeted approaches that have been made possible through the development of genetic engineering.

It is now becoming increasingly possible to transfer genes between almost any organisms and to induce them to express the desired trait. For example,

there have been many successful attempts to transfer genes for insect resistance from *Bacillus thuringiensis* to a range of different crop plant species. The total diversity of interest to plant breeders has thus, at least in theory, been extended from the crop of concern and its wild relatives to the entire gene pool of all life forms.

Despite these advances and our growing ability to manufacture “artificial” genes, breeders continue to rely heavily on genes from within the gene pool for a crop and its wild relatives and are likely to do so for many years to come. Yet many of these gene pools are threatened, and urgent measures are needed to conserve them. The threat comes from many sources. In 1996, the Food and Agriculture Organization (FAO) of the United Nations published its *Report on the State of the World's Plant Genetic Resources for Food and Agriculture*, which lists the following among the major reasons for the loss of genetic diversity:

- Replacement of local varieties with new ones
- Land clearing and environmental damage
- Overgrazing and overexploitation
- Changing agricultural systems
- Civil strife
- Legislative and political factors

It is ironic that the major reason given for the loss of crop genetic diversity is its replacement by the products of breeding. Breeders, perhaps more than any other group, have a vested interest in the conservation of plant genetic resources; yet, as in crop improvement for marginal areas, there is a market failure in the case of the conservation of genetic resources. In the face of reduced public financing for plant breeding, it is critical that funding mechanisms be found to continue and expand conservation programs in the public interest.

Conservation can take place both *in situ* and *ex situ*. *In situ* conservation means maintaining plant populations in the location where they acquired their characteristic properties, for example, as landraces in farmers' fields or as wild plants in nature reserves or other protected areas. Under these conditions, plants can continue to evolve under human or natural selection. *Ex situ* conservation involves collecting material and conserving it in gene banks away from their place of origin. Such gene banks may consist of collections of seed samples in cold storage, living collections growing in the field, or collections of plant tissues maintained *in vitro*, possibly cryopreserved at very low temperatures using liquid nitrogen. Materials maintained *ex situ* are generally easier for plant breeders to access, and a well-managed collection will have useful data on the accessions it holds. Modern information systems enable large quantities of data to be assembled and made widely available, for instance over the Internet, thus greatly increasing the usefulness of these collections.

Unfortunately, many collections are not well maintained. In many parts of the world there are insufficient human, institutional, and financial resources to maintain the materials and regenerate them to sustain their viability. Indeed, 95 percent of the countries submitting information on regeneration during the process leading up to the International Technical Conference reported the need for a far higher level of regeneration. In addition, many of the accessions held in *ex situ* collections are insufficiently or poorly documented.

The 150 countries attending the FAO International Technical Conference on Plant Genetic Resources for Food and Agriculture, held in Leipzig, Germany in June 1996, adopted the Global Plan of Action for the Conservation and Sustainable Utilization of Plant Genetic Resources. This plan calls for urgent attention to be given to safeguarding existing collections throughout the world and to regenerating their accessions. The lack of resources to do this at the national level in many countries requires that the international community assist in the task.

With the growing use of genetic engineering as a crop improvement tool and the consequent widening of the gene pool of potential interest to plant breeders, conservation needs have expanded. It is clearly impractical, for both financial and technical reasons, to consider developing systems for the *ex situ* conservation of all genetic resources of potential interest. Thus special attention needs to be given to *in situ* methods, both to help ensure that the widest possible range of genetic diversity is conserved and to promote its continued evolution under natural and human selection pressures. Our current understanding of the scientific basis for *in situ* conservation of genetic diversity is limited, however, and further research is urgently required to underpin the development of effective and efficient *in situ* management systems.

THE ROLE OF BIOTECHNOLOGY IN CONSERVING GENETIC DIVERSITY

New biotechnological methods have a key role to play not only in the use of agrobiodiversity through marker-assisted selection or gene transformation but also in its conservation. Until DNA-based molecular genetic techniques became available for widespread application, our understanding of diversity was largely confined to the phenotypic level. Now, however, such techniques provide an important tool to help increase our understanding of events at the genotypic level.

Molecular genetic techniques can, for example, enable us to gain a better picture of the patterns of genetic diversity in *ex situ* collections and provide the means to assist in their management. They can help in identifying duplicate accessions and assembling core collections (a subset of accessions that aims to include the maximum genetic variation). They also provide a tool for monitoring, and hence controlling, genetic drift during regeneration and for characterizing and evaluating collections.

Molecular genetic data can also be used to monitor genetic erosion in the field and, especially when coupled with computer-based geographic information systems (GIS), can be very useful for surveying and mapping the spatial distribution of genetic variation. Such distribution information is particularly valuable for targeting collecting expeditions and for identifying areas of high genetic diversity for *in situ* conservation.

The development of new varieties requires the movement of genetic resources within and between countries. Materials collected in the field are transferred to gene banks at home or abroad. From gene banks, samples are distributed to plant breeders, who in turn send out materials for testing in multiple locations, often to several different countries, and for multiplication and distribution of seed to farmers. DNA-based techniques are becoming increasingly useful in helping to ensure the safe movement of genetic resources and to make certain that diseases are not distributed along with the plant materials. Diagnostic probes, such as for detecting virus diseases, can assist greatly in the identification of infected materials. Other biotechnological techniques, such as certain tissue culture methods and heat treatments, can be used therapeutically to help clean up infected materials.

Tissue culture techniques are also valuable for conserving species that are vegetatively propagated or that produce seeds that cannot be dried for storage at low temperatures without losing their viability. Large collections of such plants can be maintained as tissue cultures growing in petri dishes or test tubes. These may be maintained in growth chambers and on culture media that minimize the growth rate of the cultures and thus maximize the period of time needed between successive regenerations. The possibility of storing plant tissues at very cold temperatures, down to -196°C , using liquid nitrogen, is of particular interest for their long-term conservation. This biotechnological method, known as cryopreservation, is becoming possible for an ever-increasing number of species.

THE POLICY ENVIRONMENT

In the 1970s and early 1980s, plant genetic resources were widely considered the common heritage of humankind. Access by breeders was for the most part unrestricted. Expeditions to collect indigenous landraces and farmers' varieties were conducted throughout the world and there was a strong tradition of sharing materials among breeders.

In recent years however, intellectual property protections have increasingly been applied to the products of plant breeding — initially through plant variety protection measures but increasingly through patents as well — accompanied by the rapid expansion in the use of biotechnologies and the growing influence of the private for-profit sector. This has led many countries, especially developing countries rich in genetic diversity, to call for measures to protect their interests

and to ensure that they share in the benefits derived from the use of their resources by others. Legislation is being enacted in many countries to regulate access to genetic resources, and there is a strong movement to implement farmers' rights which recognize the contribution of past, present, and future rural communities and indigenous people to the development and conservation of genetic resources. Such rights are seen as a counterbalance to the growing application of intellectual property rights to germplasm, especially in developed countries.

The Convention on Biological Diversity, which came into force in December 1993, encapsulates this new paradigm in an internationally legally binding instrument that explicitly recognizes national sovereign rights over the genetic resources existing within a country's territory. The earlier, nonbinding instrument, the FAO International Undertaking on Plant Genetic Resources, is now being renegotiated to bring it in line with the convention. The revised International Undertaking, which may become a protocol to the convention, seeks to establish multilaterally agreed upon terms and conditions for accessing plant genetic resources for food and agriculture. The outcome of these negotiations is likely to greatly influence the way plant breeders will access plant genetic resources in the future, whether for use in biotechnological or conventional breeding programs.

CONCLUSIONS

Recent advances in biotechnology have opened up enormous and exciting possibilities for plant breeding. The development of varieties adapted to new environments, with resistance or tolerance to biotic and abiotic stresses or with new characteristics of interest to consumers, could make a substantial contribution to increasing productivity and alleviating poverty in a sustainable way. But, the global trend to reduce publicly funded research, for both economic and ideological reasons, and the growing concentration of biotechnological expertise in the private sector have aroused fears that the poorest segments of society will be neglected and will not share in the potential benefits that the new technologies could bring to their lives. They could even find their situation deteriorate as they become less able to compete with the increasing productive capacity of farmers who are well cared for by research and who have the means to purchase the new research products.

The use of genetic engineering gives rise to widespread environmental and health concerns, particularly with regard to the release and consumption of genetically modified organisms. Although many of these fears might prove to be unfounded, caution is certainly in order. As a result of global concerns over biosafety, a protocol to the Convention on Biological Diversity is currently being negotiated that, when implemented, should go a long way toward reducing the inherent risks.

Biotechnological methods contribute not only to our ability to use agricultural biodiversity, but also to the effectiveness and efficiency of our efforts to conserve it. Despite the promise that biotechnology holds for conservation, however, the financial resources necessary for conservation in general remain limited. It is essential that the international community find the means to make these resources available, especially to developing countries, which are home to the greatest diversity of potential interest to all humanity.

Issues of ownership and access to genetic diversity, as well as concerns over the application of intellectual property protection to the products of biotechnology, are currently receiving considerable attention in various international forums. The debates on these issues are complex and highly politically charged. Yet it is essential that they be resolved if the full potential contribution of biotechnology for improving the human condition and protecting the natural environment is to be realized.