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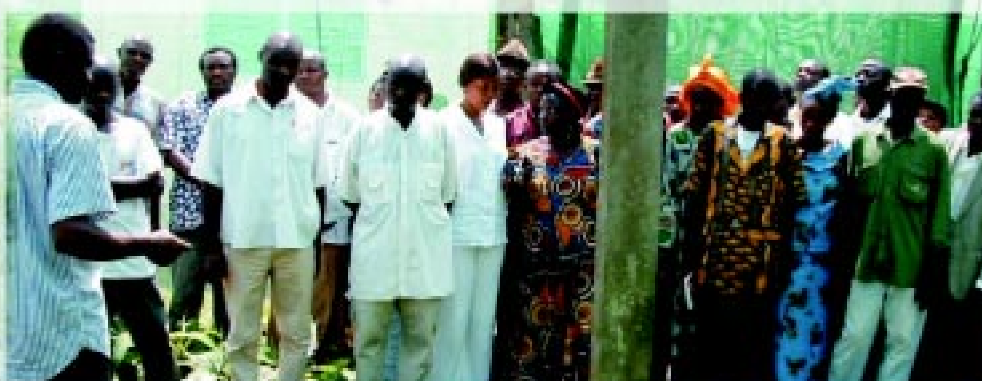

Biotechnology and Developing Countries: The potential and the challenge

In This Issue:

Editor's Notes

By Lisa Jategaonkar, Editor

Can GM technology improve food security in developing countries? This is a topic that has been the subject of much debate and controversy. In order to explore this issue, we discuss some examples where GM technology is being used to improve food production in developing countries. Recognizing that GM technology is not a cure-all, but only one tool to aid in improving food production, we have also asked our contributors to describe the challenges, be they technical, economic, or social in applying biotechnology towards this goal.

The MS Swaminathan Research Foundation (MSSRF) is a non-profit trust with the mandate to impart a pro-nature, pro-poor and pro-women orientation to a job-led economic growth strategy in rural areas through harnessing science and technology for environmentally sustainable and socially equitable development. Its founder, MS Swaminathan, is recognized as the Father of the 1960s Green Revolution that saw significant increases in food production in India. In 1987 he was recognized for this remarkable contribution by receiving the first World Food Prize. Dr. Rajalakshmi Swaminathan, Senior Scientist with the MSSRF discusses the need for another revolution, one that involves a decreased use of chemical synthetic products but allows reclamation of areas that have been abandoned for production due to environmental stress.

Dr. C.S. Prakash and Gregory Conko are cofounders of AgBioWorld Foundation, a network organization that brings together scientists and members of the policy community with an interest in the agricultural applications of biotechnology. Conko and Prakash discuss the uptake of GM crops in developing countries and the social and economic challenges of implementing these technologies.

In his article, Dr. Peter Hackett, former Vice-President of the National Research Council of Canada, discusses some of the ways in which this Canadian federal government research organization can contribute to developing countries.

The Consultative Group on International Agricultural Research (CGIAR) is a strategic alliance of countries, international and regional organizations, and private foundations that support 15 international agricultural Centers. The alliance mobilizes agricultural science to reduce poverty, foster human well being, promote agricultural growth and protect the environment. The CGIAR generates global public goods that are available to all.

Two CGIAR centers are represented in this issue. One of the organizations, the International Maize and Wheat Improvement Center (CIMMYT), is currently conducting field trials on GM drought tolerant wheat in Mexico. These crops are discussed in detail by Dr. Alessandro Pellegrineschi with CIMMYT. Dr. Emile Frison, Director General of CGIAR's International Plant Genetic Resources Institute and his colleagues, discuss the application of biotechnology to bananas and plantains, both major staple foods in developing countries.

FROM GREEN REVOLUTION TO GENE REVOLUTION

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Overall food production in recent years has increased at an annual rate of 1.3%, while the world's population has maintained an annual growth rate of 2.2%. Thus, the global food and health situation is a cause for concern, with the conclusion that the use of genetically modified organisms represents a tool and an option that should be given serious consideration.

"...the global food and health situation is a cause for concern..."

Faced with a choice between cultivating new land and thereby destroying forests which are storehouses of biodiversity and serve to moderate climate change, or, increasing the productivity of existing agro-ecosystems, the second option is definitely preferred. Biotechnologies, and especially genetic engineering, can contribute to research that ensures new varieties, at the same time guaranteeing safety in use for both humans and the environment. This involves a decreased use of chemical synthetic products (pesticides, fertilizers, herbicides), while at the same time permitting the reclamation of areas of land that are adequately productive but which have gradually been abandoned because of environmental stress.

In India, agriculture is now at a crossroads. Our national capability in frontier areas of science and technology such as biotechnology, information, communication and space technologies, nuclear and renewable energy technologies and in management science has opened up uncommon opportunities for achieving an evergreen revolution, i.e. sustainable advances in crop productivity per units of land, water and time without associated ecological harm.

Green Revolution

The first 60 years of the 20th century were marked by a sense of despair and frustration regarding India's capability to achieve a balance between human numbers and the production of food grains and other agricultural commodities.

In 1963, Dr. Norman Borlaug with the International Wheat Rust Nursery in Mexico sent a wide range of semi-dwarf plant material to the Indian Agricultural Research Institute via the USDA. This provided the initial material for stimulating an accelerated advance in wheat productivity and production. In 1964, a National Demonstration Programme was started in farmers' fields, both to verify the results obtained in research plots and to introduce farmers to the new opportunities opened up by semi-dwarf varieties for considerably improving the productivity of wheat. These small farmers harvested over five tonnes of wheat per hectare and its impact on the minds of other farmers was electric. The popularity of these seeds grew and the area under high yielding varieties of wheat rose from four hectares in 1963-64 to over four million hectares in 1971-72. A small Government programme thus became a mass movement. The rest of the history is recorded in a book on the Wheat Revolution (Swaminathan, 1993). Wheat production in India rose from 10 million tonnes in 1964 to 17 million tonnes in 1968, and similar results were obtained with semi-dwarf varieties of rice. In 1968, Dr William Gaud of the United States coined the term “Green Revolution” to stress that that the changes occurring in the wheat and rice fields of Asia was revolutionary, not just evolutionary, progress.

As early as 1967, Prof Swaminathan had observed that farmers in northwest India with relatively large holdings tended to use large quantities of fertilizers and grow single genetic strains in large, contiguous areas. In his Presidential Address to the Agricultural Sciences Section of the Indian Science Congress, he stressed the need for considering ecological sustainability in efforts to improve yield. “The initiation of exploitative agriculture without a proper understanding of the various consequences of every one of the changes introduced into traditional agriculture and without first building up a proper scientific and training base to sustain it, may only lead us, in long run, into an era of agricultural disaster rather than one of agricultural prosperity” (Swaminathan,1968).

An increasing population leads to increased demand for food but reduced per capita availability of arable land and irrigation water. Improved purchasing power and increased urbanisation can also lead to higher per capita grain requirements, due to increased consumption of animal products. At the same time, there is increasing damage to the ecological foundations of agriculture (land, water, forests, biodiversity, atmosphere) and distinct possibilities for adverse changes in climate and sea level. While dramatic new technological developments are taking place, particularly in the field of biotechnology, their environmental, safety and social implications are yet to be fully understood. Finally, gross capital formation in agriculture is declining in both public and private sectors.

The processes of agricultural evolution are currently moving ahead at an unprecedented pace. This progress ranges from classic genetics (genetic maps, cytogenetics) to mutagenesis and *in vitro* culture, not to mention genetic transformation, studies on the structure, function and regulation of genes, molecular genetics, gene transfer, the use of molecular markers and the regeneration of organisms from transformed cells. This could provide new opportunities for increasing and improving the quality of production, for reducing costs which would allow a larger part of the population to access the goods and services produced, and for controlling pests and diseases which destroy more than a third of all plant products each year.

The green revolution has so far helped to keep the rate of growth in food production above the population growth rate. The green revolution was the result of public good research, supported by public funds. However, the technologies of the emerging gene revolution are, in contrast, spearheaded by proprietary science and can come under monopolistic control.

Paddy cultivation in India

The Gene Revolution

It is now clear that the present century may witness changes in temperature, precipitation, sea level and ultraviolet radiation as a result of global warming. Such changes in climate are expected to adversely affect India and Sub-Saharan Africa. All human induced calamities affect adversely the poor nations and the poor among all nations the most. This led scientists at the MS Swaminathan Foundation to initiate an anticipatory research programme to breed salt tolerant varieties of mustard and other crop plants for coastal areas, in order to be prepared for seawater intrusion into farmland as a result of a rise in sea level. The germplasm donor of salt tolerance is a mangrove species *Avicennia marina*. Transferring genes for tolerance to salinity from mangrove tree species to rice, mustard or tobacco would be an impossible task without recourse to recombinant DNA experiments. Thus, the immense benefits that can accrue from genomics and molecular breeding are clear.

Principal Concerns

The professionals, public and political leaders of developing countries are all equally concerned about the food and environmental safety aspects of GMOs. The viewpoints of countries in the North on the ethical and social issues relating to GM crops have been dealt with in detail in a report published by the Nuffield Council on Bioethics in January 2004.

Additional issues of concern to developing countries are:

1. Biosafety: The safe and responsible use of biotechnology will enlarge our capacity to meet the challenges ahead, including those caused by climate change. At the international level, the Cartagena Protocol on Biosafety provides a framework for risk assessment and aversion. At the national level, there is need for a regulatory mechanism, which inspires public, political and professional confidence.

2. Expansion of proprietary science and shrinking of public good research supported from public funds may lead to a situation where the technologies of the future remain in the hands of a few transnational corporations. Only resource-rich farmers may have access to them, thereby widening further the already wide rich-poor divide.

3. The monopolistic control over crop varieties could lead to a situation where large areas are covered by very few genetic strains or hybrids. It is well known that genetic homogeneity enhances genetic

vulnerability to biotic and abiotic stresses. A need for a crop insurance scheme needs to be incorporated to compensate farmers for such losses (Task Force on Applications of Agricultural Biotechnology, 2004).

4. The potential impact of GM foods on biodiversity: This aspect has two dimensions. The first deals with the replacement of numerous local cultivars with one or two GM strains, thereby leading to genetic erosion. The local cultivars have often been the donors of many useful traits, including resistance to pests and diseases. Under small farm conditions every farm is a genetic garden, comprising several crops, both annual and perennial, and several varieties of each crop. The need of the hour is to enlarge the food basket and not shrink it further.

The other aspect of GM foods and biodiversity relates to the equitable sharing of benefits between biotechnologists and the primary conservers of genetic resources and the holders of traditional knowledge. At present, the primary conservers remain poor, while those who use their knowledge (for example, the medicinal properties of plants) and material become rich. This has resulted in accusations of biopiracy. It is time that genetic engineers promote genuine biopartnerships with the holders of indigenous knowledge and conservers of genetic variability, based on principles of ethics and equity in benefit sharing. The Protection of Plant Varieties and Farmers' Rights Act (2001) and the Biodiversity Act (2002) have provisions for recognizing and rewarding tribal and rural women and men for their contributions to genetic resources conservation and enhancement.

Ecotechnologies are knowledge-intensive. Fortunately, modern information technology provides opportunities for reaching the unreached. Computerised, networked "Virtual Colleges", which link scientists to people living in poverty, can be established to launch a knowledge and skill revolution. Genome clubs in schools and at grassroot / panchayat level can generate awareness at a massive scale. This will help to create better awareness of the benefits and risks associated with GMOs, so that both farmers and consumers get better insights into the processes leading to the creation of novel genetic combinations.

Productivity improvement will be possible only if greater attention is paid to improving the efficiency of input use, particularly the use of nutrients and water. To cite just one example, cotton yields in India are less than 20% of the yields achieved in several other countries, such as Egypt and the USA, yet Indian farmers use 25 times more water to raise a ton of cotton than farmers in California. Even in the case of rice and wheat, the present average yield is just 40 per cent of what can be achieved even with technologies currently on the shelf. Therefore a massive effort should be made to launch a productivity revolution in farming.

Another area that needs attention is enlarging the food basket. There are considerable opportunities for increasing the production of under-utilized or minor crops. With increasing urbanization, the demand for processed food increases. There is much scope for including the minor crops in the manufacture of processed and semi-processed foods. Farming systems intensification, diversification and value-addition are all important for achieving the goal of food for all.

The Green Revolution provided a breathing spell, allowing countries to achieve a balance between population growth and food production. However, the production technologies adopted must be both environmentally and socially sustainable. Achieving sustainable advances in the productivity of major farming systems and the well being of farming families is the pathway towards an Evergreen Revolution in agriculture.

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NRC'S ROLE IN INTERNATIONAL DEVELOPMENT: IMAGINING THE FUTURE

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The 2002 Kananaskis Summit of the G8 in Alberta, and the ensuing commitment to build a new partnership for Africa's development (NEPAD), helped move the issue of global human development higher on the federal government's agenda and beyond the traditional scope of development agencies, such as the Canadian International Development Agency (CIDA) and the International Development Research Centre (IDRC). Former Prime Minister Chrétien and now Prime Minister Martin have both expressed and demonstrated their support for global development through alternative forms of assistance and collaboration with developing countries including innovation and S&T cooperation. In a recent address to the nation, Paul Martin stated that Canada's "long-term goal as a country should be to devote no less than 5% of our R&D investment to a knowledge-based approach to develop assistance for less fortunate countries".

This perspective points towards the need for a new bold direction and linkage between Canada's innovation and foreign policies by calling for Canada's innovation capacity to be mobilized and strengthened to address major global challenges faced by developing countries. As the premier R&D organization of the federal government, the National Research Council has been a leader in domestic innovation policy. We submit that it is now time for NRC to show leadership in this new policy direction.

Historically NRC has made contributions to global development. For example, in the seventies, Dr. Kutty Kartha, now Director General of the NRC Plant Biotechnology Institute (NRC-PBI) in Saskatoon, worked extensively toward the development of techniques to regenerate whole cassava plants from *in vitro* cultured shoot apical meristems in a project supported by IDRC. Over 500 million people in developing countries grow cassava as their staple food. In the early 70s, it was reported that cassava mosaic disease was hampering the rapid expansion of cassava production, reducing yield by as much as 65-95%. The technique developed at NRC-PBI (then the Prairie Regional Laboratory), enabled the production of mosaic disease-free plants and was transferred to International Tropical Agricultural Research Centers located in Colombia, Africa and India. In the same period, Dr. Kutty Kartha also developed a cryopreservation technology for the long-term storage of cassava germplasm in a disease-free and genetically stable condition. The technology was transferred to the International Center for Tropical Agriculture (CIAT), Colombia.

However in the eighties, as Canada's innovation policies became internally focused, dealing with debt and deficit, NRC researchers and managers turned away from the challenge of global development, limiting our global connections to collaborations with the international scientific community in the form of R&D partnerships, missions, visits and exchanges.

We submit it is now time to turn back. In fact NRC is already expanding its sphere of influence in the international community and strengthening its international R&D collaborations especially with developing and transitioning countries to foster the generation of new knowledge, new technologies and new business opportunities that lead to improved quality of life in these countries.

For example, the NRC Biotechnology Research Institute (NRC-BRI), in Montreal, is currently involved in a collaboration with ProMetic Life Sciences, an international bio-pharmaceutical company with headquarters in Montreal, who recently announced a high-level strategic alliance with the Institut Pasteur de Tunis and the Tunisian state corporation – *La Pharmacie Centrale de Tunisie* – to establish a biopharmaceutical company in Tunisia. This new company will manufacture and commercialize affordable high value drugs to combat hepatitis and cancer to a market of 500 million people in Africa, the Middle East and parts of Europe. Together, NRC-BRI and ProMetic will provide a fully integrated service for the development and scale up of therapeutic protein production. This is a very promising effort which is estimated to generate a market opportunity of 2 billion dollars and to transform Tunisia into a pivotal regional biotechnology centre.

"...the National Research Council has been a leader in domestic innovation policy."

NRC-BRI is also involved in collaborative research activities with traditional healers in Ghana and Cameroon, as well as with the Lyceum Research Company in New Brunswick, to develop traditional African medicines into well characterized natural health products for the local African market and for export markets in developed countries such as Canada and the US.

Recently some NRC institutes have submitted proposals to the Bill and Melinda Gates Grand Challenge in Global Health Initiative, a US$200 million program for funding research that to could lead to important advances against diseases of the developing world. For example, NRC Institute for Biological Sciences (NRC-IBS) submitted a grant application for a single dose tuberculosis vaccine in collaboration with the Tuberculosis Research Centre in India. As well, the NRC Industrial Materials Institute (NRC-IMI) has put forward a proposal for the development of rapid and affordable molecular diagnostic tests for human infections in developing countries where the lack of convenient and accurate point of care assessment tools means that health risks and illnesses remain poorly defined and receive inappropriate treatment. This lab-on-a-chip device will be compact, battery-operated, easy to use and suitable for the rapid detection and identification of targeted infectious diseases at field sites, in clinics, or in hospitals in developing countries.

Just recently, Dr. Eleonora Altman from NRC-IBS, together with another researcher, received a C$261,000 grant under the Global Health Research Initiative (GHRI) co-funded by IDRC, CIDA, Canadian Institutes of Health Research and Health Canada. With this funding, Dr. Altman will conduct research towards the development of vaccines against childhood diseases for non-industrial countries under the GHRI Canadian International Immunization Initiative.

NRC's efforts in linking domestic research capabilities with developing countries don't stop with R&D partnerships. NRC is also seeking opportunities for the private sector in those countries to develop capacities and access markets and expertise in the developed world. These efforts could lead to new relationships and new R&D alliances, and become the seeds of new dynamic innovation systems in the regions of the world where it is most needed.

A champion in this area is the NRC Industrial Research Assistance Program (NRC-IRAP), with dedicated efforts towards the transfer of innovations skills to SMEs in developing countries. For example, NRC-IRAP has been working with Thailand's National Science and Technology Development Agency to set up the Industrial Technology Assistance Program modeled after IRAP. ITAP will provide Thai SMEs with the services required to help them innovate. NRC-IRAP has also recently joined a Canadian consortium of financial institutions to help African SMEs gain entrepreneurial and business skills and boost local innovation capacity in key industrial sectors in Africa. The consortium has launched a pilot project with Senegal that will be delivered over the Internet. Under this initiative, NRC-IRAP will share Canadian best practices for networking and technology transfer with African partners.

NRC-IRAP has also taken part in a project in South Africa coordinated through IDRC. For over 3 years NRC-IRAP has been working with South-African research and technology organizations such as the Council for Scientific and Industrial Research (CSIR) to assist in the creation of an IRAP-like program in South Africa. Targeting three cities initially, the program was expanded in 2002 to 30 cities. The Saskatchewan Research Council joined NRC-IRAP to assist in the delivery of services and training modeled after the Canadian Technology Network (CTN).

NRC also supports the transfer of various competencies ranging from research management to codes and standards to strengthen the S&T capacity of developing countries.

For example, Dr. Prabhat Arya, an organic chemist at the NRC Steacie Institute for Molecular Sciences (NRC-SIMS), has developed strong ties with the National Chemical Laboratory in India where he gave several lectures and organized a number of networking meetings. With NRC's endorsement, Dr. Prabhat is also contemplating a scheme for cross appointments where he could mentor and help develop future research leaders from that country.

At the organizational level, NRC's Canada Institute for Scientific and Technical Information (NRC-CISTI) has established particularly close ties with the S&T library community in Morocco and continues to provide expert advice to S&T information organizations in developing countries. CISTI has also reached an agreement with the international Programme for the Enhancement of Research Information (PERI) to provide NRC Research Press e-journals to developing countries.

Similarly, the NRC Institute for Research in Construction (NRC-IRC) has completed a CIDA-funded project to promote Canadian housing technologies in Russia. The project, managed by Canada Mortgage and Housing Corporation (CMHC), with technical support from NRC-IRC and Underwriters' Laboratories of Canada (ULC), has resulted in the Russian adoption of new building codes for low-rise housing which should open the door to greater use of Canadian light-frame construction in Russia.

As part of a more focused effort targeting transitioning countries, NRC has recently led major Canadian missions to India, Brazil and China to expand scientific and technical collaborations between these countries and Canada.

Last summer, NRC sent a major delegation to India to explore potential collaborations in sectors such as information and communication technology, software development, aquaculture, e-commerce, biotechnology, pharmaceuticals and nanotechnology. Several leads were identified and follow-up activities are now in progress.

Also, with India and China in particular, there are significant opportunities for collaboration in the development of fuel cell systems, hydrogen storage and related infrastructure. It is widely believed that the most important market for fuel cell technology lies in these countries since the direct transition to a distributed power generation system would happen without the creation of a power grid as found in North America. Today, NRC Institute for Fuel Cell Innovation (NRC-IFCI) is actively involved in collaborations with these countries and is confident that NRC technology will have a strong impact on these countries' economy.

NRC is also involved in consultations with other key players in global human development such as IDRC and CIDA to explore ways to direct and leverage Canada's research and technology efforts towards transitional and developing countries, particularly in areas such as biotechnology and sustainable development. As well, NRC is committed to work with Dr. Peter Singer of the University of Toronto's Joint Centre for Bioethics, to examine, in a vein similar to his work on the top 10 biotechnologies for the developing world (Daar *et al.*, 2002), the top 10 nanotechnologies for the developing world.

NRC has been instrumental in efforts to develop a new action plan that would marshal integrated efforts of research performers inside government, universities and Canadian industry in order to leverage Canada's R&D investment for the benefit of global development. By linking domestic research capabilities with developing countries and striking new R&D alliances that can create the synergy needed to develop new approaches and bring solutions to some of the global problems, NRC could have an important role to play in helping Canada position itself as an international leader in developmental research.

Over the years NRC has responded to national and world pressures by aligning its research efforts along new priorities and reinventing itself in the process. With Innovation and Global Reach as two pillars of its Vision, NRC is again prepared and eager to rise to the challenge, fully realizing the complexity of the task.

The challenges in the developing world are profound and will not be solved simply by incremental progress. Rather, we must use our imagination. Imagine a world in which these challenges have been beaten, a world in which a global innovation system can be mobilized to meet global problems, a world in which the developing world provides efficient new markets, a world in which the developing world leads effective partnerships, and a world in which the developing world has efficient innovation systems of its own. Having imagined that new world we must chart bold new strategies to get there. These strategies may become Canada's challenge for the new century and these strategies could define Canada's place in the world.

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CAN GM CROPS PLAY A ROLE IN DEVELOPING COUNTRIES?

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In 2002, while more than 14 million people in six drought-stricken southern African countries faced the risk of starvation, efforts by the U.N.'s World Food Programme were stifled by the global "GM" food controversy. Food aid, containing kernels of bioengineered corn from the United States, was initially rejected by all six governments, even though the very same corn has been consumed daily by hundreds of millions in North and South America and has been distributed by the World Food Programme throughout Africa since 1996.

Four of those governments later accepted the grain on condition that it be milled to prevent planting, but Zimbabwe and Zambia continue to refuse to this day, and recently Angola also joined this group. Zambian President Levy Mwanawasa said his people would rather starve than eat bioengineered food, which he described as "poison." The actually starving Zambian people felt differently, though. One news report after another described scenes of hungry Zambians rioting and overpowering armed guards trying to release tens of thousands of tons of the corn locked away in warehouses by the government.

This is one of the tragic consequences of global fearmongering about recombinant DNA technology and bioengineered crops. Although many varieties that are of use to resource-poor farmers in less developed countries are at very early stages of the development process, even ones that have already been commercialized in such countries as Canada and the United States are being kept from farmers by governments skeptical of "genetic modification".

In the most fundamental sense, however, all plant and animal breeding involves -- and always has involved -- the intentional genetic modification of organisms. And though critics of recombinant DNA believe it is unique, there have always been Cassandras to claim that the latest technology was unnatural, different from its predecessors, and inherently dangerous.

As early as 1906, Luther Burbank the noted plant breeder said that, "We have recently advanced our knowledge of genetics to the point where we can manipulate life in a way never intended by nature. We must proceed with the utmost caution in the application of this new found knowledge," a quip that one might just as easily hear today regarding recombinant DNA modification.

But just as Burbank was wrong to claim that there was some special danger in knowledge or technology, so are today's skeptics wrong to believe that modern genetic modification poses some inherent risk. It is not genetic modification *per se* that generates risk. Recombinant DNA-modified, conventionally modified, and unmodified plants could all prove to be invasive, harm biodiversity, or be harmful to eat. It is not the technique used to modify organisms that makes them risky. Rather risk arises from the characteristics of individual organisms, as well as how and where they are used.

That is why the use of bioengineering technology for the development of improved plant varieties has been endorsed by dozens of scientific bodies. The UN's Food and Agriculture Organization and World Health Organization, the UK's Royal Society, the American Medical Association, and the French Academies of Medicine and Science, among others, have studied bioengineering techniques and given them a clean bill of health. Moreover, bioengineered crop plants may be of even greater value in less developed countries than in industrialized ones.

In a report published in July 2000, the UK's Royal Society, the National Academies of Science from Brazil, China, India, Mexico, and the U.S., and the Third World Academy of Science, embraced bioengineering, arguing that it can be used to advance food security while promoting sustainable agriculture. "It is critical," declared the scientists, "that the potential benefits of GM technology become available to developing countries." And an FAO report issued in May 2004 argued that "effective transfer of existing technologies to poor rural communities and the development of new and safe biotechnologies can greatly enhance the prospects for sustainably improving agricultural productivity today and in the future," as well as "help reduce environmental damage caused by toxic agricultural chemicals."

Today, some 740 million people go to bed daily on an empty stomach, and nearly 40,000 people—half of them children—die every day due to hunger- or malnutrition-related causes. Despite commitments by industrialized countries to increase international aid, Africa still is expected to have over 180 million undernourished citizens in 2030, according to a report published this year by the UN Millennium Project Task Force. Although bioengineered crops alone will not eliminate hunger, they can provide a useful tool for addressing the many agricultural problems in Africa, Asia, Latin America, and other poor tropical regions.

Indeed, recombinant DNA-modified crops have already increased crop yields and food production, and reduced the use of synthetic chemical pesticides in both industrialized and less developed countries. These advances are critical in a world where natural resources are finite and where hundreds of millions of people suffer from hunger and malnutrition. Critics dismiss such claims as nothing more than corporate public relations puffery. However, while it is true that most commercially available bioengineered plants were designed for farmers in the industrialized world, the increasing adoption of biotech varieties by underdeveloped countries over the past few years demonstrates their broader applicability.

Globally, bioengineered varieties are now grown on more than 165 million acres (67.7 million hectares) in 18 countries, such as Argentina, Australia, Brazil, Canada, China, India, Mexico, the Philippines, South Africa, and the United States, according to the International Service for the Acquisition of Agri-Biotech Applications (ISAAA). Nearly one-quarter of that acreage is farmed by some 6 million resource-poor farmers in less developed countries. Why? Because they see many of the same benefits that farmers in industrialized nations do.

The first generation of biotech crops—approximately 50 different varieties of canola, corn, cotton, potato, squash, soybean, and others—were designed to aid in protecting crops from insect pests, weeds, and plant diseases. As much as 40 percent of crop productivity in Africa and Asia and about 20 percent in the industrialized countries of North America and Europe is lost to these biotic stresses, despite the use of large amounts of insecticides, herbicides, and other agricultural chemicals. Poor tropical farmers may face different pest species than their industrial country counterparts, but both must constantly battle against these threats to their productivity.

That's why South African and Filipino farmers are so eager to grow bioengineered corn resistant to insect pests, and why Chinese, Indian, and South African farmers like biotech insect-resistant cotton so much. Indian cotton farmers and Brazilian and Paraguayan soy growers didn't even wait for their governments to approve biotech varieties before they began growing them. It was discovered in 2001 that Indian farmers were planting seed obtained illegally from field trials of a biotech cotton variety then still under governmental review. Farmers in Brazil and Paraguay looked across the border and saw how well their Argentine neighbors were doing with transgenic soybean varieties and smuggling of bioengineered seed became rampant.

When the Indian government finally approved bioengineered cotton in 2002 for cultivation in seven southern states it proved to be highly successful. A study conducted by the University of Agriculture in Dharwad found that more insect damage was done to conventional hybrids than to the bioengineered variety and that the bioengineered cotton reduced pesticide spraying by half or more, delivering a 30-40 percent profit increase.

During the 2002-2003 growing season, some Indian cotton farmers saw no increased yield from the more expensive biotech varieties, but droughts during that year generated harsh conditions throughout India's southern cotton belt. Many growers of conventional crop varieties also suffered unanticipated and tragic crop losses. Most of the farmers who grew bioengineered cotton decided to plant it again in 2003, however, and total planted acreage grew from approximately 1 million acres in 2002-2003 to an estimated 3.3 million acres in 2003-2004.

When the planting of bioengineered soybean was provisionally legalized in Brazil for the 2003-2004 growing season, over 50,000 farmers registered their intent to plant it -- including almost 98 percent of the growers in the southern-most state of Rio Grande do Sul, where the soybeans originally bred for Argentine climatic conditions will grow best. What is especially noteworthy is that the government decree did not legalize commercial sales of the biotech soybean, it only authorized the planting of illegal seed already in the possession of farmers. Thus, by registering their intent to grow the bioengineered variety, farmers were informing the government of their prior guilt.

There are few greater testaments to the benefits of biotechnology than the fact that thousands of poor farmers are willing to acknowledge having committed a crime just to gain access to the improved varieties. The clear lesson is that, where bioengineered varieties become available (legal or not), most farmers themselves are eager to try them.

There is even evidence that biotech varieties have literally saved human lives. In less developed nations, pesticides are typically sprayed on crops by hand, exposing farm workers to severe health risks. Some 400 to 500 Chinese cotton farmers die every year from acute pesticide poisoning because, until recently, the only alternative was risking near total crop loss due to voracious insects. A study conducted by researchers at the Chinese Academy of Sciences and Rutgers University in the U.S. found that adoption of bioengineered cotton varieties in China has lowered the amount of pesticides used by more than 75 percent and reduced the number of pesticide poisonings by an equivalent amount. Another study by economists at the University of Reading in the U.K. found that South African cotton farmers have seen similar benefits.

"When the Indian government finally approved bioengineered cotton in 2002 ... it proved to be highly successful."

The productivity gains generated by bioengineered crops provide yet another important benefit: they could save millions of acres of sensitive wildlife habitat from being converted into farmland. The loss and fragmentation of wildlife habitats caused by agricultural encroachment in regions experiencing the greatest population growth are widely recognized as among the most serious threats to biodiversity. Thus, increasing agricultural productivity is an essential environmental goal, and one that would be much easier in a world where bioengineering technology is in widespread use.

Opponents of biotechnology argue that organic farming can reduce pesticide use even more than bioengineered crops can. But organic farming practices are less productive, because there are few effective organic controls for insects, weeds, or pathogens. Converting from modern, technology-based agriculture to organic would mean either reducing global food output significantly or sacrificing undeveloped land to agriculture. Moreover, feeding the anticipated population of eight or nine billion people in the year 2050 will mean increasing food production by at least 50 percent.

As it is, the annual rate of increase in food production globally has dropped from 3 percent in the 1970s to 1 percent today. Additional gains from conventional breeding are certainly possible, but the maximum theoretical yields for most crop plants are being approached rapidly. Despite the simplistic claims made by critics of plant technology, providing genuine food security must include solutions other than mere redistribution. There is simply no way for organic farming to feed a global population of nine billion people without having to bring substantially more land into agricultural use. Dramatically improving crop yields will prove to be an essential environmental and humanitarian goal.

We have already realized significant environmental benefits from the biotech crops currently being grown, including a reduction in pesticide use of 20 million kg in the U.S. alone. A

2002 Council for Agricultural Science and Technology report also found that recombinant DNA-modified crops in the US promote the adoption of conservation tillage practices, resulting in many other important environmental benefits: 37 million tons of topsoil preserved; 85 percent reduction in greenhouse gas emissions from farm machinery; 70 percent reduction in herbicide run-off; 90 percent decrease in soil erosion; and from 15 to 26 liters of fuel saved per acre.

And, as we have seen, while the first generation of bioengineered crops was not designed with poor tropical farmers in mind, these varieties are highly adaptable. Examples of the varieties that now are being designed specifically for resource-poor farmers include virus-resistant cassava, insect-resistant rice, sweet potato, and pigeon pea, and dozens of others. Chinese scientists, leaders in the development of both bioengineered and conventional rice have been urging their government to approve commercialization of their biotech varieties that have been thoroughly tested and ready for market for several years.

The next generation of products, now in research labs and field trial plots, includes crops designed to tolerate climatic stresses such as extremes of heat, cold, and drought, as well as crops designed to grow better in poor tropical soils high in acidity or alkalinity, or contaminated with mineral salts. A Mexican research group has shown that tropical crops can be modified using recombinant DNA technology to better tolerate acidic soils, significantly increasing the productivity of corn, rice and papaya. These traits for greater tolerance to adverse environmental conditions would be tremendously advantageous to poor farmers in less developed countries, especially those in Africa.

Africa did not benefit from the Green Revolution as much as Asian and Latin American nations did because plant breeders focused on improving crops such as rice and wheat, which are not widely grown in Africa. Plus, much of the African dry lands have little rainfall and no potential for irrigation, both of which play essential roles in productivity success stories for crops such as Asian rice. And the remoteness of many African villages and the poor transportation infrastructure in landlocked African countries make it difficult for African farmers to obtain agricultural chemical inputs such as fertilizers, insecticides and herbicides -- even if they could be donated by aid agencies and charities. But, by packaging technological inputs within seeds, biotechnology can provide the same, or better, productivity advantages as chemical or mechanical inputs, but in a much more user-friendly manner. Farmers could be able to control insect pests, viral or bacterial pathogens, extremes of heat or drought and poor soil quality, just by planting these crops.

And the now-famous Golden Rice, with added beta carotene, is just one of many examples of bioengineered crops with improved nutritional content. Indian scientists have recently announced development of a new high-protein potato variety available for commercial cultivation. Another team of Indian scientists, working with technical and financial assistance from Monsanto, is developing an improved mustard variety with enhanced beta-carotene in its oil. One lab at Tuskegee University is enhancing the level of dietary protein in sweet potatoes, a common staple crop in sub-Saharan

Africa. Researchers are also developing varieties of cassava, rice, and corn that more efficiently absorb trace metals and micronutrients from the soil, have enhanced starch quality, and contain more beta-carotene and other beneficial vitamins and minerals.

Ultimately, while no assurance of perfect safety can be made, breeders know far more about the genetic makeup, product characteristics, and safety of every modern bioengineered crop than those of any conventional variety ever marketed. Breeders know exactly what new genetic material has been introduced. They can identify where the transferred genes have been inserted into the new plant. They can test to ensure that transferred genes are working properly and that the nutritional elements of the food have been unchanged. None of these safety assurances have ever before been made with conventional breeding techniques. We have always lived with food risks. But modern genetic technology makes it increasingly easier to reduce those risks.

Societal anxiety over the new tools for genetic modification is, in some ways, understandable. It is fueled by a variety of causes, including consumer unfamiliarity, lack of reliable information on the current safeguards in place, a steady stream of negative opinion in the news media, opposition by activist groups, growing mistrust of industry, and a general lack of awareness of how our food production system has evolved over time. But saying that public apprehension over biotechnology is understandable is not the same as saying that it is valid. With more than thirty years of experience using recombinant DNA technology, and nearly two decades worth of pre-commercial and commercial experience with bioengineered crop plants, we can be confident that it is one of the most important and safe technologies in the plant breeder's toolbox. It would be a shame to deny biotechnology's fruits to those who are most in need of its benefits.

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DROUGHT TOLERANT CROPS AND TRANSGENIC BREEDING: JUST A UTOPIAN VISION?

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Agriculture has been expanding to meet growing food needs, and this has led to deteriorating growing conditions in many parts of the world. Desertification, erosion, and salinization of soils are the consequences and at the same time the causes of these developments. Currently, about 20% of farmland around the world is irrigated, and this land produces 40% of the global food supply. Drought and water shortages threaten the ability of many developing countries, especially those in Africa, to feed themselves.

"Drought and water shortages threaten the ability of many developing countries, especially those in Africa, to feed themselves."

Abiotic stress reactions, especially to water deficiency and high levels of salt, are complex morphological and physiological phenomena in plants (Evans *et al.* 1975, Wang *et al.* 2003). At the cellular level, water shortages cause osmotic stress. There is a flux of water from the cells as a result of alterations in extracellular solute concentrations. This water loss causes a decrease in turgor and an increase in concentrations of intracellular solutes, which puts a strain on membranes and macromolecules. Acute water deficiency impairs photosynthesis (Gallagher *et al.*, 1975). If chloroplasts are exposed to excess excitation energy at the same time, water deficiency leads to the production of toxic substances such as superoxides and peroxides, which damage membranes and enzymes, in the cell.

The activity of osmoprotective compounds most likely mediates biochemical functions such as ion exclusion, ion export, cell wall modification, osmotic adjustments, and osmoprotection, which are involved in the response of the plant cell to osmotic stress. Furthermore, plant cells contain antioxidant enzyme systems, such as peroxidases and superoxide dismutases, which scavenge reactive oxygen intermediates (Moffat 2002; Yoshimura 2000). Plants commonly transport sodium ions to vacuoles, which are huge storage compartments and a hallmark of plant cells (Carden *et al.* 2003).

Several traits are responsible for plant tolerance to this stress (Reddy *et al.* 2002). Many characters are highly hereditary and also additive, which indicates that there is considerable room for improvement to abiotic stresses. Outstanding results obtained by breeders in different crops prove these observations.

The first molecular approach to help breeders in their efforts to increase drought tolerance has been with molecular markers, genomics and "post-genomics strategies" (Nguyen *et al.* 2004; Lanceras *et al.*2004; Robertson 1989). The dissection of the genetic basis of quantitative traits into their single components, the so-called QTLs (Quantitative Trait Loci), provides direct access to valuable genetic diversity for important physi-

Harvesting wheat with a sickle in Syria.
(CIMMYT Photo, Courtesy of CGIAR)

ological processes that regulate the adaptive response to drought (Wayne and McIntyre 2002; Masahiro and Takuji 1997). This allows scientists/breeders to deploy marker-assisted selection (MAS) for enhancing crop performance in breeding regimes. However, despite impressive progress in molecular techniques and the large number of QTLs described that influence yield in drought-stressed crops, the overall impact of MAS and other genomics applications on the release of drought-resilient cultivars has so far been marginal (Quarrie *et al.* 1997; Tuberosa, 2004). QTL discovery should be viewed as the first step of a longer process aimed at identifying and isolating the underlying molecular polymorphism of the functional variation revealed through QTL analysis.

Harvesting wheat.
(CIMMYT Photo, Courtesy of CGIAR)

The use of transgenics to provide enhanced drought tolerance is still experimental in nature, though progress is being made (Dubouzet *et al*., 2003; Garg *et al.*, 2002; Kasukabe *et al*., 2004; Pellegrineschi *et al.*, 2004). The obvious next step is to investigate the impact of the introduced gene by measuring the growth and yield of transgenic plants in a field environment. This is an important step because the desiccation stress applied to the transgenic plants to evaluate their response has until now been done under greenhouse conditions that do not fully represent the environment in the field. Under greenhouse conditions, transgenic plants are grown in small pots that have less soil volume than the field has, and they are subjected to rapid stress cycles that range from an hour to several days. When stress is imposed rapidly, a greater number of responses will be injury-induced than under a slower, long-term application of water-deficit stress.

South Asian farmers winnowing wheat.
(CIMMYT Photo, Courtesy of CGIAR)

The three most important elements of drought characterization for successful stress tolerance breeding are probably timing, duration, and stress intensity. For most crops, including wheat, drought tends to develop slowly as the soil dries out. Plants that are subjected to drought conditions in this gradual manner accumulate solutes that maintain cell hydration and undergo complex adjustments in their morphology and physiological characteristics. Since most experiments that have been published thus far are based on a rapid, severe water deficit treatment, it is important to conduct experiments under conditions that more closely approximate stress development in the field. Such an experiment will permit a better understanding of the potential functions of the introduced gene in stress tolerance.

Several genes have been tested that have great potential to help us understand and manipulate plant stress response (Pflieger *et al.* 2002). Work done in wheat at CIMMYT headquarters in El Batan, Mexico is a recent example of this strategy (Pellegrineschi *et al.* 2004). An earlier study focused on transgenic wheat for the *DREB/CBF* (*DRE-binding protein/ C-repeat binding factor*), which showed enhanced resistance to moisture stress in greenhouse conditions. The objective of the latest study is to understand the principal effects of the *DREB/CBF* gene in transgenic wheat under a prolonged drought stress cycle.

Preliminary field testing of the transgenic lines showed a lower canopy temperature (1-2° Celsius less) and, in general, the transgenic lines showed a relatively higher water content, more biomass, lower chlorophyll content, and increased seeds production. The transgenic lines responded better to returning their normal phenotype after irrigation (rehydratation) and were better able to continue and complete the normal field cycle, ultimately producing viable seeds and a higher grain yield. Clearly, these results need to be verified in a larger trial with selected transgenic lines.

This trial is the first time that a food crop carrying the *DREB* gene has advanced to this level of testing. Following this trial, CIMMYT wishes to test other *DREB* genes isolated from rice by Dr. Yamaguchi-Shinozaki (JIRCAS) as well as the soluble starch synthase (*SSS*) gene. Conventional wheat will be transformed with these genes to determine whether the resulting plants can use water as efficiently as, or more efficiently than wheat expressing the recently tested *DREB* gene. Increasing the expression of the *SSS* gene, a key enzyme involved in amylopectin biosynthesis, is believed to increase the speed of grain filling, which is one of the major problems caused by drought stress. The synthesis of starch in the endosperm of cereals occurs via an enzymatic mechanism that uses ADPglucose as the glucosyl donor. In barley and other cereals ADPglucose is thought to be synthesized by separate ADPglucose pyrophosphorylases located in the cytoplasm and in the amyloplast, and the chain elongation (starch synthases) involving branching and debranching enzymes occur in the amyloplast.

Given that the initial *DREB1A* wheat transgenics do not meet CIMMYT standards for GM products (e.g., low copy, contains marker genes), scientists are now developing transgenic wheat lines that meet the Center's criteria. This will be done in collaboration with scientists in Chile and Argentina where such transgenic products could be tested and potentially deployed. CIMMYT will also develop similar transgenic lines containing the additional *DREB* genes obtained from JIRCAS and the *SSS* gene. It is anticipated that if the *DREB1A* wheat lines continue to perform well, a full proposal will be developed that will ultimately lead to the safe and effective deployment of these products to National Agricultural Research Systems in the Americas, Africa, and Asia.

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APPLYING BIOTECHNOLOGY IN BANANA AND PLANTAIN: IMPLICATIONS FOR DEVELOPING COUNTRIES

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Introduction

Banana and plantain are important crops for developing countries in two distinct, but interlinked, ways. In the first instance, bananas, usually one of the closely related Cavendish varieties exported to industrialised countries, are an important source of foreign exchange and employment, especially for developing countries in Latin America and the Caribbean, but also to a lesser extent in Africa and South-East Asia. Secondly, a great diversity of dessert bananas, cooking bananas and plantains are consumed locally and sold into local markets in more than 100 countries, providing both a major staple food and an important source of income for some 400 million people, especially in South and South-East Asia, Africa, and in parts of South America. Despite the prominence of the commercial export banana in international trade, it is the latter, local-consumption sector, that accounts for some 87% of global production. The two sectors are linked both through sharing of technologies and, to some extent, through the spill-over of problems, including pest and disease threats, environmental hazards and the impacts of economic fluctuations. A range of biotechnologies are of actual or potential importance to both the genetic improvement and the production of banana and plantain. Many of these technologies were initially developed in the public sector and targetted towards locally-consumed bananas and plantains but such technologies are now being re-applied on a large scale, or are being specifically developed, in the private sector for use in export bananas.

Much of the interest in using biotechnologies in banana and plantain is stimulated by a suite of disease and pest problems that are broadly shared across regions and across the large-scale commercial and smallholder sectors, though their relative importance and the nature of the solutions proposed differs among regions and sectors. Two fungal diseases are of over-riding importance. Panama disease, a vascular wilt caused by *Fusarium oxysporum* f. sp. cubense, was largely responsible for the demise of the first widely-grown commercial banana variety, Gros Michel, and the spread of new races of this pathogen now threatens its successors, the various forms of Cavendish. The second, black leaf streak disease (popularly known as 'black Sigatoka'), caused by *Mycosphaerella fijiensis*, is the most widespread and important of three major species of leaf-spot diseases affecting banana and plantain, and stimulates heavy applications of fungicide in commercial plantations, accounting for some 40% of the cost of production. Plant parasitic nematodes, of which the most widespread and important is *Radopholus similis*, are important throughout the tropics, leading many commercial producers to apply nematicides that are expensive, as well

Plants being "hardened" in a shade house in preparation for planting out in the field.

as hazardous to the health of workers and the environment, while the banana weevil, *Cosmopolites sordidus*, is mainly important where banana or plantain production involves long-lived plantings, especially in Africa. Finally, three virus diseases are of major importance. Banana streak badnavirus is of limited economic impact but acts mainly as a constraint to the exchange of germplasm because some forms of this highly variable virus become fully integrated into the 'B genome' of certain banana and plantain (see below) and may subsequently be expressed, under circumstances that are not fully understood. Banana bunchy top babuvirus and banana bract mosaic potyvirus cause locally serious losses in several Asian countries. Biotechnology-based solutions are either already being applied or are under development for all of these problems.

The special incentive to use biotechnology to address problems in banana breeding and production arises from the domestication of banana and plantain as parthenocarpic, vegetatively propagated crops, which are now functionally sterile. Commercially-grown export bananas are triploid varieties, denoted as 'AAA' because their genome derives from wild *Musa acuminata* ('A genome'), while plantains and the various locally consumed dessert and cooking bananas, may be diploid, triploid or, in the case of modern hybrids, tetraploid, and their genome may derive, either from *M. acuminata* or *Musa balbisiana* ('B genome'), or from various combinations of the two. Domesticated banana and plantain varieties tend to be highly sterile, making cross-breeding a slow process, complicated by the different ploidy levels of potentially interesting breeding parents. Crossing cultivars with fertile wild relatives, or their immediate improved derivatives, offers the possibility of bringing desirable traits into the crop, including disease resistance, but disrupts desirable agronomic or fruit characteristics, many of them complex traits under the control of multiple genes, that may be critical to acceptability for either commercial production or local consumption.

Biotechnology is important in conserving the genetic diversity that provides the foundation for breeding and in providing various tools to facilitate conventional breeding. It provides ways to multiply and disseminate improved varieties and new options that offer alternatives to conventional production systems threatened by disease outbreaks and, through transgenic approaches, promises new solutions to the problems posed by pests, diseases and other production constraints. This review looks briefly at the ways in which biotechnology has already proved of value in banana and plantain conservation, breeding and production, before reviewing the state of the art in genetic modification of Musa, which for the moment offers considerable promise but has yet to deliver finished technologies to either the large-scale commercial or smallholder sector.

In vitro *conservation of germplasm*

Because domesticated banana and plantain are seedless, genetic diversity must be maintained either in field collections of plants, which are costly to maintain and vulnerable to disease outbreaks and adverse weather, or in *ex situ* collections as *in vitro* plants derived from culture of meristem tissue. Most varieties in the international Musa germplasm collection are now stored in this way at Leuven, Belgium, under the auspices of the United Nations Food and Agriculture Organization (FAO). Under low light and low temperature, each accession needs to be sub-cultured only once a year and, after due precautions to exclude viruses (including cryotherapy and/or thermotherapy, followed by third-party indexing), clean plants can be readily distributed to users around the world. Further reductions in costs and an increase in long-term security are now possible with the development of cryopreservation techniques, involving the storage of meristems in liquid nitrogen, a technique which avoids the occurrence of somaclonal variants that are common in Musa and allows accessions to be safely stored indefinitely. By 2006 it is expected that a duplicate of the entire Musa collection will be cryopreserved, making this the first complete crop genebank to be managed in this way.

Biotechnology in support of genetic improvement

Although most of the banana and plantain varieties currently in large-scale production have arisen either from farmer selection of naturally occurring mutants or from conventional breeding, various biotechnology-based tools have recently been deployed by Musa breeders and used to produce high-yielding, disease-resistant, improved varieties.

Flow cytometry allows the rapid determination of ploidy levels in potential breeding parents and has been used to determine the ploidy level of the entire international Musa germplasm collection, while various molecular techniques (STMS, RFLP, RAPD, AFLP) have already been applied to characterize Musa diversity. Under a project of the Generation Challenge Programme of the Consultative Group on International Agricultural Research (CGIAR), launched in 2003, the most effective markers are being identified and used to characterize the majority of available varieties (some 1000 accessions) of banana and plantain. The results will be made available on-line, along with morphological characterizations and field performance evaluation data already available, in the Musa Germplasm Information System. In addition, more and more sequences of the banana genome are becoming available, as well as molecular probes for specific plant characteristics such as dwarf growth habit, that allow such traits to be identified without having to grow plants to maturity in costly field trials. Building partly on knowledge already available from other crops, especially rice, the Global Musa Genomics Consortium has been formed to coordinate the search for knowledge of the Musa genome, including structural and functional genomics, that will facilitate conventional breeding as well as providing a platform for transgenic approaches.

Conventional breeding benefits from *in vitro* culture in several ways, including rapid multiplication of selected parents to increase the number of identical crosses that can be made (and so increase the initially very low probability of obtaining useful seed), the management of growth cycles to ensure simultaneous flowering and the rescue of embryos resulting from crosses which might not otherwise be viable. After intensive multi-site evaluation organized under the International

An African scientist practicing tissue culture techniques.

Musa Testing Programme, promising varieties can be rapidly multiplied for distribution to farmers. In northern Tanzania, for instance, the rapid multiplication and dissemination of 24 cultivars resulted in the cultivation of 2.5 million plants of improved varieties, in addition to local disease-susceptible cultivars, and provided yield increases of 22 to 150%. Similar projects, involving evaluation by farmers and dissemination using tissue culture, are now under way in at least 15 countries in Africa, Latin America and Asia.

Novel production systems

Banana was one of the first crops to use *in vitro* multiplication widely in the commercial production of planting material. Commercial tissue culture laboratories in countries such as France, Israel, Costa Rica and South Africa annually supply several million plants to large-scale growers mainly in Latin America and Africa, achieving gains in uniform plant establishment and the reduction of soil-borne pests and diseases. In Asia, especially in Taiwan and the Philippines, the adoption of short-duration production cycles, based on the massive use of tissue culture plants, has allowed large-scale production to continue in the face of intense disease pressure, in particular from Fusarium wilt and banana bunchy top babuvirus. Economies of scale have minimized the costs of producing plants *in vitro* and, especially in Taiwan, the systematic collection of somaclonal variants has allowed disease-tolerant materials to be identified and established in commercial production. Routine use of tissue culture planting material and short-duration cropping is now being developed to help small-scale growers to overcome disease problems, for instance in the Philippines where banana bunchy top babuvirus has been particularly destructive. Short-term production of plantains, coupled with measures such as the use of green manure cover crops, is being developed in various Latin American and African countries as a strategy for combating declining soil fertility and soil-borne pests, especially nematodes.

Genetic modification of Musa

In view of the constraints to conventional breeding of banana and plantain already mentioned, the case for using transgenic approaches to improve these crops is particularly compelling. In addition, the lack of cross-fertile wild relatives in many banana-producing areas, as well as the male and female sterility of most edible bananas and plantains, reduces to negligible levels the risk of gene escape. During the 1990s, after the public sector had developed the transformation technology, large-scale commercial producers of banana invested considerable additional resources in the search for transgenic solutions, especially to the problems of black leaf streak disease and nematodes. They made considerable progress but failed to reach the stage of deploying commercially useful varieties. This effort has left a legacy of relevant technologies but the use of many of them, at least beyond the stage of experimentation, is severely limited by intellectual property constraints, many of which remain ill-defined in the absence of a clear policy on the use of transgenic banana by the private sector.

Considerable progress has thus been made in the areas of (1) developing cell suspensions, (2) transforming these cells through particle bombardment or using Agrobacterium, (3) achieving high expression of foreign genes, (4) inserting or introgressing multiple genes, (5) inserting resistance gene analogues from banana and (6) developing fungal resistance. Many hundreds of transformed lines have been generated and screened under greenhouse conditions in Belgium for disease resistance and the most promising lines of transgenic bananas and plantains are currently being evaluated in the greenhouse and field in Cuba and Costa Rica.

Elsewhere in developing countries, Uganda opened a national biotechnology centre during 2003, with support from an international consortium of research organizations, which is specifically tasked with developing transgenic, pest- and disease-resistant varieties of the East African highland banana varieties that provide the national staple food, matooke. Meanwhile, national research groups in Colombia and South Africa are developing and evaluating transgenic resistance to black leaf streak disease, banana weevil and nematodes. For viruses, a transgene that induces a hypersensitive response has been developed in Australia to provide resistance to banana bunchy top babuvirus while posttranscriptional gene silencing is expected to provide resistance to banana bract mosaic potyvirus. In the UK and Nigeria a gene silencing approach has also been pursued for banana streak badnavirus, though its success may be constrained by the extreme variability of this virus.

Genetic modification of banana has also been considered as a path towards increasing the value of this crop to health and nutrition in developing countries. As a crop that is widely consumed as a weaning food by children and as a starchy staple by all sectors of the community in some countries, banana has been advocated as a carrier for vaccines and as a source of carotenoids that can counteract debilitating Vitamin A deficiency. However, although much of the necessary technology is now available, these applications have yet to advance to the stage of practical evaluation.

In the absence of commercial transgenic banana varieties, there has not been the level of private sector investment in biosafety testing that has preceeded the introduction of, for instance, genetically modified maize and cotton to developing countries. However, with the entry of countries such as Brazil and South Africa, which already have substantial areas of transgenic crops, into the field of genetic modification of Musa, more rapid progress is now likely. Meanwhile a number of developing countries are putting in place the necessary legal

Bananas being grown in a greenhouse in Leuven.

framework for testing and dissemination of genetically modified crops, either specifically in order to facilitate the development of transgenic bananas, as in the case of Uganda, or in order to benefit from a range of transgenic crops that may in due course include banana and plantain.

Conclusion

In view of the tremendous losses incurred by smallholder Musa farmers due to pest and disease attack, and the economic, environmental and health costs associated with plant protection measures in large-scale commercial plantations of banana, it is very much to be hoped that the remaining technical, intellectual property and regulatory obstacles to the deployment of transgenic bananas and plantain can soon be overcome. It is not anticipated that transgenic varieties will threaten the diversity of existing varieties grown by banana farmers. Rather, studies in East Africa suggest that varieties modified for pest- or disease-resistance will be incorporated into the range of varieties already grown as part of a strategy to reduce risk, provide multiple products and satisfy varying tastes. In the meantime, various biotechnologies are already contributing to conventional breeding efforts and are expected to become even more effective in this area as genetic maps and markers are refined. The use of tissue culture plants is already contributing to the development of novel production systems for smallholder farmers and, as part of a balanced programme of deploying biotechnologies cost-effectively in developing countries, tissue culture is expected to be much more widely used in increasing the productivity and sustainability of such systems in the future.

Further reading

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