# Agricultural Biotechnology and the Poor: Promethean Science

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Prometheus, according to Greek mythology, was a Titan, responsible for introducing fire to humans, a remarkable innovation at the time, but having benefits and risks, depending on its use. *Promethean* has since come to mean *daringly original and creative.*

Science is an elegant way of getting at the truth, according to science writer Rick Weiss. It should follow then that molecular biology and other tools of modern biotechnology add elegance and precision to the pursuit of solutions to thwart poverty, malnutrition and food insecurity in too many countries around the world. In agriculture these enemies are manifest as pests, diseases, drought and other biotic and abiotic stresses that limit the productivity of plants and animals.

But not all appreciate the elegance of science in the pursuit of truth. The current debate about the potential utility of modern biotechnology for food and agriculture presents a challenge for modern science to contribute to the solution of human problems. This debate is currently focused on the initial applications of modern biotechnology in industrial country agriculture and its potential risks to human health and the environment. It is also intertwined with other often understated societal concerns such as food safety, animal welfare, industrialized agriculture, and the global role of large private-sector corporations.

A debate based on the best available empirical evidence on the relevance of modern science for poor people in developing countries is urgently needed. Its purpose would be to identify the most appropriate ways that molecular biology-based research might contribute to the solution of poor people's problems. These problems and the socioeconomic context in which they occur are so different from the problems and context of the countries where most of the biotechnology debate currently takes place that the positions and conclusions from the current debate are largely irrelevant for poor farmers and poor consumers in developing countries. Despite this, many of the arguments in the current debate are extrapolated to conclusions about the potential utility of biotechnology for poor countries and poor people. There is an urgent need for a more focused debate on the role of modern agricultural biotechnology in developing countries, a debate that should and is being led by people from developing countries themselves (Pinstrup-Andersen and Cohen 2000).

Because land and water for agriculture are diminishing resources, there is no option but to produce more food and other agricultural commodities from less arable land and irrigation water. The need for more food has to be met through higher yields per units of land, water, energy and time. As Swaminathan (2000) says, "*we need to examine how science can be mobilized to raise further the biological productivity ceiling without associated ecological harm. Scientific progress on the farms, as an ever-green revolution, must emphasize that the productivity advance is sustainable over time since it is rooted in the principles of ecology, eco-*

*nomics, social and gender equity, and employment generation."*

## Current Status of Agricultural Biotechnology

### *The Gene Revolution*

Mendel's laws of genetics were rediscovered in 1900. Mendel had published his work on inheritance patterns in pea in 1865, but it took 35 years for others to grasp their significance. Since 1900, we have witnessed steady progress in our understanding of the genetic makeup of all living organisms ranging from microbes to humans. A major step in human control over genetic traits was taken in the 1920s when Muller and Stadler discovered that radiation can induce mutations in animals and plants.

In the 1930s and 1940s, several new methods of chromosome and gene manipulation were discovered, such as the use of colchicine to achieve a doubling in chromosome number, commercial exploitation of hybrid vigor in maize and other crops, use of chemicals such as nitrogen mustard and ethyl methane sulphonate to induce mutations, and techniques such as tissue culture and embryo rescue to make viable hybrids from distantly related species. The double helix structure of DNA (deoxyribonucleic acid), the chemical substance of heredity, was discovered in 1953 by James Watson and Francis Crick. This triggered explosive progress in every field of genetics. As we head into the 21st century, we see a rapid transition from Mendelian to molecular genetic applications in agriculture, medicine, and industry.

This brief capsule of genetic progress from 1900 to 1999 (Swaminathan 2000) stresses that knowledge and discovery represent a continuum, with each generation taking our understanding of the complex web of life to a higher level. It would therefore be a mistake to worship or discard experimental tools or scientific innovations because they are either old or new. Just as it took 35 years for biologists to understand fully the significance of Mendel's work, it may take a couple of decades more to understand fully the benefits and risks associated with new genetically improved organisms.

The 1990s have seen dramatic advances in our understanding of how biological organisms function at the molecular level, as well as in our ability to analyze, understand, and manipulate DNA molecules, the biological material from which the genes in all higher organisms are made. The entire process has been accelerated by the Human Genome Project, which has invested substantial public and private resources into the development of new technologies to work with human genes. The same technologies are directly applicable to other organisms, including plants and animals. Thus, the new scientific discipline of *genomics* has arisen, which has contributed to powerful new approaches to identify the functions of genes and their application in agriculture and medicine. These new discoveries and their commercial application have helped to promote the biotechnology industry, mainly in North America and Europe.

Several large corporations in Europe and the United States have made major investments to adapt these technologies to produce improved plant varieties of agricultural importance for large-scale commercial agriculture. The same technologies have equally important potential applications to address food security and poverty of people in developing countries (see Box 1).

## Agricultural Biotechnology in Developing Countries

The current use of modern biotechnology in Asia, Latin America and the Caribbean, sub- Saharan Africa, and West Asia/North Africa was reviewed at an international conference in October 1999 in Washington D.C. Senior policymakers from these regions led the discussion by addressing the following questions:

- What are the challenges?
- What are the opportunities for deploying biotechnological approaches?
- What are the constraints to using these approaches?
- How can the international agricultural research centers (IARCs) supported by the Consultative Group on International Agricultural Research (CGIAR) further assist?

### *Asia/Pacific*

The current status of agricultural biotechnology in China, India, the Philippines, and Thailand was

### Box 1 Definitions of Biotechnology and Its Component Technologies

Biotechnology is any technique that uses a living organism or substances from those organisms to make or modify a product, improve plants or animals or develop microorganisms for specific uses. The key components of modern biotechnology are:

- *Genomics*: the molecular characterization of all species.
- *Bioinformatics:* the assembly of data from genomic analysis into accessible forms.
- *Transformation*: the introduction of one or more genes conferring potentially useful traits into plants, livestock, fish and tree species.
- *Molecular breeding*: the identification and evaluation of desirable traits in breeding programs by the use of marker assisted selection, for plants, trees, animals and fish.
- *Diagnostics:* the use of molecular characterization to provide more accurate and rapid identification of pathogens and other organisms.
- *Vaccine technology:* the use of modern immunology to develop recombinant DNA vaccines for improving control against lethal diseases.

*Source:* Persley and Doyle 1999.

reviewed at the conference. All are committed to the use of modern biotechnology in agriculture, and are investing significant human and financial resources to this policy and have done so over the past decade.

*China* sees the greatest challenge as the use of biotechnology to increase food production and improve product quality in an environmentally sustainable manner. China has moved quickly to adopt new technologies. Over 103 genes have been evaluated for improving traits in 47 plant species. The crops include rice, wheat, corn, cotton, tomato, pepper, potato, cucumber, papaya, and tobacco. A variety of traits were targeted for improvement including disease resistance, insect resistance, herbicide resistance, and quality improvement. Approximately 50 genetically improved organisms (GIOs) have been approved for commercial production, environmental release or small-scale field testing in China. In a few cases, new genetically improved varieties have been approved for large-scale commercial production. These are being grown commercially on approximately 1 million hectares of land in China in 1999. It is expected that the area planted will increase rapidly in the next few years (Zhang 2000).

*India* has allocated large public resources toward infrastructure and human resources development in biotechnology. Current efforts are toward applications in improving agricultural productivity; bioremediation in the environment; medical biotechnology for the production of new vaccines, diagnostics and drugs; industrial biotechnology; and bioinformatics (Sharma 2000). Research and development (R&D) priorities in agriculture include new regeneration protocols for rapid multiplication of citrus, coffee, mangrove, vanilla and cardamom. Yield of cardamom has increased 40 percent using tissue-cultured plants.

*Thailand* is focusing on the applications of biotechnology to traditional foods, fruits and export commodities. R&D priorities are to raise production and cut costs by using new biotechnology on crops such as rice, sugarcane, rubber, durian, and orchids. An early success in Thailand has been in the application of biotechnology to develop new molecular diagnostics for the diagnosis and control of virus diseases in shrimps. These diseases cost the shrimp export industry over US$500 million in lost production in 1996 (Morakot 2000).

*The Philippines* began its biotechnology programs in 1980 with the creation of the National Institutes of Molecular Biology and Biotechnology, with a focus on agricultural biotechnology. In 1997, the Agriculture Fisheries Modernization Act recognized biotechnology as a major strategy to increase agricultural productivity. The Act will provide a budget for agricultural biotechnology of almost US$20 million annually for the next 7 years (4 percent of the total R&D budget), an increase from US$1 million per year. In 1998, five high level biotechnology research projects were funded by government: Development of new varieties of banana resistant to banana bunchy top virus and papaya resistant to ringspot virus; delayed ripening of papaya and mango; insect-resistant corn; marker-assisted breeding in coconut; and coconut with high lauric acid content. Public concerns have been vocal in the Philippines and this is constraining the commercial use of modern biotechnology in agriculture (de la Cruz 2000).

All four countries have regulatory systems in place at the national and institutional level to govern R&D programs and commercial developments where appropriate. Intellectual property management was considered to be a difficult issue for all four countries.

### *Latin America and the Caribbean*

Agricultural biotechnology was reviewed in Brazil, Costa Rica, and Mexico, as examples of the diversity of uses and views of biotechnology across the region. The main challenges identified for the region were: management of intellectual property in relation to major and minor crops; assessment of several research options, not only a molecular approach, in assessing how best to tackle problems and challenges to improve agricultural productivity; identification of beneficiaries; prioritization of work on favored and/or marginal areas; use of GIOs as indicators of environmental damage; and need to monitor the behavior of GIOs in the environment after release. The ecological research effort for monitoring GIOs is needed to satisfy public concerns about the behavior of GIOs in the environment, and needs to focus on the key questions of : What are the specific concerns? How to do it? Who will do it? Who will pay for it?

In *Brazil*, many lines of research and development are benefiting from the application of biotechnology tools such as marker-assisted plant and animal breeding, genomic mapping of several species including sugarcane, embryo transfer applied to different animal species, genetic resources characterization and conservation, and use of genetic improvement to introduce new traits, such as papaya resistant to papaya ring spot virus and beans resistant to golden mosaic virus. The issues of field testing of genetically improved plants need to be addressed. Tropical agriculture is very different from the temperate fields where most of the new genetically improved products have been tested. Protocols are required for field trials, risk assessment (environmental and food safety), registration of products, and public acceptance. The need is urgent, because these are constraints that will intensify as new genetically improved organisms become an integral part of the research agenda in the region (Sampaio 2000).

*Mexico* was one of the first developing countries to begin the evaluation of genetically improved plants in the field, commencing in 1988, with trials of plants genetically improved for insect resistance (corn and cotton), virus resistance (potato), and delayed ripening (tomato) (Alvarez-Morales 2000). Some of these materials such as the virus-resistant potato are now being grown by Mexican farmers. There is a current debate in Mexico as to the desirability of testing genetically improved corn in Mexico, as it is the center of origin of the crop and wild relatives occur. Regulatory officials in Mexico are interested in continuing field trials with such new varieties if there is a clear benefit to Mexican agriculture, such as new varieties of corn with tolerance to aluminum. This phenotype has great potential to reclaim for agriculture tropical acid soils that were lost due to high levels of soluble aluminum ions (Herrera-Estrella 1999). Future field evaluations of corn are likely to be accompanied by a scientific monitoring program after release.

In *Costa Rica*, there is particular interest in using the tools of biotechnology to characterize and conserve biodiversity (Sittenfield and others 2000). Costa Rican institutions have developed some innovative partnerships for bioprospecting, which could serve as a model for other countries. In agriculture, pesticide use has increased three fold between 1993 and 1996, on crops such as banana, coffee, and rice. Much of this is used to control banana diseases where the excess pesticide use is leading to poisoning of field workers and contamination of land, water, and animals. Biotechnology-based solutions are urgently needed to replace chemical control of banana diseases. New virus resistance is being introduced into local rice varieties.

### *Sub-Saharan Africa*

The current status of policy and programs using biotechnology in *Kenya, South Africa, and Zimbabwe* were reviewed and were complemented by interventions on the situation in other African countries. The major challenge identified was the persistent poor performance of agriculture in Africa, which is leading to a food and a poverty crisis. The issues concerning many countries are how to improve food security, increase productivity, conserve biodiversity, reduce pest management costs, deal with increasing urban migration,

## Box 2 Molecular Breeding: Biotechnology at Work for Rice

Marker-aided selection (MAS) is the application of molecular landmarks-usually DNA markers near target genes-to assist the accumulation of desirable genes in plant varieties. There are many reasons why molecular markers are useful in plant breeding. The improvement of disease resistance in rice is a good example.

Bacterial blight is a widespread disease in irrigated rice-growing areas. In the pre- green revolution period, it caused widespread yield loss. The incorporation of host plant resistance through conventional breeding has been the most economical means of control, and has eliminated the need for pesticides. There are now over 20 genes available for use in rice improvement, but not all of these genes are equally effective in different production environments. The pest eventually overcomes the resistant gene. Using conventional approaches the plant breeder must be continually adding and changing genes just to maintain the same level of resistance. Breeding effort spent in "maintenance" is a potential loss of gains in other traits.

A more sustainable system can be developed by deploying more than one resistance gene at the same time. The challenge is to find the right combination of genes and put them into varieties most suitable for local production. When two or more genes are incorporated into the variety it is called "gene pyramiding." Up to four genes for bacterial resistance have been pyramided in rice, and there is evidence that collectively they are more effective than would be ascribed to their additive effects. Because each gene may mask the presence of another gene, it is difficulty to pyramid more than two genes by conventional breeding and selection; but it can be done with molecular markers.

Over the past several years, scientists at the International Rice Research Institute (IRRI) and its national partners in the Asian Rice Biotechnology Network (ARBN) have applied DNA marker technology to address the bacterial blight problem. First, DNA markers are used to tag nearly all the bacterial blight resistance genes in available genetic stocks. Second, DNA markers are used to describe the composition of pathogen populations unique to each region. This parallel analysis of the host and the pathogen has enabled scientists to determine the right combination of genes to use in each locality.

In Asia, a number of resistance genes (Xa4, xa5, Xa7, xa13, Xa21), all with molecular tags, have been introduced in various combinations into locally adapted varieties. For example, in the Punjab of India, the popular variety PR106 carrying two-gene and three-gene combinations have been produced and are being evaluated by farmers. Similar gene pyramiding work is being conducted in eastern India but using different local varieties. In Indonesia and the Philippines, single- and two-gene pyramids for bacterial blight resistance have been produced in variety IR64. These lines are in the final stage of field evaluation before release to farmers.

ARBN is promoting sharing of these elite lines and gene pyramids from different countries amongst other countries in Asia so that the useful MAS products can be rapidly disseminated through collaborative field testing across the region.

Marker-aided selection has delivered some of the promises of biotechnology, and there are other examples of use in rice. The impact of MAS will continue to be significant particularly in an increasingly intellectual property(IP)-conscious environment. Marker technology is based on knowledge of endogenous DNA sequences; this has important practical implications as the rice genome will be completely sequenced by an international effort, led by the Rice Genome Research Program of Tsukuba, Japan. As long as there is a public commitment to maintain a rice genome sequence in the public domain, useful genes for MAS should be readily accessible to national and international rice breeding programs. Thus, because of their relative simplicity, easy integration into conventional breeding, and minimal background intellectual property, DNA marker technology and MAS are expected to be strong driving forces in crop improvement in the future.

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and reduce poverty. Specific issues related to biotechnology are how to develop institutional capacity for risk assessment and management, to access information on developments in biotechnology elsewhere that may have application in Africa, and to develop the necessary human resources and infrastructure.

Several success stories are coming out of Africa, where biotechnological approaches have contributed to the solution of specific problems, reduced the cost of pest control, and created new employment opportunities in towns and villages. They include the wide adoption by farmers of rapid multiplication of disease-free banana plantlets in Kenya; use of new genetically improved pest-resistant cotton varieties by small farmers in South Africa; and use of new vaccines against animal diseases in Kenya and Zimbabwe

(Chetsanga 2000; Ndiritu 2000, Njobe-Mbuli 2000).

Some of the problems and constraints identified include: lack of awareness of the benefits and risks associated with modern biotechnology; lack of capacity in some countries to deal with assessing these benefits and risks and in regulating the use of modern biotechnology; high investment costs associated with biotechnological innovations; and increasing concerns being expressed in the media about the potential negative impacts of biotechnology and the need for public awareness of the issues.

In sub-Saharan Africa the need is both to improve awareness and institutional capacity to develop biotechnology-based products and, perhaps as importantly, for African scientists and policymakers to articulate an African scientific agenda and to participate in critical global debates on trade, economic growth, and the role of science (Njobe-Mbuli 2000).

### *West Asia and North Africa*

Country status papers were presented for *Egypt, Iran,* and *Jordan* as examples from the region.

One of the major targets for biotechnology in Egypt is the production of transgenic plants conferring resistance to biotic and abiotic stresses, which are major agricultural problems leading to serious yield losses in many economically important crops in Egypt. AGERI (Agricultural Genetic Engineering Research Institute) was established in 1990 with the aim of mobilizing the most recent technologies available worldwide to address problems facing agricultural development (Madkour 2000).

The challenges identified were the need to increase agricultural productivity while preserving the fragile natural resource base in the region, and the need to conserve the rich indigenous plant and animal species. The opportunities include: using modern biotechnology to develop crop varieties tolerant to biotic and abiotic stresses, especially drought and salt tolerance; improving the nutritional quality of agricultural commodities; producing biofertilizers and biopesticides; and improving the availability of soil nutrients.

The main constraints in the region are inadequate financial resources, lack of qualified personnel, poor infrastructure, and insufficient regional and international collaboration. There is also a lack of clear strategies, policies, and regulatory frameworks to guide the use of modern biotechnology in most countries of the region.

### *Common Themes*

The outcomes of all the regional reviews summarized above stressed the importance of making safe and effective use of the new developments in modern biotechnology to solve agricultural problems. The application of biotechnological advances could help countries deal with the major challenges of feeding expanding populations from the existing land and water resources, and also to alleviate poverty by stimulating the growth of bioscience-based industries, with an associated growth in employment. Developing countries that are pursuing the safe and effective use of modern biotechnology recognized the need to have in place effective regulatory systems at the national and institutional levels, compatible with international best practice. There was also a widely held view that intellectual property management is a major issue, in terms of enabling access to other people’s technology and in stimulating rewarding local innovation. Countries need to have sufficient knowledgeable people to deal with these issues nationally, and in international negotiations and bilateral contractual arrangements.

### *Increasing Activity in Developing Countries*

There is considerable work in progress in the use of modern biotechnology in developing countries, probably much more than is commonly recognized internationally. Much of the R&D in developing countries is being funded by national governments, and some by bilateral and multilateral development agencies. It is estimated that at least twice as much of the biotechnology-related R&D in the public sector in developing countries is being funded by national governments, as by the international development community at present. Only a small amount comes from the private sector. The total R&D effort is still substantially less than the high private sector investments in biotechnology in North

### Box 3 Commercial Applications of Biotechnology in Crop Agriculture

Sustainable agriculture and sustainable intensification of agricultural systems are the challenges of the future. Sustainable agriculture is defined as the production of food to meet the needs of today without hindering the ability of future generations to meet their needs while maintaining a sustainable healthy environment.

World food supplies will have to more than double by 2025 to ensure sufficient quantity and quality, not only to meet increases in population, but also as a result of greater urbanization and spending power. In the past, world agriculture was in a position to produce enough healthy food for the growing population by gradually introducing yield-increasing technologies such as high-yield seeds, crop protection products, fertilizers, and improved irrigation systems and introducing more land to agriculture. Despite this, about 800 million people throughout the world are still undernourished. Full utilization of all technologies in crop production, including modern biotechnology, will play a decisive role in increasing yield to maintain sustainable global self-sufficiency in food.

In 1999 over 70 genetically modifed (transgenic) varieties of crops were registered for commercial cultivation worldwide. These include new varieties of cotton, chicory, potato, pumpkin, corn, soybean, rape, papaya, tobacco, tomato and clove). More than 15,000 field trials have been undertaken globally. New genetic modifications of more than 100 plant species are growing in laboratories, greenhouses, or in the field for experimental purposes.

The first wave of biotechnology crops is being grown commercially in the field, providing farmers with new agronomic traits, particularly herbicide tolerance and pest resistance that enable them to grow these crops more easily and more profitably**.** In 1999 the global area under genetically improved crops was 40 million hectares, mainly of corn (maize), soybean, cotton, canola (rapeseed) and potatoes. Eighty five per cent was grown in the USA, Canada, Australia, France and Spain and approximately 15 percent of the area was in developing countries, notably Argentina, China, Mexico and South Africa.

The private sector accounts for more than 80 percent of international biotechnology research. During 1997-99 transactions by the biosciences companies in the seeds industry have reached about US$18 billion. These investments were made to have access to the different crops and markets.

The second generation of genetically improved crops coming to commercialization over the next five years will include both other commodity and specialty crops, and also the introduction of new traits to improve the quality and nutritional value of the crops. There is also increasing interest in using crops to produce medicallly and/or industrially important compounds, such as vaccines in potatoes and biodegradeable plastics in corn.

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America, Europe, and other Organization for Economic Cooperation and Development countries. Nevertheless, there is movement toward a critical mass of public sector investments in biotechnology in several developing countries (see also Box 3).

## Agricultural Biotechnology in Industrial Countries

The greater specificity in the handling of genes has meant that inventors could protect their discoveries by means of patents and other forms of intellectual property rights. This has led to an explosion of private investment in the biosciences in the last 15 years, leading to a "biotechnology revolution." The greatest number of modern biotechnology applications are in health care, where they offer new hope to patients with AIDS, genetically inherited diseases, diabetes, influenza, and some forms of cancer. Biotechnology-based processes are now used routinely in the production of most new medicines, diagnostic tools, and medical therapies. The global market for these products in 1998 was approximately US$13 billion.

New developments in agricultural biotechnology (Box 3) are being used to increase the productivity of crops, primarily by reducing the costs of production by increasing the efficiency of use and decreasing the need for inputs of pesticides and herbicides, mostly in crops grown in temperate zones. The applications of agricultural biotechnology are developing new strains of plants that give higher yields with fewer inputs, can be grown in a wider range of environments, give better rotations to conserve natural resources, provide more nutritious harvested products that keep much longer in storage and transport, and continued low cost food supplies to consumers.

Private industry has dominated research, accounting for approximately 80 percent of all R&D.

Consolidation of the industry has proceeded rapidly since 1996, with more than 25 major acquisitions and alliances worth US$15 billion.

During the past decade, the commercial cultivation of transgenic plant varieties has commenced. In 1999, it is estimated that approximately 40 million hectares of land were planted with transgenic varieties of over 20 plant species, the most commercially important of which were cotton, corn, soybean, and rapeseed (James 1999). The value of the global market in transgenic crops grew from US$75 million in 1995 to US$1.64 billion in 1998.

The traits these new varieties contain include insect resistance (cotton, corn), herbicide resistance (corn, soybean), and delayed fruit ripening (tomato). The benefits of these new crops are better weed and insect control, higher productivity, and more flexible crop management. These benefits accrue primarily to farmers and agribusinesses, although there are also economic benefits accruing to consumers in terms of maintaining food production at low prices. Health benefits for consumers are also emerging from new varieties of corn and rapeseed with modified oil content and reduced levels of potentially carcinogenic mycotoxins.

The broader benefits to the environment and the community through reduced use of pesticides contribute to a more sustainable agriculture and better food security.

Other crop/input trait combinations presently being field-tested include virus-resistant melon, papaya, potato, squash, tomato, and sweet pepper; insect-resistant rice, soybean, and tomato; disease-resistant potato; and delayed-ripening chili pepper. There also is work in progress to use plants such as corn, potato, and banana as minifactories for the production of vaccines and biodegradable plastics.

## Scientific Advances

Further scientific advances will likely result in crops with a wider range of traits, some of which are likely to be of more direct interest to consumers, for example, by having traits that confer improved nutritional quality to food. Crops with improved output traits could confer nutritional benefits to millions of people who suffer from malnutrition and deficiency disorders. Genes have been identified that can modify and enhance the composition of oils, proteins, carbohydrates, and starch in food/feedgrains and root crops. For example, a gene encoding beta carotene/vitamin A formation has been incorporated experimentally in rice. This would enhance the diets of the 180 million children who suffer from the vitamin A deficiency that leads to 2 million deaths annually. Similarly, introducing genes that increase available iron levels in rice three-fold is a potential remedy for iron deficiency that affects more than 2 billion people and causes anemia in about half that number.

Applications of biotechnology in agriculture are in their infancy. Most current genetically improved plant varieties are modified only for a single trait, such as herbicide tolerance or pest resistance. The rapid progress being made in genomics may enhance plant breeding as more functional genes are identified. This may enable more successful breeding for complex traits such as drought and salt tolerance, which are controlled by many genes. This would be of great benefit to those farming in marginal lands worldwide, because breeding for such traits has had limited success with conventional breeding of the major staple food crops.

## Functional Genomics for Trait Discovery

Although much of the discussion about molecular biology applications is focused on the opportunity of crop improvement by gene transfer through transformation, the same science brings new tools to assist plant breeders transfer genes through more conventional approaches. The complex traits for adaptation to abiotic stress are often difficult to identify. These are often difficult to identify and utilize in a breeding program without the additional help of modern science. Plant genomics is the engine to drive trait discovery and help solve intractable problems in crop production. To fully exploit the wealth of structural information obtained from the genome we must understand the specific biological functions encoded by a DNA sequence through detailed genetic and phenotypic analyses. Thus functional genomics requires diversity of scientific expertise as well as biological resources. In many important food crops the public sector has a large investment in biological resources, in plant breeding programs, and a long and skilled history of understanding biological function through national variety evaluation networks, as well as the global crop networks of the international agricultural research centers. These biological resources, scientific knowledge and expertise will become increasingly important in gaining knowledge about the function of genes and in developing markers for assisting the breeding process. (See also Box 2 on marker assisted selection in rice.)

## Global Challenges

In order to better understand where science can contribute to achieving the goal of sustainable global food security in the 21st century, it may be useful to identify areas of consensus among the number of analyses and predictions that are currently available on world food supply, population, and poverty. These also relate the achievements/failures of the past to the prediction of important forces for change through the first quarter of the 21st century.

In global terms, increases in world food production have more than kept pace with the increases in the global population to date. The consensus of the various projections is that, although the world agricultural growth rate has decreased from 3 percent in the 1960s to 2 percent in the last decade, the aggregated projections show that, given reasonable initial assumptions, world food supply will continue to outpace world population growth, at least to 2020. Worldwide, per capita availability of food is projected to increase around 7 percent between 1993 and 2020 (IFPRI 1997). Therein lies a paradox.

The first aspect of the paradox is that despite the increasing availability of food, currently approximately 0.8 billion of the global population of 6 billion are food insecure. They dwell among the 4.5 billion inhabitants of the developing countries in Asia (48 percent), Africa (35 percent), and Latin America (17percent). Of these 0.8 billion a quarter are malnourished children (IFPRI 1997).

Children and women are most vulnerable to dietary deficiencies. Dietary micronutritional deficiencies accompany malnutrition. Vitamin A deficiency is prevalent in the developing countries and it is estimated that over 14 million children under five years of age suffer eye damage as a result. Up to 4 percent of severely affected children will die within months of going blind and even mild deficiencies can significantly increase mortality rates in children. Iron deficiency affects one billion people in the developing world, particularly women and children, and its effects are compounded by common tropical diseases. The anemia that results from the deficiency can diminish learning capacity and increase morbidity and mortality.

The second aspect of the paradox is that food insecurity is so prevalent at a time when global food prices are generally in decline. Over the 30 year period 1960-1990, world cereal production doubled, per capita food production increased 37 percent, calories supplied increased 35 percent and real food prices fell by almost 50 percent (McCalla 1998).

The basic cause of the paradox is the intrinsic linkage between poverty and food security. Simply put, people's access to food depends on income. Currently it is estimated that more than 1.3 billion people in the developing countries are absolutely poor, with incomes of a dollar a day or less per person, while another 2 billion people are only marginally better off (World Bank 1997). Rural poverty currently represents a very high percentage of the overall poverty. However with increasing urbanization, an increasing proportion of poor people will be living in the cities of the developing countries in the next century.

The most important global challenges are:

- Alleviating poverty, improving food security, and reducing malnutrition, especially amongst children;
- Providing sufficient income for the rapidly increasing numbers of urban poor;
- Using new technologies for environmentally sustainable development.

### *Global Problems Facing Agriculture and the Environment*

The global problems facing agriculture are described by Swaminathan (2000) as:

- First, increasing population leads to increased demand for food and reduced per capita availability of arable land and irrigation water.
- Second, improved purchasing power and increased urbanization lead to higher per capita

food grain requirements due to an increased consumption of animal products.

- Third, marine fish production is becoming stagnant.
- Fourth, there is increasing damage to the ecological foundations of agriculture, such as land, water, forests, biodiversity, and the atmosphere, and there are distinct possibilities for adverse changes in climate and sea level.
- Finally, while dramatic new technological developments are taking place, particularly in biotechnology, their environmental and social implications are yet to be fully understood.

Knowledge is a continuum. There is much to learn from the past in terms of the ecological and social sustainability of technologies, including traditional technologies and those that underpinned the Green Revolution (Pinstrup-Andersen and Cohen 2000, Swaminathan 2000). New developments in science have opened up new opportunities to develop technologies that may lead to high productivity without adverse impact on the natural resources base. Blending traditional and frontier technologies leads to the birth of *ecotechnologies* with combined strength in economics, ecology, equity, employment, and energy.

## Risks and Benefits

In considering the potential risks and benefits of modern biotechnology, it is useful to distinguish technology-inherent and technology-transcending risks (Leisinger 2000). Technology-inherent risks are those where the technology itself has potential risks to human health, ecology, and the environment. Technology-transcending risks include those that are not specific to the technology but where its use may have risks. For biotechnology these include the risk of increasing the poverty gap within and between societies, reducing biodiversity, and antitrust and international trade issues.

### *Risks to Human Health*

Potential health risks of genetically improved organisms relate to assessing and minimizing the risk of food allergens in genetically improved food. New biotechnology based methods allow the identification, characterization, and minimization of risks of food allergens.

Genetically improved crops and food, and the risk of allergens associated with them, are now a concern throughout the world, especially in industrial countries. More than 90 percent of food allergens that occur in 2 percent of adults and 4-6 percent of children are associated with eight food groups. Allergenicity of genetically improved foods can be raised in crops and foods either by raising the level of endogenous allergen or by introducing a new allergen (Lehrer 2000).

Assessment of the risk of allergens is a challenge. The International Life Sciences Institute (ILSI) has developed a decision tree that provides a framework for risk assessment (Lehrer 2000). It uses the following criterion: that an introduced protein in a food is not a concern if there is (1) no history of common allergenicity, (2) no similar amino acid sequence to known allergens, (3) rapid digestion of the protein, and (4) the protein is expressed at low levels. Protocols enable assembly of the data to judge food against this criterion.

It is also important to inform consumers of any potential risk. A key concern of consumers is being able to identify where allergens are found. Consumers want to know where the potential for food allergens exists. Any protein added to food should be assessed for potential allergenicity, whether it is added by genetic engineering or by manufacturing.

There are several related areas of concern with regard to potential human health risks of genetically improved foods: toxicity, carcinogenicity, food intolerances; the risk of the use of gene markers for antibiotic resistance; other macromolecules aside from protein that could be potential allergens; and nutritional value. Methods of testing and evaluating risks of toxicity and carcinogenicity are well established for food (Lehrer 2000).

The question remains as to whether developing countries can implement and use currently available technologies and protocols to assess food allergens and other health risks. The techniques are well established, and should be readily implementable by trained professionals. Although no clear cases of harmful effects on human health have been documented from new genetically improved food, that does not mean that risks do not exist and they should be assessed on a case by case basis.

### *Ecological and Environmental Risks*

The risks policymakers and regulators need to assess include the potential for spread of traits from genetically improved plants to the same or related species, plants (including weeds), the buildup of resistance in insect populations, and the potential threat to biodiversity posed by widespread monoculture of genetically improved crops.

- A transparent, science-based framework is required, which assesses risks on a case by case basis and takes account of all stakeholder views.
- Environment-related issues to be considered in each case include the possibilities for gene transfer, weediness, specific trait effects, genetic and phenotypic variability, and expression of pathogenic genes.
- Risk management needs to consider the prospects for managing any specific risks identified with a proposed release
- Experience is accumulating in the management of the Bt genes in transgenic cotton varieties in several countries and this needs to be closely monitored.
- An agricultural sustainability protocol that balances risks and benefits may have value for the approval and use of new crop varieties.

Cook (2000) describes the findings of recent field trials that conclude there appears to be no new issues in the testing of genetically improved plants. The same protocols to assess the effect in the environment of the introduction of genetically improved plants should apply to plants derived through conventional plant breeding. The "bar" should not be higher for genetically improved plants, and the protocols must cover all plants regardless of the process. This being the case, there seems minimal environmental risk in the plant itself. The risks lie in the management of the cropping system involving soil, water and other inputs. There is a need for the establishment of baseline information in the environment where such introductions are to be made. There is very little known on this, although some understanding has been gained over recent years, and further R&D is required (Cook 2000).

The information derived from such an assessment needs to be handled through risk management associated with "plants as plants." Risk management involves the consideration of traditional cultural practices that have evolved over time, and new knowledge gained from research in agronomy, plant pathology, entomology, weed science, plant biology, soils, microbiology, and other disciplines.

### *Biotechnology and Biodiversity*

Risks to biodiversity and wildlife are important issues in particular environments.

Careful assessment is necessary of the risks associated with the possible creation of new selection pressures coming from the introduction of genetically improved organisms into the environment. Of special concern is the potential impact on biodiversity of genetically improved organisms as the selection pressures wield influence in the species composition of the ecosystem. These concerns merit further study, especially on the behavior of genetically improved organisms in the open environment. The framework for strategic planning in the deployment of genetically improved organisms should be formulated with sustain-ability as the primary concern (Johnson 2000).

### *Regulatory Systems*

Both food safety and biosafety regulations should reflect international agreements and best practice and a given society's acceptable risk levels, including the risks associated with not using biotechnology to achieve desired goals.

The principles and practices for assessing the risks on a case-by-case basis are well established in most Organization for Economic Cooperation and Development (OECD) countries and several emerging economies. These principles and practices have been summarized in a series of OECD reports published over the past decade or more. National, regional, and international guidelines for risk assessment and risk management provide a basis for national regulatory systems. Biosafety guidelines are available from several international organizations including the OECD, United Nations Environment Program, United Nations Industrial Development Organization, and the World Bank.

Regulatory trends to govern the safe use of biotechnology to date, include undertaking scientifically based, case-by-case, hazard identification and risk assessments; regulating the end product rather than the production process itself; developing a regulatory framework that builds on existing institutions rather than establishing new ones; and building in flexibility to reduce regulation of products after they have been demonstrated to be of low risk.

## Technology Transcending Risks

Biotechnology is not inherently different to other technologies with respect to economic and social impacts, as long as it focuses on the problems that affect poor people.

One important difference is that research on biotechnology has largely taken place in the private sector with proprietary technologies and an orientation to commercial agriculture. This implies the need for a strong role for the public sector, including increased resources, to address developing country priorities.

### *Socioeconomic Impact*

- There is a risk that modern science may bypass the needs of poor people.
- Biotechnology is only one tool in addressing the challenges of food security and poverty.
- There is a need for biotechnology to be integrated with appropriate policies and other conventional R&D programs.
- The positive and negative impacts of biotechnology should be monitored over time in terms of who and what are affected and how they are affected. Monitoring impact will provide guidance for public policymakers in the future.

*Pro-poor policies*. Unless countries have policies in place to ensure that small farmers have access to delivery systems, extension services, productive resources, markets, and infrastructure, there is a risk that the introduction of agricultural biotechnology could lead to increased inequality of income and wealth. In such cases, larger farmers are likely to capture most of the benefits through early adoption of the technology, expanded production, and reduced unit costs.

## Weighing Risks and Benefits of Biotechnology

Biotechnology has potential to reduce input use, reduce risk to biotic and abiotic stress, increase yields, and enhance quality—all traits which should enable the development of new crop varieties that are appropriate to poor producers and consumers.

Modern biotechnology is not a silver bullet for achieving food security, but, used in conjunction with other agricultural research, it may be a powerful tool in the fight against poverty. It has the potential to help enhance agricultural productivity in developing countries in a way that further reduces poverty, improves food security and nutrition, and promotes sustainable use of natural resources. Solutions to the problems facing small farmers in developing countries could benefit both farmers and consumers.

The benefits and risks need to be assessed on a case by case basis, weighing the risks and benefits for each particular situation.

The benefits of new genetically improved food to consumers are likely to vary according to how they earn their income and how much of their income they spend on food. Consumers outnumber farmers by a factor of more than 20 in the European Union, and Europeans spend only a tiny fraction of their incomes on food. Similarly, in the United States, farms account for less than 2 percent of all households, and the average consumer spends less than 12 percent of income on food. In the industrial countries, consumers can afford to pay more for food, increase subsidies to agriculture, and give up opportunities for better-tasting and better-looking food. In developing countries, poor consumers depend heavily on agriculture for their livelihoods and spend the bulk of their income on food (Pinstrup-Andersen and Cohen 2000).

Strong opposition to genetically improved foods in the European Union has resulted in restrictions on modern agricultural biotechnology in some countries. The opposition is driven in part by perceived lack of consumer benefits, uncertainty about possible negative health and environmental effects, widespread perception that a few large corporations will be the primary beneficiaries, and ethical concerns.

## Ethical Issues

In regard to ethical issues:

- Environmental and food safety risks may sometimes be overstated as a means of gaining attention to technology-transcending risks and ethical concerns.
- It is important to pursue a dialogue on ethical issues to clarify the ethical and moral issues of concern and how they might be addressed in different societies.

The ethical challenges include the role of science, its risks, benefits, and impact on society. Moral and ethical standards are being used to develop laws governing some aspects of biotechnology (for example, in medicine laws governing human cloning). In 1998, the CGIAR system agreed to a statement of ethical principles underlying the work of the CGIAR centers in biotechnology (Box 4).

A major ethical concern is that "genetic engineering" and "life patents" accelerate the reduction of plants, animals, and microorganisms to "mere commercial commodities, bereft of any sacred character." However, all agricultural activities constitute human intervention into natural systems and processes, and all efforts to improve crops and livestock involve a degree of genetic manipulation.

## Intellectual Property Management

Many R&D programs face the challenge and opportunities of managing intellectual property. Partnerships are critical to effective manage-

### Box 4 Ethical Principles Underlying the Use of Biotechnology by the CGIAR Centers

**Transparency**

CGIAR scientists, whose research relies heavily on a wide range of partnerships, must do more than just honor their personal ethical codes. The system as a whole needs clear and uniformly applied ethical principles. These must be known and respected by all CGIAR staff and well understood outside the system. Such principles can exert a significant influence on the nature and extent of the partnerships that are formed with other organizations and individuals. The most effective partnerships are likely to occur when partners share common ethical principles. It is thus critical that the CGIAR system be transparent about its ethical principles, not least those underpinning its work in biotechnology, so that its partners will know what the system stands for—what it will and will not do, how it will and will not do it, and why.

**Trust**

There seems to be a growing mistrust of science and scientists in many parts of the world. The widespread publicity given by the media to biotechnology and especially to its negative aspects, requires that all involved in this work must be especially concerned that their behavior conforms to the highest ethical and moral standards. Relevant principles are those relating to honesty, intellectual rigor, openness and transparency, accountability, and precautionary approaches.

**Statement of Ethical Principles**

In 1998 the CGIAR adopted a Statement of Ethical Principles Relating to Genetic Resources, that asserts: *The CGIAR was founded on the ethical imperative of eliminating hunger and starvation and has…followed certain ethical principles. Increasing food security and alleviating poverty have long been central to the system's science-based humanitarian mission.* It further states that: *Greater transparency …is important in enabling strong and unambiguous relationships to be forged with a wide range of partners….. The CGIAR works for the attainment of equity in the conservation, sustainable use and the sharing of benefits derived from genetic resources. This commitment to fairness requires that emphasis be given to the needs of resource poor communities and to disadvantaged members of society…. As trustees of genetic resources, the CGIAR Centers recognize their responsibility to be impartial, transparent and fair in their administration of the trust; to respect and observe national regulations and international conventions; to be accountable for their actions; and to exercise due care and diligence in conserving the material for the use of present and future generations and in making it readily available for use for the public good.* In relation to respect, responsibility and integrity in science, the statement says: *The CGIAR's work on genetic resources respects the general scientific principles of good faith and the search for truth. However, the CGIAR is guided by its particular humanitarian and equity-based concerns, and not the pursuit of knowledge for its own sake.*

*Geoffrey Hawtin, IPGRI*

ment and investment in intellectual property protection.

- Learning to manage intellectual property is a critical issue for many countries and institutions.
- Intellectual property management includes clarifying the role of institutions, developing an inventory of IP, developing ownership of intellectual property where appropriate, undertaking technology transfer, and marketing of the intellectual property.
- Human resource development is a major need in this area.
- Benefit sharing with holders of indigenous knowledge and genetic resources is an important issue that must be addressed.

It is most important to build up human resource capacity in intellectual property for scientists, managers, policymakers, and society as a whole. Societal changes are reflected in changing IPR requirements, and further changes are likely to result from further strengthening of IP protection and finding ways to reflect the contribution of indigenous knowledge.

## Key Players

### *Public Investment is Critical to Food Security and Poverty Alleviation*

Agriculture must figure prominently in poverty alleviation strategies of developing countries. Accelerated public investments are needed to facilitate agricultural and rural development through:

- Yield-increasing crop varieties, including those that are drought and salt tolerant and pest resistant, and improved livestock and fish
- Yield-increasing and environmentally sustainable production technologies
- Reliable, timely, and reasonably priced access to appropriate inputs as well as the credit often needed to purchase them
- Strong extension services and technical assistance to communicate timely information and developments in technology and sustainable resource management to farmers and to relay farmer concerns to researchers
- Improved rural infrastructure and effective markets
- Particular attention to the needs of women farmers, who grow much of the locally produced food in many countries
- Primary education and health care, clean water, safe sanitation, and good nutrition for all.

These investments need to be supported by good governance and an enabling policy environment, including trade, macroeconomic, and sectoral policies that do not discriminate against agriculture, and policies that provide appropriate incentives for the sustainable management of natural resources. Development efforts must engage poor farmers and other low-income people as active participants, not passive recipients; unless the affected people have a sense of ownership, development schemes have little likelihood of success (Pinstrup-Andersen and Cohen 2000).

Agricultural biotechnology can contribute to food security in developing countries, provided that it focuses on the needs of poor farmers and consumers in those countries, identified in consultation with poor people themselves. It is also critical that biotechnology be viewed as one part of a comprehensive sustainable poverty alleviation strategy, not a technological “quick-fix” for world hunger and poverty.

Biotechnology needs to go hand in hand with investment in broad-based agricultural growth. There is considerable potential for biotechnology to contribute to improved yields and reduced risks for poor farmers, as well as more plentiful, affordable, and nutritious food for poor consumers.

### *Public/Private Sector Roles*

In order to maximize the use of modern molecular knowledge, both public and private sector research is required to bring innovation and choices to farmers and consumers. The private sector is likely to focus on those areas of opportunity which will repay their investmet in innovation. The public sector must maintain the freedom to operate in an era of increasing propriety technology. In developing countries the public sector will need to develop technologies that meet the needs of the non-commercial sector, including the needs of resource-poor farmers and poor consumers.

Public-private roles have been changing due to declining public sector investments in R&D, and increasing private sector investments especially in biotechnology. There are three dimensions to this change:

- change in leadership in biological research (from public to private)
- change in ownership of technology
- change in markets (the private sector is now more interested in developing country markets).

These changes have led to a major new issue: the private sector is interested in protecting its technology investments, and the public sector is interested in gaining access to private sector technologies. The challenge is: how to bridge the gap between the interests of the public and private sectors and redefine their roles.

The following lessons have been learned from public-private partnerships in biotechnology to date (Lewis 2000):

- Learning each others' ways is important for partnership success (differences in cultural perspectives need to be bridged).
- Both parties must have confidence in the technology being transferred.
- Trust is the glue that holds partnerships together. Scientist-to-scientist relations help establish trust.
- Having a capable catalytic/facilitating/intermediary institution is important (for example, USAID/Michigan State University, Rockefeller Foundation, CGIAR), as is generating seed funding.
- Developing awareness and understanding of IPR is important. This may require training and institution building with the partner in a developing country.
- IPR concerns should be addressed up front for the partnership to succeed.

### *How to Move Forward*

There is a need for more investment in public research in NARS and the IARCs, to develop appropriate products. There is also agreement that this must be done in partnership with the private sector (especially local companies), and that farmers and consumers must be actively involved in driving the R&D agenda. Partnerships and dialogues with nongovernmental organizations and civil society are also needed to reach consensus. New institutional arrangements will be needed to facilitate new partnerships, including institutional experimentation.

## Communicating About Biotechnology and Addressing Public Concerns

A special session on communications at the international conference on biotechnology in October 1999 concluded:

- Public opinion may sometimes not be based on scientific fact, but it cannot be ignored; fears based on perceptions are nonetheless very real.
- Improved dialogue is necessary to involve all stakeholders, including farmers and consumers and civil society, in the assessment of the risks and benefits of modern biotechnology.
- Trust is the key element to pursue in addressing public perceptions.
- Communicating about biotechnology is perception management, not just handing out information but engaging in dialogue.
- Dialogue needs to be specific about which applications of biotechnology are being pursued, for what purpose, and the potential risks and benefits (see also Box 5).

## Issues Outstanding/Actions Required

There are uncommon opportunities now to harness the power and synergy of biotechnology and information technology to address contemporary development issues. Swaminathan (2000) notes that modern information technology provides opportunities to reach the unreached.

The future livelihood of small farm families will also depend on **precision agriculture**, which involves the use of the right inputs at the right time and in the right way. Biotechnology may play an important role in the major components of precision farming: integrated gene management, soil health care, efficient water management, integrated pest management, integrated nutrient supply, and efficient postharvest management. Ecotechnology-based precision farming can help to cut costs, enhance marketable surplus, and eliminate ecological risks. This is the pathway to an ever-green revolution in small-farm

### Box 5 Communicating About Biotechnology: Case Studies

*The German experience*. The deep public opposition to genetic engineering in Europe is based on experience with previous food scandals (BSE, hormone beef) which were not handled well by governments and regulators, and which have led to a mistrust of people in their regulating agencies. In Germany, public opinion on biotechnology is grounded in an alliance of a subtle anti-Americanism and a not-so-subtle opposition to large multinational companies (which happen to be mostly American). Another public relations problem lies in the fact that the first-generation GIOs were perceived to be industry-driven, with very little benefit to the consumers. Although the public opinion battle on GIOs seems to have been lost in Germany, there might still be ways to turn it around. This would need a pro-active campaign, much like the Jubilee 2000 initiative on forgiving developing country debts. What is needed (and soon) are success stories that show how biotechnology can be used to alleviate poverty and reduce malnutrition in developing countries.

*Carola Kaps*

*The Indian experience*. There are many examples of biotechnologies that are not controversial, such as tissue culture and embryo transfer. It is the media's responsibility to provide a balanced viewpoint, and to provide an active platform for information exchange. The media also plays a role in awakening the public to potentially harmful technologies. Emerging issues in India relate to biopiracy and IPRs. Farmers' views are often not heard on these issues. The media in India also covers stories related to indigenous and local knowledge.

*Govindan Venkataramani*

*The Corporate experience*. How society accepts biotechnology will depend mainly on how well biotechnology-related issues are communicated. Communicating about biotechnology is perception management – not just handing out information, but engaging in a dialogue. It is extremely important to differentiate among the various fields of application (microorganisms, animals, plants, humans), and to be very precise in what is being debated - the fears of the public are different for different fields of application (e.g., ecological damage, public health).

*Walter von Wartburg*

*The U.K. experience*. The public is not as ignorant of the issues as many believe. People may not know every scientific detail, but they have a sharp sensitivity to the broad issues. The re-gulatory bodies, however, have not adequately addressed public concerns. The public wants answers to questions such as: Is GI food needed? Who stands to gain and lose? Are there are some ethical issues involved. How do we communicate biotechnology? Do we switch from scientific issues to legal, ethical and social issues? Do we move to a more participatory style of decision-making, involving the public more?

*Jagdish Patel*

agriculture. This is why increased public support to both the CGIAR and NARS is important for strengthening health and food security (Swaminathan 2000).

## Role of the CGIAR System

Critical roles for the CGIAR system in the future are to enhance its role as:

- Protector of the interests of the poor and facilitator and bridge-builder in biotechnology partnerships.
- Facilitating public policy and innovative institutional arrangements.

The CGIAR centers could develop, for the benefit of developing countries, more comprehensive partnerships with the private sector and also with universities and other advanced research institutions. This would give developing countries access to a minimum intellectual property platform that would help guarantee that new products developed by their research institutes would reach farmers and consumers.

### *Suggestions for the CGIAR System*

Country needs are not all the same, so it is important to deal with the experience and needs of specific countries, and the specific problems in their agricultural sectors. There is a need to move the debate forward from the general to the specific. This would enable clarification of where the problems are and what can be done to solve them.

Specific suggestions emerged on areas of activity and issues where the various elements of the CGIAR system, especially the IARCs supported by the CGIAR could play a useful role in the future.

*Facilitating information sharing.* The CGIAR system could play a useful role, possibly in association with other cosponsors of the conference, in assembling and making accessible the factual information about what is happening in the use of modern biotechnology in developing countries. This could include analyses of the specific problems that need to be addressed in terms of the priorities, the science, the transfer of technology, the assessment and management of risks, and the associated public policy questions. These include regulation, public acceptance of new technologies, intellectual property management, trade and antitrust issues, capacity building, and investment.

*Identifying problems and priority setting*. The CGIAR system could assist in identifying the priority problems and opportunities to mobilize science to address the problems of the poor, and to identify specific technical, policy, and institutional problems and opportunities that need to be addressed, at the national, regional, or international level.

*Supporting national capacity building.* The CGIAR centers could provide further technical support for capacity building in NARS, in the centers' areas of expertise. They would be working with individual countries, UN and other international agencies, and other sources of expertise to assist countries to develop expertise in knowledge management, regulatory affairs for environmental and health risk assessment and management, legal and patent issues, science and technology, and financial and business management.

*Ensuring compliance with agreed biosafety standards*. The IARCs need to ensure that they comply with agreed national and international biosafety requirements and best practice in their host and partner countries. The IARCs may also be able to assist partner countries in the monitoring of environmental releases of GIOs and in identifying and using best practices in this rapidly evolving field.

*Managing intellectual property.* There is an urgent need for better management of intellectual property by the IARCs and NARS, in line with national policies and legislation, facilitating access to, and freedom to operate with, appropriate technologies, and finding means to stimulate and reward traditional innovation and local inventions. The current initiatives, such as the central advisory service for intellectual property at ISNAR and other initiatives, will go some way toward meeting this need.

*Public/private partnerships.* The CGIAR system should strengthen its efforts to develop and implement specific public/private sector partnerships, building on the experience of past efforts, and explore new modalities.

*Communicating and addressing public concerns.* Constant communication with stakeholders is required, to address public concerns and to engage in dialogue with proponents and opponents of new technologies, focusing on real issues that will have an impact on the poor in developing countries.

## Actions Required

Beyond the work of the CGIAR, there is a need for:

- More public and private R&D investments on targets that affect the livelihoods of the poor, and that are perceived to benefit both farmers and urban consumers
- Local start-up companies to commercialize and distribute new technologies, including the continuing importance of local seed companies in the distribution of new plant varieties
- Innovative mechanisms to stimulate more R&D on the problems important to the rural and urban poor, including exploring the feasibility of tax concessions in OECD countries and a global competitive grants facility
- The need to explore new modalities for public/private sector partnerships, learning from past experience of those already in operation, especially in relation to intellectual property management.

## Conclusion

Biotechnology is only one tool, but a potentially important one, in the struggle to reduce poverty, improve food security, reduce malnutrition, and improve the livelihoods of the rural and urban poor. The uncertainties and the risks are yet to be fully understood, and the possibilities are as yet not fully exploited. It seems important not to deny people access to new technology, so long as they are fully informed of the potential risks and benefits and able to make their own choices.

By assessing the current and potential usefulness of modern biotechnologies for the solution of specific problems in agriculture, new ground is being broken in analyzing how best to assess and mobilize:

- Rapid developments in science and technology
- New public policy requirements
- New institutional arrangements
- Dialogue amongst all interested parties.

The exchange of a wealth of knowledge, information and experience, and the discussion of a variety of sometimes differing perspectives, will be valuable in moving ahead with the responsible dialogue and debate on the use of the new developments in science and technology for the benefit of society.

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