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Agricultural Biotechnology in the 21st Century: Promises and Pitfalls

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I will begin with some brief definitions that I find useful when talking about biotechnology. I restrict biotechnology to mean techniques involving the use of molecular biology of DNA. These techniques facilitate two related but different applications: the extremely specific identification of the DNA in a biological organism, and the transfer and biological functioning of DNA from one organism to another. The first has led to the ability to detect the presence or absence of genes in plants and animals using techniques collectively called molecular markers. The second has led to the ability to transfer genes from one organism to another, that is, transformation. These two abilities generate both the promises and the pitfalls of biotechnology.

This paper considers how these biotechnology abilities may be applied to plants. Four broad goals have been pursued relative to plants: to change product characteristics like storability or taste, to incorporate resistance to insects, diseases, or agrichemicals such as herbicides, to increase innate yield potential, and to enable plants to produce products they were heretofore incapable of producing. In turn, a number of promises have been identified, including the following:

- The potential to raise agricultural productivity and thereby the hope that we will be better able to feed the world.
- An increase in agricultural research investment.
- A reduction in pesticide use in agriculture, a more sustainable agricultural system, and other environmental benefits.
- The use of genes from new sources.
- The production of pharmaceuticals from plants.

For each of the promises, however, one can identify potential pitfalls, and the following can be enumerated:

- Are we focusing attention on the genes that will give the traits that will increase productivity?
- Are we paying enough attention to the problems that will have to be solved to feed the word?
- Will the property rights that accompany the increased investment mean that the benefits are inappropriately concentrated?
- Will the technology lead to an increase in the intensity of pesticide use rather than a reduction?
- How will biotechnology contribute to sustainable agriculture?
- Is it really practical to produce pharmaceuticals using plants?

Increase Productivity

The promise that plant biotechnology may raise innate productivity rests largely on the belief that because it opens so many possible ways of changing the genetics of plants there must be a way to apply that knowledge to increase productivity. Photosynthesis, the basic process by which plants use the sun's energy, water, nutrients, and carbon dioxide, is known to use only a small fraction, less than 10 percent, of the sun's energy. It stands to reason that there may be a way to increase that proportion and thereby increase innate productivity, but to date no generally accepted means for doing so has been found.

Likewise, making plants more drought-resistant, or able to better use available water, would seem to offer great opportunities to increase productivity. But little progress has been made in achieving greater drought resistance, and little of the energy of biotechnology is directed toward this goal. Incorporating into cereal crops the capacity to fix nitrogen biologically is another approach that would seem to increase productivity, but again, progress has been slow.

More positively, biotechnologists have developed new approaches to creating hybrid crops, opening the possibility of hybrid wheat and hybrid rice, as well as other hybrids. As these strategies are proven they likely will lead to higher yields. There are also other traits that may lead to increased yields — one that increases the starch content of potato, and another that keeps sorghum leaves green for a longer period of time than normal, extending the period of grain filling and thereby promising higher yields.

Feed the World

The challenge of feeding the world is reflected most dramatically in the observation that per capita food production in Sub-Saharan Africa has fallen by 20 percent over the past 30 years, leaving that region in desperate need of additional food production. Furthermore, that area faces the challenge of the most rapid rate of population growth of any region. Over the past 30 years, per capita food production increased in most countries outside Africa, especially in Asia. There the challenge remains high, driven by rapid growth of per person income.

An acceptable long-term solution to feeding the world requires most countries to have a reasonable degree of food self-reliance, meaning that countries either produce their own food or produce and export something else with which to purchase food. For largely rural countries, the alternatives to food are most often other agricultural products. Hence it is reasonable to ask to what extent biotechnology is being used to address the agricultural needs of the developing world.

For the results of biotechnology to be applied in a specific place, the plants incorporating those results will have to be field tested, and seeds incorporating the traits will have to be multiplied and distributed to farmers. Data on field tests indicate, therefore, the prospects for contributions from biotechnology in the next few years.

Clive James and Anatole Krattiger from the International Service for Applied Agricultural AgroBiotechnology (ISAAA) have tabulated the data on field trials of genetically engineered crops. Some 3,700 trials have been conducted through the end of 1995. About 40 percent of those trials have been of crops that have been transformed to be herbicide resistant. About 22 percent were of crops transformed for insect resistance or product quality, and another 15 percent or so of crops were transformed to be resistant to fungal or virus diseases. Some 555, another 15 percent, have been crops transformed with other traits. Except for this last category, which includes a few tests each on a wide variety of traits, none of the field trials to date have been directed specifically at increasing productivity. Of course, it is likely that some increase in yield will be observed in plants that are pest resistant, but the direct objective is quite different, supporting the observation that limited resources are directed at increasing productivity.

Some of the traits that may be most needed in the developing world, in addition to productivity increases, include the ability to tolerate low soil fertility, the ability to tolerate soil salinity or alkalinity, the ability to reproduce apomictically, and techniques for producing biological pesticides. In addition, molecular markers for these and other desirable traits would contribute to advances in the genetic improvement of crops through plant breeding.

Application of biotechnology to address the needs of the developing world requires that it be applied to crops of interest to the developing world. James and Krattinger show the distribution of field tests among crops. Almost 30 percent of all field trials have been conducted on maize, a crop of importance in the developing world, especially in Africa. But, the other crops that have been the focus of attention — tomato, canola, cotton, tobacco, potato — are of little or no food significance in developing countries.

Maize yields in developing countries may be affected by biotechnology if genes useful in tropical countries are discovered in the course of the massive work being done on maize in the United States. Although most of the work on maize is being done by private firms, some of the discoveries may be made available for application in developing countries, either at no cost or at low enough cost as to make their use commercially feasible. Biotechnology applications on cassava are further in the future, as are those on smallholder banana and other crops of importance in the developing world.

It is unlikely that the balance of work between the industrialized and developing worlds will change soon because only a small amount of the estimated $2.5 billion of research spending on agricultural biotechnology around the globe is carried out in the developing world. The best available estimates suggest that between $50 and $75 million per year is spent on agricultural biotechnology in the developing world, about half of that by the Consultative Group for International Agricultural Research (CGIAR) Centers. The rest is divided among private research (multinational and local) and government-supported research.

A functioning global agricultural research system — the CGIAR — exists, but over the past five years the financial support for that system has weakened, in no small part because of falling support by the United States. Whereas in 1992 the United States was the single largest donor, providing $48.1 million to that system, in 1996 that figure fell to $30.5 million, even though the system is acknowledged to be one of the most effective uses of foreign assistance to which the United States contributes.

The CGIAR, which is extremely effective at research that can be shared across countries, can be complemented by efforts that enable countries to adapt the research findings to their particular situations. There is still a great need to improve the national capacity for agricultural research and management in developing countries, especially in Africa.

I know of five coherent, coordinated programs directed specifically at enhancing biotechnology research on developing-country crops: one supported by the United States Agency for International Development (USAID), one by the Dutch government, one by the McKnight Foundation, one by the Rockefeller Foundation, and one by the Asian Development Bank.

The USAID-supported project on Agricultural Biotechnology for Sustainable Productivity (ABSP), headquartered at Michigan State University, was implemented by a consortium of U.S. universities and private companies. It is targeted at five crop/pest complexes: potato/potato tuber moth, sweet potato/sweet potato weevil, maize/stem borer, tomato/tomato yellow leaf virus, and cucurbits/several viruses. An outgrowth of the earlier USAID-supported tissue culture for crops project, ABSP builds on the network of scientists associated with that project.

The cassava biotechnology network, sponsored by the Netherlands Directorate General for International Cooperation, held its first meeting in August 1992. It aims to bring the tools of biotechnology to modify cassava so as to better meet the needs of small-scale cassava producers, processors, and consumers. More than 125 scientists from 28 countries participated in the first network meeting. Funding to date has been about $2 million. An important initial activity is a study of farmers' needs for technical change in cassava, based on a field survey of cassava producers in several locations in Africa. Funding beyond 1997 is not assured.

The Rockefeller Foundation's support for rice biotechnology in the developing world started in 1984. The program has two objectives: to create biotechnology applicable to rice and produce improved rice varieties suited to developing-country needs; and to ensure that developing-country scientists know how to use biotechnology techniques and are capable of adapting them to their own objectives. Approximately $70 million in grants have been made by the program through 1996. A network of about 200 senior scientists and 300 trainee scientists are participating, in all the major rice-producing countries of Asia, as well as several industrialized countries. Researchers in the network transformed rice in 1988, a first for any cereal. Transformed rice has been field tested in the United States, and a significant number of lines transformed with agronomically useful traits now exist. Molecular maps are being used to assist breeding, and some rice varieties developed by advanced techniques not requiring genetic engineering are now being grown by Chinese farmers.

The McKnight Foundation has provided about $12 million for biotechnology research on agriculturally important problems to teams of researchers from advanced and developing-country labs. This innovative program used a global call for proposals and competitive process to award the grants across a range of subject matter of interest to the investigators. The research under the first set of grants is currently under way, but no plans have been announced for further funding.

The Asian Development Bank provides about $300,000 annually to fund the Asian Rice Biotechnology Network that links the International Rice Research Institute (IRRI) and Asian countries so they can share information and cooperate in the development of tools of biotechnology for rice.

It is unlikely that these five focused crop biotechnology efforts, taken together, entail in excess of $35 million annually, or about one-half of total agricultural biotechnology research spending in the developing world, which is likely between $50 and $75 million annually. China, India, Egypt, Brazil, and a few other countries have a reasonable base for plant biotechnology.

It is evident that the efforts directed at biotechnology for developing-country agriculture are small, especially when compared to those directed at the industrialized world. Still, some important contributions should come from the former. Training of developing-country scientists under various programs provides a small cadre of plant molecular biologists in developing countries.

The Rockefeller Foundation's support of rice biotechnology is beginning to pay off in the form of new rice varieties available to some Asian farmers. In China, a rice variety produced at the Shanghai Academy of Agricultural Sciences through anther culture and which incorporates genes for resistance to pathogens and cold has been field tested on over 3,000 hectares in Anhui and Hubei provinces, resulting in yields from six to 24 percent higher than the most popular previous varieties.

Rices with several different genes for resistance to two major rice diseases, blast and bacterial blight, have been produced using genetic markers. These are being field tested for the durability of their resistance, which is expected to be high. In addition, dozens of genetically engineered rices are being evaluated in facilities in Asia. We expect that the contributions to rice yield increases from biotechnology in Asia will be on the order of 10 to 25 percent over the next ten years. These increaseswill come from improved hybrid rice systems, largely in China, and in other Asian countries from rice varieties transformed with genes for resistance to pests and diseases.

The speed with which varieties get into farmers' hands depends largely on national conditions — the closeness of linkages between biotechnologists and plant breeders; the ability of scientists to identify the most limiting conditions, identify genes that overcome those constraints, and get those genes into good agronomic backgrounds; and the efforts plant scientists and others have put into crafting biosafety regulations.

Increase Research

The advent of biotechnology has stimulated agricultural biotechnology research. It has certainly encouraged a significant increase in private corporate research. The potential pitfall associated with this increase is the intellectual property rights conditions that go along with private research. Some observers believe that the cost of seeds may be higher than it would be if the research were done by the public sector, although there is a question of whether the same results would be forthcoming from the public sector. It is clear that the fact that property rights can be enforced, because of the capability to very closely identify biological organisms and their components, has stimulated great inventive efforts. But some voices question the appropriateness of property rights associated with nature.

Reduce Pesticides

The potential of biotechnology to reduce pesticide use has been one of the major points stressed by its supporters. Genes for resistance to insects and plant viruses are projected to replace the use of pesticides by farmers. The first broad-scale commercial production of crops with *Bacillus thuringensis*, the first of such genes, was conducted in 1996. Many other such genes are being tested, supporting the idea that biotechnology will lead to a reduction in the use of pesticides.

Critics of biotechnology point out that herbicide-resistant genes encourage farmers to use more of those chemicals than they might otherwise, shifting the balance in the other direction. In addition, there is concern by "organic" farmers who apply *Bt* directly to crops that its widespread introduction into genetically engineered crops will put so much pressure on pests that insects resistant to *Bt* will be created, thereby eliminating the usefulness of that relatively benign pesticide.

Sustainable Agriculture

The idea that biotechnology will hasten the age of sustainable agriculture has been promoted by some. But the concept of sustainable agriculture has been defined in so many different ways by so many different people that it is difficult to determine what would have to happen to make agriculture sustainable and whether biotechnology will help bring it about.

New Gene Sources

There is little doubt that genetic engineering will make new sources of genes available for use in plants. The genes that code for the Bt toxin come from bacteria, the genes that code for the coat protein of viruses have been inserted into plants to make them resistant to the virus, genes that enable cowpeas to have natural resistance to insects have been inserted into cereal crops, and so on. This transgenic capability is one of the characteristics that have generated the excitement about biotechnology. But this capability also generates unexpected consequences, mainly apprehension about the technology.

Some people's opposition to genetic engineering is based on ethical grounds: they believe that transferring genes across species is too close to the act of creation and therefore not something people should do. Others oppose genetic engineering because of the unknown possibilities that may result — of new viruses emerging from transformed plants, or of proteins that cause allergic reactions being unknowingly transferred into plants. And while those who have examined the scientific information about the probabilities of such events indicate they are small, apprehension remains because the probabilities are not zero. Still others oppose biotechnology because it has led to the patenting of genes, a practice they oppose on the grounds that genes are not inventions but rather parts of nature.

A significant number of people have expressed the fear that genetically engineered crops may not be safe. In the United States, those responsible for ensuring that the food supply is safe base judgments about food safety of genetically engineered crops on consideration of the nature of genes that have been inserted and the nature of the plants into which they have been inserted. If no evidence of danger exists and no reasonable argument for danger can be made, products can be grown and consumed. As of the middle of 1997, 20 genetically engineered crops have been approved for general commercial production without restriction. The regulatory bodies have found no evidence of any danger associated with their production or consumption.

The apprehension that food made from genetically engineered crops may not be safe is strong in some European countries. Surveys show that as much as 60 percent of people in some countries believe genetically engineered crops may not be safe, while in the United States only 21 percent hold that belief.

Fears have led some to demand that genetically engineered crops or foods made from such crops should be labeled. In the United States there is not strong support for the idea, but in some European countries there is considerable support.

SUMMARY

Plant biotechnology promises many advantages. It may significantly improve the productivity of agriculture, help feed people in developing countries, reduce the use of pesticides, and lead to a more sustainable agricultural system. Some people question each of these promises, but the balance of scientific opinion holds that the potential dangers associated with genetically engineered crops is small, especially compared to the potential benefits for regions of the world that will require considerably increased production over the coming years.

REFERENCES

James, Clive and Anatole Krattiger, 1996. *Global Review of the Field Testing and Commercialization of Transgenic Plants: 1986 to 1995, The First Decade of Crop Biotechnology.* Published by ISAAA, Ithaca, NY.

Hoban, Thomas J., 1997. *Consumer Acceptance of Biotechnology: An International Perspective.* Nature Biotechnology 15, 232–234.

IRRI. (1996): *IRRI 1995-1996: Listening to the Farmers*. International Rice Research Institute, Los Baños