riculture and the environment. This raises the following question: How should science, industry, and governments respond?

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VIEWPOINT

Biotechnology and Food Security in the 21st Century

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Biotechnology can contribute to future food security if it benefits sustainable small-farm agriculture in developing countries. Presently, agrobiotechnology research cites ethical, safety, and intellectual property rights issues. Protection of intellectual property rights encourages private sector investment in agrobiotechnology, but in developing countries the needs of smallholder farmers and environmental conservation are unlikely to attract private funds. Public investment will be needed, and new and imaginative public-private collaboration can make the gene revolution beneficial to developing countries. This is crucial for the well-being of today's hungry people and future generations.

The human family has achieved outstanding progress in the 20th century. Developing countries have covered as much ground over the past 35 years in challenging poverty, hunger, disease, and ignorance as the industrialized nations covered in more than a century. The developing countries have doubled school enrollments, halved infant mortality and adult illiteracy, reduced malnutrition by a third, and extended life expectancy at birth by 20 years (*1*).

One of the greatest achievements since the Second World War has been the phenomenal increase of research-based agricultural productivity that has fed millions and served as the basis of economic transformation in many poor countries, especially on the Indian subcontinent (*2*). This "Green Revolution" has avoided dire predictions of death and famine in Asia (*3*). Food production has instead outpaced population growth, mainly because of substantially higher yields and increased irrigated land area. Food availability per capita grew and prices fell.

However, much remains to be done despite these gains. Poverty continues to limit access to food, leaving hundreds of millions of people undernourished in developing countries (*4*). Increased population, income growth, and urbanization will drive sustained growth in food demand, with a doubling of food needs in developing countries possible over the next four decades (*5*). Will the world continue to provide the supplies to meet this demand?

A priori, biotechnology—one of many tools of agricultural research and development—could contribute to food security by helping to promote sustainable agriculture centered on smallholder farmers in developing countries. Yet, biotechnology is now a lightning rod for visceral debate, with opposing factions making strong claims of promise and peril (*6*).

The World on the Eve of the New Century

Today the world is marked by aggregate affluence, but also by economic uncertainties, poverty, hunger, and violent conflict. Averages mask or divert attention from inequalities within and among societies. The natural resources on which future progress depends are imperiled (*7*). Population growth adds about 86 million persons a year, mostly in the poorest countries (*8*). Poverty and environmental degradation go hand in hand, for it is the poor who suffer the consequences of desertification and live the misery of unsanitary conditions. Tackling these problems is closely related to the policies that will be followed in transforming agriculture in developing countries (*9*).

Despite some problems, the Green Revolution has been a great success. There are, however, questions about whether a new, "doubly green revolution"—environmentally sustainable as well as yield-increasing—could help food needs over the next two decades. This revolution will need the political will to remove policy distortions that discriminate against poor people, investments in rural health and education, as well as rural roads, credit institutions, and high-quality research, within which biotechnology will have an increasing role (*2*, *9*).

Feeding the World in the 21st Century

Nobel laureate Norman Borlaug estimates that to meet projected food demands by 2025, average cereal yield must increase by 80% over the 1990 average (*10*). Making this formidable task even more difficult is that, to ensure that food production is coupled with both poverty reduction and environmental conservation, it will be essential that this increase occur in the complex smallholder farming systems of the poorest countries (*11*).

That requires policies and actions to promote agriculture and rural development, an enabling regulatory framework, fair trade, flexible and responsive institutions, increased investments in health and education, especially for women, and access to credit, roads, marketing, and extension. Research is a necessary but not sufficient condition for sustainable agricultural development, just as food production is a necessary but not sufficient condition for food security (*9*). The transformation will require access to and ability to apply technological advances, since future growth in food production will have to come largely from agricultural intensification on existing land. Most land suited to agriculture is already in use. More efficient use of water, energy, and labor is also essential (*12*).

A Double Shift in the Agricultural Research Paradigm

Two shifts in the research paradigm are necessary. The first involves integration of crop-specific research, which has been so successful in the past, into a broader vision that

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includes sound management of natural resources, as well as the productivity and profitability of smallholder farming; promoting synergies among livestock, agroforestry, food and cash crop, and aquaculture production, all on a hectare or so; integrated management of soil, water, and nutrients; integrated pest management; attention to postharvest losses; and recognition of the socioeconomic realities of farmers, including gender issues. In many developing countries, women produce the bulk of food crops (*2*, *9*, *11*, *12*).

Doubling the yields of complex farming systems in an environmentally sound manner is a difficult challenge (*13*). It is even harder than pushing the yield frontier on a particular crop. But such daunting challenges advance science.

The second shift is to harness the genetic revolution. Cutting-edge work associated with genetic mapping, molecular markers, and biotechnology must be focused on benefiting poor people and the environment. It is vital to realize the promise of this revolution while avoiding the pitfalls.

Delivering on the Promise of Biotechnology for the Poor

The initial successes in plant genetic engineering marked a significant turning point in crop research. Particularly in the 1990s, there has been an upsurge of private sector investment in agricultural biotechnology. Some of the first products were plant strains capable of synthesizing an insecticidal protein encoded by a gene (Bt) isolated from the bacterium *Bacillus thuringiensis*. Bt cotton, maize, and other crops are now commercially grown. There are also crop varieties tolerant to or capable of degrading herbicides. Proponents stress the value of these crops in minimum-tillage soil conservation (*14*).

Over the last 3 years, there have been dramatic and continuing increases in the area planted to transgenic crops. From 2.8 million hectares in 1996, the area increased nearly 10-fold to 11 million hectares in 1997 and rose to 27.8 million hectares in 1998. The United States alone accounted for 74% of the area planted to transgenics. Argentina was the only developing country with a significant transgenic hectarage (Fig. 1). The five principal transgenic crops were soybean, maize, cotton, rapeseed/canola, and potato (*14*, *15*).

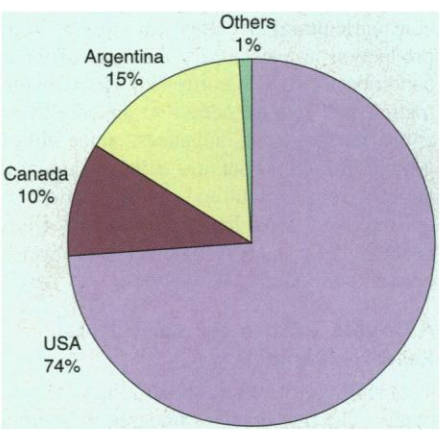

Fig. 1. Distribution of global area planted to transgenic crops [adapted from (*14*)].

Total transgenic crop sales grew more than sixfold, from U.S. $235 million in 1996 to $1.2 to $1.5 billion in 1998. The market is projected to increase to $3 billion or more in the year 2000, to $6 billion in 2005, and to $20 billion in 2010 (*15*). Consolidations in the form of acquisitions, mergers, and alliances continue to be a dominant feature of the biotechnology industry. Since 1996, more than 25 major acquisitions and alliances valued at $15 billion have taken place among agrobiotech, seed, and farm chemical firms (*16*).

This biotechnology revolution is very relevant to the problems of food security, poverty reduction, and environmental conservation in the developing world. But for many, it raises important questions relating to ethics, intellectual property rights, and biosafety (*17*). There have been widespread protests against the spread of agro-biotechnology. Some of the concerns come from scientists who fear that "novel" products will destroy agricultural diversity, thus changing agricultural patterns into unrecognizable and uncontrollable forms. Many protests have been made by civil society institutions on ethical or ecological grounds. The dominance of a highly concentrated private sector has raised fears of a new phase of comparative disadvantage and increased dependency in the developing world (*18*).

Also very much at issue are patenting and intellectual property rights. Supporters of patenting point out that if the private sector is to mobilize and invest large sums of money in agrobiotechnology R&D, it must protect and recoup what it has put in (*19*). On the other side of the argument is fear that patenting will lead to monopolization of knowledge, restricted access to germplasm, controls over the research process, selectivity in research focus, and increasing marginalization of the majority of the world's population (*20*).

These concerns cannot and must not be ignored. Effective regulatory mechanisms and safeguards need to be universal so that the impact of agrobiotechnology is both productive and benign. Every instrument of agricultural transformation should be mobilized in efforts to promote food security and help poor people.

Take the so-called Terminator Gene Technology. The Consultative Group on International Agricultural Research (CGIAR), which sponsors a global network of 16 international agricultural research centers, has announced that it will not release any germplasm that contains technologies that would prevent smallholder farmers from holding and replanting seeds (*21*). Instead, CGIAR centers are pursuing the apomictic gene to assist smallholders to replant hybrid varieties (*22*). But it is legitimate to study the sophisticated terminator technology, and learn from it, or seek out possible benign applications, such as a platform that would bond novel transgenes in desirable varieties, preventing their escape through unwanted gene flow.

Caution is warranted concerning the long-term effect of technologies, even if their application is benign. If terminator technologies were to become widespread, even if economically feasible and advantageous to the smallholder farmer, what would become of the constant introduction of variability that farmers bring to the plant gene pool? If there were large-scale agricultural homogeneity, what would the loss of local biodiversity mean? Would it destroy the environmental "early warning system" that enabled humans to recognize potential problems before they had major impacts on humans, as in the case of DDT (*23*)?

The answers to these questions are not yet known. Scientific research on such issues must be guided by ethical and safety principles, as well as respect for the private sector's need to earn a decent return. It is essential to harness the benefits of new technologies in sustainable ways for poverty eradication.

The promise that biotechnology holds for smallholder agriculture in the developing world is not yet realized. To do so will require addressing the issues of ethics, biosafety, and intellectual property rights. Potential risks remain the primary reason for slow acceptance of transgenic crops. To address such concerns, a global biosafety protocol is under negotiation.

More complex and contentious are intellectual property rights (IPR) issues. Application of intellectual property concepts to agriculture attracts much debate because technological development in agriculture, particularly in developing countries, has been driven primarily by public investment. Most of the products of agricultural research, including those generated by CGIAR centers, are considered "public goods." The largest germplasm collections of important crops in the developing world are held in trust by these centers and remain in the public domain (*21*, *23*).

Supporters of patenting argue that it enables and drives large private sector investments in biotechnology research. But the applications and their benefits are currently skewed to the markets of the rich and largely exclude the concerns of the poor.

Released transgenic crop varieties are mainly suitable for North America. The growing gap between the developed and developing worlds in the rapidly evolving knowledge frontier is exacerbated by privatization of scientific research. An emerging "scientific apartheid" would further marginalize poor people.

This results in the ethical dilemma posed by conflict between two competing claims to just and fair treatment. Intellectual property protection and private sector participation in research are keys to continued technological innovations, but there is also a moral obligation to ensure that scientific research helps address the needs of poor people and safeguards the environment for future generations.

Toward New Public-Private Partnerships

The way out may lie in establishing more precise domains of intellectual property. Public goods should be left to the public, and private goods that stand at the pathway of achieving these public goods should also be treated differently from private goods that are produced by the private sector in direct relation to the end user. In the past, CGIAR research centers could access the knowledge generated by basic research and apply it to the problems of poor people, leaving the results available to all for free. Today this arrangement is seriously threatened or is no longer possible because of patenting of both processes and products.

Private sector companies should certainly have patents for the products that they develop and choose to sell. However, it becomes a serious concern if their patents prevent CGIAR centers or the national agricultural research systems (NARS) of developing countries from using the same basic scientific processes to develop products that would benefit poor people and that the private sector patent holders would not develop, precisely because of their public goods nature, that is, because the initial investment would likely not be recovered. There is an ethical question here, and not just a legal one. The answer lies not in abolition of patenting or discouraging private research. Rather, an imaginative approach is needed, one that recognizes the interest of poor people.

There are many areas of research with potential benefits to poor people that are not being carried out by the private sector. Tomatoes with a long shelf life are now available and profitable. Research remains to be done on drought-resistant millet, with a much less certain commercial payoff, but a high food security impact among poor Africans. In cases where the public sector has recognized its role and decided to invest in such "orphaned" areas of research, its work is hampered by inability to use freely basic but proprietary knowledge generated by private research.

For developing countries to benefit from biotechnology research, public sector institutions (CGIAR centers and the NARS) must develop new partnerships with the private sector and advanced research institutions, just as they develop in parallel partnerships with nongovernmental organizations and farmer associations. Some arrangements involving transfer of proprietary technologies by private companies to developing countries without royalties are already taking place. These usually involve cases where a developing country's use of the technology does not compete with use in targeted markets. For example, the Monsanto company has entered into agreements with Kenyan and Mexican agricultural research institutes on developing virus-resistant crops.

These partnerships seem to have worked well. However, they are few, highly bilateral, and components of philanthropic programs. New and more comprehensive collaboration with the private sector, while respecting IPR protection, is needed to access the process side of biotechnology for "public-goods" research in developing countries. Partnerships with legally binding agreements on sharing results have to be developed.

The international public research system has a critical role in ensuring that access to potential benefits of new technologies are guaranteed for poor people and environmental conservation. There must be a recognition of the need for increased public involvement with biotechnology and for complementing private sector research, to ensure transparency and accountability and to promote a broad range of public goods research just as markets expand for results of private goods research. There is a need for win-win-win scenarios for all concerned actors, and for creative efforts to identify and put to work enabling mechanisms for the developing countries to benefit from the gene revolution. For the sake of today's poor, marginalized, and hungry people, and for future generations, we must not shirk this important challenge.

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