Modern Biotechnology for Food and Agriculture: Risks and Opportunities for the Poor

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The current debate about the potential utility of modern biotechnology for food and agriculture, and the associated potential risks and opportunities, is focused on the initial applications of such biotechnology in industrial country agriculture. The debate is also intertwined with other concerns such as food safety, animal welfare, industrialized agriculture, and the role of private-sector corporations. At present, there is very little commercial utilization of results from modern biotechnology research in developing countries. As a result, the potential contributions of biotechnology to poverty alleviation and enhanced food security and nutrition in developing countries has received little attention, beyond blanket statements of support or opposition.

A debate based on the best available empirical evidence relevant for poor people in developing countries is urgently needed, 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 for poor countries and poor people. We will attempt to provide input into a more focused debate on the role of modern agricultural biotechnology in developing countries, a debate that should and will be led by people from developing countries themselves.

The Problem

Small-scale farmers in developing countries are faced with many problems and constraints. Pre- and postharvest crop losses due to insects, diseases, weeds, and droughts result in low and fluctuating yields, as well as risks and fluctuations in incomes and food availability. Low soil fertility and lack of access to reasonably priced plant nutrients, along with acid, salinated, and waterlogged soils and other abiotic factors, contribute to low yields, production risks, and degradation of natural resources as poor farmers try to eke out a living. They are often forced to clear forest or farm ever more marginal land to cultivate crops. Poor infrastructure and poorly functioning markets for inputs and outputs together with lack of access to credit and technical assistance add to the impediments facing these farmers.

These farmers and other rural and urban poor people suffer from food insecurity and poor nutrition, caused in large measure by poverty and lack of nutritional balance in the diet they can afford. About 1.2 billion people, or one of every five humans, live in a state of absolute poverty, on the equivalent of US$1/day or less (World Bank 1999). About 800 million people are food insecure (FAO 1999a), and 160 million preschool children suffer from energy-protein malnutrition, which results in the death of over 5 million children under the age of five each year (ACC/SCN and IFPRI 1999). A much larger number of people suffer from deficiencies of micronutrients such as iron and vitamin A. For example, 2 billion people (one of every three) are anemic, usually as a result of iron deficiency. Food insecurity and malnutrition result in serious public health problems and lost human potential in developing countries.

Around 70 percent of poor and food-insecure people reside in rural areas, although poverty and food insecurity appear to be growing in urban areas as urbanization proceeds apace in developing countries. The World Bank forecasts that poverty's center of gravity will remain rural in the early decades of the 21st century (McCalla and Ayers 1997).

Most rural poor people depend directly or indirectly on agriculture for their livelihood. Poor people in rural or urban areas spend as much as 50–70 percent of their incomes on food (Deaton 1997). Low productivity in agriculture is a major cause of poverty, food insecurity, and poor nutrition in low-income developing countries. This is true for urban and rural poor people alike. Low productivity means low incomes for farmers and farm workers, little demand for goods and services produced by poor nonagricultural households in the rural areas, and unemployment and underemployment in urban areas. It also means high unit costs for food, which translate into reduced consumer purchasing power. High food prices are a serious matter for households that spend a large share of their budget on food. In low-income developing countries, agriculture is the driving force for broad-based economic growth and poverty alleviation. A healthy agricultural economy offers farmers incentives for sound management of the natural resource base upon which their livelihood depends.

These relationships are borne out not only by research but also by history in both developing and industrial nations. Productivity increases in European and U.S. agriculture were extremely important to broad-based economic growth during earlier periods of development. More recently, productivity increases in agriculture, led by agricultural research — the Green Revolution — formed the locomotive of rapid broad-based economic growth and poverty reduction in many Asian countries, including China, Indonesia, South Korea, and India. Recent IFPRI research in four African countries found similar strong linkages between agricultural productivity growth and general economic growth (Delgado and others 1998).

Productivity gains are essential not only for economic growth and poverty alleviation, but to assure that food supplies remain adequate for a growing world population. According to United Nations projections, world population will increase by 25 percent to 7.5 billion in 2020. On average, 73 million people will be added annually. Over 97 percent of the projected growth will take place in developing countries (United Nations Population Division 1998).

Public Investment Critical to Food Security

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

- Yield-increasing crop varieties, including those that are drought and salt tolerant and pest resistant, and improved livestock
- Yield-increasing and environmentally friendly production technology
- Reliable, timely, and reasonably priced access to appropriate inputs such as tools, fertilizer, and, when needed, pesticides, 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 developing 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, such as secure property rights for small farmers. 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.

Developing countries must reverse present declining levels of public investment in agriculture. On average, they devote 7.5 percent of government spending to agriculture (and just 7 percent in Sub-Saharan Africa) (FAO 1996). For their part, donor countries must redress the precipitous decline in aid to agriculture and rural development, which plunged by nearly 50 percent in real terms between 1986 and 1996 (FAO 1998). Overall development aid has also fallen in recent years (Michel 1999). Ironically, our research has found that aid to developing country agriculture not only is effective in promoting sustainable development and poverty alleviation, but it leads to increased export opportunities for industrial countries as well, including, paradoxically, increased agricultural exports (Pinstrup-Andersen, Lundberg, and Garrett 1995; Pinstrup-Andersen and Cohen 1998). Donors must also rethink their rather inflexible emphasis of the past two decades on less government and a smaller public sector, which has contributed to public disinvestment in agriculture in the developing countries (FAO 1996).

Agricultural Research is Essential

Public investment in agricultural research is of particular importance for achieving food security in developing countries. The private sector is unlikely to undertake much of the research needed by small farmers because it cannot expect sufficient returns to cover costs. IFPRI research has shown that the annual rates of return to agricultural research and development are, on average, 73 percent (Alston and others 1998). Benefits to society from agricultural research can be extremely large but will not be obtained without public investments. We have also found that even minor increases in aid to agricultural research for developing countries can significantly accelerate food supplies, while relatively small cuts could have serious negative effects (Rosegrant, Agcaoili-Sombilla, and Perez 1995).

Despite this evidence, low-income developing countries grossly underinvest in agricultural research: less than 0.5 percent of the value of their agricultural production, compared to 2 percent in higher-income countries. Sub-Saharan Africa, which desperately needs productivity increases in agriculture, has only 42 agricultural researchers per million economically active persons in agriculture, compared with 2,458 in industrial countries (Pardey and Alston 1996).

Efforts to improve longer-term productivity on small-scale farms, with an emphasis on staple food crops, must be accelerated. Research and policies are also needed to help farmers, communities, and governments better cope with risks resulting from such factors as poor market integration, poorly functioning markets, and climatic fluctuations. More research must be directed to the development of appropriate technology for sustainable intensification of agriculture in resource-poor areas, where a high percentage of poor people live, and where environmental risks are severe. The needed research must join all appropriate scientific tools together, with better use of the insights of traditional indigenous knowledge.

Research and technology alone will not drive agricultural growth. The full and beneficial effects of agricultural research and technological change will materialize only if government policies are conducive to and supportive of poverty alleviation and sustainable management of natural resources.

Agricultural Biotechnology and Food Security

Can molecular biology-based research contribute to the solution of the problems outlined earlier? Are the potential social and economic benefits likely to exceed potential risks or costs? If these questions are answered in the affirmative, issues related to the design of the technology and the needed policies and institutions must be tackled.

Although conventional applications of biotechnology, such as tissue culture and fermentation amongst others, is under way in several developing countries, little genetically improved (transgenic) seed material has been grown in the poorer developing countries to date so ex post assessment is virtually impossible. A great deal is known, however, about the social and economic risks and benefits associated with traditional Mendelian plant breeding as exemplified by the Green Revolution. The analysis, therefore, begins with the identification of similarities and differences between the Green Revolution and modern biotechnology, and an attempt is made to draw lessons from the Green Revolution and to look at the difference between that technology package and modern biotechnology to try to assess the likely social and economic risks and benefits of modern agricultural biotechnology ex ante.

Comparing the Green Revolution and Modern Biotechnology

Shift to private sector research. There are three differences of particular importance for an assessment of social and economic risks and benefits. The research leading to the Green Revolution was undertaken by the public sector and the improved seed was usually freely available for seed multiplication and distribution. Although breeders' rights may permit an initial charge for the improved materials, the intellectual property rights (IPR) did not extend beyond the initial release. Having acquired the seed, farmers could reuse it without further payment, although reuse of hybrid seed would drastically reduce the yield advantage. This is in keeping with the principle of "farmers' rights" included in the 1983 International Undertaking on Plant Genetic Resources (Wright 1996; FAO 1999b).

In contrast, the bulk of modern agricultural biotechnology research is undertaken by private sector firms, which protect IPRs through patents that extend beyond the first release. Farmers, therefore, cannot legally plant or sell for planting the crop produced with the patented seed without the permission of the patent holder. Patent holders, currently seeking ways to enforce their rights, are considering approaches such as legal agreements and technologies that will activate and deactivate specific genes. However, monitoring and enforcing contracts that prohibit large numbers of small farmers from using the crops they produce as seed would be expensive and difficult.

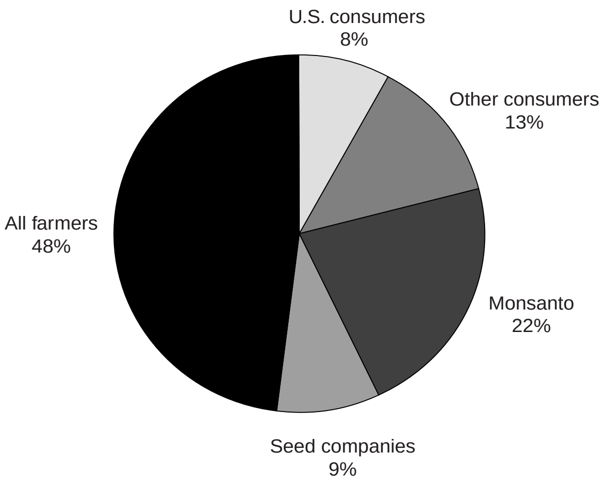
The so-called terminator gene is the first patented technology aimed at biological IPR protection. It is not appropriate for small farmers in developing countries because existing infrastructure and production processes may not be able to keep fertile and infertile seeds apart. Small farmers could face severe consequences if they planted infertile seeds by mistake. Commercialization of the terminator gene now seems unlikely in the short term.

Research is under way on other biological approaches to IPR protection that would not impose such risk on small farmers. These include, for example, genetically engineered seeds that contain desired traits, such as pest resistance or drought tolerance, but in which these are activated only through chemical treatment. Otherwise, the seed would maintain its normal characteristics. Thus, if a farmer planted an improved seed, the offspring would not be sterile; rather they would revert to normal seeds, without the improved traits. The farmer would have the choice of planting the seed and doing no more, or activating the improved traits by applying the chemical. This approach complies with the principle of doing no harm.

It is important to note that even when patents permit a private company to enjoy monopoly or near-monopoly rights over a product it has developed, the firm is unlikely to capture 100 percent of the economic benefits. A recent study of the distribution of the economic benefits generated by the use of herbicide-tolerant soybean seed in the United States in 1997 found that the company, Monsanto, received 22 percent, while seed companies gained 9 percent. Consumers of soybean and soybean products in the United States and other countries reaped a 21 percent share, whereas farmers worldwide obtained 48 percent (Figure 1). The share of U.S. farmers was actually 51 percent of the benefits, but farmers elsewhere experienced net losses of 3 percent (Falck-Zepeda, Traxler, and Nelson 1999).

Rise of proprietary research processes and technologies. A second, and related, difference between the Green and Gene revolutions involves the patenting of processes as well as products. The main

Figure 1 Distribution of 1997 economic surplus from U.S. use of Roundup Ready™ soybean seed (total US$360 million)



(*Source:* Falck-Zepeda and others 1999).

process behind the Green Revolution was conventional plant breeding technology, which lies in the public domain, carried out by public institutions. Today, the processes used in modern agricultural biotechnology are increasingly subjected to IPR protection, along with the products that result.

This means that public sector research institutions may not be able to gain access to basic but proprietary knowledge and processes needed in research, including research on the so-called orphan crops such as cassava and millet. These are critical staples in the diets of many poor people, but they do not offer promising economic returns to private sector R&D efforts, so efforts to develop disease-resistant cassava or drought-tolerant millet, whether through genetic modification or conventional breeding, must come from the public sector. Some firms have agreed to transfer proprietary technologies, without charging royalties, to developing countries where there are few potential commercial prospects. Monsanto, for example, has entered into agreements with Kenyan and Mexican government agricultural research institutes to develop virus-resistant crops (see Lewis, this volume). Arrangements such as these are few and generally involve the philanthropic arms of the private firms (Serageldin 1999).

Enlightened adaptation vs. direct transfer. A third difference involves the adaptation of industrial country agricultural research to developing country conditions. Although based on earlier research in industrial countries, the Green Revolution was focused on solving specific problems in developing countries. Current application of modern biotechnology is focused on industrial country agriculture.

Industrial country research institutions had begun working on development of higher yielding crop varieties in the late 19th century. For example, in Japan, rice breeding under the auspices of the Ministry of Agriculture and public universities led to large yield gains in the early part of the 20th century, with a second wave of major gains after 1945.

During the early decades of Soviet history, under the leadership of geneticist Nikolai Ivanovich Vavilov, the government carried out extensive crop improvement programs and established one of the world's largest germplasm collections. In the United States, hybrid maize research began in the 1920s. Much of the basic research was done by public institutions, such as land grant universities, state experiment stations, and the U.S. Department of Agriculture (USDA). Applications to particular farming conditions and the mass marketing of the new varieties were, in turn, handled by private seed firms such as Pioneer Hi-Bred and DeKalb. The research focused not only on developing higher yielding seeds to bolster food supplies for domestic consumption (which was a critical U.S. concern up to the 1940s), but also on animal feed and production for export.

This research could not simply be transferred to poorer developing countries, where the need was for improved varieties of locally-consumed staples. The research that led to the Green Revolution involved further adaptation to the agroecological conditions of tropical and semitropical areas. It also focused on rice, wheat, maize, root and tuber crops, and tropical fruits and vegetables. The public sector role was, if anything, even more prominent, with international agricultural research centers (IARCs) and national agricultural research systems (NARS),particularly in Asia and Latin America, playing a prominent role. Financial support came from donors of official development assistance and large private foundations, such as Ford, Rockefeller, and Kellogg.

In contrast, modern agricultural biotechnology is still in an early phase, and the focus is overwhelmingly on production on industrial country farms and for industrial country markets. In 1998, 85 percent of the land planted to genetically improved (GI) crops was in just five developed countries (Australia, Canada, France, Spain, and the United States), with the United States alone accounting for about 75 percent of the area. Argentina, China, Mexico, and South Africa cultivated the remaining 15 percent, and the countries other than China include a substantial number of large-scale, capital-intensive farms that produce primarily for industrial country markets. Among the crops produced in these four developing countries are insect-resistant cotton and maize, herbicide-resistant soybean, and tomatoes with a long shelf life. Globally, herbicide-resistant soybean, insect-resistant maize, and genetically improved cotton (containing insect resistance and/or herbicide tolerance genes) account for 85 percent of all plantings. Both the area planted to genetically improved crops and the value of the harvests grew dramatically between 1995 and 1999: from less than 1 million hectares to 28 million in 1998 and approximately 40 million in 1999, and from US$75 million in 1995 to US$1.64 billion in 1998 (James 1999; James and Krattiger 1999; Juma and Gupta 1999).

Private industry has dominated research (there are a few exceptions: for example, Rockefeller Foundation support for research on rice, USDA's role in developing the terminator technology, and modest programs at IARCs). Consolidation of the industry has proceeded rapidly since 1996, with more than 25 major acquisitions and alliances worth US$15 billion.

Little private-sector agricultural biotechnology research so far has focused on developing country food crops other than maize. Moreover, little adaptation of the research to developing country crops and conditions has occurred through the "enlightened" (that is, not for profit, public goods oriented) public and philanthropic channels prominent in the Green Revolution of the developing countries. Some of the exciting international and regional programs are described by Cohen (1999). A program directed at public/private sector linkages is that of the International Service for the Acquisition of Agri-biotech Applications (ISAAA), which transfers and delivers appropriate biotechnology applications to developing countries and builds partnerships amongst institutions.

Relatively little biotechnology research currently focuses on the productivity and nutrition of poor people. The Rockefeller Foundation's agriculture program is one example; in 1998, it provided about US$7.4 million for biotechnology research relevant to developing countries, mainly through IARCs and NARS in developing countries, with a major emphasis on rice. This sum pales by comparison with Monsanto's 1998 R&D budget of US$1.3 billion, much of which funded agricultural biotechnology research (Rockefeller 1999; Monsanto 1999).

As with the Green Revolution, the challenge is to move from the scientific foundation established by industrial country-oriented research efforts to research focused on the needs of poor farmers and consumers in developing countries. Direct transfers of the fruits of agricultural biotechnology research to the developing countries will not work, in most cases. More appropriate research for the developing world might focus on biotechnology and conventional breeding to develop alternative forms of weed resistance, such as leafier rice that denies weeds sunlight rather than incorporating herbicide tolerance into rice. The West Africa Rice Development Association (WARDA), a public IARC in Côte d'Ivoire, has used a combination of conventional plant breeding and tissue culture to develop such rice (WARDA 1999).

Insect-resistant crops would have great potential value for poor farmers. So far, however, the development of crops containing genes from the *Bacillus thuringiensis* (Bt) bacterium, which produces a natural pesticide, has focused largely on the crops and cropping environments of North America. The new crop varieties containing the Bt gene require extremely knowledge-intensive cultivation. They might well be transferable to larger scale operations in some developing countries such as Argentina. The potential usefulness of this application in crops grown by small farmers is open to question. There is considerable debate about risks of the development of resistance in pests, harm to beneficial insects, and cross-pollination of wild and weedy plants with the novel gene. The evidence on these issues is still inconclusive and warrants careful monitoring before the application of Bt is tried on a large scale in crops grown by subsistence farmers.

Research on crops and problems of relevance to small farmers in developing countries will require the allocation of additional public resources to agricultural research, including biotechnology research, that promises large social benefits. There is no reason to believe that this research will offer lower rates of return than other agricultural research and development.

Private-sector agricultural research currently accounts for a small share of agricultural research in most developing countries. The public sector can expand private-sector research for poor people by converting some of the social benefits to private gains, for example, by offering to buy exclusive rights to newly developed technology and make it available either for free or for a nominal charge to small farmers. The private research agency would bear the risks, as it does when developing technology for the market. IARCs have an important role to play as intermediaries in facilitating such arrangements.

Without more enlightened adaptation, continued expansion of genetically improved crop production in the industrial countries may well have a negative impact on small farmers in developing countries. Some developing country consumers would benefit, but those consumers who also farm could experience net losses. In addition, the development of industrial substitutes for developing country export crops, such as cocoa (which in many developing countries is produced by small farmers) could have a devastating impact on developing country farmers' livelihoods.

In sum, the biggest risk of modern biotechnology for developing countries is that technological development will bypass poor farmers and poor consumers because of a lack of enlightened adaptation. It is not that biotechnology is irrelevant, but that research needs to focus on the problems of small farmers and poor consumers in developing countries. Private sector research is unlikely to take on such a focus, given the lack of future profits. Without a stronger public sector role, a form of "scientific *apartheid*" may well develop, in which cutting edge science becomes oriented exclusively toward industrial countries and large-scale farming (Serageldin 1999).

Lessons from the Green Revolution. The outcomes of the Green Revolution offer some guideposts for assessing the likely risks and benefits of agricultural biotechnology for developing countries. Risks and benefits may be inherent in a given technology, or they may transcend the technology (Leisinger 1999). The policy environment into which a technology is introduced is critical. For example, IFPRI research has found that in Tamil Nadu State in India, the adoption of high-yielding grain varieties meant not only increased yields and cheaper, more abundant food for consumers, but income gains for small and larger-scale farmers alike, as well as for nonfarm poor rural households. Increased rural incomes contributed to nutrition gains for these households (Hazell and Ramasamy 1991). Because the Tamil Nadu state government has pursued active poverty alleviation strategies, including extensive social safety net programs and investment in agriculture, rural development, and a fair measure of equity in access to resources such as land and credit, the benefits were widely shared. Where increased inequality followed the adoption of Green Revolution technology, it was not because of factors inherent to the technology, but rather a result of policies that did not promote equitable access to resources. And even in these areas, rural landless laborers usually found new job opportunities as a consequence of increased agricultural productivity, particularly where appropriate physical infrastructure and markets developed.

Successful adoption of Green Revolution technology, however, depended on access to water, fertilizer, and pesticides. Thus, inequality between well-endowed and resource-poor areas increased because of the properties of the technology itself. Likewise, excessive or improper use of chemical inputs led to adverse environmental impacts in some instances. This problem was offset, to some extent, by characteristics that were also inherent in the technology: by allowing yield gains without expanding cultivated area, the technology kept cultivators from clearing forests and moving onto wild and marginal lands.

Overall, the Green Revolution was extremely successful in enhancing productivity in rice, wheat and maize; in increasing incomes and reducing poverty; and in preserving forests and marginal lands by improving yields within existing cultivated areas. By reducing unit costs and prices for food, it greatly benefited poor consumers, and by boosting farmers' incomes, it contributed to gains in nutrition. Would agricultural biotechnology produce similar results in developing countries? The answer depends on whether the research is relevant to poor people and on its ownership, that is, the nature of the intellectual property rights arrangements.

Weighing Risks and Benefits of Biotechnology

Modern biotechnology is not a silver bullet for achieving food security, but, used in conjunction with traditional or conventional agricultural research methods, it may be a powerful tool in the fight against poverty that should be made available to poor farmers and consumers. 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 will benefit both farmers and consumers.

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 (U.S. Bureau of Labor Statistics 1999; U.S. Census Bureau 1998; U.S. National Agricultural Statistics Service 1998). 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.

Strong opposition to GI 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.

Potential benefits. There are many potential benefits for poor people in developing countries. Biotechnology may help achieve the productivity gains needed to feed a growing global population, introduce resistance to pests and diseases without costly purchased inputs, heighten crops' tolerance to adverse weather and soil conditions, improve the nutritional value of some foods, and enhance the durability of products during harvesting or shipping. New crop varieties and biocontrol agents may reduce reliance on pesticides, thereby reducing farmers' crop protection costs and benefiting both the environment and public health. Biotechnology research could aid the development of drought-tolerant maize and insect-resistant cassava, to the benefit of small farmers and poor consumers. Research on genetic modification to achieve appropriate weed control can increase farm incomes and reduce the time women farmers spend weeding, allowing more time for the child care that is essential for good nutrition. Biotechnology may offer cost-effective solutions to micronutrient malnutrition, such as vitamin A- and iron-rich crops.

Research focused on how to reduce the need for inputs and increase the efficiency of input use could lead to the development of crops that use water more efficiently and extract phosphate from the soil more effectively. The development of cereal plants capable of capturing nitrogen from the air could contribute greatly to plant nutrition, helping poor farmers who often cannot afford fertilizers.

By raising productivity in food production, agricultural biotechnology could help further reduce the need to cultivate new lands and help conserve biodiversity and protect fragile ecosystems. Productivity gains could have the same poverty-reducing impact as those of the Green Revolution if the appropriate policies are in place.

Policies must expand and guide research and technology development to solve problems of importance to poor people. Research should focus on crops relevant to small farmers and poor consumers in developing countries, such as banana, cassava, yam, sweet potato, rice, maize, wheat, and millet, along with livestock.

Health and environmental risks. Genetically improved (GI) foods are not intrinsically good or bad for human health. Their health effect depends on their specific content. GI foods with a higher iron content are likely to benefit iron-deficient consumers. But the transfer of genes from one species to another may also transfer characteristics that cause allergic reactions. Thus, GI foods need to be tested for allergy transfers before they are commercialized. Such testing avoided the possible commercialization of soybeans with a Brazil nut gene. GI foods with possible allergy risks should be fully labeled. Labeling may also be needed to identify content for cultural and religious reasons or simply because consumers want to know what their food contains and how it was produced. While the public sector must design and enforce safety standards as well as any labeling required to protect the public from health risks, other labeling might best be left to the private sector in accordance with consumer demands for knowledge.

Failure to remove antibiotic-resistant marker genes used in research before a GI food is commercialized presents a potential although unproven health risk. Recent legislation in the European Union requires that these genes be removed before a GI food is deemed safe.

Risks and opportunities associated with GI foods should be integrated into the general food safety regulations of a country. International agencies and donors may need to assist some developing countries build the capacity to develop appropriate regulatory arrangements. These regulatory systems are needed to govern food safety and assess any environmental risks, monitor compliance, and enforce such regulations. The regulatory arrangements should be country-specific and reflect relevant risk factors. Progress on achieving a global agreement on biosafety standards is urgently needed (Juma and Gupta 1999). The development of a public global regulatory capacity has lagged far behind the pace of economic globalization.

The ecological risks policymakers and regulators need to assess include the potential for spread of traits such as herbicide resistance from genetically improved plants to unmodified plants (including weeds), the buildup of resistance in insect populations, and the potential threat to biodiversity posed by widespread monoculture of genetically improved crops. Seeds that allow farmers the option of "turning off" genetic characteristics, mentioned earlier, offer great promise for assuring that new traits do not spread through cross-pollination.

Both food safety and biosafety regulations should reflect international agreements and a given society's acceptable risk levels, including the risks associated with not using biotechnology to achieve desired goals. Poor people should be included directly in the debate and decisionmaking about technological change, the risks of that change, and the consequences of no change or alternative kinds of change.

Socioeconomic risks. Unless developing countries have policies in place to ensure that small farmers have access to delivery systems, extension services, productive resources, markets, and infrastructure, there is considerable risk that the introduction of agricultural biotechnology could lead to increased inequality of income and wealth. In such a case, larger farmers are likely to capture most of the benefits through early adoption of the technology, expanded production, and reduced unit costs (Leisinger 1999).

Growing concentration among companies engaged in agricultural biotechnology research may lead to reduced competition, monopoly or oligopoly profits, exploitation of small farmers and consumers, and extraction of special favors from governments. Effective antitrust legislation and enforcement institutions are needed, particularly in small developing countries where one or only a few seed companies operate. Global standards regarding industrial concentration must also be developed; international public policies in this area have not kept pace with economic globalization. Effective legislation is also required to enforce IPRs, including those of farmers to germplasm, along the lines agreed to within the WTO and the Convention on Biological Diversity.

Ethical questions. 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. This is far from a trivial consideration. 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. Continued human survival depends on precisely such interventions.

Conclusion

Expanded enlightened adaptive research on 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. 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. It is not, as some critics have charged, "a solution looking for a problem." The problems are genuine and momentous. Public sector research, particularly through IARCs and NARS, is essential for ensuring that molecular biology-based science serves the needs of poor people. It is also urgent that internationally accepted biosafety standards and local regulatory capacity be strengthened within developing countries.

Evaluation of genetically improved crops needs to increase in developing countries; at present, about 90 percent of the field testing occurs in industrial countries. Without field testing, it is virtually impossible to assess potential environmental and health risks. Hence, destruction of test plots by anti-GI activists should cease. Open debate about the issues involved is essential, but physical attacks on research and testing efforts contribute little to the free exchange of ideas or the formulation of policies that will advance food security.

If the appropriate steps, including those outlined above, are not taken, modern biotechnology could bypass poor people. Opportunities for reducing poverty, food insecurity, child malnutrition, and natural resource degradation will be missed, and the productivity gap between developing and industrial country agriculture will widen. Such an outcome would be unethical indeed.

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