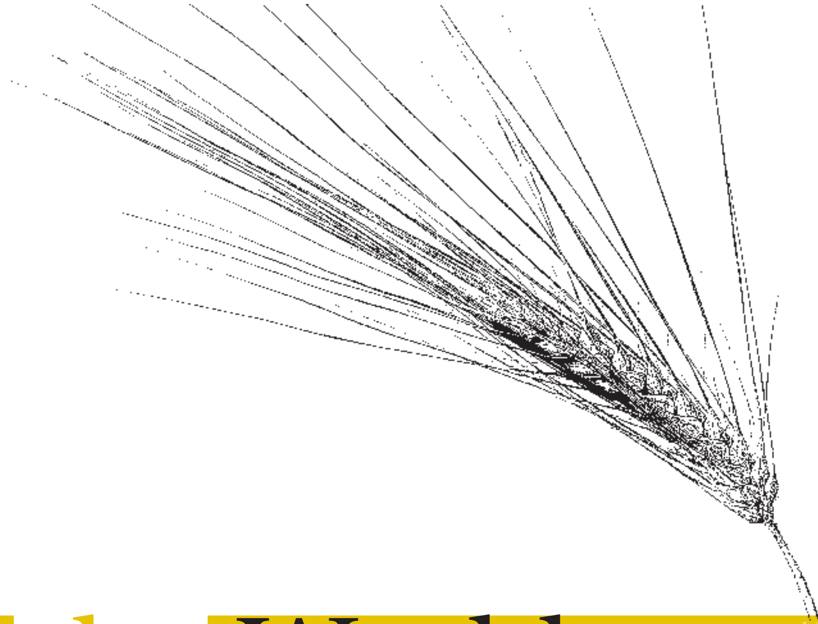

# Feeding the World

## A LOOK AT BIOTECHNOLOGY & WORLD HUNGER

**A brief prepared by**
**the Pew Initiative on Food and Biotechnology**

**MARCH 2004**

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 This report was supported by a grant from the Pew Charitable Trusts to the University of Richmond. 

# Preface

**One of the most controversial issues surrounding genetically modified foods is whether biotechnology can help address the urgent problems of global hunger. According to the Food and Agriculture Organization of the United Nations, the number of chronically undernourished people in developing nations has risen in recent years to 798 million. Proponents of biotechnology argue that it offers the best prospect for helping less developed nations feed their hungry citizens by improving plant genetics to increase crop yields, in the same way that improved rice and wheat varieties led to the Green Revolution beginning in the 1960s. Critics respond that genetically modified foods pose risks to human health and the environment. Both sets of arguments are embedded in the context of broader and deeper conflicts over development, globalization, and the role of technology in agriculture.**

The potential use of biotechnology to address hunger is also an important aspect of the larger policy debate about genetically modified foods within the United States. Consumer opinion surveys consistently show that Americans view the potential of genetically modified foods to help feed hungry people as one of the strongest reasons to support biotechnology. In initiating a trade complaint with the World Trade Organization about the European Union's *de facto* moratorium on genetically modified crop approvals, the Bush Administration cited the impact of the EU's policies on decisions by some southern African nations to reject U.S. food aid that included genetically modified corn.

To help understand why such strong disagreements exist about the promises and concerns associated with the application of biotechnology to address hunger, the Pew Initiative on Food and Biotechnology commissioned this paper to provide a summary of the positions on both sides of the issue. The paper focuses particularly on the debate over the potential of biotechnology to develop new food crop varieties that could help meet the demand for more food in subsistence populations, largely because that issue figures so prominently in the public debate. It is important to note, however, that this paper is by no means a comprehensive review of the complex issue of global hunger. In particular, the paper does not discuss the important question of whether biotechnology crops could help improve the incomes of subsistence, small-scale or commercial farmers in the developing world. This paper does not contain policy recommendations, but rather identifies some of the policy issues relevant to this topic.

We would like to acknowledge the principal authors of this report, Andrew C. Fish, Esq., former U.S. Assistant Secretary of Agriculture, and Larisa Rudenko, Ph.D., DABT, formerly with Integrative Biostrategies, LLC. Dr. Rudenko is currently the Senior Advisor for Biotechnology at the Center for Veterinary Medicine at FDA. This document represents Dr. Rudenko's work in her personal capacity as an expert in biotechnology, and is not reflective of any policy or opinions of the U.S. Food and Drug Administration. We would also like to acknowledge the helpful reviews of Don Doerring (World Resources Institute), Per Pinstrup-Anderson (International Food Research and Policy Institute), Robert Goodman (University of Wisconsin), and Robert Paarlberg (Wellesley College and Harvard University).

*Michael Rodemeyer*
*Executive Director*

# Contents

We will not be able to feed the people of this millennium with the current agricultural techniques and practices. To insist that we can is a delusion that will condemn millions to hunger, malnutrition and starvation, as well as to social, economic and political chaos.

*Norman Borlaug* [1]

[T]he practice of international agricultural development has been dominated by technical questions, ignoring the more fundamental social and economic ones, and neglecting competing kinds of knowledge, such as traditional farmers' knowledge and perspectives from the social sciences. The result has been the imposition of inadequate development models, of which biotechnology is the latest variant.

*Miguel A. Altieri and Peter Rosset* [2]

# Introduction

**Hundreds of millions of people around the world cannot grow or obtain food in sufficient quantity or quality to sustain healthy life. The Food and Agriculture Organization of the United Nations (FAO) finds that the number of undernourished people worldwide and in developing nations has risen over the past four years for which data is available. Currently, 842 million people worldwide are believed to be undernourished, nearly three times the population of the United States, and 798 million of these live in developing nations.[3] Recently, the effects of drought on food production have put additional millions of people in sub-Saharan Africa at risk of not just malnutrition but starvation.**

**The topic of global hunger has become a prominent backdrop for the worldwide debate over genetically modified (GM) food crops. The possible use of biotechnology to boost food production and quality in developing countries has become a focal point for biotechnology advocates and critics alike.[i]**

In some respects, the debate about the appropriateness of GM crops for developing countries is not all that different from the debate occurring in the industrialized world. Proponents of the technology point to the potential benefits of the technology to increase food production, reduce crop losses from diseases, insects, and drought, and improve the nutritional content of traditional foods. Critics point to possible human health risks from GM foods, such as new allergens or toxins, or potential environmental and economic concerns, such as the spread of a transgenic trait through wild ecosystems or conventional crops that could threaten biodiversity or trade with nations that reject GM crops.

i This paper uses “agricultural biotechnology” to refer to the modification of food crops by inserting a gene from another species into a plant through recombinant DNA techniques. In other contexts, the term is used to encompass a wide range of agricultural sciences, including such ancient technologies as fermentation, and other modern advances, such as tissue culture.

While this "benefit versus risk" argument raises issues similar to those in the debate about GM foods in the developed world, the social and economic context of the debate regarding the developing world differs considerably. It is one thing to discuss the impact of a new agricultural technology on a society that already produces abundant, safe, diverse, and affordable foods; where farmers have experience with technology and access to capital for technology investments; where public and private research and development meet evolving agricultural needs; and where a well-developed regulatory system is in place. It is quite another question to understand the net impact of the technology in a society that fails to produce enough food to feed its people; where one or a few foods dominate diets; where farmers lack the basic infrastructure to transport, store, and sell the food they do grow; where farmers lack the income and access to credit necessary for investments in technology; where little public or private investment exists for developing appropriate technologies; or where there is little, if any, capacity to manage possible risks associated with the technology. These broader social and economic factors may have as much to do with the potential impact of biotechnology as the narrower issues of specific benefits and risks.

As a result, one central question is whether biotechnology addresses the underlying causes of hunger in developing nations. Some observers argue that the cause of hunger is not inadequate food production, but inequitable food distribution, and that biotechnology—indeed, any agricultural technology—does not address that inequity. Critics also argue that the private sector has little financial incentive to develop GM crops to benefit developing country subsistence farmers. Moreover, if such crops were to be developed, critics are concerned that large multinational seed companies could exercise undue market power over small farmers by controlling seed supplies. On the other hand, others contend that any technology that can increase yields or improve nutrition in places where there is inadequate food wields great promise and should be welcomed. Many would assert that public investment in agricultural research on how to better utilize technology to solve the problems of the poor in developing countries is essential because it would not only impact hunger but could alleviate some of the concerns about private control of the technology and access in these regions. Toward that goal, some advocate increased involvement of the international donor community to enable more public sector investment in GM crops in developing countries.

This paper intends to illuminate some of the key issues pertaining to the appropriate role of biotechnology in addressing hunger and food production in the developing world. It does not attempt to resolve the debate, but rather aims to give the reader a basic understanding of the contours of the debate. Its focus is on hunger reduction, as opposed to poverty reduction. Therefore, the discussion is oriented toward the adoption of GM crops primarily by smallholder and subsistence farmers to increase production of food crops and enhance their nutritional characteristics, as opposed to generating income through commercial scale farm operations. While the latter issue is of obvious significance given that an approximate 1.2 billion people live on less than one dollar per day, poverty reduction is not addressed in this paper.[ii] Finally, the paper is an overview of the issues and does not contain a comprehensive evaluation of the benefits and risks of GM crops in specific regions of the world, which can only be addressed adequately on a case-by-case basis.



ii For example, biotechnology could potentially improve the yields or qualities of commodity or specialty crops that developing nations could export to provide income and improve food security. Indeed, the technology underlying GM crops can be applied to non-food crops as well (*e.g.*, insect-resistant cotton or crops producing substances for use in pharmaceutical or industrial applications), potentially increasing the economic potential of the agricultural sectors in developing countries.

# Global Food Production and Hunger

## THE GREEN REVOLUTION

The latter half of the twentieth century saw a dramatic worldwide increase in food production generated by coupling higher yielding plant varieties with such increasingly intensive technologies as irrigation and chemical fertilizers and pesticides.

Norman Borlaug summarized the gains in an op-ed in the Wall Street Journal in 2000:

> In 1960 in the U.S., the production of the 17 most important food, feed, and fiber crops was 252 million tons. By 1999, it had increased to 700 million tons. It is important to note that the 1999 harvest was produced on 10 million fewer acres than were cultivated in 1960. If we had tried to produce the harvest of 1999 with the technology of 1960, we would have had to increase the cultivated area by about 460 million acres of land of the same quality—which we didn't have.[4]

This dramatic increase in food production was dubbed the Green Revolution and is credited with staving off the worst predictions of global food shortages that some feared would accompany the world's burgeoning population. The population growth experienced over the last thirty years was partly offset by an 18 percent overall increase in food production (measured as calories per person), combined with growing cereal exports to developing countries.[5]

## HUNGER REMAINS

The encouraging global statistics cited above, however, mask the persistence of hunger in a number of countries. Increases in food production have not been evenly distributed. Consequently, while the world currently produces enough food on a caloric basis to nourish the global population, food production and access to food vary widely among countries.[iii] The Food and Agriculture Organization of the United Nations reports that:

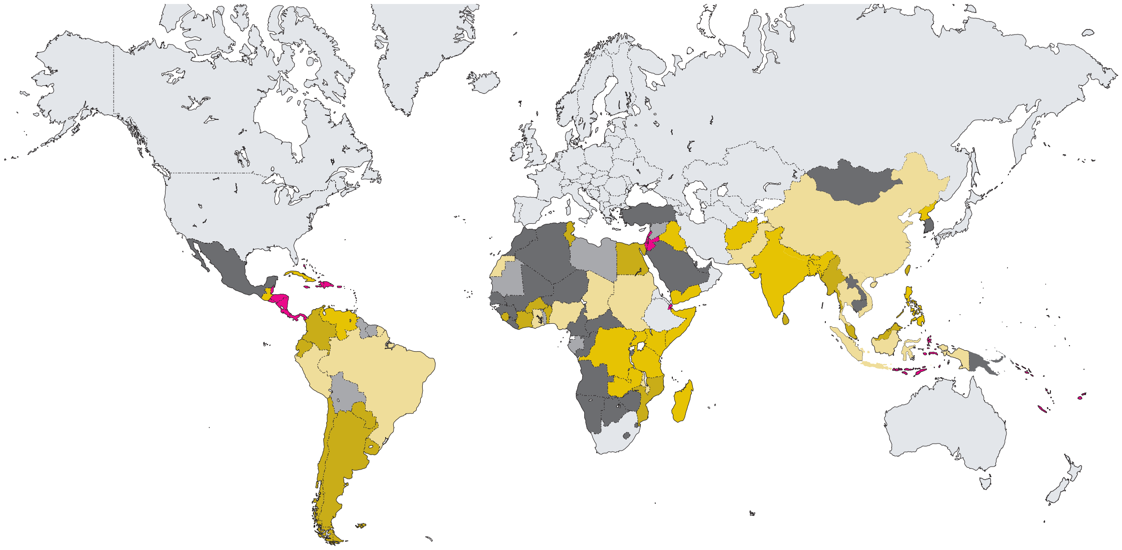
> After 50 years of modernization, world agricultural production today is more than sufficient to feed six billion human beings adequately. Cereal production alone . . . could to a large extent cover the energy needs of the whole population if it were well distributed. However, cereal availability varies greatly from one country to another . . . Moreover, within each country, access to food or the means to produce food is very uneven among households . . . World food security, therefore, is not an essentially technical, environmental or demographic issue in the short-term: it is first and foremost a matter of grossly inadequate means of production of the world's poorest peasant farmers who cannot meet their food needs.[6]

iii For a detailed discussion of global food production, see The State of Food and Agriculture 2002, Food and Agriculture Organization of the United Nations (Rome, 2000).

Countries that already were the most productive realized the greatest gains, although the Green Revolution did result in significant gains in India, the Philippines, and other targeted nations. Despite recent increases, the overall number of undernourished people in the developing world was reduced during the last 30 years from 956 million to 798 million. This decline was realized while per capita food production simultaneously fell in the majority of developing countries as populations grew.[7] Global hunger and malnutrition persist as a continually growing population demands more food and as gains in agricultural productivity begin to slow. A report jointly prepared by seven international academies of science titled Transgenic Plants and World Agriculture states that:

> The global increase in food production, therefore, reflects an increasing disparity between the most productive and least productive nations. This is particularly apparent in sub-Saharan Africa, where the number of chronically undernourished people has more than doubled in the past 30 years.[8] [See Figure 1.[9]] During this time, the rate of food production increases also slowed, from 3% per year in the 1970s to 1% per year in the 1990s.[10]

Figure 1 — Changes in the Number of Undernourished between 1990-92 and 1997-99



- REDUCTION OF 1 MILLION OR MORE
- REDUCTION OF LESS THAN 1 MILLION
- NO SIGNIFICANT CHANGE
- INCREASE OF LESS THAN 1 MILLION
- INCREASE OF 1 MILLION OR MORE
- COUNTRIES FOR WHICH NO ESTIMATES WERE MADE OR FOR WHICH ONLY ONE PERIOD WAS ESTIMATED.

Sources: FAQ estimates.

## CONSTRAINTS TO FURTHER INCREASES IN FOOD PRODUCTION IN DEVELOPING NATIONS

Constraints on food production in less developed countries are both environmental and economic. High quality agricultural land is concentrated in relatively few countries and, while the equitable distribution of land is the prevailing problem in some developing countries, many less developed countries struggle due to lower quality lands and inhospitable climates. Although the technologies of the Green Revolution helped compensate for these deficiencies, significant additional production gains using conventional crops may not be possible without prohibitively expensive inputs (pesticides, herbicides, fertilizers, machinery, fuel, and water). In addition, the Green Revolution's irrigation- and chemical-intensive farming practices can have adverse environmental impacts. Pinstrup-Andersen and Schipler explain in their book, *Seeds of Contention,* that:

> One reason for the success of the Green Revolution was that it was a package deal. Fertilizer enabled high-yielding plants to more fully exploit their yield potential, and agrochemicals restricted losses due to weeds, pests, and diseases. But in many places—again with Africa and parts of Asia as notable exceptions—the consumption of agricultural inputs has reached dangerously high levels. There is a logical limit to how much extra expenditure can be justified in return for only marginal gains in yield—quite apart from the strain on the environment.[11]

Even where existing technologies might increase production on a sustainable basis, there are practical and economic barriers to adoption of those technologies. Farmers cannot effectively apply technology without sufficient infrastructure for transfer of knowledge and continuing education. In addition, input-intensive farming requires initial capital, access to inputs, and access to markets where prices are high enough to yield a profit as costs of production rise. In various areas of the world, limited transportation infrastructures impede the movement of seeds, chemicals, machinery, and fuel to farmers. Civil strife also disrupts production, markets, transportation systems, and the flow of any potential capital. All of these factors create barriers to the agricultural development necessary for increasing food security. As a result, many now are concerned that conventional agricultural technologies promise only a limited increase in food production. A May 2001 statement from the Director-General of the United Nations Food and Agriculture Organization states:

> We can no longer depend on bringing significant new areas of virgin lands into the food production chain and further expansion of food production must come from increased yields on the lands already farmed by the poorest of small farmers and the larger farms alike. This raises the twin challenges of raising productivity on the more fertile lands farmed by the better-off farmers together with an improvement in the output and range of food crops that can be grown on the less well-endowed fragile marginal lands. It is now widely recognised that we are at a post-Green Revolution standstill and that yield ceilings of the main food crops have already been reached in conventional breeding programmes.[12]

## CONSTRAINTS ON EQUITABLE DISTRIBUTION

While insufficient production levels continue to contribute to hunger among subsistence farming communities in developing countries, many point out that hunger could be greatly minimized with improved mechanisms for distributing the food that is produced. Many of the constraints on food production cited above also serve as barriers to equitable food distribution at regional, national and international levels. Consequently, even if populations in developing countries had sufficient money to purchase food, problems with infrastructure and social stability would continue to impede distribution and access to food commodities.

Over eighty developing countries lack sufficient food to feed their populations and the money to import food supplies.[13] In response, international development focuses both on poverty reduction and hunger reduction. Individual country agencies such as the U.S. Agency for International Development and international institutions like the World Bank provide funds to both improve agricultural productivity and support business development through education and training and access to capital and technology.

The international community attempts to alleviate global hunger through short-term relief efforts, as well as longer-term agricultural and economic development programs, but the solutions to hunger are as elusive as its causes are complex. The United Nations recently estimated that it will take 130 years to eliminate global hunger at the current pace of progress.[14]

## BARRIERS TO DEVELOPMENT

Nations who seek to develop self-sufficient agricultural systems face many obstacles including poverty, poor soils, environmental degradation, drought, plant diseases, limited crop diversity, civil strife, epidemic illness, and poor agricultural and transportation infrastructures. Each of these obstacles contributes to hunger and malnutrition. Some barriers to development are more easily overcome than others. Such discrete tasks as building irrigation systems, starting small businesses, establishing community facilities, and creating lending programs may be manageable. Other development challenges, such as inadequate transportation systems, insufficient regulatory and legal systems, limited access to national markets, and a lack of trained professionals, are more formidable. Finally, the ability to produce sufficient food to sustain individual families or local and regional populations is severely limited where key agricultural inputs (land, water, fertilizer, pesticides, and seed) are unaffordable or unobtainable, or where combinations of weather and disease take a frequent and substantial toll.

# Breeding and Genetically Modified Crops

## CONVENTIONAL BREEDING

In the late nineteenth century, plant breeders began using hybridization and crossbreeding more aggressively as a means of improving agricultural crops.[15] Since then, the application of a growing body of knowledge about plant genetics, combined with the application of statistical methods to plant breeding and the development of effective field trial protocols, has led to the development of hardier and more productive varieties of corn, wheat, and other staple crops. The use of these techniques to enhance desirable traits (the physical characteristics of a plant generated by its genetic makeup) dominated plant breeding efforts for much of the twentieth century, famously marked by the awarding of the 1970 Nobel Peace Prize to Norman Borlaug for his development of high-yield wheat varieties using these methods. The application of advanced conventional breeding technologies has made much of the production gains of the Green Revolution possible.

## THE DEVELOPMENT OF MODERN BIOTECHNOLOGY

As these advances in conventional plant breeding led to the development of hardier and more productive varieties of food crops, scientists began using recombinant DNA (rDNA) techniques as a new tool for developing crops with beneficial traits. Recombinant DNA techniques allow scientists to isolate certain desired gene sequences from various organisms and introduce (recombine) them into other organisms (or insert multiple or reverse copies of an organism's genes to alter various metabolic functions).

Using this new technique, scientists have modified such traditional food crops as corn and soybeans to incorporate new traits that protect them from harmful insects and create resistance to specific herbicides, which has the potential to both increase crop yields and decrease the labor required of farmers. *Bt* corn and cotton, for example, are GM varieties of those crops into which scientists inserted a gene sequence from the bacterium *Bacillus thuringiensis (Bt)* which produces an insecticide in the tissue of the plant to kill certain species of insect pests.

However, some see rDNA techniques as fundamentally different from conventional plant breeding, which is generally based on sexual reproduction, because rDNA techniques can introduce genes into a crop plant from sexually incompatible plants and even from other living organisms as is the case with *Bt* crops. This ability to introduce novel genes into food crops has led to concerns about the possibility of introducing unrecognized toxins or allergens into the food supply, or disrupting the environment by spreading novel genes to wild relatives of the modified plants, potentially threatening biodiversity.

## STATUS OF GM CROPS WORLDWIDE

GM crops currently approved for commercialization in the United States possess at least one of six general traits—insect resistance, herbicide resistance, virus resistance, delayed ripening, altered oil content, and /or pollen control. The vast majority—over 99 percent—of the acreage of commercialized GM crops are corn, soybeans, cotton, and canola that incorporate genes for resistance to insects and herbicides. These GM varieties account for almost one-fifth of the total global acreage of these crops.[16] Although most of the acreage of GM crops is in just four countries (see Fig. 2), over three-quarters of the 5.5 million farmers planting GM crops in 2002 were cotton farmers in China and South Africa.

Adoption of GM crops has been rapid. The estimated global area of all GM crops was 167 million acres in 2003, nearly forty times the GM acreage planted in 1996.[17] Data from 2003 indicates that genetically modified soybeans account for the majority of acres planted, with corn, cotton, and canola accounting for virtually all of the rest (See Fig. 3).[18] Additional GM crops that have been planted (although several only at an experimental level) include rice, wheat, beet, potato, tomato, peanut, rapeseed, and sweet pepper in China, and rice, rapeseed, potato, eggplant, and cauliflower in India.[19] Scientists have also developed genetically modified avocadoes, pineapples, and mangos.[20] In the U.S., GM crops at the field test stage include apples, broccoli, carrots, grapes, lettuce, pears, peppers, plums, and strawberries.[21] However, some of the most economically significant crops, such as wheat, still have not been commercialized.

**Fig. 2 – Country Percentage of GM Acreage 2003**

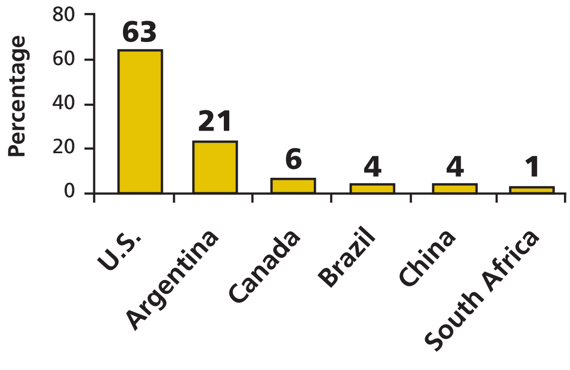
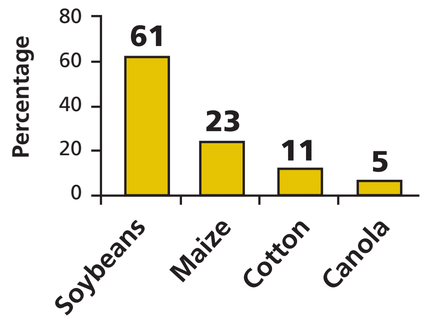



**Fig. 3 – Crop Percentage of GM Acreage 2003**



# Potential Benefits of Biotechnology

## INTRODUCTION

Agricultural biotechnology is intended to address some of the challenges faced by farmers. These challenges are similar for farmers in developed and developing countries and include threats to crop yield from disease, pests, weeds, and weather, and lack of critical growing inputs such as nutrients and water. Typically, farmers in developing countries need crops that offer disease resistance (to viruses, fungi, and bacteria), insect resistance, environmental stress resistance (to heat, drought, salinity, flooding, soil pH), quality improvement (nutritional improvement, increased yield), and reduced post-harvest losses. In addition, ease of use is important for farmers who may have limited access to educational or extension services. Crop improvements and other technologies that reduce manual labor may be of particular value in developing countries where labor savings could be used for other activities including water and fuel collection, childcare, and education.

While conventional technology has resulted in many hardier crops, biotechnology proponents believe that the new technology offers significant additional opportunities to meet the need for improved crop varieties. Scientists can modify both agronomic traits (traits that determine how well a plant is suited for its environment, such as drought tolerance) and quality traits (such as the oil content of a soybean) of crops.

From a technological standpoint, one advantage of agricultural biotechnology is that the technological input (in the case of biotechnology, the new trait) is contained in the seed itself. Relative to other technologies such as intensive irrigation or chemical pesticides, seeds are relatively easy to transport and require no new technical expertise to plant. However, as discussed in more detail later, the proper management of certain kinds of GM crops may require new expertise. Nonetheless, if certain traits were made available at an affordable cost, farmers could adopt GM crops without disrupting traditional agricultural practices. In theory, a farmer could reduce intensive irrigation by using a crop variety modified for drought resistance. This could lower the cost of production in areas with high irrigation costs or enable production in areas that lack sufficient water altogether.

While this discussion has focused on the potential of biotechnology to increase yields or improve nutrition, many also argue that associated environmental benefits could be realized. Higher yields from land already under cultivation also may make it possible to avoid the conversion of biologically diverse natural habitats such as rainforests, wetlands, or grasslands to farmland. Drought tolerant crops, for example, could reduce the use of irrigation in areas with a limited water supply or reduce production risks in areas without irrigation. Insect-resistant crops also could reduce the use of more persistent or toxic pesticides. Higher yields may obviate the needs to cultivate steep hillsides or wetlands critical for watershed protection, flood control, and soil retention. On the other hand, some argue that the increased ability to use marginal lands that would otherwise be unsuitable for cultivation acts as a disincentive to critical conservation efforts.

## AGRONOMIC TRAITS

Improved agronomic traits can help increase crop yields in numerous ways: (1) increasing the actual amount of food produced per plant; (2) reducing crop loss due to pests, disease, or weeds; (3) compensating for inhospitable environments that limit or prohibit planting; (4) extending growing and harvest seasons; and (5) reducing production risks.

The potential benefits of improved agronomic traits are lower costs of production, greater consistency of production, higher yields, and the ability to use lower quality lands that would otherwise be inhospitable for agricultural production. Increased productivity may result in surplus crops for sale at local markets and reduced labor requirements which can create time for other income-generating activities, as well as adult and child education.

### *Pest Resistant Plants*

Although consistent data on global crop losses is difficult to find, some estimates indicate that pests destroy over half of global crop production, and that pre- and post-harvest crop losses due to disease and pests represent an annual cost of approximately $100 billion.[22] Regional losses compared to actual production show that losses from pathogens, insects, and weeds may equal the quantity of successfully harvested crops in regions such as Africa and be nearly 50 percent of the amount successfully harvested in regions such as North America.[23] For rice alone, one study estimates that 50 million metric tons are lost each year from fungal diseases, 26 million tons from insects, and another 10 million tons from viral diseases.[24]

GM crops clearly hold significant potential to boost crop production through insect loss prevention. One study estimates that the adoption of existing and possible future *Bt* crops (cotton, rice, corn, fruits, and other vegetables) could save over $2.6 billion of the over $8 billion spent annually on insecticides.[25] This study also suggests that widespread adoption of *Bt* fruit and vegetable crops could dramatically reduce crop losses to pests and thus benefit numerous developing countries, including nearly all of Africa, Asia, and Latin America, and that the introduction of *Bt* corn and rice could likewise benefit China, India, Bangladesh, Philippines, Thailand, Indonesia, Vietnam, Colombia, Paraguay, Peru, Bolivia, Mexico, Argentina, Costa Rica, Ghana, Cameroon, Zimbabwe, Nigeria, Tanzania, and Ethiopia. A number of studies have been conducted to estimate the benefits GM crops have afforded various countries and regions in comparison with traditional varieties. [26, 27] GM cotton was found to produce 5-80 percent more than non-GM cotton.

In addition to potential gains in crop yields, adoption of pest-resistant plants could confer environmental and human health benefits to the extent that such adoption would reduce the use of chemical pesticides. Reports on pesticide reductions due to adoption of GM crops vary, but the National Center for Food and Agricultural Policy recently reported that the adoption of insect resistant corn and cotton, herbicide tolerant canola, corn, cotton, and soybeans, and virus resistant papaya and squash in the United States led to a total reduction in pesticide use in 2001 of 46 million pounds.[28] One estimate indicates that the use of *Bt* cotton in China has reduced the amount of insecticide applied by 20 percent[29] or as much as 78,000 tons.[30] While recent studies have suggested that herbicide use may be on the rise in some parts of the world employing herbicide-tolerant GM crops,[31] other studies have noted that these crops promote the use of conservation tillage practices and of herbicides that are less persistent.[32]

Many competing factors may be responsible for the variance observed in the magnitude of yields obtained and pesticide used on GM crops compared with non-GM varieties. These include differences in insect pressures, horticultural practices, land quality, access to inputs (e.g. irrigation), and annual weather occurrences in various regions.

In addition to creating new varieties of insect- and herbicide-resistant crops, biotechnology can develop new varieties of virus-resistant crops.[iv] Virus-resistant varieties of squash and papaya, for example, are among the GM foods approved in the United States. In Africa, work is ongoing to develop a virus resistant sweet potato, and scientists are performing similar research around the world on such crops as banana and cassava.[v] Because certain viruses can wipe out a large portion of a season's crop, enhanced virus resistance could significantly improve the food resources and security of a community or country that is highly dependent on a staple crop such as the sweet potato.

### *Hardier Plants*

Scientists are also developing crop varieties with improved environmental hardiness with the potential to significantly increase crop yields and open up or restore agricultural lands. In addition, GM plants that mature more quickly could help raise production in areas with shorter growing seasons. Among the many traits in various stages of research and development are drought tolerance (beans, groundnuts), cold tolerance (sorghum), and aluminum tolerance.[33] In areas that have been subject to intensive irrigation, for example, salts that have accumulated in the soil can render it useless. In an attempt to address this agricultural challenge, a number of researchers have investigated genes that may confer resistance to salt stress in various plant species.[34] These kinds of GM crops could prove beneficial in countries where these hostile conditions limit agricultural production.

iv For a more complete review of traits in research, development and production, see *Harvest on the Horizon: Future Uses of Agricultural Biotechnology,* Pew Initiative on Food and Biotechnology, September 2001.

v This work is ongoing under the auspices of the Kenya Agriculture Research Institute (KARI).

## QUALITY TRAITS

Biotechnology also has the capability to develop new crop varieties with improved qualities beyond those developed by conventional methods. Improved quality traits may benefit both the farmer and the consumer. Two crops genetically engineered to include quality traits have received marketing approval in the United States (altered oil content in oilseeds and delayed ripening in tomatoes), and a variety of others are in the research and development stage (such as delayed ripening in a variety of fruits and improved nutrition in crops such as carrots and potatoes). Value-added traits could help farmers in less developed countries realize a higher return on their marketed crops and lower prices for consumers—a significant factor for poor consumers who traditionally spend 50-80 percent of their income on food. Traits that enhance nutritional content and improve handling characteristics also offer important opportunities to mitigate malnutrition and hunger.

### *Nutrition*

The use of biotechnology to modify the nutritional make-up of crops has also been cited as a means to reducing malnutrition in developing countries. Researchers in India recently announced the creation of a genetically modified potato in which protein content is increased by a third (including the essential amino acids lysine and methionine).[35] Proponents of the GM potato, which has been submitted for regulatory approval, say the enriched potato could improve nutritional deficiencies in the diets of the country's poorest populations, particularly for children for whom these amino acids are essential for proper development. Other advances in nutritional enhancement include the continuing development of so-called "golden rice," rice genetically modified to produce beta-carotene, which serves as a source for the vitamin A lacking in the diets of populations for whom rice is a staple crop (See sidebar: **Golden Rice**). Researchers are also working to develop "golden mustard" that would yield cooking oil high in beta-carotene.

Other traits in the research and development stage that could enhance quality include: elevated levels of iron (rice), modified starch content (cassava), reduced alkaloid content (potatoes), and reduced phytic acid, which interferes with the body's absorption of iron (corn).[36, 37] Although currently in the research stage, modifications such as these could significantly improve the diets of hundreds of millions of people who live primarily on one or a few types of crops.

The International Food Policy Research Institute explains how work toward increased nutritional value is complimentary that toward increased food production:

> [In] the case of trace minerals (iron and zinc, in particular), the objectives of breeding for higher yield and better human nutrition do largely coincide. That is, mineral-dense crops offer various agronomic advantages, such as greater resistance to infection (which reduces dependence on fungicides), greater drought resistance, and greater seedling vigor, which in turn, is associated with higher plant yield.[38]

## GOLDEN RICE

Vitamin A deficiency is a significant global health problem estimated to affect over 130 million children worldwide, killing almost two million children each year and causing blindness in millions more. This deficiency results from diets dominated by one or just a few staple crops, such as rice, that do not provide sufficient beta-carotene, the precursor chemical from which the human body produces vitamin A.

Vitamin A deficiency is particularly pronounced in Asia, where over 90 percent of the world's rice is grown and where rice is by far the most important food crop. In Southeast Asia, five million children are afflicted with at least partial blindness each year.

Dr. Ingo Potrykus at the Swiss Federal Institute of Technology and Dr. Peter Beyer at the University of Freiburg developed a strain of rice that produces beta-carotene in the grain itself. (The green parts of the rice plant that are not eaten do contain some beta-carotene.) Due to the yellow hue that the beta-carotene gives the grains of rice (in the same manner that beta-carotene colors carrots), this modified rice has been dubbed "golden rice."

The scientific work that helped form the basis for the development of golden rice was conducted over the last couple of decades, with many millions of dollars in funding from the Rockefeller Foundation. Golden rice is a japonica rice genetically modified to contain new metabolic pathway for the conversion of a naturally occurring beta-carotene precursor into beta-carotene itself in the rice endosperm (the edible grain). The creation of this new pathway required the creation and insertion of complex genetic "constructs" involving two genes from the daffodil and a third from a bacterium. When successfully integrated into the japonica genome, these new gene sequences produce three separate enzymes that drive the production of beta-carotene.

The announcement of this development generated excitement at the possibility that the substitution of golden rice could mitigate vitamin A deficiency among populations subsisting on rice dominant diets. Advocates of golden rice point to the difficulty and cost of using existing systems for distributing vitamin A supplements, and believe that it would be easier to deploy golden rice varieties than to diversify current diets.

The creation and proposed use of golden rice also has generated a variety of criticisms, including skepticism that golden rice can produce beta-carotene in sufficient amounts to have a significant dietary impact and concerns about the potential environmental risks associated with GM crops in general.

The intellectual property (IP) issues associated with golden rice are complex, involving over 15 separate components in which IP could be obtained and as many as 70 relevant patents (although it is less clear how many enforceable patents actually have been issued). The research that led to the development of golden rice was facilitated by the donation of intellectual property licenses from Syngenta Seeds AG, Syngenta Ltd, Bayer AG, Monsanto Company Inc., Orynova BV, and Zeneca Mogen BV.

Although critics have raised questions about who will control access to and profit from golden rice, a public-private collaboration was formed to make golden rice available at no cost for humanitarian uses and for small-scale farmers in the developing world. Under an arrangement among the numerous parties involved in the project, including patent holders, researchers, the Rockefeller Foundation and the International Rice Research Institute (IRRI), a "Humanitarian Board" is overseeing the continued development of golden rice and its distribution according to the humanitarian aims of the collaboration.[viii] Syngenta will hold commercial rights to golden rice for potential markets in developed countries.

IRRI continues to develop and test golden rice varieties in coordination with the Rockefeller Foundation and Syngenta. Work on commercializing golden rice is ongoing under a collaboration between IRRI and the Indian Council of Agricultural Research, and researchers hope to have a variety ready for farmer planting by 2006.

viii *International Rice Research Institute Begins Testing 'Golden Rice',* Press Release, Syngenta, 22 January 2001.

### *Handling*

In areas with slow transportation or inadequate storage facilities, the ability to preserve a harvested crop on its way to market could provide considerable economic value. Research regarding ways to delay ripening or provide post-harvest pest resistance through genetic modification could mitigate current barriers to food distribution in developing countries. For example, altering a fruit's production of the ripening agent ethylene could reduce rot by extending shelf life and increasing the amount of time the fruit could spend in transportation. Researchers have accomplished this in tomatoes; development is underway for delayed ripening raspberries, strawberries, bananas, and pineapples.[39]

### *Safety*

As previously discussed, because pest-resistant GM crops may decrease the need for pesticides, the occupational exposure of farmers and their family members to these chemicals could be reduced. In addition to this safety advantage, agricultural biotechnology may provide enhanced food safety to consumers.

Enhanced food safety may be realized if scientists can modify conventional crops to eliminate or reduce allergens or toxins. Crops for which allergen removal research is ongoing include soybeans and peanuts, and researchers are also exploring ways to remove the ricin toxin from castor plants to make the waste products from castor processing safer.[40] Cassava, which requires proper preparation because it contains potentially harmful levels of cyanide, is an example of a staple crop where genetic modification could improve safety.[41]

# Potential Risks of Biotechnology

As with benefits, some of the concerns expressed about biotechnology in developing nations do not differ from the concerns in developed nations. The concerns about the possible risks from GM food to human health or the possible risks from GM plants to the environment are fundamentally similar. However, the impacts realized from those risks may differ considerably in developing and developed countries.

## ENVIRONMENTAL RISKS

Some of the environmental concerns raised in response to the Green Revolution focus on sustainability. In a March 2003 speech, Gordon Conway stated that:

> [The Green] Revolution had real failings. The new rice and wheat varieties were designed for irrigated land. They had short stems and required only shallow root systems. They were bred to put all of their growth energy into seed production — that is, wheat and rice grain. To thrive, they needed more water and fertilizer than traditional varieties, a lot more. Increased use of pesticides created pesticide resistance, while killing off some beneficial insects. Fertilizers allowed farmers to avoid costly and labor-intensive work on agricultural preparation and maintenance, such as soil aeration, crop rotation, and working organic matter into the soil. But these steps, we understand today, are key to long-term sustainability. The results of omitting them were soil erosion, nutrient depletion, falling water tables and salinization, even in some of the world's most fertile regions like India's vast Punjab. US and European intensive agricultural systems have similar drawbacks.[42]

Indeed, critics have voiced similar concerns about the sustainability of biotechnological modifications to agricultural systems. Specifically, some believe our growing dependence on "technology-based" approaches for global food production is not sustainable and that the economic value in the trade-off between cost of labor and cost of mechanization is questionable.

The history of agricultural technology is one of continuing innovation both in methods of production and in the crops produced. To date, society has adopted increased mechanization of production because of the significant gains in productivity. However, critics have also argued that "modern agriculture is intrinsically destructive of the environment."[43] The application of biotechnology to crop production raises new questions about the ongoing challenges of balancing environmental sustainability with the inherent ecological interventions of farming—the manipulation of the natural environment to produce food and fiber.

Beyond broad sustainability questions, genetically modified crops raise some specific environmental concerns. One such frequently cited environmental risk is the potential for movement of novel genes from genetically modified crops to other plants ("gene flow"). With respect to gene flow, there is concern that a GM crop might breed with a wild relative ("outcross") to produce a "super weed"—a hardier plant that could displace native plants or become an agricultural pest that interferes with crop cultivation. Some have expressed concern that the movement of new genes from GM crops into indigenous relatives may reduce the presence of native strains, which might be of particular concern in areas aiming to preserve biological diversity. For example, researchers recently reported evidence of a gene sequence from *Bt* corn in native maize landraces in Mexico.[44] While this study has been strongly criticized, a general agreement exists that gene flow from transgenic corn into conventional corn and native maize varieties is likely unless steps are taken to prevent it. In fact, conventionally bred crops have long been known to outcross with wild relatives; it is highly unlikely that transgenic crops would behave differently without specifically designed control measures.

The ramifications of these environmental concerns are not limited to ecology. Both ecological and economic consequences of outcrossing between GM crops and conventional or wild relatives exist, the significance of which depend on the specific genes introduced, traits expressed, and the environment which such varieties are grown. For example, if a genetically modified variety contaminated a conventionally bred food crop via outcrossing, it is possible that all of that commodity would become ineligible for export to countries that had not approved the specific genetic modification. Such trade ramifications could induce significant economic harm for countries involved in food export. Similarly, niche markets such as those served by organic farmers, which can often command higher prices for their crops, may face adverse impacts from outcrossing with GM varieties; this also raises the possibility that GM crops may negatively impact markets.

As a result, many continue to advocate for the development and implementation of technical, regulatory, and enforcement approaches to minimize gene flow with either non-GM commercial crops or wild relatives of GM crops. Some research has focused on limiting the possibility of gene flow biologically. Just as scientists can alter the genome of plants using rDNA techniques to incorporate new agronomic or nutritional traits, some have also investigated methods of altering the ability of a plant to reproduce. Insertion of genes that confer infertility, frequently referred to as "terminator genes," would serve multiple purposes. This technology would protect the developers of genetically modified crops by limiting illicit use of their seeds as well as limiting the ability for outcrossing to produce viable new undesirable varieties. Efforts to limit outcrossing between GM and other crop and wild plant varieties by inserting terminator genes were greeted by many with hostility. Limiting the reproductive viability of GM varieties was viewed by some as an attempt by large international corporations to control markets and undermine the independence of small resource-poor farmers in the very countries suffering from the worst hunger.

The risk of gene flow from any particular GM plant and methods for managing this risk will depend on a large variety of factors and will require assessment on a case-by-case basis. As developers incorporate a wider variety of new traits into more GM crops that are then introduced into new areas of the world, the potential for gene flow must be addressed at each stage of research, development, testing, and regulation.

A second set of environmental concerns frequently cited by critics highlight the interactions of pest resistant crops with both non-target organisms (organisms that are not the intended target of the pesticide) and on the pests themselves. Some suggest that plants engineered to produce pesticides could harm populations of non-target species. Concern has also been expressed that such crops could accelerate the development of pesticide resistance in pest populations.

Finally, the effect this technology may have on patterns of land use is also somewhat uncertain. While some GM crops may increase yields on existing agricultural land and reduce the need to press additional environmentally sensitive land into production, GM crops with agronomic traits that expand the range of environments in which crops can be grown also could increase pressures to farm on marginal lands with potentially harmful impacts on the ecosystem. The development of hardier GM crops, better suited for previously inhospitable environments, raises the possibility that fragile lands, ill suited for intensive agriculture, will be degraded by new or increased production (through increased erosion, for example). Expanding or intensifying agricultural areas could lead further to indirect negative effects on the ecology of the surrounding ecosystem (by altering forage resources for native animals, for example).

To some extent, the environmental issues discussed here are not exclusive to agricultural biotechnology. Conventional breeding techniques have been used to develop new varieties of crops that, like transgenic crops, can also mate with native and wild relatives and potentially threaten regional biodiversity. The use of conventional chemical pesticides, commonly applied to conventionally bred plants, presents significant risks to non-target organisms and may accelerate the development of pesticide resistance. Lastly, conventionally bred plants have also expanded land use to areas otherwise not used for agricultural development.

Although these parallels suggest that risks associated with agricultural biotechnology could be evaluated in the context of traditional practices, genetic modification allows for the incorporation of an otherwise unachievable variety of genes and related traits. The unique potential offered to crop development via agricultural biotechnology may also require a unique approach when considering the risks associated with GM crops.

## HUMAN HEALTH RISKS

GM crops have been consumed widely and no harm to human health has yet been verified. Despite this, it is still appropriate to monitor GM crops for potential health effects, especially those that may be a result of long-term exposure. Companies seeking to bring new GM foods to market routinely assess for a variety of food safety and quality factors, however, an effective regulatory system might require such an analysis.

The human health risk most commonly discussed with respect to GM crops is the potential for these crops to produce allergens and toxins which in turn could enter the food supply.[vi] A protein produced by a gene in a GM crop that was previously not in that crop, or not in the traditional food supply at all, could be an allergen. Likewise, a new gene introduced into a GM crop conceivably could produce a new toxin or alter the levels of a naturally occurring toxin. Another potential health risk arises from the possibility that the genetic modification of a GM crop might negatively affect its nutritional makeup (by lowering the level of an important nutrient, for example).

It is also theoretically possible that the health risks to consumers from GM crops might vary among populations. Consumers whose diet is dominated by a limited number of staple crops, for example, may be more vulnerable to risks associated with those crops. An allergenic protein in a staple food of a certain population might have an effect that would not occur in a population that consumes the same food as a much smaller part of a more diverse diet. Similarly, nutritional deficiencies in a GM staple crop could be more serious for populations that rely heavily on that crop as a predominant part of the diet. Food modifications could potentially affect a population suffering from chronic malnutrition or diseases that compromise the immune system in ways that would not take place in a healthy population.

vi Potential exposure to allergens includes occupational exposure, such as inhalation of dust produced during the harvesting or handling of a GM crop.

# Concerns and Challenges: Delivering Benefits, Managing Risks

Most of the potential benefits of, and possible concerns about, agricultural biotechnology for small-scale developing nation farmers do not differ remarkably from those that exist for developed nations. The context of those impacts is what makes the debate so different. Given the underlying institutional, environmental, and financial constraints that make it so difficult for conventional agriculture to meet the needs of the local population, biotechnology poses both opportunities and unique challenges and concerns for developing nation small farmers.

## DEVELOPMENT, DEPLOYMENT, AND CAPACITY

The extent to which biotechnology will be an effective tool in the fight against global hunger depends, in part, on whether new GM crop varieties will meet the specific needs of small farmers in developing nations such as drought tolerance in a regional staple crop. A number of significant barriers exist to the development and deployment of GM technology in these countries. First, it is unlikely that the potential market for such products is large enough to entice the private sector to invest in the needed research and development. Even if incentives are developed to encourage private sector participation or partnerships, the public sector would likely be the primary source for such research and development funding. Second, deployment of the technology to the farmers requires an institutional infrastructure for distribution and education. Finally, ensuring food and environmental safety requires a regulatory capacity. In order to overcome each of these barriers, the public sector must commit scarce resources, which is a difficult proposition for many developing nations already hard-pressed to deliver basic services. In addition, governments in developing nations face many immediate needs and therefore find it difficult to make long-term investments in agricultural research, thus leading to a continuing cycle of lost opportunities.

As previously mentioned, the private sector may have little market incentive to invest in the development and marketing of crops raised by subsistence farmers in the developing world. It is also unclear whether subsistence farmers could generate the income needed to buy commercial GM seed varieties, particularly if developers do not permit farmers to continue the practice of saving seed for future plantings. Similarly, while only a small number of GM crop traits have been commercialized to date, others that hold promise for less developed countries are either at earlier stages of research or are only theoretical. Thus, the possibility of biotechnology providing immediate and dramatic benefits to alleviate hunger or poverty seems relatively low, except perhaps in specific areas with a limited number of crops.[45]

Biotechnology companies have much of the essential research expertise and have led in investments in the research and development of GM crops. The private sector finances approximately 50 percent of biotechnology research in industrialized countries, but only about 10 percent in developing countries.[46] As much as 77 percent of GM crop field trials worldwide are attributed to private industry.[47] Most private sector investment aims to develop GM varieties of commercially significant commodity crops, such as corn, wheat, rice, and soybeans. Due to the limited commercial promise in developing countries, making GM varieties available to the small developing nation farmer will probably require development by universities, governments, and international public research centers and distribution at subsidized prices.

The Assistant Director General of the Agriculture Department of the Food and Agriculture Organization of the United Nations (FAO), Louise O. Fresco, recently characterized the gap between public and private funding as a critical barrier to realizing the full promises of biotechnology for food security in the developing countries. She stated that:

> It is no exaggeration to say that we are witnessing a molecular divide. The gap is widening between developed and developing countries, between rich and poor farmers, between research priorities and needs, and above all between technology development and actual technology transfer....Today 85% of all plantings of transgenic crops globally are herbicide-resistant soybean, insect-resistant maize and genetically improved cotton varieties, designed to reduce input and labour costs in large scale production systems, not to feed the developing world or increase food quality. There are no serious investments in any of the five most important crops in the semi-arid tropics — sorghum, pearl millet, pigeon pea, chickpea and groundnut. This is largely because 70% of the agricultural biotechnology investments are by multinational private sector research, mostly in developed or advanced developing countries. These investments concentrate on GMOs and biotic stresses. Barring a few initiatives here and there, there are no major public sector programmes to tackle more critical problems of the poor and the environment or targeting crops such as cassava or small ruminants. The widening molecular divide which generates a gap between promise and reality of the impact of biotechnology is a cause for concern.[48]

In some cases where market incentives have not warranted commercial investment, the private sector has indicated a willingness to donate expertise and intellectual property to support public research undertakings. For example, Monsanto announced two years ago that it would provide royalty-free licenses to all of its technologies that could help the development of golden rice and other pro-vitamin A-enhanced rice varieties. At the same time, Monsanto opened up its rice genome sequence database to the International Rice Genome Sequencing Project (IRGSP).

More recently, the Rockefeller Foundation announced the formation of the African Agricultural Technology Foundation, designed to secure royalty-free access to patented processes and materials and provide technical assistance for the deployment of new GM crops in Africa. Biotechnology companies, including Monsanto, DuPont, Syngenta, and Dow AgroSciences have announced their support of the Foundation's efforts.[49] The technological capacity of developing countries to perform their own research and development for GM crops varies widely. A few countries such as India, China, Brazil, and South Africa have well established agricultural research systems, while many others have much more limited research capacity. Of course, some existing research and development may also be of use to developing countries, as is the case with *Bt* cotton (which numerous farmers plant in China and Africa).

Furthermore, many countries have no regulatory system for governing the import, development, testing, and use of GM crops, as well as the intellectual property rights involved. Even where such systems exist, the scientific and legal capacity to implement and enforce regulations may be very limited.

International agreements affecting biotechnology trade and transfer are additional factors that developing countries must consider as they build legal and technical capacity and seek access to biotechnology. The Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organization establishes baseline principles of patentability and protection that member countries must provide. TRIPS includes a specific reference ensuring the patentability of plant varieties,[50] although TRIPS would recognize the laws of most developing nations that preserve rights for both breeders and farmers to make extensive use of protected varieties. The Cartagena Protocol on Biosafety to the Convention on Biological Diversity establishes various agreements and mechanisms for making regulatory risk assessment decisions, sharing information, and informing countries of when genetically modified organisms are transported across national borders.[51]

A number of international institutions provide resources aimed at developing and distributing GM crops in developing countries and helping these countries build scientific and legal capacity to properly manage crop development, risk assessment, and intellectual property management. The Consultative Group on International Agricultural Research (CGIAR), an association of public and private donor agencies that funds sixteen international research centers, conducts research to support agricultural productivity, including biotechnology, in developing countries.[52] The International Service for the Acquisition of Agri-Biotech Applications (ISAAA), whose activities are supported by a number of private companies, non-profit organizations, and government agencies, focuses on the identification, assessment, and adoption of new crop biotechnology applications in Africa and Asia.[53] The World Bank, the United Nations, and a number of other public institutions also provide various forms of assistance for biotechnology transfer to and among developing countries.[54]

Donor country agencies and private institutions also provide both direct funding for research and development of biotechnology transfer and management capacity. In the United States, for example, the Agency for International Development's Collaborative Agricultural Biotechnology Initiative encompasses a number of programs that fund biotechnology research and adoption. Many of the projects funded by USAID are executed by international collaborators such as a program intended to develop vitamin A enriched sweet white corn for African nations. The

International Maize and Wheat Improvement Center in Mexico, the International Institute of Tropical Agriculture in Nigeria, Wageningen University of the Netherlands, the University of Illinois, Iowa State Univeristy, and Monsanto are all participants in this USAID sponsored endeavor. Likewise, the Canadian International Development Agency supports agricultural development in a number of developing countries. This support includes strengthening the human and institutional resources required to integrate and react to advances such as biotechnology in agricultural systems. As a private institution, the Rockefeller Foundation has spent over $100 million on plant biotechnology research and has trained hundreds of scientists from Africa, Asia, and Latin America. Since 1993, the McKnight Foundation has committed over $50 million to fund crop improvement research, some of it using GM methods, in partnerships led by developing public sector scientists linked with advanced labs around the world.

To effectively deploy GM crops throughout many developing countries, it may be necessary to build appropriate scientific and regulatory expertise in those countries, and to transfer genetic resources, technology, and intellectual property rights to those institutions and companies that can develop GM crops appropriate for targeted countries. In addition, education and communications programs will have to be established to ensure that farmers are informed users of the technology and that consumers can make informed purchasing decisions.

## RISK MANAGEMENT

Just as the potential benefits of GM crops will be realized only through a combination of technology, resources, and infrastructure, the potential risks of GM crops can be identified and managed properly only when requisite scientific expertise is applied under an appropriate regulatory system. The risks and benefits of GM crops are highly dependent upon the specific traits, specific crops, and the context in which they are grown. Meaningful risk assessment must be conducted on a case-by-case basis. Whether *Bt* corn presents a risk of outcrossing, for example, depends on the specific conditions and region in which it will be grown, and risk management will have to be tailored to those conditions. The Human Development Report of 2001 asks:

> Could the genes flowing from genetically modified organisms into non-target organisms endanger non-target populations? It depends on how genetically modified organisms interact with their environment....Whether or not these harms could possibly occur is a matter of science—but if the possibilities are real, the extent to which they become risks depends on how the technologies are put to use....Debates today, however, sometimes proceed as if risks about specific products can be isolated from the context in which they occur.[55]

Therefore, concerns have been raised about the capacity of less developed countries to properly manage GM crops. These concerns may apply to both the governmental and individual levels, since GM crop management requires not only competent regulation, but also farmers educated in risk management practices. Although it was pointed out earlier that planting a GM seed theoretically requires little technical support or infrastructure, management of the GM crop itself may entail new practical requirements (such as planting refuges of conventional corn to mitigate the development of insect resistance to *Bt* corn).

Furthermore, the context of risk management matters significantly. Less developed countries may weigh the benefits of a particular GM crop more heavily, and the risks less heavily, than those not directly affected by food shortages or oppressive poverty. The balancing of benefits and risks is a value judgment that those societies must make. As the Human Development Report of 2001 explains:

> [E]ven when societies and communities consider all sides, they may come to different decisions because of the variety of risk and benefits they face and their capacity to handle them. European consumers who do not face food shortages or nutritional deficiencies see few benefits of genetically modified foods; they are more concerned about possible health effects. Undernourished farming communities in developing countries, however, are more likely to focus on the potential benefits of higher yields with greater nutritional value; the risks of no change may outweigh any concerns over health effects. Choices may differ even between two developing countries that need the nutritional benefits of genetically modified crops, as one may be better able to handle the risk.[56]

Also, effective regulatory systems facilitate the apportioning of responsibility and ensure accountability. Some fear that biotechnology companies will have too free a hand in less regulated countries without an appropriate balance set by government policy to protect the interests of farmers, consumers, and the environment. Some also raise concerns about corrupt governments in a number of developing nations, calling into question decisions about use of the technology and enforcement of regulatory protections.

## SOCIOECONOMIC ISSUES

The socioeconomic impact of GM crops is also of concern. Some see negative aspects of globalization in the rise of the biotechnology industry and use biotechnology examples to make broader points about global capitalism.

Some suggest that large multi-national companies will gain inappropriate control over indigenous farmers through control of the technology. Similarly, some fear that biotechnology companies will acquire property rights in genes obtained from indigenous plants without appropriately compensating host countries or indigenous societies.

Others believe the adoption of GM crops will simply exacerbate what they see as existing problems in modern agriculture such as the use of technology-intensive practices and monoculture farming that may not be compatible with sustainable land management, as well as rising technology and input costs that demand farmland consolidation and accelerate divisions between relatively wealthy and relatively poor farmers. These critics raise concerns about directing public sector research and development funds into transgenic technologies rather than into what they see as sustainable agriculture and agroecology.[vii]

Some developing nations also fear being flooded with exports of GM crops from the United States and Europe, undermining local markets and local food production. They see local food production as essential to providing the income and jobs necessary for alleviating in part the poverty that is at the heart of hunger.

The transformation of traditional subsistence farm economies into global market economies unquestionably involves change that can pose challenges to important traditional social and cultural values and structures. Some view such change as emblematic of traditional values succumbing to global capitalism and technology for technology's sake. To the extent that biotechnology is seen as a tool for economic change, it may invoke these fears. On the other hand, the intensive farming practices of the developed world have been adopted around the world because they are effective at increasing food production to meet the needs of growing human populations.

vii For one critical view of biotechnology in Africa, see Devlin Kuyek, *Genetically Modified Crops in Africa: Implications for Small Farmers,* Genetic Resources Action International, August 2002.

# Summary

**Some argue that poverty and the uneven distribution of food are fundamental sources of global hunger. While world hunger indeed could be significantly alleviated if current food production or global income were more equitably shared, distribution is only one piece of a much more complex solution. Given the various complex barriers to global food or income redistribution, this is not a promising short-term solution. In addition, the argument that world hunger should be solved solely through food redistribution (through aid and assistance programs) seems partly at odds with the goals of economic development and self-sustainability that are advanced on behalf of developing countries. Local food production will continue to be a primary way of addressing hunger.**

There are, however, major systemic barriers to increasing agricultural production in many developing nations. Civil strife, weak governmental institutions, lack of public funds and private capital, lack of access to agricultural inputs, and inadequate agricultural and transportation infrastructure are all barriers to adequate production. Agricultural biotechnology as a whole does not offer solutions to these broad systemic problems.

Agricultural biotechnology may, however, provide the means for developing crop varieties tailored for particular regions that could play an important role in addressing hunger. Traits such as disease, pest, and drought resistance could help to increase food production and thereby help meet local food needs. Increased food production and reduced pest control and labor costs could also help to address rural hunger through increased income. Surplus production and reduced post-harvest losses may also help deal with hunger in urban areas. In addition to helping address hunger through increasing production and availability of food, biotechnology may help address critical nutritional deficiencies by enhancing the nutritional value of staple crops in the developing world.

While biotechnology offers the prospect for hardier crops, it also raises environmental and human health considerations; risks that must be considered during the development and deployment of new genetically modified crops. Such an assessment will frequently require a case-by-case examination of specific crops in specific environments that also considers the potential environmental benefits of specific applications. If significant risks are identified, parallel concerns will arise about the capacity of small farmers and regulators to manage those risks without training and resources.

To capture the improvements in crop yield and food nutrition that biotechnology promises while managing risks may require a commitment of public resources from nations that have few, if any, public resources to spare. Each nation is likely to face those choices with a different perception of how to weigh the benefits against the risks, and how to deal with the changes that new technologies often bring.

Finally, it must be realized that these decisions are being made in the context of a broader political and philosophical dialogue about the impacts technology and globalization have on our world. Where some see biotechnology as a means of assuring food security for impoverished populations and argue that there are high risks to not taking advantage of it, others see this technology and the complications associated with access to it as a potential vehicle for capitalist exploitation. Many of these differences are rooted in perspectives that are far broader than the biotechnology debate itself and cannot be resolved solely within the confines of that debate.

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50 The World Trade Organization can be found on the web at www.wto.org, where information pertaining to TRIPS can be found.

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