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Standard Review

Biotechnology and food security in developing countries

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Food security is a necessity for every individual, home, community and nation. In developing countries, food security could be substantially improved by increased investment and policy reforms. Biotechnology's ability to eliminate malnutrition and hunger through production of crops resistant to pests and diseases, having longer shelf-lives, refined textures and flavours, higher yields per units of land and time, tolerant to adverse weather and soil conditions, and generate employment, cannot be over-emphasized. This technology can be applied to improve agriculture in order to improve food production for the human population in an environmentally sustainable manner. However, there is need for government and public-private collaborations to invest in agricultural biotechnology-based companies, researches, or initiatives, in order to make the gene revolution beneficial to developing countries.

Key words: Biotechnology, food security, developing countries, agriculture, public investment, policy reform.

INTRODUCTION

The increasing world population has led to increased demand for food and reduced per capita availability of arable land and irrigation water. Compounding this problem is the fact that most farmers in the developing world own only small plots of land that have the potential to feed one family and generate income. Low soil fertility and crop losses from pests and droughts have reduced harvests to below subsistence levels (Vasil, 1998; Conway and Toenniessen, 2003). This situation has, undeniably, led to serious food insecurity.

Availability of food, access to food, and risks related to either availability or access are the essential determinants of food security (von Braun et al., 1992). National food security implies that within a country the amount of food available, if evenly distributed, is enough to meet people's food needs. At the household level, "a household is food secure when it has access to the food needed for a healthy life for all its members (adequate in terms of quality, quantity, safety, and culturally acceptable), and when it is not at undue risk of losing such access" (UN ACC/SCN, 1991).

Both 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, 1999), 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 anaemic, basically as a result of iron deficiency. Food insecurity and malnutrition result in serious public health problems and loss of human potential in developing countries (Pinstrup-Andersen and Cohen, 2000).

Because land and water for agriculture are diminishing resources, there is no option but to produce more food and other agricultural commodities from less arable land and irrigation water. Thus, the need for more food has to be met through higher yields per units of land, water, energy and time. There is need, therefore, to examine how science can be mobilized to raise further the biological productivity ceiling without associated ecological harm (Swaminathan, 2000).

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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 (Pinstrup-Andersen and Cohen, 2000). Biotechnology-based agriculture combines elements of ecological agriculture with crop varieties designed to perform well under low-input and stress conditions, uses inorganic inputs very judiciously, and engages farmers themselves in analyzing their needs and adapting new varieties and agronomic practices to their own conditions. Greater commitments and new partnerships are needed to sustain and expand this revolution in agriculture to small-scale farming families across all Africa (Conway and Toenniessen, 2003).

Biotechnology research could aid the development of drought-tolerant and insect-resistant crops, 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. This technology may also offer cost-effective solutions to micronutrient malnutrition, such as vitamin A- and iron-rich crops (Pinstrup-Andersen and Cohen, 2000).

CAUSES OF FOOD INSECURITY

Food is the most basic of human needs. Despite the "green revolution" between 1970 and 1990 almost half of the world's less developed countries suffer a decline in aggregate food supply, and more than a quarter suffer an increase in hunger. Malnutrition is a major barrier to economic and social development, leaving populations unable to maintain normal lives and to be economically and socially less productive (Jenkins and Scanlan, 2001; Conway, 1999).

Population growth and urbanization

Within the next 20 years, more poor and under-nourished people in developing countries will live in the cities than in rural areas. High rates of urbanization mean that urban food insecurity and malnutrition are concerns even for regions like Africa and Asia, where current levels of urbanization are relatively low (Ruel et al., 1998). By the year 2030, the rural population would have grown by more than 235 million, but the urban population would have grown by 2.4 billion (United Nations, 1998). The number of people living in cities in Africa will be more than triple, from 251 million to 864 million.

Poverty

Food availability means that the overall supply should potentially cover overall nutritional needs in terms of quantity (energy) and quality (providing all essential nutrients); furthermore, it should be safe (free of toxic factors and contaminants) and of good food quality (taste, texture, and so on). Also, the types of foodstuffs commonly available (nationally, in local markets, and eventually at the household level) should be culturally acceptable (Oshaug, 1994). Food expenditures can make up as much as 60 to 80 percent of total income among low-income urban households (Tabatabai, 1993; Maxwell et al., 1998).

The importance of being able to earn cash income also means that the ability to stay healthy, to get a good job (and therefore the ability to acquire good education and training), and to have access credit to smooth consumption, or expand, or start up businesses, are all critical to urban food and nutrition security. With enough income, prices can rise and families can still buy enough to eat. Millions of urban poor, however, are vulnerable to price rises or sharp declines in income, say due to illness or loss of job by the principal income-earner. The majority of the urban labour force works in sectors like petty trade and services where wages are low and job tenure uncertain. In urban Nigeria and most of sub-Saharan Africa, employment in sectors that pay regular wages, such as manufacturing and industry, accounts for less than 10 percent of total employment (Rondinelli and Kasarda, 1993). Urban poverty thus is not primarily the result of lack of work but the lack of well-paying, steady jobs (Ruel et al., 1998).

Health

Health is determined by a series of factors that act at three levels. At the community level, factors such as the quality of the overall environment (biological pathogens and chemical pollutants in air, food, and water), and the availability, cost, and quality of services such as water, electricity, sewage, refuse disposal, and health services are important health determinants. At the household level, the most important factors include the general conditions of the household, including the type of housing, the availability and cost of water and hygienic facilities, and the number of rooms per household member (an indicator of crowding); the availability of food; and household caring behaviours related to the use of preventive and curative health services, the use of water and hygienic facilities to provide a healthy, hygienic and safe environment, and food-related behaviours such as the acquisition of food, the intra-household allocation of resources, feeding practices (including breast-feeding), and food preparation methods. At the individual level, the determinants of health relate to the interactive mechanisms among an individual's food and nutrient intake, nutritional status, and health status (Ruel et al., 1998).

High rates of malnutrition and escalating rates of diet-related diseases such as diabetes and hypertension in developing countries are attributable to various concerns: inadequate sources of dietary protein, foods with high levels of anti-nutritional components and toxicants, a disproportionate amount of highly digestible, high glycaemic index carbohydrates which constitute the staple foods such as yams, maize and rice, and limited alternatives. In addition, socio-economic factors such as urbanization and migration to urban areas have led to changes in lifestyles to include imported highly processed foods and modification in eating patterns and food habits. In many rural areas, there are challenges of protein malnutrition as well as inadequate vitamin and mineral intake. Furthermore, these problems are compounded by inadequate prenatal nutrition which leads to deficiencies in both mothers and children. Nutritional needs of postpartum nursing mothers are often not met, subsequently leading to inadequate nutrition in children. The quality of staple foods and other foods that are commonly consumed in most of these areas could be optimized to improve their quality (Niba, 2003).

In developing countries where mechanization is still limited, human labour provides much of the power for productive economic work. For the poor, labour is their most important asset. Work capacity, performance, and productivity of workers are therefore generally important for income (Pryer and Crook, 1988). This can lead to a situation where poor, malnourished workers perform poorly because of decreased working capacity, and therefore do not get access to better-paying jobs. Various studies support this assumption, showing positive associations between wage achievement and nutritional status as proxied by either body weight, body-mass index, stature, or caloric and protein intake (Haddad and Bouis, 1991; Strauss and Thomas, 1996; Satyanarayana et al., 1980; Pryer and Crook, 1988). Furthermore, the poor sanitary conditions of many developing-countries are notorious, and this combined with poor hygiene practices, create a situation in which food safety is severely compromised (Ruel et al., 1998).

Outdated farming system

Small-scale farmers in developing countries are faced with many problems and constraints. Pre- and post-harvest 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 water-logged 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 (Pinstrup - Andersen and Cohen, 2000).

Politics

Eight hundred million people on earth are poor and malnourished. They live on less than a dollar a day and cannot be sure that their fields will yield enough food or that they will earn enough money to buy food. Forty thousand people die each day of malnutrition, one-half of them children. The increase in food production enabled by the Green Revolution unfortunately did not solve the problems of malnutrition and hunger. There were about a billion hungry people some 40 years ago, and population projections show that there may still be 600 million poor people by 2025, when the earth's population would have grown to 8 billion. The Green Revolution did many things, but it did not wipe out poverty. Not enough jobs were created in either the rural areas or the cities to generate the purchasing power that provides farmers with the incentive to grow more food. It is ironic that hunger persists while the prices for agricultural commodities are at an all-time low (Chrispeels, 2000). Several countries that have millions of hungry people are exporting food and other agricultural products to countries where people are already well fed. Yet, most of these countries that are poor, with so many hungry people, seem to be able to grow food quite abundantly (Clover, 2003).

COMBATING FOOD INSECURITY

To eliminate malnutrition and hunger, food production and purchasing power both need to increase in developing countries. In addition, food production needs to increase in developed countries as well so that grain can be exported at a price the poor can afford. Agricultural biotechnology as the solution to the problem of global food insecurity has been reviewed by Soetan (2008). Since land and water are the most limiting resources for food production, there is only one option: to increase yields on the available land. Indeed, there is very little extra land that can be put to the plow. By 2020, the world's farmers will have to produce 40% more grain (200 million extra tons in the developed countries and 500 million extra tons in the developing countries).

According to the forecasts of the International Food Policy Research Institute in Washington, DC

(Pinstrup-Anderson et al., 1999), the less-developed countries will double their grain imports (mostly maize and wheat) by 2020. The reason is that the projected production increase of 500 million tons in those less-developed countries will still not satisfy demand. The imported grains will come from North America, Australia, the European Union, and the former Soviet Union. Thus trade will increase (assuming that prices remain stable and low), but redistribution is not the answer to the problem of hunger because there is not enough production capacity in the developed countries to satisfy the expected world demand.

The answer to the problems of the poor, according to a number of organizations that oppose genetically modified (GM) crops, is more organic, regenerative agriculture. There is certainly the need for more sustainable regenerative agricultural practices (Pretty, 1995), but "organic" farming is the type of agriculture already practiced by the poor, primarily because they do not have the means to buy fertilizers, pesticides, and irrigation equipment. According to Dyson (1999), sub-Saharan Africa, where most food crop production is "organic," is unlikely to see much improvement in its already dismal food situation. Exhaustion of the soil caused by the lack of fertilizers is depressing yields and pushing agriculture onto more erodable soils. Organic agriculture is nearly always nitrogen starved unless land is set aside for the sole purpose of producing green manures, a luxury the poor can ill afford. Agriculture as it is practiced now in much of sub-Saharan Africa is environmentally unsustainable and a new approach that will require considerable investment in agricultural research is needed. This new approach must be research-driven and will most certainly include GM crops (Chrispeels, 2000).

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 producing 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 (Pinstrup-Andersen and Cohen, 2000).

There are many aspects of providing food for the poor that are well beyond the control of either laboratory scientists or agricultural advisors in the field. The government must realize that agriculture can be an important engine of economic growth and therefore must invest more in agricultural research. Agricultural development and creation of rural infrastructure that will permit crop surpluses to be marketed should be encouraged. Cheap food policies that favour the urban poor are attractive to city dwellers but discourage development of food production capacity in the countryside. Such policies amount to a transfer of wealth from the agricultural sector to the industrial sector. Developing countries need to examine whether these policies would benefit only the big farmers who rely primarily on purchased outside inputs, or also the smaller farmers who might be engaged in more sustainable practices. If the entire framework for supporting agricultural development is put into place, then biotechnology can also play a role. "Biotechnology is only one tool, but a potentially important one, in the struggle to reduce poverty, improve food security (Rosegrant and Cline, 2003; Serageldin, 1999), reduce malnutrition, and improve the livelihoods of the rural and the urban poor" (Persley, 1999).

BIOTECHNOLOGY AND FOOD PRODUCTION

Scientific innovation and its derivative benefits have had profound implications to humanity within the last century. The exciting discipline of biotechnology has drawn the interests of traditional biologists, biochemists, microbiologists, medical and agricultural scientists into applying mathematical and engineering models to understanding biology. Furthermore, several scientists in the exact sciences of mathematics, physics, and chemistry have begun to use system approaches to unravel the mystery and complexity of biology. And from the side, diagnostic, biopharmaceutical, biochemical and agriculcultural industries are rapidly drawing from and applying the research results of biotechnology. Biotechnology is experiencing a revolution like none before in the life sciences and is affecting every facet of our lives, from crop improvement to commerce, and drugs to sustainable development (Tonukari et al., 2003; Soetan and Abatan, 2008). This technology has the potential to address problems not solved by conventional research. At the same time, biotechnology may speed up research process and increase research precision. GM crops have been developed and rapidly disseminated since the early 1990s (Huang et al., 2002).

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, enhanced food security and nutrition in developing countries have received little attention, beyond blanket statements of support or opposition (Pinstrup-Andersen and Cohen, 2000).

The gene revolution

Mendel's laws of genetics were rediscovered in 1900. Mendel had published his work on inheritance patterns in pea in 1865, but it took 35 years for others to grasp their significance. Since 1900, there has been steady progress in our understanding of the genetic makeup of all living organisms ranging from microbes to man. A major step in human control over genetic traits was taken in the 1920s when Muller and Stadler discovered that radiation can induce mutations in animals and plants. In the 1930s and 1940s, several new methods of chromosome and gene manipulation were discovered, such as the use of colchicine to achieve a doubling in chromosome number, commercial exploitation of hybrid vigour in maize and other crops, use of chemicals such as nitrogen mustard and ethyl methane sulphonate to induce mutations and techniques like tissue culture and embryo rescue to get viable hybrids from distantly related species. The double helix structure of DNA (deoxyribonucleic acid), the chemical substance of heredity, was discovered in 1953 by James Watson and Francis Crick. This triggered explosive progress in every field of genetics.

Just as it took 35 years for biologists to understand the significance of Mendel's work, it may take a couple of decades more to understand fully the benefits and risks associated with genetically improved foods. It would be prudent to apply scientific and precautionary principles in areas of human health and environmental safety. The 1990s have seen dramatic advances in our understanding of how biological organisms function at the molecular level, as well as in our ability to analyze, understand, and manipulate DNA molecules, the biological material from which the genes in all organisms are made. The entire process has been accelerated by the Human Genome Project, which has poured substantial resources into the development of new technologies to work with human genes. The same technologies are directly applicable to all other organisms, including plants. Thus, the new scientific discipline of *genomics* has arisen, which has contributed to powerful new approaches in agriculture and medicine, and has helped to promote the biotechnology industry (Swaminathan, 2000).

The quality of food and food plants can be modified and optimized to meet the nutritional and health needs of at-risk and compromised populations prevalent in most of the developing countries. High rates of malnutrition, infectious disease as well as diet-related diseases such as diabetes and hypertension are prevalent in many developing countries. These are as a result of compromised immune function, inadequate sources of nutritious and quality foods and limited access to healthy and suitable foods. Biotechnology and genetic modification techniques have been proposed and applied for the improvement of the quality of various food crops. These have typically been geared towards increasing yields and pest resistance of cash crops. Furthermore, the application of biotechnology techniques for the development of functional food plants with higher levels of bioactive components or increased availability of nutrients would greatly benefit most populations in developing countries and improve the health and nutritional status overall (Niba, 2003).

In certain areas, biotechnology and genetic modification techniques are being optimized for the production and development of healthy foods, and improvement in the levels and activity of biologically active components in food plants (phytochemicals). Biotechnology techniques in developing countries however have mostly been targeted at increasing yields of cash crops. Food crops or the improvement of food quality and functional foods have garnered much less attention.

Techniques applied in genetic modification include mutation breeding, improved conventional breeding, transgenic modifications, DNA insertion, gene transfer and somatic hybridization (Bouis et al., 2003; Christou, 1997; Mazur, 2001; Mackay, 1991; Yan and Kerr, 2002).

While there has been some hesitation with regard to the acceptability and adoption of biotechnology products in certain developing countries, achievements such as the development of high-vitamin A rice have greatly increased the acceptability of biotechnology for human food applications among hitherto skeptical consumers. Furthermore, it provides insights into the potential for application of biotechnology in developing improved quality and functional foods for human nutrition and health (Soetan and Abatan, 2008), rather than simply for use in agricultural technology for improved yields and pest resistance. The production of increased levels of beta-carotene (the precursor to vitamin A) in plants is especially important, as its precursor, lycopene has been shown to have physiological chemo-preventive effects with regard to various cancers (Yan and Kerr, 2002). Furthermore, lycopene, commonly found in various carotenoid containing plants such as tomatoes and carrots, is an essential ingredient in maintaining eye health and vision.

Modifications that have been targeted and developed by various biotechnology companies include improvement in the oil content and composition of oil seeds such as legumes (Mazur, 2001; Mazur et al., 1999; Uzogara, 2000). Improvement in soybean oil quality includes stabilization of the unsaturated fatty acids by increasing levels of the antioxidant, vitamin E (Yan and Kerr, 2002). These successes indicate a relevant and important role for biotechnology in improving food quality and developing functional foods, particularly those targeted for needy populations in developing countries, such as children and pre-natal women (Niba, 2003).

Genetically modified (GM) crops

Modern agricultural biotechnology is still in an early phase, and the focus is overwhelmingly on production in industrial country farms and for industrial country markets. In 1998, 85% of the land planted with 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% of the area. Argentina, China, Mexico, and South Africa cultivated the remaining 15%, 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.

The unprecedented rapid adoption of transgenic crops during the initial five-year period (1996 - 2000) when genetically modified (GM) crops were first adopted, reflects the significant multiple benefits realized by large and small farmers in industrial and developing countries that have grown transgenic crops commercially. Between 1996 and 2000, a total of fifteen countries - 10 industrial and 5 developing - contributed to more than a twenty five fold increase in the global area of transgenic crops from 1.7 million hectares in 1996 to 44.2 million hectares in 2000. The accumulated area of transgenic crops planted in the five-year period 1996 - 2000 total 125 million hectares, equivalent to more than 300 million acres.

Adoption rates for transgenic crops are unprecedented and are the highest for any new technology by agricultural industry standards. High adoption rates reflect growing satisfaction with products that offer significant benefits ranging from more convenient and flexible crop management, higher productivity and/or net returns per hectare, health benefits and a safer environment through decreased use of conventional pesticides, which collectively contribute not only to improved weed and insect pest control (attainable with transgenic herbicide-tolerant and insect-resistant *Bt* crops) but also benefits of lower input and production costs; genetically modified crops offer significant economic advantages to farmers compared with corresponding conventional crops. The severity of weed and insect pests varies from year to year and hence this will have a direct impact on pest control costs and the consequent economic advantage (James, 2003).

Despite the on-going debate on GM crops, particularly in countries of the European Union, millions of large and small farmers in both industrial and developing countries continue to increase their plantings of GM crops because of the significant multiple benefits they offer. This high adoption rate is a strong vote of confidence in GM crops, reflecting grower's satisfaction. Many recent studies have confirmed that farmers planting herbicide-tolerant and insect-resistant *Bt* crops (*Bacillus thuringiensis* toxin- or Bt toxin-producing crops) are more efficient in managing their weed and insect pests. An estimated 3.5 million farmers grew transgenic crops to health and economic advantages.

In coming years, the number of farmers planting GM crops is expected to grow substantially and the global area of GM crops is expected to continue to grow. Global population would exceed 6 billion by 2050, when approximately 90% of the global population will reside in Asia, Africa and Latin America. Today, 815 million people in the developing countries suffer from malnutrition and 1.3 billion are afflicted by poverty. Transgenic crops, often referred to as GM crops, represent promising technologies that can make a vital contribution to global food, feed and fibre security (James, 2003).

During the six-year period 1996 - 2001, the global area of transgenic crops increased by more than 30-fold, from 1.7 million hectares in 1996 to 52.6 million hectares in 2001. This high rate of adoption reflects the growing acceptance of transgenic crops by farmers using GM technology in both industrial and developing countries (Table 1). During the six-year period 1996 - 2001, the number of countries growing transgenic crops more than doubled, increasing from 6 in 1996 to 9 in 1998, to 12 countries in 1999 and 13 in 2000 and 2001 (James, 2003).

The experience of the first six years, 1996 to 2001, during which a cumulative total of over 175 million hectares (almost 440 million acres) of transgenic crops were planted globally in 16 countries, 10 industrialized and 6 developing, has vindicated the vision of the pioneers of crop biotechnology who have seen their early promises of transgenic crops fulfilled - GM crops have met the expectations of large and small farmers planting transgenic crops in both industrial and developing countries.

The unprecedented rapid adoption of transgenic crops during the first six-year period, 1996 - 2001, reflects the significant multiple benefits realized by large and small

Table 1. Global area of transgenic crops in 2000 and 2001: by countries (million hectares).

	2000	%	2000	%	+/-	%
USA	30.3	68	35.7	68	+5.4	+18
Argentina	10.0	23	11.8	22	+1.8	+18
Canada	3.0	7	3.2	6	+0.2	+6
China	0.5	1	1.5	3	+1.0	+200
South Africa	0.2	<1	0.2	<1	<0.1	+33
Australia	0.2	<1	0.2	<1	<0.1	+37
Mexico	<0.1	<1	<0.1	<1	<0.1	-
Bulgaria	<0.1	<1	<0.1	<1	<0.1	-
Uruguay	<0.1	<1	<0.1	<1	<0.1	-
Romania	<0.1	<1	<0.1	<1	<0.1	-
Spain	<0.1	<1	<0.1	<1	<0.1	-
Indonesia	-	-	<0.1	<1	<0.1	-
Germany	<0.1		<0.1	<1	<0.1	-
France	<0.1	<1	-	-	-	-
Total	44.2	<1	52.6	100	+8.4	+19%

Source: James (2003).

farmers. There is a growing body of evidence that clearly demonstrates the improved weed and insect pest control attainable with transgenic herbicide-tolerant and insect resistant *Bt* crops that also benefit from lower input and production costs. Despite the ongoing debate on GM crops, particularly in countries of the European Union, millions of large and small farmers in both industrial and developing countries continue to increase their plantings of GM crops because of the significant multiple benefits they offer. More specifically, the use of transgenic crops results in:

- More sustainable and resource-efficient crop management practices that require less energy and fuel and conserves natural resources.
- More effective control of insect pests and weeds.
- A reduction in the overall amount of pesticides used in crop production, which impacts positively on biodiversity, protects predators and non-target organisms and contributes to a safer environment.
- Less dependency on conventional pesticides that can be a health hazard to producers and consumers; the potential health benefits associated with fewer pesticide poisonings from *Bt* cotton in China is an important finding, with significant implications for other developing
- Countries where small farmers may be at similar risk from heavy and over-use of conventional pesticides.
- *Bt* maize, which has reduced levels of the fumonisin mycotoxin provides safer and healthier food and feed products.
- Greater operational flexibility in timing of herbicide and insecticide applications.
- Conservation of soil moisture, structure, nutrients and control of soil erosion through no or low-tillage practices as well as improved quality of ground and surface water with less pesticide residues.

There is now considerable evidence that transgenic crops are delivering significant economic benefits. The global economic advantage to farmers deploying herbicide tolerant (HT) soybean, HT canola and *Bt* corn was estimated to be of the order of $ 700 million in 1999, equally shared between developing and industrial countries. In addition to these direct economic advantages that farmers derive from transgenic crops, there are also significant additional indirect benefits to others in society. For crops such as herbicide-tolerant soybean, these indirect benefits to consumers globally can be of the same order of magnitude as the direct economic advantages to farmers. Thus, the global direct and indirect economic advantage of GM crop in 1999 was of the order of $ 1 billion or more.

2001 is the initial year of the second quinquennium (2001 - 2005) during which GM crops is being comercialized. In 2001, coincidental with increased political, policy and institutional support for GM crops due to their acknowledged contribution to global food security, the global area of transgenic crops benefited from renewed growth which resulted in a 19% increase in global GM crop area in 2001 - almost twice the growth rate in 2000. The number of farmers that benefited from GM crops increased from 3.5 million farmers in 2000 to an estimated 5.5 million in 2001. More than three-quarters of the GM farmers that benefited from GM crops in 2001 were resource-poor farmers planting *Bt* cotton, mainly in eight provinces in China and also in the Makathini Flats in KwaZulu Natal province in South Africa. The well documented experience of China with *Bt* cotton presents a remarkable case study where 5 million small resource-poor farmers in 2001 are already benefiting from significant agronomic, environmental, health and economic advantages - this is a unique example of how biotechnology can impact on poverty alleviation, as advocated in the 2001 UNDP Human Development Report. The China experience with *Bt* cotton lends itself for introduction and replication to carefully selected developing countries in Asia, Latin America and Africa where resource-poor farmers can learn, share and benefit from the rich experience of China – the majority of the hectare of global cotton is grown in developing countries. Following a successful launch of *Bt* cotton in 2001, Indonesia is also expected to expand its *Bt* cotton in 2002, and India, the largest cotton growing country in the world, has approved commercial cultivation of *Bt* cotton in 2002.

There is cautious optimism that global area and the number of farmers planting GM crops will continue to grow in 2002 in the six principal countries already growing GM crops - USA, Argentina, Canada, China, South Africa and Australia. The other seven countries growing transgenic crops in 2001 are expected to report modest growth in GM crop area in 2002. The commercialization of herbicide-tolerant soybean in Brazil will be dependent on resolving the outstanding regulatory issues between the Ministries of Agriculture, Environment and Justice. The commercialization of GM crops in India and Brazil would represent a watershed for GM crops in developing countries in that the three most populous countries in Asia - China, India and Indonesia with 2.5 billion people, as well as the three major economies of Latin America - Argentina, Brazil and Mexico, plus South Africa would then all be commercializing and benefiting from transgenic crops.

As new and novel products with input and output traits will become available for commercialization in the near future, it is critical that these products be deployed in an integrated strategy in which both conventional and biotechnology applications are applied to attain the challenging goal of global food security. Adoption of such a strategy will allow society to continue to benefit from the vital contributions that both conventional and modern plant breeding offer. Technology is only one of several elements that can contribute to an integrated global food security strategy where population control and improved food distribution systems are also essential elements. Biotechnology can play its appropriate and essential role in achieving food security in the developing world. The experience of China, Argentina and South Africa, that are already deriving significant benefits from GM crops, can be shared with other developing countries in the three continents of the South which face similar challenges (James, 2003).

Adapting biotechnology for increased crop production

What is needed in developing countries is an understanding that goes beyond conventional, orthodox wisdom to work more strategically in developing and implementing effective, international, national and regional policies (Clover, 2003). Funding for agricultural research has declined 50% on a worldwide basis. Funding for research in general is at a dismal low in developing countries. The intrusion of intellectual property rights into the arena of crop improvement, while beneficial to the economies of the developed world is making the lives of many researchers even more difficult. Private industry has dominated research in biotechnology (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 (Pinstrup-Andersen and Cohen, 2000).

Production of genetically modified crops is not a complex technology and is clearly within the capabilities of national research institutes in many developing countries. Genetic modification of crops using recombinant DNA technology is also within reach of the institutes of the Consultative Group on International Agricultural Research (CGIAR), including Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT) in Mexico, International Rice Research Institute (IRRI) in The Philippines, and the International Institute for Tropical Agriculture (IITA) in Nigeria. Furthermore, these institutes have already assumed responsibility for biotechnological research and a number of crop improvement projects are under way. These institutes see biotechnology as a tool and not as an end in itself. Crop improvement through biotechnology need not be equated with transgenic plants. For example, marker-assisted breeding is a powerful biotechnology that can find widespread application with the crops of the poor. Detailed linkage maps of these crops will be tremendously useful. As these CGIAR institutes focus on their needs, they will want and need to reach out to public institutions in developed countries. Alliances such as the Cassava Biotechnology Network that bring together researchers from many countries are an effective way to create synergy toward a common goal.

The private sector leads in every aspect of the agricultural biotechnology revolution and activities in the public sector will have to marshal the strength of the private sector through public-private partnerships. Such partnerships must be based upon mutual trust and common goals. The private sector can work with the CGIAR institutes and with national research institutions (the foreign equivalents of the U.S. Department of Agriculture) of developing countries to transfer technologies, train scientists, provide hands-on experience in intellectual property management, and facilitate the no-cost or low-cost licensing of inventions. Since the cost of these inventions is being charged to the consumers in developed countries, such approaches amount to a transfer of wealth by large corporations from the developed world to the developing world.

The application of biotechnology to the problems of the poor will not be straightforward and the models we have from developed countries will probably not be applicable. Agricultural research for the crops and problems of the poor has to proceed from the bottom up, not from the top down. Crops have to be created that fit not only in the agro-ecology of the poorest regions often characterized by marginal and heterogeneous environments, but the crops must also fit into the social and economic systems. Agricultural research has to start with studying farming practices (so called "on-farm research"), asking the farmers - men and women - what they want, allowing the farmers to make choices between often conflicting objectives such as higher yield versus yield stability, and examining the possibility of marketing the excess production. Researchers have to begin by soliciting the help of the farmers to describe farming practices and analyze these practices to pinpoint problem areas and opportunities. Together, the researchers and farmers have to generate a range of choices that the farmers could implement. The major objective of this approach is not the transfer of technology, but empowerment of the farmer to improve production (Chrispeels, 2000).

PRESPECTIVES

Inadequate nutrition, sub-par quality foods and limited food processing capabilities have led to compromised, sub-par health status and a prevalence of diet-related diseases in many developing countries, most especially among children, prenatal and post-partum women. There is clear potential for the application of biotechnology and genetic modification as tools to combat these challenges and improve the situation of at-risk populations. While there is concerted and dedicated focus on combating more apparent challenges such as infectious disease and producing enough food to feed the growing populations, the quality of the foods produced ought to be an important consideration. The feasibility and cost of applying modern and emerging genetic modification technologies in these areas is certainly a daunting task, as sometimes the primary need is often just survival. However, as scientists and policy makers make progress towards alleviating these debilitating conditions, consideration should also be given to the possibility and potential for augmenting food quality and developing functional foods for improved nutritional and health status (Niba, 2003).

In spite of an impressive stockpile of scientific discoveries and technological innovations, poverty and social and gender inequities are increasing. According to the World Bank, 1.3 billion people lived on less than US$1 per day and another 3 billion lived on less than US$2 per day in 1993. Illiteracy, particularly among women, is still high in many developing countries. It is not only in opportunities for education that children of many developing countries remain handicapped, but even more alarming, in opportunities for the full expression of their innate genetic potential for physical and mental development.

There are now uncommon opportunities to harness the power of such synergy to address contemporary development issues such as the growing rich-poor divide, feminization of poverty, famine of jobs, human numbers exceeding the population-supporting capacity of ecosystems, climate change, and loss of forests and biodiversity. Whether in economics or in ecology, experience has shown that a trickle-down approach does not work. Fortunately, modern information technology provides opportunities to reach the unreached. Virtual colleges (computer-aided and internet-connected) linking scientists and women and men living in poverty can be established at local, national, and global levels to launch a knowledge and skill revolution. This will help to create better awareness of the benefits and risks associated with genetically improved organisms, so that both farmers and consumers will get better insights into the processes leading to the creation of novel genetic combinations.

The future of small scale farm families will depend on precision agriculture, which involves the use of the right inputs at the right time and in the right way. Biotechnology will play an important role in the major components of precision farming: integrated gene management, soil health care, efficient water management, integrated pest management, integrated nutrient supply, and efficient post-harvest management. Ecotechnology-based precision farming can help to cut costs, enhance marketable surplus, and eliminate ecological risks. This is the pathway to an ever-green revolution in small-farm agriculture (Swaminathan, 2000).

The ethical considerations of genetic engineering of crops pale in comparisons to the ethical considerations of not improving the lives of the poor (Chrispeels, 2000). Those who oppose GM crops are also quick to point out that this technology primarily benefits the multinational corporations that sell the seeds, and that these corporations are more interested in their own bottom line (always referred to as "corporate greed") than in "feeding the poor." True enough, the big corporations are not working on the crops of the poor, such as cassava, millets, sorghum, sweet potatoes, yams, and legumes (other than soybeans). Furthermore, they are not giving away their technology to poor countries because they want to recover the costs of their investments in biotechnology. The poor will not have the resources to purchase transgenic seeds from multinationals. Research on these crops in the public sector is also unfortunately quite limited. Rice, an important crop of the poor, is an exception, with some research in the corporate sector and considerable research in the public sector taking place, primarily as a result of the Rockefeller Foundation's initiatives (Chrispeels, 2000).

An important feature of the Green Revolution is that the research was carried out in the public domain, and that the genetically improved crop varieties were given away free to the farmers without concerns for the intellectual property rights of those who produced them. Food production was raised substantially in large areas of the developing world, but other areas, especially Africa, were bypassed. It is unfortunate that "public-sector support for agricultural development has collapsed across the board" according to Robert Paarlberg, with a 57% drop in foreign aid to agriculture in poor countries between 1988 and 1996 and a 47% decrease in lending by the World Bank for agriculture and rural development between 1986 and 1998 (Paarlberg, 2000).

Research focused on how to reduce the need for inputs and increase the efficiency of input 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 (Pinstrup-Andersen and Cohen, 2000).

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. Public investment in agricultural research is of particular importance for achieving food security in developing countries (Pinstrup-Andersen and Cohen, 2000). 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.

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