African Journal of Biotechnology Vol. 6 (14), pp. 1597-1602, 18 July 2007
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2007 Academic Journals

Review

Roles of agricultural biotechnology in ensuring adequate food security in developing societies

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Accepted 2 April, 2007

Agriculture is asked to satisfy two apparently contradictory needs; to become more productive and at the same time more sustainable, that is, to supply the food needed without depleting renewable resources. While agricultural biotechnology holds enormous promise for significantly increasing food production and relieving already strained land and water resources in most developing societies, it has become an emotional issue creating the strongest sense of unease and resistance among some consumers, developing countries farmers, environmental groups and some societies. This review appraises the food and fibre situations in developing societies so as to understand the roles which agricultural biotechnology could play therein. It revealed that the outlook for developing societies in food and fibre production is particularly grim; however, increases in crop and animal yields and therefore the availability of food to feed the ever growing population of developing societies can be achieved through the adoption of biotechnology practices. The paper concludes with the recommendation that individual countries need to identify their specific national priorities and preferences in food production, and harness the growing body of science and innovations in genetic engineering to address specific issues.

Key words: agricultural biotechnology, developing societies, food situations and roles.

INTRODUCTION

The growing human population and the concomitant increase in use of natural resources are generating a series of negative effects on ecosystems, such as pollution, loss of genetic diversity, soil fertility decline, climatic changes, decline in yields, deforestation and desertification. Agriculture is asked to satisfy two apparently contradictory needs; to become more productive and at the same time more sustainable, that is, to supply the food needed without depleting renewable resources.

The human race is totally dependent on agriculture and as world populations continue to expand, there must be continuous reassessment of agricultural practices to optimize their efficiency. In many parts of the developed world such as Europe and the United States of America, agriculture is a highly efficient industry and continues to demonstrate annual increases in productivity. In contrast, many developing countries are still not self-sufficient in food production due to many reasons such as lack of good agricultural practices, hostile climate, or political instability. Many developing societies are intrinsically poor and lack the ability to take advantage of new technology hence they suffer from food crisis situations. Breeding crops and animals that produce higher yields of better quality but do not adversely affect the ecosystem can be achieved only through a very broad scientific input. In response to the food crisis in developing countries, governments, research institutions and donor agencies have come up with a variety of technical, policy and institutional interventions, ranging from refocusing agricultural research and reviewing food security policies to the provision of emergency food aid (Mugabe, 2003).

Biotechnology which is the application of indigenous and or scientific knowledge to the management of (part of) micro-organisms, or of cells and tissues of higher organisms so that these supply goods and services of use to human beings (Bunders et al., 1996), represents the latest front in the ongoing scientific progress of this millennium. Biotechnologies used in agriculture are developed through two different innovative systems: the informal system at farm or village level responsible for most

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traditional products and processes, and the formal institutional system linking farmers with research and technology transfer services in the development and dissemination of modern technologies.

The distinctive characteristic of the informal system is that producers themselves are the major innovators. In a process of trial-and-error, they develop solutions to locally perceived problems with the means at their disposal, the use of external inputs being rare. This is evident in many traditional foods and medicinal products. Modern science-based biotechnology has provided a new impetus to formal agricultural research. This new set of tools has already demonstrated its capacity to generate innovations for industrial and commercial agriculture. At the same time science-based biotechnology also holds great promise for improving traditional farming systems in developing countries. The degree to which science-based biotechnology research can be directed towards meeting the needs of resource-poor farmers in developing countries remains to be determined. Among the many institutions that shape the direction of such research are transnational corporations, international agricultural research centers, the national biotechnology programmes and research systems of developing and developed countries, universities, private sector, non-governmental organizations (NGOs) and farmers. The wide variety of actors involved ensures that diverse biotechnological development paths are followed.

A key public policy question that has emerged is: what role can agricultural biotechnology play to ensure adequate food security of developing societies in this millennium? Specifically, this paper aims to achieve the following objectives: review the food and fibre situations in developing societies; and examine the roles which agricultural biotechnology could play to ensure adequate food security in developing societies.

FOOD AND FIBRE SITUATION IN DEVELOPING SOCIETIES

The outlook for developing societies in food and fibre production is particularly grim. A developing society according to Wikipedia (2006) is a society with a rela-tively low standard of living, undeveloped industrial base, and moderate to low Human Development Index (HDI). Since 1971, the United Nations has denominated "Least Developed Countries" (LDCs) a category of low income states that are deemed structurally disadvantaged in their development process and facing more than other countries the risk of failing to come out of poverty. Generally, three criteria are being used to classify developing societies. They include:

i) *Low income*, based on a three-year average estimate of the gross national income per capita (under $750 for cases of addition to the list, above $900 for cases of graduation);

ii) *Weak human assets*, in the light of a composite *Human Assets Index* (HAI) based on indicators of: (a) nutrition; (b) health; (c) school enrolment; and (d) adult literacy;

iii) *Economic vulnerability*, in the light of a composite *Economic Vulnerability Index* (EVI) based on indicators of: (a) instability of agricultural production; (b) instability of exports of goods and services; (c) diversification from traditional economic activities; (d) merchandise export concentration; and (e) economic smallness.

From a world view, it was observed that in 1995, over 700 million people did not have sufficient food for a healthy and productive life (Pinstrup et al., 1994) while up to a billion survive on less than a dollar a day (Brown et al., 1994). Chassy (2003) put it at 800 – 850 million people that are malnourished. More than 200 million of these are children; many of whom will never reach their full intellectual and physical potential. Another 1 – 1.5 billion humans have only marginally better access to food and often do not consume balanced diets containing sufficient quantities of all required nutrients. Chassy (2003) further noted that majority of this nutritionally at – risk population live in developing countries. Most, perhaps 75% live in rural agricultural regions and are poor. The United Nations Food and Agriculture Organi-zation (FAO) estimate that two out of five children in the developing societies are stunted, one in three is underweight, and one in ten is 'wasted' due to under-nourishment (Dupont and William, 2000).

When agriculture began, around the tenth century B.C., the doubling time for the world's human population was 8000 years. Now it is a mere 40 years. By 2025, our planet will contain about 8.5 billion people, over three quarter of whom will live in the developing countries (Bunders et al, 1996). The authors maintained that global food production will have to rise by 2.6 billion tones just to maintain current per capita food consumption. If diets are to improve among the world's poor and hungry societies, an extra 4.8 billion tones of food will be needed.

Unless current trends alter, food production in 2025 in Asia and Sub-Saharan Africa (SSA) will fall 40 and 60% short of needs, respectively (Bunders et al., 1996). Sub-Saharan Africa, which comprises most of the developing societies, is a region where growth in agricultural production has not kept pace with expanding need. As a whole, the region has some of the poorest and most depleted agricultural soils. Only four percent of the farmed land is irrigated (Chassy, 2003). Significant areas of agricultural land are at risk of becoming desert while in some parts of the region, excessive humidity and high temperatures contribute to a high incidence of diseases and pests. Droughts are commonplace in some parts of the region. Outright crop failure is common and poor yields are endemic. There is clearly a need to develop crop varieties and management strategies that are more productive under these conditions.

The economies of Sub-Saharan Africa for example, are heavily dependent on agriculture, which contributes more

Table 1. Agriculture and food production growth rates in Sub-Saharan Africa.

Year	Agriculture	Crops	Cereal	Roots and Tubers	Livestock	Food
1997	0.5	0.2	-4.2	2.0	1.4	0.3
1998	3.7	4.1	4.1	5.5	2.6	3.9
1999	1.9	1.8	-0.6	4.2	2.5	2.5
2000	-0.3	-1.0	-3.2	0.5	1.4	-0.3
2001	0.8	0.9	2.4	0.7	0.5	0.6

Source: FAO, 2002.

than 30 percent of Gross Domestic Product (GDP) and employs at least 45 percent of the regions 850 million people (Mugabe, 2003). About 70 percent of Africans for example live in rural areas and depend directly or indirectly on agriculture for their livelihood. Unfortunately, the agricultural sector's performance has been poor over the past three decades; Sub-Saharan Africa is the only region where agricultural output has fallen behind population growth (Mugabe, 2003). Overall agricultural production fell by 0.3 percent in 2000, after an increase of about 1.9 percent in 1999 (Table 1). Cereal production fell by at least 3 percent while livestock production increased only marginally, after drastic falls in the late 1990s. Average cereal yields in SSA are half of those in Asia (FAO, 2002).

On a sub-regional basis, Mugabe (2003) observed that agricultural output fell by 0.5 percent in 2000 in Eastern Africa. It declined by 1 percent in central Africa, while in the Sahelian countries cereal production fell by almost 13 percent in the year 2000. Western Africa experienced sluggish or slow growth of the agricultural sector. In southern Africa (excluding South Africa), agricultural production fell by 3.3 percent in 2000, after increasing by 14.2 percent in 1999, crop and livestock production fell by 3.0 and 3.9 percent, respectively (FAO, 2002). In Southern Africa, reduced maize harvest caused by drought led to food shortages in 2002. Maize output in Malawi, Angola, Zambia and Zimbabwe declined by more than 25 percent in 2001 and declined further in 2002 (FAO, 2002). The case of Zimbabwe is worst with the exodus of white farmers, political instability and isolation by western democracies.

Drought has had severe impacts on livestock population, also reducing productivity in Eritrea, Ethiopia, Kenya and Sudan. Livestock production has fallen considerably because of infestation by diseases, such as the tse-tse- transmitted African animal trypanosomiasis, which infests 37 percent of the continent and affects more than 20 countries. The disease leads to loss of productivity in animals and, without treatment, is frequently fatal. Large areas of land are today left with relatively few cattle because of the presence of the tsetse fly, and the estimated losses in agricultural output and productivity are very significant (Mugabe, 2003).

Developing societies and especially Africa is now the world's largest recipient of food aid. Approximately 1.3 million people in Eritrea, 5.2 million in Ethiopia, 1.5 million in Kenya and 2 million in Sudan required emergency food aid in 2002 and in Southern Africa, emergency food assistance is required by at least 14 million people (Mugabe, 2003). Food security assessments conducted by the World Food Programme (WFP) in September 2002 showed that more than 70 percent of households in Malawi and Zambia had no cereal seed while in Zimbabwe more than 94 percent of farmers were without seeds. In Angola, the number of people in need of emergency food aid has increased to 1.9 million from 1.42 million (World Food Programme, 2003).

In many developing countries, the ecologically acceptable expansion of arable land is no longer possible. The economic power structures in these countries, which are expressed as land ownership and production systems, are generally not in favour of application of methods and techniques that make small-scale and energy-efficient production possible. All in all, this means that due to either simple poverty or the huge imbalances in economic power, the dominant technologies in many developing countries now threaten the foundations of existence.

Growth rates in yields have been decreasing in most parts of developing societies and this declining trend is expected to continue if nothing urgent is done. At current rates of growth, developing country's food supply will not be sufficient to feed the increasing population over the next 25 years, even if current per capita levels of consumption do not rise. In many developing countries especially in Africa, food self-sufficiency is on the decline (World Bank, 1993).

Although the problems of hunger and malnutrition are complex and production increases alone cannot solve them, it is one of the necessary interventions. Mugabe (2003) observed that to meet increasing demand for food and enlarge the prospects for food security (access to adequate food to maintain an active healthy life), increases in agricultural productivity will be required. This will not be through expansion of cultivated area, but, rather, will require improvements in crop and livestock yields. The FAO estimates that for malnourishment to be eradicated by 2010, food output will have to more than double (Leisinger, 1996). To achieve the productivity improvements, greater attention must be paid to measures that will enhance the ability to harness and apply new scientific and technological advances.

An international conference of experts convened by the World Bank, the United Nations Development Program (UNDP), and FAO in 1992 concluded that a solution to the problem of securing world food supplies while preserving the environment is virtually inconceivable without recombinant genetics and biotechnology. Modern agricultural biotechnology provides new technological tools that developing societies should harness to increase crop and livestock production. It promises to change current agricultural production practices and related management systems. For example, the development of crops genetically engineered to resist certain insect pests and withstand harsh environmental conditions is poised to significantly reduce the use of chemical insecticides. Herbicide-tolerant crops will allow the adoption of conservation tillage practices with environmental benefits. Additional promises are seen for the future in protecting and restoring the environment. Increased knowledge of plant and microbial metabolism and genomes was seen as leading to the production of plants and other organisms with enhanced ability for bioremediation of contaminated soils and water.

AGRICULTURAL BIOTECHNOLOGY AND ADEQUATE FOOD SECURITY

Assuring food security for the next 25 years in developing societies requires meeting a number of political, social, economic and technical challenges (Leisinger, 1996). The first step in assessing the usefulness of new technology to agriculture is to identify the problems that have proved intractable using conventional approaches. This intractable problem remains food shortages among others which biotechnology now has prospects to remedy. Research in recombinant genetics and biotechnology aims to develop plant varieties that provide reliable high yields at the same or lower costs by breeding-in qualities such as resistance to disease, pests, and stress factors. Realization of these goals could lead to tremendous gains in food production.

Biotechnologies play a decisive role in agriculture because of their ability to directly modify plants, animals, and agricultural processes in response to new needs. Biotechnology should be seen not only as a means of solving problems when traditional techniques have failed, but also as a way of generating a better understanding of crop plants and animals through the cooperation of scientists from different disciplines. However, the International Institute of Tropical Agriculture (IITA) and the Technical Centre for Agricultural and Rural Cooperation (CTA) (1992), observed that the increasing importance of agricultural biotechnology, at least in plant improvement, should not obscure the fact that traditional plant breeding, based on hybridization followed by selection and evaluation of a large population in the field, accounts for over 50% of the global increase in agricultural productivity.

Biotechnologists and the biotechnology industry claim that biotechnology will help to increase crop yields and therefore the availability of food to feed the ever growing population of developing societies. They point to projections of population growth, increases in food demand, and declining rates of growth in yields from Green Revolution technologies to support their claims. They claim that modification of crop plants can contribute to sustainability by reducing the amount of fertilizers, herbicides and pesticides used in farming and improving the efficiency of water and fertilizer use.

Recent advances in molecular biology and genomics greatly enhance the plant breeder's capacity to introduce new traits into plants. Commercial applications of agricultural biotechnology have already produced crops such as Bt-maize, rice, potatoes, cotton and sweet corn (sweet maize) that can protect themselves against insects; virus – resistant papaya, squash and potatoes; and herbicide – tolerant crops such as wheat, maize, sugar cane, rice, onions and beets that allow more effective weed management. It is obvious from the list that traditional food crops such as roots and tubers consumed widely in developing societies have been left out of this development apparently because biotechnology research is dominated by western multinationals whose major objective is economic. This poses a challenge to national agricultural research systems in developing societies to rise to the occasion. Some genetically modified foods and traits available in the market are shown in Table 2. There is accumulating evidence that these biotechnology crops can be more productive and profitable for farmers (Chassy, 2003). Major reductions in costs for labour, energy and chemicals have been documented which contribute to farmers' profitability index.

There is also an emerging international consensus of scientific and regulatory opinion that crops derived through biotechnology are safe to eat as food and feed and beneficial to the environment (Chassy, 2003). These and other promising technologies are now being directed at improving the production and yield of African staple crops like cassava, yam, maize, millet, rice, soybean, sweet potato, sorghum, banana, oil crops, peanut and wheat. Protein - enhanced sweet potatoes and carotene - enhanced rice and oilseeds promise to improve the nutritional value of the diet.

Generally, agricultural biotechnology inventions can be in the form of products or processes. For products, these can be considered either as:

i) Living entities of natural or artificial origin such as animals, plants and micro-organisms, cell lines, organelles, plasmids and DNA sequences; or
ii) Naturally occurring substances, primary or secondary, derived from living systems.

For processes, these can include those of isolation, cultivation, multiplication, purification and bioconversion.

Table 2. Some genetically modified (GM) crops and traits in the market.

Product Traits	Crops
Bt crops are protected against insect damage and thus reduce pesticide use. Plants produce a protein (toxic only to certain insects) found in a common soil bacterium (Bacillus thuringiensis, or Bt).	Corn, cotton, potatoes. Future: sunflowers, soybeans, canola, wheat, tomatoes
Herbicide-tolerant crops allow farmers to apply a specific herbicide to control weeds without harm to the crop. This gives farmers greater flexibility in pest management and promotes conservation tillage	Soybeans, cotton, corn, canola, rice. Future: Wheat, sugar beets.
Disease-resistant crops are armed against destructive viral plant diseases with the plant equivalent of a 'vaccine"	Sweet potatoes, cassava, rice, corn, squash, papayas. Future: tomatoes, bananas
High-performance cooking oils maintain texture at high temperatures, reduce the need for processing and create healthier food products. The oils are either high oleic or low linoleic (in the future, high stearate)	Sunflowers, peanuts and soybeans
Healthier cooking oils reduce saturated fat	Soybeans
Delayed-ripening fruits and vegetables have superior flavour, colour and texture, are firmer for shipping and stay fresh longer	Tomatoes Future: raspberries, strawberries, cherries, tomatoes, bananas, pineapples.
Increased solid tomatoes have superior taste and texture for use in processed tomato pastes and sauces	Tomatoes
rBST is a recombinant form of a natural hormone, bovine somatotropin, which causes cows to produce milk. rBST increases milk production as much as 10 – 15 percent. It is used to treat over 30% of US cows.	rBST (milk production)
Food enzymes, including a purer, more stable form of chymosin used to curdle milk in cheese production (used to make 60% of hard cheeses). Replaces chymosin of rennet from slaughtered calves' stomachs	Chymosin (in cheese) – the first biotechnology product in food
Nutritionally enhanced foods will offer increased levels of nutrients, vitamins and other healthful phytochemicals. Benefits range from helping developing nations meet basic dietary requirements to boosting disease – fighting and health – promoting foods.	Future: Protein – enhanced sweet potatoes and rice; high vitamin A canola oil; increased – anti oxidant fruits and vegetables

Source: www.bio.org/food&ag/transgenicprod.html.

Such processes can be involved in the isolation or the creation of the above products, for example, antibiotic production; the production of substances through bioconversion of products, for example, enzymic conversion of sugar to alcohol; the use of the products for any purpose, for example, monoclonal antibodies for analysis or diagnosis; the use of microbes for biocontrol of pathogens.

Some traditional agricultural biotechnology practices include:

Pest control through intensive mixed cropping system to maintain biodiversity.
Protection of the natural resource base and maintenance of soil fertility through shifting cultivation practices, bush fallowing and composting.
Natural fermentation processes used widely to prepare foods and beverages example, beer, wine etc.

Some modern agricultural biotechnology practices include:

Food processing: Fermentation, enzyme technology and monoclonal antibody technology.
Plant nutrition and health: Biofertilizers, biocontrol agents and diagnostics.
Animal nutrition and health: Feed (enzyme technology), digestion, metabolism (genetic modification), drug and vaccine development (fermentation technology, genetic modification) and diagnostics.
Germplasm improvement and conservation: selection and breeding (tissue culture, genetic markers, genetic modification, mutation induction, somatic hybridization and cybridization), reproduction (mass propagation, detection of hormone levels, embryo technology); germplasm conservation (tissue culture, isozyme analysis).

The indigenous knowledge gained by small-scale farmers over generations, should be inventoried and harmonized with modern science to evolve a diversified technology base. Researchers must accept that they need to learn from the farmer and to build on farmers innovations in order to make their findings relevant. Farmers on the other hand must fill gaps in their knowledge and learn new technologies that will underpin sustainable gains in production. In summary, biotechnology promises the following benefits to the developing society's agriculture:

Increased yields and productivity.
Improved quality and shelf life of products.
Improved resistance to pests and diseases.
Substitution of one crop for another or, alternatively, a synthetic for an agricultural commodity.
Substitution of renewable (agriculture) for non-renewable (fossil fuel) energy sources.
Adaptation of existing crops and livestock to different environments.
Shift in marketed surplus to farmers, regions and nations with high productivity.
The reduced reliance of biotechnology varieties on chemical inputs means less water pollution.
Reduced chemical usage results in safer water supplies and higher quality drinking water as well as a better environment for wildlife.
Higher yielding biotechnology crops can help ease the strain of land resource, reducing the need for expansion onto more fragile areas and thus allowing for greater conservation of natural habitats.

Energy usage on biotechnology crops is lower because there are fewer passes through fields in applying chemicals. Less fuel use means less carbon entering the atomsphere as carbon dioxide (Co_2).
Herbicide-resistant crops encourage the adoption of conservation tillage, especially no-till, which reduce erosion of topsoil.

Thus, over the long term, agricultural biotechnology promises to play a crucial role in improving agricultural productivity and reducing the environmental impact of agriculture leading to agricultural sustainability and food security in developing societies. However, it should be noted that agricultural biotechnology alone is not the panacea to food security problems in developing societies but in combination with other traditional breeding technologies, infrastructural development, and sound political and economic reforms aimed at overall agricultural development.

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