African Journal of Biotechnology Vol. 2 (11), pp. 394-416, November 2003
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2003 Academic Journals

Special Anniversary Review

Harmonizing the agricultural biotechnology debate for the benefit of African farmers

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Accepted 24 October 2003

The intense debate over agricultural biotechnology is at once fascinating, confusing and disappointing. It is complicated by issues of ethical, moral, socio-economic, political, philosophical and scientific import. Its vocal champions exaggerate their claims of biotechnology as saviour of the poor and hungry, while, equally loudly, its opponents declare it as the doomsday devil of agriculture. Sandwiched between these two camps is the rest of the public, either absorbed or indifferent. Biotechnology issues specific to the African public must include crop and animal productivity, food security, alleviation of poverty and gender equity, and must exclude political considerations. Food and its availability are basic human rights issues—for people without food, everything else is insignificant. Although we should discuss and challenge new technologies and their products, bringing the agricultural biotechnology debate into food aid for Africa where millions are faced with life-or-death situations is irresponsible. Agricultural biotechnology promises the impoverished African a means to improve food security and reduce pressures on the environment, provided the perceived risks associated with the technology are addressed. This paper attempts to harmonize the debate, and to examine the potential benefits and risks that agricultural biotechnology brings to African farmers.

Key words: Agriculture, biotechnology, biotechnology debate, biotechnology and Africa, biotechnology issues, food security, poverty alleviation.

INTRODUCTION

On average, about 73 million people—about three times Uganda's current population—will be added to the world's population every year between 2000 and 2020.That is, the world's population will increase by 25% from 6000 million in 1995 to about 7500 million by 2020. About 97.5% of this increase is expected to occur in today's developing world (Pardey and Wright, 2002), where three of every four people—900 million in all—live in rural areas and depend directly or indirectly on agriculture for their livelihoods.

Agriculture is the single most important sector in the economies of most low-income countries, accounting for one-fourth to one-half of the gross domestic product (GDP) and the bulk of export earnings. About 75% of Africans depend solely on income from agriculture and agribusiness, which, in turn, constitutes 40% of the GDP of African nations (Machuka, 2003). Productive

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agriculture, with concomitant increases in incomes, is needed to raise food-purchasing power and to reduce poverty. Poor people's links to the land are critical for sustainable development. The front line of any successful assault on poverty and environmental degradation must therefore have a focus on agriculture and rural development.

Africa's current population is projected to rise to 1700 million by 2050 (Pinstrup-Andersen and Pandya-Lorch, 1999). Demand for imported food—mostly cereals and legumes—will increase from 50 to 70 million tons per year. If the current economic situation of Africa does not improve, food-deficit nations are unlikely to have the resources to purchase such a huge volume of food on a commercial basis. Several countries are already regular recipients of food aid. Even if food aid continues, it often misses the rural poor. To prevent future human catastrophes, African countries will have to develop and implement strategies for increasing agricultural productivity.

Agricultural productivity can be increased sustainably in numerous ways, such as using inorganic and organic fertilizers; improving disease, pest and weed control; practising soil and water conservation; and using improved plant varieties developed either traditionally or through biotechnology.

Biotechnology can be defined broadly to include technologies ranging from microbial fermentations to genomics (Persley and Doyle, 1999). Farmers and homemakers have been using some form of biotechnology for as long as they have been growing crops, baking breads, making cheese and preparing alcoholic drinks. These techniques, however, are not part of the biotechnology debate, which is fuelled instead by recent developments. Modern biotechnology has undergone, and is undergoing, a remarkable evolution, with numerous key discoveries being made, many of which have been subject of high-profile recognitions such as Nobel Prizes (Table 1).

Agricultural biotechnology encompasses a variety of laboratory methods. These include cell, tissue and embryo culture; clonal propagation of disease-free plants; identification of chromosome regions (quantitative trait loci, or QTLs) that carry important multigenic traits; gene identification and isolation; genetic engineering for traits such as pest and disease resistance, better adaptation to environmental stresses, greater nutritive value and reduced postharvest losses; and genetically engineered male sterility to facilitate hybrid seed production. Properly integrated into traditional farming systems, biotechnology applications could make a difference in improving food security in developing countries.

For many years, plant breeders have used conventional plant breeding methods to genetically modify plants, and to help speed natural selection and evolution by combining genes for resistance to biotic (diseases and pests) and abiotic (low soil fertility, drought and salinity) stress factors, crop yield, quality, seed colour and many other traits of agronomic importance.

Conventional methods of genetic modification differ from modern recombinant DNA technology in that the latter is faster and more precise in introducing specific genes of interest, which themselves can originate practically from any organism. A resulting new plant with a gene from another organism can subsequently serve as a parent to cross with another related plant in a conventional breeding technology. Recombinant DNA and conventional breeding technologies can therefore go hand in hand to solve some of the world's crop production constraints. A major advantage of agricultural biotechnology is that it often generates strategies for genetic improvement that can be applied to many different crops, animals and beneficial organisms.

Previous reviews on biotechnology in Africa have highlighted its status (Johanson and Ives, 2001); constraints to consider when implementing strategies (Brink et al., 1998); examples of initial applications and potential for development (Ndiritu, 1999; Woodward et al., 1999); and important issues for African policy makers to consider when developing an agricultural biotechnology strategy for the continent (Ives and Wambugu, 2001). This review attempts to harmonize the agricultural biotechnology debate and to examine the potential benefits and risks that agricultural biotechnology brings to African farmers.

AFRICA: LAND OF POVERTY AMID PLENTY

As a continent, Africa has vast natural resources, ranging from precious metals and stones to plant genetic diversity. Over generations, Africa has contributed greatly to the world's agriculture, including important crops such as coffee (origin Ethiopia), barley (Ethiopia), tropical forage grasses of the *Brachiaria* genus (eastern and central Africa), teff [*Eragrostis tef* (Zucc.) Trotter] (Ethiopia) and Madagascar periwinkle (*Catharanthus roseus* (L.) G. Don. Other significant contributions include:

- Supplying unique sources of resistance to diseases and pests of crops of African origin.
- The alkaloids vinblastine and vincristine, which derive from the Madagascar periwinkle and form the basis of two anticancer drugs (Velban® and Oncovin®, respectively). Used to treat breast cancer and Hodgkin's lymphoma, these drugs earn pharmaceutical companies an estimated income of more than US$100 million a year.
- Teff, an ancient crop that traces back to about 3359 BC (Mengesha, 1965), not only provides more than two thirds of the Ethiopian diet, but recently, has also found its place as a health food product in USA. It has very high contents of iron, calcium, phosphorus,

Table 1. Key milestones in the development of biotechnology.

Year	Development	Reference
1877	Louis Pasteur and Joules F. Joubert first describe inhibition of bacterial growth	Persidis, 1999
1922	Insulin[1] is first isolated	Banting and Best, 1922
1929	Alexander Fleming[2] develops the first effective antibiotic (penicillin) from the fungus *Penicillium* sp.	McFarlane, 1984; Persidis, 1999
1944	DNA is first identified as the hereditary material in cells; this discovery was later confirmed in 1952	Avery et al., 1944; Hershey and Chase, 1952
1953	F. H. C. Crick and J. D. Watson[3] discover DNA's double-helix structure	Watson and Crick, 1953a, b
1960	Genetic code is deciphered[4]	Crick et al., 1961
1970	Discovery of DNA ligase as catalyst for the ligation of DNA fragments	Sgaramella et al., 1970
1970	Specific restriction endonucleases are discovered[5]	Smith and Wilcox, 1970
1973	The first event of genetic engineering occurs: development of molecular cloning	Cohen et al., 1973
1976	First biotechnology firm is established (Genentech, USA)	Genentech, Inc.
1977	Methods of DNA sequencing are described[6]	Maxam and Gilbert, 1977; Sanger et al., 1977
1977	Rat insulin genes are cloned	Ullrich et al., 1977
1979	cDNA, containing the entire coding of human growth hormone mRNA, is cloned	Martial et al., 1979
1980	USA Supreme Court rules that micro-organisms can be patented	Chakrabarty, 1980
1980	*Agrobacterium tumefaciens* is successfully used to introduce foreign DNA into plants	Hernalsteens et al., 1980
1982	First pharmaceutical substance (insulin; Eli Lilly's Humulin®) produced by a genetically engineered bacterium approved for sale in USA and UK	Eli Lilly and Company, 2003
1982	First transgenic animal is produced (growth hormone gene transferred from a rat to a mouse)	Palmiter et al., 1982
1984	First transgenic plant is produced, using an *Agrobacterium* transformation system	De Block et al., 1984
1985	K. B. Mullis[7], working for Cetus Corporation, California, invents the polymerase chain reaction (PCR)	Saiki et al., 1985
1985	U.S. Patent Office extends patent protection to genetically engineered plants	Hibberd, 1985
1985	First transgenic farm animals are produced (pig, rabbit and sheep)	Hammer et al., 1985
1988	U.S. Patent Office extends patent protection to genetically engineered animals	Leder and Stewart, 1988
1988	Thermal stable DNA polymerases are isolated from thermophylic bacteria, making PCR a very useful procedure	Innis et al., 1988
1988	Human genome mapping project starts	NRC, 1988
1990-1992	First transgenic wheat and maize plants are produced, extending genetic engineering to cereals	Gordon-Kamm et al., 1990; Vasil, 1999; Vasil et al., 1992
1993	First gene for plant disease resistance (Pto) is cloned	Martin et al., 1993
1994	Genetically modified tomato is marketed in USA	Kramer and Redenbaugh, 1994
1996/97	A cloned sheep named Dolly is born at the Roslin Institute, Scotland	Campbell et al., 1996; Wilmut et al., 1997
2002	Draft sequences of the rice genome are published	Goff et al., 2002; Yu et al., 2002
2001	National Center for Food and Agricultural Policy quantifies, for U.S. farmers, the benefits of crop biotechnology in 30 crops	Gianessi and Silvers, 2001
2002	About 59 million hectares of land are planted to genetically modified crops	James, 2002
2003	The famous cloned sheep Dolly is put to sleep in February 2003, after being diagnosed with a progressive lung disease	Giles and Knight, 2003

The following Nobel Prizes were awarded in connection with advances in biotechnology:

[1] 1923, Physiology or Medicine, to F. G. Banting and J. J. R. Macleod (both of the University of Toronto, Canada) for the discovery of insulin.

[2] 1945, Physiology or Medicine, to A. Fleming (University of London, UK), and E. B. Chain and H. W. Florey (both of Oxford University, UK) for their discovery of penicillin and its capacity to cure various infectious diseases.

[3] 1962, Physiology or Medicine, to F. H. C. Crick (Institute of Molecular Biology, Cambridge, UK), J. D. Watson (Harvard University, Cambridge, MA), and M. H. F. Wilkins (University of London, UK) for their discoveries in the molecular structure of nucleic acids and its significance for information transfer in living organisms.

[4] 1968, Physiology or Medicine, to R. W. Holley (Cornell University, Ithaca, NY), H. G. Khorana (University of Wisconsin, Madison, WI), and M. W. Nirenberg (National Institute of Health, Bethesda, MD) for their interpretation of the genetic code and its role in protein synthesis.

[5] 1978, Physiology or Medicine, to H. O. Smith and D. Nathans (both of the School of Medicine at the Johns Hopkins University, Baltimore, MD), and W. Arber (Biozentrum der Universität Basel, Switzerland) for their discovery of restriction enzymes and their application to molecular genetics.

[6] 1980, Chemistry, to P. Berg (Stanford University, Stanford, CA) for his work on the biochemistry of nucleic acids and recombinant DNA; and to W. Gilbert (Biological Laboratories, Cambridge, MA) and F. Sanger (MRC Laboratory of Molecular Biology, Cambridge, UK) for their work on nucleic acid sequencing. The 1958 Nobel Prize in Chemistry had also been awarded to F. Sanger for his work on protein structure, specifically that of insulin.

[7] 1993, Chemistry, to K. B. Mullis (La Jolla, CA) for his invention of the polymerase chain reaction; and to M. Smith (University of British Columbia, Vancouver, Canada) for his contributions to the understanding of oligonucleotide-based, site-directed mutagenesis.

copper, aluminium, barium and thiamine (Mamo and Parsons, 1987; Mengesha, 1965).

African and European scientists are exploring Africa's genetic diversity in a project to document and compile a database of about 7000 useful plants in Africa (Sanides, 2002).

Despite natural genetic wealth, many parts of Africa are crippled by poverty and chronic food shortages exacerbated by natural and man-made disasters. About 70% of the continent's population lives in rural areas and depends largely on agriculture (UNECA, 2002). Most are small farmers with few or no resources and using very few agricultural inputs if any. Many grow low-yielding landrace varieties on nutrient depleted soils. Diseases, pests and weeds cause heavy yield losses. As a result, crop and livestock yields are far lower than they could be. For example, average cereal yields in Africa are half of those in the rest of the developing world (FAO 2001b; Ongaro, 1999), indicating the potential for improvement using existing conventional methods like plant breeding, soil-fertility management, and disease, pest, weed and other constraint management. Deforestation for agricultural expansion, firewood and building materials has further contributed to environmental degradation.

A major challenge for Africa is to feed its growing population. During the last two decades of the 20th century, the per capita food production in Africa declined (Machuka, 2003), because of dropping agricultural productivity and rapid population growth, which, in Kenya's case, was almost 4%—one of the highest—during the mid-1980s and early 1990s. Decline in agricultural productivity was associated with several biophysical and socio-economic factors, including an inability to replenish declining soil fertility; use of poor quality seeds; drought; inability to control heavy yield losses to pests, diseases and weeds; limited access and participation in local, regional and international markets; lack of, or ineffectual, implementation of supportive policies to boost agricultural production; poor infrastructure; and, particularly today, immense healthcare problems.

HIV/AIDS is ravaging the continent, altering its demography, reducing farmer productivity, leaving children as orphans, and overwhelming the already desperate healthcare systems. According to the World Health Organization, Africa suffers the world's highest rates of death from HIV/AIDS (81%), malaria (90%), and tuberculosis (about 23%) (WHO, 2001). Considering that about 70% of Africans depend on agriculture for their livelihoods, such death rates have a direct and negative impact on agriculture and food security.

The Food and Agriculture Organization of the United Nations (FAO) grimly projects that, by 2020, the agricultural labour force will have dropped anywhere between 12% and 26% in the 10 most-affected African nations: Botswana, Central African Republic, Kenya, Malawi, Mozambique, Namibia, Republic of South Africa, Tanzania, Uganda and Zimbabwe (FAO, 2001a). Vital indigenous knowledge on agriculture may also be evaporating as the rates of premature deaths increase with the continent's several epidemics. The loss of labour not only directly affects agricultural production and food security, but it also alters cropping systems as farmers switch to alternative crops that demand less labour.

THE AGRICULTURAL BIOTECHNOLOGY DEBATE: ISSUES AND THEIR IMPLICATIONS FOR AFRICA

Inconsistencies

The potential role of agricultural and medical biotechnology in improving the livelihoods of the poor as well as the rich has been and is being debated vigorously. A burgeoning gap exists between the fast-advancing modern tools of biotechnology and the general public's understanding of these tools and the processes involving them. Unfortunately, both opponents and proponents of biotechnology have made the debate seem either black and white, missing the whole range of colours in between. The public debate, as reported by the press, is usually presented by highly vocal extremists with passionate views. Labels such as 'Frankenstein food' (referring to genetically modified crops) have been coined to scare the public. Others have dismissed probable disadvantages, expressing exaggerated and overly optimistic views of the potential of agricultural biotechnology to the point of insisting that biotechnology holds the key to eradicating hunger. But it is not that simple. We must steer a responsible path between the two extremes, examining the prospective benefits of agricultural biotechnology while recognizing its latent pitfalls. For African farmers, we must somehow harmonize the biotechnology debate and see how agricultural biotechnology can maximize potential benefits for them.

The current agricultural biotechnology debate is skewed towards concerns that do not necessarily include alleviation of hunger and poverty and increasing productivity—the major and daily concerns of African nations. We do not wish to imply that environmental, moral or ethical concerns are not of interest to Africans, nor suggest that agricultural biotechnology will, single-handedly, solve Africa's problems by making Africans self-sufficient in food. Instead, we need to recognize that, because they depend heavily on agriculture, many African countries stand to benefit from technologies that can increase crop productivity, enhance nutritional quality, improve soil fertility and minimize forest destruction. The United Nations Economic Commission for Africa (UNECA) concludes that agricultural biotechnology should be but one part of a comprehensive and sustainable strategy to solve Africa's poverty problems (UNECA, 2002).

Regarding agricultural biotechnology, Europe has perhaps the most concerned public. The fourth Eurobarometer Survey revealed interesting insights into the public's psyche. For example, it differentiates between different applications of biotechnology and does not summarily dismiss biotechnology as a whole. That is, while it opposes genetically modified (GM) foods, the public strongly supports biotechnology applications for medicine and the environment (Gaskell et al., 2000). With GM crops, Europeans are more concerned about perceived food safety rather than potential environmental impacts. In general, for biotechnologies with perceived high benefits, these benefits overrule the perceived risks associated with them, whereas those perceived as having few or modest benefits receive no support, even if they have few or no risks. In other words, the public is willing to take risks if they perceive substantial benefits. The European public has no shortage of food and, understandably, sees no reason for modifying the current method of food production in a way that suggests 'meddling with nature'.

In November 2002, Europe introduced a law to label as 'genetically modified' food that has more than 0.9% of detectable GM ingredients. In addition, 'accidental contamination' of up to 0.5% is permitted without labelling, even for GM ingredients that have not yet been approved in Europe. GM crops for animal feed and animal feed containing GM-derived ingredients are required to be labelled as such, but meat and dairy products from animals feeding on GM crops do not have to be labelled. The debate over this law has already started, and the European Parliament is expected to approve the law during 2003.

Genetically modified organisms (GMOs) that have elicited little or no controversy include those used worldwide in healthcare products (e.g. insulin, hepatitis vaccine, medication for cardiovascular diseases and gene therapy) and industry (e.g. bioremediation, food additives and food processing). For example, the cloning and expression of sequences encoding the human growth hormone is considered a medical breakthrough. The hormone was initially available as minute extractions from human cadavers. The production of the hormone, using recombinant DNA technology, is an excellent example for which no other preferred or equivalent source exists and, thus, no controversy on the methodology used to produce the product. The same applies to various vaccines. Perhaps the general public has no sympathy or appetite for debates involving healthcare products?

In Africa, chronic food shortages, famines and malnutrition determine choices between life and death. Are these issues not as important as pharmaceutical drugs? Food is a basic need, and access to food is a basic human rights issue. If one does not have food, everything else becomes insignificant, as a Chinese proverb vividly puts it: 'A person who has food has many problems; a person who has no food has only one'. Discussing and debating environmental or ethical issues is hard with destitute people who have lost their dignity and their hope for life because they have nothing to eat. If we want to address biotechnology issues relevant to Africa, we must include crop and animal productivity, food security, alleviation of poverty and gender equity, and exclude political considerations. While we should debate and challenge new technologies and their products, bringing the GMO debate into food aid in Africa when millions are faced with life-and-death situations is irresponsible. When people are reduced to eating grass, is it ethical to prevent them from consuming GM foods that are nevertheless being consumed by millions of people around the world? Who really would prefer to die rather than eat GM foods?

It is misleading to merge all GM crops together and discuss their potential benefits and perceived risks as if they were all one and the same. Discussion should be on a case-by-case basis, according to the origin of the introduced foreign gene, the sought-after benefit, the nature of the particular crop, the region and location of GM deployment and the perceived risks. Genes cloned and introduced into plants are various, including:

- Genes from plant viruses to enhance virus resistance (Baulcombe, 1996).
- Bacterial toxin genes for insect resistance (Schnepf et al., 1998).
- Bacterial genes for herbicide resistance (De Block et al., 1989; Padgette et al., 1995).
- Bacterial genes for abiotic stress tolerance (Garg et

al., 2002).

- Plant genes for improving either resistance to biotic stresses (Martin et al., 2003) or crop quality (Ye et al., 2000).
- Direct modifications of a plant's own genes such as in the modified Flavr Savr® tomato (Kramer and Redenbaugh, 1994).
- Genes from humans or animals for biopharmaceuticals (Giddings et al., 2000).

Each of these genes has different potential risks and benefits and should be analysed as such. For example, Hawaiian crops of papaya, a tropical fruit rich in vitamins A and C, were being wiped out by the devastating viral disease, papaya ringspot. Transgenic papaya was the only effective alternative for developing resistance to ringspot. A group of researchers from Cornell University, University of Hawaii and others (Gonsalves, 1998; Gonsalves et al., 1998) introduced the virus's coat protein gene into commercial papaya cultivars, creating GM papayas that were highly resistant to the virus. These new resistant papayas are believed to have saved an estimated US$47 million for the Hawaiian papaya industry.

The potential of GM plants is vast, once the genome sequences of various plants are available and the functions understood. Modifying and controlling expressions of several traits of interest would be within easy reach without introducing controversial foreign genes. Current examples include delayed fruit ripening (e.g. tomatoes), altered plant height, controlled flowering time and gene expression in specific tissues. We envision a future when cloned genes for various important agronomic traits can be purchased—just like a bag of fertilizer or package of pesticide—and introduced into a plant of interest with the user knowing little or nothing of how to do so.

The potential risks of products of modern biotechnology that are being debated (mainly GMOs) generally fall into four categories: (1) food safety issues, which include toxic reactions, allergies and antibiotic resistance; (2) environmental issues such as damage to beneficial insects, gene flow, creation of super weeds, creation of new viruses; (3) socio-economic issues ('Terminator' gene technology; high concentration of biotechnology research and development in developed countries widening the income disparity between developed and developing countries, and small and large farmers); and (4) ethical and religious issues.

Food safety issues

Food safety is an important issue to be addressed. Several toxic fungal metabolites associated with some of our foods have been known for centuries (Cardwell et al., 2001), long before the appearance of GM crops. Well-known toxins include aflatoxin, fumonisins and ergot alkaloids, and some are even carcinogenic, as is aflatoxin (Hall and Wild, 1994). The cost of regulating aflatoxin is high for African countries exporting peanuts. Catastrophic effects of ergot alkaloids on human health were observed in some parts of Ethiopia in the 1970s (A. Mengistu, April, 2003, personal communication). Thus, food safety issues are concerns that apply to all our food products, irrespective of the methods applied to produce them. Neither are they unique to GM products.

The highly publicized food safety scare of the 'mad cow disease' (nothing to do with GM foods) in Europe, and other food safety concerns, has made—unsurprisingly so—the public sensitive to GM food issues. Even though the case of the 'mad cow disease' has little to do with modern agricultural biotechnology, it is worth looking at because of its impact on the public's perception of food safety and its ultimate mistrust.

A physician, C. Gajdusek (of the National Institute of Health, Bethesda, MD) was awarded the 1976 Nobel Prize in Physiology or Medicine for his work in the 1950s to determine the infectious nature of an unusual disease among the females of a New Guinean tribe. Affected females developed unsteadiness and shaking of the limbs and eventually died of neurological deterioration. He hypothesized that the condition was associated with the traditional custom of females eating the brains of dead people. Subsequent experiments with chimpanzees, using extracts from brains of people who died from the disease revealed the infectious nature of the condition. Cannibalism was then banned in 1959.

A similar disorder in sheep called 'scrapie' (affected sheep tend to scrape themselves against fences and trees, hence the name) has been known in UK since the 18th century (Brown and Fischbach, 1997). The causal agent of the disease was identified as a protein (designated as 'prion', a combination of the words 'protein' and 'infection') in the 1980s.

In 1986, 'mad cow disease' broke out in UK. It soon became apparent that the cattle with this disorder had been fed meat-and-bone meal prepared from sheep infected with scrapie, raising the possibility that the prion had probably jumped the species barrier between sheep and cattle. Moreover, meat-and-bone meal supplements had also been prepared from cattle and fed to cattle—a direct parallel to the old cannibalism practiced by the New Guinean tribe.

Although the number of people afflicted with the human form of the disease from eating infected beef is very small, it was enough to cause a public food safety scare and create concern to the extent of setting up trade barriers to British beef and cattle. This case teaches us that human actions can have unforeseen consequences, no matter how benign they may seem at first.

In the debates on the relationship between GM crops and food safety, allergies, toxicity and antibiotic resistance are among the concerns raised. In 2000-2001, the United States Environmental Protection Agency approved for use in animal feed a GM maize known as ‘StarLink’. The Agency had rejected it for human consumption because it had been modified to contain an insecticidal protein (Cry 9c) with characteristics that could potentially trigger allergic reactions. Yet, this GM maize found its way into food products in the USA. Claims that ‘StarLink’ caused allergic reactions in some people resulted in many product recalls and raised questions about the value of government regulation of GM products. It also caused disruptions to trade between USA and other countries.

Rigorous testing of GM crops can identify potential food safety risks before they are released for consumption (Taylor, 2002). For example, a project was halted after tests showed that some people, allergic to Brazilian nuts, developed allergies to a GM soybean containing a gene from the nuts (Nordlee et al., 1996).

Another poker inflaming the fiery GM food safety debate was a paper published by Ewen and Pusztai (1999) in *The Lancet*, which examined the effects of GM potatoes on the digestive tracts of rats. The potatoes expressed a snowdrop (*Galanthus nivalis* L.) lectin (agglutinin), which is known to be toxic to mammals. The study claimed to have found appreciable differences between the intestines of rats fed with GM potatoes and those fed with unmodified potatoes. Not only was the goal of the experiment inappropriate (introducing a gene coding for a known poison) but the methodology employed and data interpretation were also doubtful (Mowat, 1999). Unfortunately, this work continues to be cited to support health hazard claims by opponents of the GM crop technology.

Antibiotic resistance genes are frequently used as selection markers along with the specific genes of interest. There are concerns that antibiotic resistance genes may be transferred to other plants or humans, with the result that pathogens and pests, through constant exposure to their hosts, may become resistant to antibiotics and thus become much more intractable problems. However, antibiotics resistance genes confer no selective advantage to plants, making this issue of gene flow fairly academic. Since only peptides are absorbed, there is no threat of humans developing antibiotic resistance. Even so, this issue is being addressed because other markers are being developed and used (Goddijn et al., 1993; Haldrup et al., 1998; Kunkel et al., 1999). Methods are also available to remove antibiotic resistance marker genes before the modified crop is commercialized (Zubko et al., 2000). Also being developed are tissue-specific promoters, which cause transgenic genes to be expressed in a limited set of plant tissues. These types of improvements are reducing some of the potential problems associated with transgenic plants.

Current data show that transgenic crops can enhance food safety. For example, GM maize containing *Bt* has reduced predisposition to infections by mycotoxin-producing fungi such as *Aspergillus* and *Fusarium* spp. Mycotoxin levels in maize food products are therefore reduced (Munkvold et al., 1999; Windham et al., 1999). Likewise, transgene-induced gene silencing has been used to prevent allergens accumulating in crops (Herman et al., 2003). These positive findings imply that the potential benefits of transgenic crops in enhancing food safety should also be taken into account when considering potential risks.

The genetic modification of plants into “factories” for producing pharmaceutical substances (Epicyte Pharmaceutical, nd; Giddings et al., 2000) is controversial for fear of contaminating food supplies. The idea of producing vaccines, especially heat-stable vaccines, in edible fruits and vegetables is appealing because they would save many lives among the poor communities of the developing world. Vaccines against infectious diseases have been produced in potatoes and bananas (Thanavala et al., 1995). Edible HIV vaccine, containing the protein HIV gp 120, was produced in maize that was genetically modified to contain a key protein found on the surface of the monkey form of HIV. This edible vaccine was developed by ProdiGene Company (USA; *New Scientist*, 2002) and was tested in an HIV vaccine trial in Thailand in 2002. In applying such vaccines, we have to ask two questions: whether this would endanger our food sources; and whether introductions of genes from one animal species to another would weaken species barriers, enabling certain diseases to jump species, and thus endangering targeted populations.

Finally, much of the soybean and maize produced in USA consists of transgenic varieties, and people have been consuming GM food products for some time now. So far, no cases of ill health from such consumption are known, bringing us to the question of why Africans cannot safely grow and consume crops genetically modified with enhanced agronomic traits of importance.

Environmental issues

Modern crop production negatively affects the environment overall through use of pesticides, fertilizers and herbicides, tillage practices and other human interventions in natural systems. To examine and understand environmental issues, we need to look back at historic cases. A good example is the pesticide dichloro-diphenyl-trichloroethane (DDT), discovered by P. H. Müller, in the laboratories of J. R. Geigy Dye-Factory Co., Basel, Switzerland, in 1939. Müller received the 1948 Nobel Prize in Physiology or Medicine for his work. DDT was seen as a miracle pesticide and used for various agricultural and non-agricultural (e.g. delousing humans and controlling mosquitoes) applications. It was cheap and easy to apply, and had a very broad spectrum of activity. It became a 'darling' worldwide, increasing yields of treated crops and reducing malaria by controlling vector mosquitoes.

However, in 1962, Rachel Carson eloquently and meticulously outlined the hazards of DDT in a book entitled *Silent Spring* (Carson, 1962). Her book helped create public awareness by highlighting the vulnerability of nature to human technological interventions. It became the foundation of the environmental movement. In 1972, a U.S. federal ban was placed on DDT. It was subsequently banned in Europe and other parts of the world, but is still being used in several developing countries, including many in Africa, mostly to combat malaria-transmitting mosquitoes. Because the consequences of malaria are more devastating than those of DDT, developing nations must choose the less dangerous of the two risks.

This case and others have perhaps created suspicions in the mind of the public against chemical companies and a mistrust of governments. Environmental groups have not forgotten that some agrochemical companies campaigned to discredit *Silent Spring*. Now, some of the same big companies are promoting commercial GM crops. Results of the Eurobarometer Survey suggest that the European public thinks that their governments are united with companies to promote biotechnology (Gaskell et al., 2000). For information on biotechnology, more opponents than supporters of biotechnology trust environmental organizations rather than other sources. Surprisingly, despite their strong opinions, about 80% of both supporters and opponents admit they are 'insufficiently informed about biotechnology' (Gaskell et al., 2000).

In 2002, almost all of the 58.7 million hectares of commercial GM crops grown possessed genes for herbicide resistance and/or insect resistance (James, 2002). *Bacillus thuringiensis* was first discovered in Germany in 1911 where its fatal effects on larvae of the flour moth were detected (Heimpel and Angus, 1960). Since then, organic farmers have used this bacterium as a biocontrol measure, and compounds containing spores of the bacterium are available on the market. The bacterium produces *Bt* toxin that affects the digestive tracts of certain insects. Through modern technologies, the bacterial gene encoding the toxin was transferred to plants. GM crops containing the *Bt* gene produce the insecticidal protein, thus, making them resistant to insect pests.

Biocontrol was one strategy that Rachel Carson had advocated. She did not advocate a complete ban on pesticides, but urged caution on using pesticides on a widespread basis, advocating an integrated approach, with a minimum of chemicals, together with biological and cultural management strategies of pests and diseases. Had she been alive today, it would have been interesting to see whether she would have supported or opposed the use of biotechnology tools to control diseases and pests.

The herbicide Roundup® (active ingredient glyphosate) was introduced in 1974. It disrupts a plant enzyme called EPSP (5-*enol*-pyruvylshikimate-3-phosphate) synthase (Steinrucken and Amrhein, 1980), which is essential for producing certain amino acids required for plant growth. Herbicide-resistant plants possess an EPSP synthase that resists disruption by glyphosate. The main issues surrounding these GM crops are:

- The possibilities of having adverse effects on non-targeted insects (Losey et al., 1999; Poppy, 2000)
- *Bt* accumulation in the soil from root exudates of *Bt* crops and its potential effect on soil biota (Saxena et al., 1999)
- Unwanted pollen transmissions to nearby non-GM crops and wild relatives (Ellstrand et al., 1999)
- Possible creation of new and 'super' weeds (Tiedje et al., 1989)

However, these concerns can apply to any improved crop variety with specific traits of interest, regardless of how the variety was developed. In addition, studies by Strickland (1999) showed that, under field conditions, unwanted *Bt* maize pollen rarely reaches the levels toxic to the larvae of the non-targeted monarch butterfly, in contrast to the findings of Losey et al. (1999), who conducted laboratory experiments.

The use of pathogen-derived resistance to control plant viruses is of concern to those who envisage a possible creation of new viruses with new host ranges and higher virulence. The potential benefit of virus-resistant transgenic crops is enormous and, thus, risk assessment of virus-resistant transgenics becomes equally important. Although virus recombination and gene transfer do occur naturally and are not unique to GM crops (Aaziz and Tepfer, 1999), the extent of their happening in virus-resistant transgenic plants, compared with non-transgenic ones, must be studied extensively (Tepfer, 2002).

Strategies to address concerns of unwanted pollen dispersion from GM crops include using tissue-specific promoters and introducing genes into plant chloroplast instead of nuclear DNA. The latter strategy would prevent transgenes spreading via pollen in those species where chloroplasts are strictly maternally inherited (Daniell et al., 1998; DeGray et al., 2001; Lutz et al., 2001; Scott and Wilkinson, 1999). The use of male-sterility tools can also minimize gene flow via unwanted pollen. As technologies advance, more techniques may become available to make the pollen transmission of introduced genes ineffective.

Socio-economic issues

With the advent of modern biotechnology, the private sector has become a major player in research. The main reason is that the possibility of obtaining and enforcing intellectual property rights (IPR) on biotechnology products and processes can make these investments potentially profitable. The dominance of the private sector, especially multinationals, has provoked strong response from some sectors of civil society. Their concerns are that by patenting IP, the private sector could potentially hamper public-sector research by limiting access to IP. This is particularly worrying because the playing field is not perceived to be even between the public and private sectors with regard to knowledge and capacity to deal with IPR issues.

Moreover, the private sector research agenda is usually different from the public one (e.g. 'Terminator' gene technology) with the result that biotechnologies may negatively affect poor farmers and further widen gaps between the rich and the poor. One case is that of genetic use restriction technology (GURT), also known as the Technology Protection System (TPS) or, more usually, the 'Terminator' technology. In March 1998, the U.S. Department of Agriculture (USDA) and the Delta and Pine Land Company (D&PL) were awarded a patent (filed June 1995) of genetic modifications that prevented seeds from germinating in the second generation (Oliver et al., 1998). In simple terms, on applying this patented work, a gene encoding a protein that enables plants to specifically kill their own seeds comes into action. Effectively, farmers are prevented from replanting in the following season, and anyone wanting to use any of the genes in a breeding programme will have little or no access to the genes. Whether one opposes the technology or not, it is, undoubtedly, creative genetic engineering at work.

This attempt—the 'Terminator' gene technology—aimed mostly to enforce patent regulations, that is, to protect IP rights. Eventually, it resulted in a public relations disaster for the organizations and agrochemical corporations involved. The technology of controlling seed germination does not benefit either farmers or consumers, being a strict biological policing strategy to force farmers to purchase seeds annually, and thus enhance corporate profits. Moreover, such a technology could harm farmers. In Africa and other parts of the world, farmers traditionally save seed from one season to plant the next. If farmers were unaware that the seeds from the GM crops would not germinate—indeed, if they were unaware that they were planting a GM crop—the resulting crop losses could have serious consequences. The potential social and economic consequences of this technology have been extensively discussed in articles and press releases by the Rural Advancement Foundation International (RAFI; now ETC group, an action group on erosion, technology and concentration, Winnipeg, Canada) (ETC group, nd).

Ethical and religious issues

The ethical and religious concerns arise from the belief that scientists are playing God and that the modern recombinant DNA technologies allow them to encroach extensively into natural processes in unnatural ways. However, one can also question whether it is ethical to dismiss technologies that may otherwise provide solutions to human and animal suffering, whether from famine or poor health. In addition, cloning is not completely unnatural. Some organisms (e.g. bacteria, yeasts, shrimps, plants with apomictic reproduction such as *Brachiaria* species and some snails) naturally reproduce by cloning themselves. Gene transfer between bacteria and plants is not unnatural either. The plant genetic engineering revolution started with understanding the natural mechanisms in which the soil-borne pathogen *Agrobacterium tumefaciens* causes crown gall disease in plants. Strains of the tumour-causing pathogen contain a TI plasmid. During infection, part of this plasmid transfers naturally into the plant genome, resulting in the tumour phenotype. A similar process also exists naturally between *A. rubi* and *A. rhizogenes* and plants.

When opposition to GMOs or other biotechnology applications is based on ethical or religious beliefs, scientific evidence is irrelevant. This attitude is basically the same as that of excluding certain foods from the diet because of religious beliefs. No one suggests that any person or group be obliged to accept agro-biotechnologies.

CHALLENGES AND OPPORTUNITIES IN AGRICULTURAL RESEARCH AND POLICY

To make an impact in Africa, biotechnology research must be pro-resource-poor farmers and pro-women and children, target crops that African farmers traditionally know how to grow and address agronomic traits of significant importance to their needs.

The currently available and widely commercialized GM traits are not good examples of technologies that will help resource-poor farmers. Most small African farmers cannot afford herbicides or pay high premiums for purchasing GM seeds. Available GM crops are not designed for poor African farmers and it is doubtful that large agricultural companies will ever design crops exclusively for the benefit of poor African farmers. African scientists, international agricultural research centres (IARCs) and other players need to join forces to tackle the specific problems that African farmers face. For specific major agricultural constraints where no conventional methods are currently available to solve them, Africans, instead of shying away, should turn to agricultural biotechnology as another potential source of solutions.

Several agricultural biotechnology initiatives are tackling constraints of importance to Africa. UNECA (2002) reports on ongoing plant biotechnology activities in several African countries; and Walter S. Alhassan (2003) describes those for West and Central Africa.

Research

Enhancing crop yield

The 'Green Revolution' largely by-passed Africa, even as it changed chronically food-deficit countries in the developing world to becoming self-sufficient to the extent that some now produce surpluses for export (e.g. India, Thailand and Vietnam as rice exporters). The second, biotechnology inspired, revolution promises further advances in humankind's ability to feed its growing population, expected to reach between 8000 and 10,000 million in 2030 (Welch and Graham, 2000). The question among policy makers and their development partners is whether Africa can afford to be by-passed again, this time by the second revolution.

Genes for dwarfing. The Norin 10 genes responsible for height reduction (gibberellin-insensitive-dwarfing genes) in the Green Revolution have been cloned and introduced into other crops (Peng et al., 1999). These genes enabled plants to be shorter, stronger and more responsive to fertilizers without lodging. In addition, plants with these genes invest more in reproductive plant parts, which are consumed, instead of vegetative parts, thus enhancing yield. These genes can be useful in certain African crops if deployed strategically to enhance food production.

Improving crop adaptation to biotic and abiotic stress factors

Biotic stresses. Diseases, pests and weeds are major constraints encountered by African farmers, most of whom lack the resources to chemically control them. Hand weeding, a backbreaking task, is often done by women and children, and consumes a large part of their time. All disease, pest and weed management methods and strategies have associated economic and/or environmental costs. Pathogens, pests and weeds for which no suitable control strategies exist are good candidates for new biotechnology approaches.

Plant genetic engineering can enhance traits to resist attacks by pathogens or insect pests (Bent and Yu, 1999; Fermin-Muñoz et al., 2000). Advances have been made in understanding the mechanisms involved in host-pathogen interactions (Keen, 2000; Michelmore, 1995). Specific resistance genes of plant origins continue to be cloned and introduced into crops to enable them to defend themselves from pathogens (Hammond et al., 1998; Tang et al., 1999; Witham et al., 1996). More than 30 genes have been isolated from various plants to provide resistance to a wide range of pathogens and pests (Hulbert et al., 2001).

Other strategies have also been used to enhance plant resistance with genes from plants (Broekaert et al., 1997; Broglie et al., 1991; Cao et al., 1998; Chamnongpol et al., 1998; Oh et al., 1999). Some innovative methods of fighting plant pathogens include:

- Pathogen-derived resistance to combat plant viral diseases (Cooper et al., 1995; Palukaitis and Zaitlin, 1997; Perlak et al., 1994; Powell-Abel et al., 1986; Smith et al., 1992; Yepes et al., 1996).
- The use of antimicrobial proteins and lysozymes from insects (Jaynes et al., 1987), animals (Vunnam et al., 1997), microbes (Lorito et al., 1998) and even humans (Nakajima et al., 1997).
- The cloning and expression of antibody molecules linked to carrier peptides in plants to combat diseases (Franconi et al., 1999) and nematodes (Baum et al., 1996).

Biotechnology tools are also important in pathogen population studies (Kelemu et al., 1999; McDonald and Linde, 2002; McDermott and McDonald, 1993) and diagnostics and detection (Kelemu et al., 2003; Martin et al., 2000; Louws et al., 1999).

Many of the landrace varieties conserved by African farmers over generations have numerous desirable traits, including disease and pest resistance (e.g. Ethiopian barley landrace varieties). Although much has been done, additional efforts are needed to combine these valuable traits through conventional plant breeding. Fortifying conventional plant-breeding methods needs to be combined with efforts to improve soil fertility and other integrated crop management strategies that enhance crop productivity. When sources of resistance are available, the control of plant diseases and pests through resistant plant varieties is the most efficient and economically viable method. African countries should invest in gene discovery from their rich plant genetic resources and untapped microbial gene pools.

Agricultural biotechnology offers some hope of controlling some major diseases for which currently available management strategies are not so effective. For example, the fungal disease black Sigatoka causes substantial yield losses in banana and plantain (*Musa* spp.) (Fullerton and Stover, 1990; Ploetz, 2001), the most important fruit crops in Africa. Because of banana's ploidy level, interbreeding to enhance resistance to diseases and pests is difficult, and chemical control has become a major component of banana production in export plantations like those found in Costa Rica and Honduras. The annual cost of fungicide applications, which are sprayed by aircraft, is about US$1000 per hectare (Ploetz, 2001). This control measure strategy is clearly not an option for small resource-poor farmers in

Africa. This is the type of problem where genetic engineering perhaps holds the best potential solution.

Another major fungal disease of an economically important crop is black pod disease, caused by *Phytophthora* spp., which attacks cacao in West and Central Africa (Erwin and Ribeiro, 1996; Evans and Prior, 1987). This region produces nearly 70% of the world's cocoa beans.

Striga is a parasitic weed of importance in Africa, infecting cereals such as maize, millet, sorghum, rice and sugar cane. Each striga plant can produce thousands of seeds that may remain dormant in the soil for several years until an appropriate host stimulates germination. The problem is more intense in dry and low soil-fertility areas. Several organizations, including Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT), International Institute of Tropical Agriculture (IITA), the International Centre of Insect Physiology and Ecology (ICIPE), several African national research organizations and universities are currently working on various strategies to combat this parasitic plant. Perhaps the most effective approach would be a concerted effort by some of these organizations and others to design control strategies, including well-thought-out biotechnology approaches similar to those proposed by Kanampiu et al. (2002).

While recognizing the potential, we need to remember that planting GM crops alone is not equivalent to waving a magic wand to solve all agricultural problems. Like the crop varieties created through conventional breeding strategies, they must be combined with other conventional approaches such as good soil-fertility management and other optimal conditions for crop production. Insect- or disease-resistant GM crops, like those developed through conventional breeding methods, will, with time, succumb to insect or pathogen pressures. Insects and pathogens have various mechanisms to overcome resistance. However, by combining different forms of resistance from different sources (organisms) through recombinant DNA technology we may gain an advantage by dramatically building a fortified barrier that is more difficult for insects and pathogens to overcome.

Postharvest losses. Farmers, particularly resource-poor farmers, who grow easily perishable but high-value crops such as fruits and vegetables may suffer postharvest losses as high as 50% (Eckert and Ogawa, 1985). Many African consumers have no refrigerator, leading to spoilage of their purchases. In developed nations, postharvest losses have been reduced through the use of agrochemicals and improved storage technologies (Eckert and Ogawa, 1988). The use of postharvest chemicals becomes unattractive as pathogens gradually develop resistance to chemicals (Holmes and Eckert, 1999) and the public's negative perception of pesticides increase. Technologies that prolong shelf life and reduce high spoilage levels in fruits, vegetables and root crops would, without question, have significant impact for both African farmers and consumers. Plant genes involved in fruit ripening have been introduced in reverse orientation to create plants (e.g. Flavr Savr® tomato) with delayed ripening and prolonged shelf life. Work in the pipeline includes that of Syngenta, which is developing banana with prolonged shelf life and may be commercialized by 2006 (ABE, 2003).

Abiotic stresses. Food shortages in Africa are strongly associated with environmental calamities. The major abiotic stress factors affecting food production in sub-Saharan Africa are low soil fertility, drought, salinity, soil acidity and heat stress. They are expressed in crops through a series of morphological, physiological, biochemical and molecular changes that affect plant growth and productivity (Wang et al., 2001). Resistance to abiotic stress factors is multigenic, as well as quantitative in nature. Attempts with conventional breeding methods to develop crop varieties resistant to multiple abiotic stresses have been only partly successful. Efficient identification, isolation and use of favourable genes for breeding stress-resistant genotypes may require other efficient tools, including molecular markers, functional genomics and transgenic technology.

Several different experimental systems, including lower and higher plants and microbes, have been analysed for plant abiotic stress responses (Grover et al., 2001). Stress response has been analysed at the molecular level to discover stress proteins, stress genes, stress promoters, trans-acting factors that bind to stress promoters and signal transduction components involved in mediating stress responses. The functional relevance of stress-associated genes is being tested in different trans-systems, including yeast and higher plants. To overcome the scarcity of abiotic-stress-specific phenotypes for conventional genetic screenings, molecular genetic analysis, using a stress-responsive promoter-driven reporter, is a potential alternative to genetically dissecting abiotic-stress-signalling networks in plants (Xiong and Zhu, 2001).

Soil fertility depletion on smallholder farms, together with the concomitant problems of weeds, pests and diseases, is the fundamental biophysical root cause for declining per capita food production in sub-Saharan Africa (Sánchez et al., 1997). An average of 660 kg N ha^{-1}, 75 kg P ha^{-1} and 450 kg K ha^{-1} has been lost during the last 3 decades from about 200 million ha of cultivated land in 37 African countries, excluding the Republic of South Africa (Smalling et al., 1997). This annual loss is equivalent to US$4000 million in fertilizer (Sánchez, 2002). Africa is losing 4.4 million t N, 0.5 million t P and 3 million t K every year from its cultivated land. These rates of nutrient depletion are several times higher than Africa's (excluding Rep. of South Africa) annual fertilizer consumption, which is 0.8 million t N, 0.26 million t P and 0.2 million t K (FAO, 1995). The potential of genetically improved crops cannot be realized when soils are depleted of plant nutrients.

The traditional way to overcome nutrient depletion is to apply mineral fertilizers. But fertilizers in Africa cost 2 to 6 times as much as those in Europe, North America or Asia. Higher prices are the result of transport costs, which, in turn, are a consequence of poor physical infrastructure and the small volumes to be distributed (Mwangi, 1997). A soil fertility replenishment approach has been promoted by the International Centre for Research in Agroforestry (ICRAF) and its national and international partners working with farmers, using resources naturally available in Africa. This approach uses different combinations of P fertilizers and organic inputs to replenish soil N and P nutrient stocks.

Growing nutrient-efficient plants on soils that are low in plant-available nutrients represents a strategy of 'tailoring the plant to fit the soil', in contrast to the traditional approach of 'tailoring the soil to fit the plant'. The approach of developing nutrient-efficient crops for sub-Saharan Africa is highly significant because, of all agricultural innovations, farmers most readily accept new cultivars. New cultivars are preferred because they yield better, demand less fertilizer input and need minimum or no changes in agricultural practices. Estimates of overall efficiency of applied fertilizer have been reported to be about or less than 50% for N, less than 10% for P and about 40% for K (Baligar et al., 2001).

Inter- and intra-specific variations for plant growth and mineral-nutrient-use efficiency are known to be under genetic and physiological control, and are modified by plant interactions with environmental variables. Breeding programmes need to focus on developing cultivars with high nutrient-use efficiency. Fertilizer-use efficiency can be greatly enhanced by identifying traits that improve the absorption, transport, use and mobilization of nutrients in plant cultivars. However, the relatively slow progress in defining the genetic, physiological and biochemical basis of nutrient efficiency has hampered development of superior nutrient-efficient cultivars through conscious conventional and molecular breeding efforts geared specifically towards that purpose (Rao and Cramer, 2002).

Scientists from Mexico succeeded in growing tobacco plants that expressed a bacterial gene that encodes the enzyme citric acid synthase. They found that the genetically engineered plants were better able to solubilize the insoluble phosphate present in acid and alkaline soils (López-Bucio et al., 2000). This work shows promise for genetically enhancing the use of scarce nutrient resources by crops. Genes for several primary ion pumps, cotransporters and ion channels have been cloned, and the characteristics of their function are being studied (Dunlop and Phung, 2002). While these advances have yet to produce cultivars that cope better with low-fertility soils, they provide powerful tools to address some important gaps in our knowledge, particularly the regulation of transporter genes.

Drought is perhaps the most limiting factor to crop production on a global scale, and the situation is expected to deteriorate in Africa. The current trends in land degradation, desertification and climatic variability have been predicted to intensify because of global warming. The erratic supply of rainfall across seasons, poor soil-water-holding capacity and poor management of water resources has led to drought occurring, on average, once every 3 years in eastern Africa for the last 30 years, causing human and environmental disasters. For instance, drought has affected common bean production in eastern, central and southern Africa to cause losses of more than 395,000 t each year (Amede et al., 2003).

Although challenging, drought resistance can be improved through conventional breeding, using existing genetic diversity. Newer methods, involving molecular markers and comprehensive gene expression profiling, provide opportunities for directing the continued breeding of genotypes that provide stable grain yield under widely varied environmental conditions (Bruce et al., 2002). Much of the genetic variation for improving drought tolerance has been lost during domestication, selection and modern breeding, leaving pleiotropic effects in the selected varieties for development and adaptation (Forster et al., 2000). Thus, searching for new gene pools from primitive landraces and related wild species may require a different strategy. Molecular markers can be used to facilitate the incorporation of specific chromosomal segments of wild species into domesticated crops.

Besides conventional breeding, several gene-transfer approaches can improve stress tolerance in plants by engineering the genetic composition in terms of biosynthetic and metabolic pathways (Bohnert and Jensen, 1996; Bohnert et al., 1995). Iuchi et al. (2000) isolated two novel, drought-inducible, genes by differential screening. One gene, VuNCED1, encodes a 9-cis-epoxycarotenoid dioxygenase that catalyses key steps in abscisic acid biosynthesis and in drought-stress response and tolerance in cowpea.

Drought-resistant genotypes can be engineered, using genes that encode enzymes to synthesize osmoregulants, scavenging enzymes and cell-wall protectants for modifying membrane composition (Sharma and Lavanya, 2002). For example, transgenic plants over-expressing one or more components of the ascorbate-glutathione pathway can induce elevated activities towards drought resistance in cotton, wheat and teff (Smirnoff and Colombe, 1988). Molecular tools can be used to elucidate control mechanisms of stress resistance by engineering genes, which regulate osmoprotection, water and ion movement, availability of functional and structural stress-induced proteins and free radical scavenging systems (Wang et al., 2001). In soybean, developing drought-resistant varieties was possible by establishing differences in mRNA levels between tolerant and sensitive genotypes for favourable genes that could be induced by drought (McLean et al., 2000). As microarray techniques are refined, plant-stress biologists will be able to characterize changes in gene expression within the whole genome in specific organs and tissues subjected to different levels of drought stress (Bray, 2002; Liu and Baird, 2003).

Scientists around the world are working on various strategies to develop drought-tolerant crops. For example, scientists in the Republic of South Africa are studying the genetic basis of a plant called ‘resurrection’, which thrives in desert habitats. This plant can ‘hibernate’ during prolonged dry periods and revive when rain is available. Once the mechanisms are understood and the genes identified in this plant, they may be used to enhance drought tolerance in important African crops.

Salinity is another major constraint to crop production and affects 85 million hectares in Africa, where the amount of rainfall is insufficient to substantially leach out salts (Pessarakli and Szabolcs, 1999). The problem is especially serious in dry areas where irrigation is practiced. Worldwide, about 33% of irrigated land is affected by salinity. Land for crop production is being lost to salinity, in countries like Sudan and Egypt, which depend entirely on irrigated agriculture. The complex and polygenic nature of salt-stress tolerance contributes significantly to the difficulties in breeding salt-tolerant crop varieties (Zhu, 2000).

Soil salinity affects growth and productivity by inducing water stress, a pH effect, a direct effect of Na ions or these factors in combination. Because the initial effect of salt stress is commonly expressed as water stress, improving soil-water availability improves salt resistance in plants. Salt tolerance can be achieved by integrating physiological mechanisms that help the plant prevent salt from entering it—either by avoidance or by high tissue resistance—by using alternative mechanisms. The higher salt tolerance of wheat and barley crop cultivars is related to a more effective restriction of shoot transport of both sodium and chloride ions (Marschner, 1995). Possibly efficient salt-tolerance mechanisms—other than osmotic adjustment—may therefore include those that help the plant either maintain cell-wall integrity or facilitate a higher uptake of K, Ca and NO_3 ions.

Researchers at Cornell University developed a GM rice for drought and salt tolerance (Garg et al., 2002). The modified rice contains bacterial genes that allow the plant to produce high levels of trehalose sugar, which protect it from not only drought but also from osmotic shock, enabling it to grow in saline soils. Other reports include salt-tolerant transgenic maize containing a gene (gutD) from the bacterium *Escherichia coli* (Liu et al., 1999), and salt-tolerant tomato plants that can accumulate salt in foliage but not in fruits (Zhang and Blumwald, 2001). Genes for salt tolerance have also been successfully transferred from a moss to a plant; and a salt-tolerance gene from mangroves (*Avicennia marina*) was cloned and introduced into other plants. These and other studies indicate that effective measures can be found to combat salinity stress in plants.

Soil acidity is spreading, not only in humid and sub-humid Africa, but also in arid parts of sub-Saharan Africa. It is caused mainly by occasional, high and intense rainfall and an improper land use that encourages leaching of cations that, in its turn, results in soil-nutrient imbalances. Soil acidity affects plant growth through low pH (high proton activity), aluminium (Al) toxicity, manganese (Mn) toxicity, nutrient imbalance and inhibition of root growth (Marschner, 1995). Low pH promotes solubilization of toxic ions such as Al and Mn, and can reduce the availability of certain plant nutrients like P, Ca, Mg, Mo and S. When the concentration of toxic ions increases, not only is the host plant severely affected but so also are symbiotic associations such as rhizobial multiplication, infection and nodulation (Munns, 1986). For example, growing legumes over many consecutive years in the tropics will acidify the soil because of preferential uptake of cations (Israel and Jackson, 1978) and pumping of residual H^+ ions by the plasma membrane into the rhizosphere.

Most crop species achieve resistance to toxic levels of Al and Mn in soil through mechanisms that either exclude the elements or permit internal tolerance (Marschner, 1995). Because growth and productivity of plants in acid soils require highly efficient uptake or use of nutrients like P, Ca and Mg, mechanisms that assist the plant to acquire such nutrients increase tolerance of acid soils. Citric acid added to soil is effective in binding Al and other toxic metals. Researchers in Mexico have genetically engineered plants to overproduce citric acid in roots and thus better tolerate the presence of Al in the soil (de la Fuente-Martínez and Herrera-Estrella, 1999; de la Fuente-Martínez et al., 1997).

Enhancing the nutritional quality of African crops

The World Health Organization (WHO) estimates that 54% of child mortality in developing countries is associated with malnutrition. About one third of the children in sub-Saharan Africa suffer stunted growth because of poor diet. Micronutrient malnutrition is now recognized as being among the most serious health challenges facing vast sectors of Africa’s population, particularly resource-poor women and children (Kimani, 2001; Smith and Macgillivray, 2000; Welch and Graham, 2000). The major micronutrient deficiencies are in iron, zinc, vitamin A and iodine. These deficiencies result from diets that are rich in energy but poor in proteins, minerals and vitamins. They are further aggravated by widespread poverty, which makes access to the more expensive animal-based products such as milk, eggs and meat—all rich in vitamins and minerals—very difficult for the vast majority.

Other aggravating factors include a limited knowledge of the nutritional value of locally available foodstuffs, and changing eating habits that often regard traditional vegetables and other non-staples as 'old-fashioned'. The preferred foods, including cereal-based products (e.g. sieved maize meal, wheat and milled rice), white potatoes and cassava, are usually low in micronutrients. These calorie-rich but micronutrient-poor foodstuffs are almost always preferred because they are readily available and cheap, and cook fast. Although many African communities keep livestock, animals are usually sold to generate income to meet other household needs. Consumption of meat products tends to be irregular, often only on special occasions.

Recent data on micronutrient deficiencies in Africa showed that national prevalence rates of clinical vitamin A deficiency (VAD) in pre-school children range from as high as 3.45% in Ethiopia to 0.2% in Botswana and Cameroon (Smith and Macgillivray, 2000). Data from the Canadian Micronutrient Initiative (MI) from 1980 to early 1990s also shows very high prevalence of iron deficiency anaemia (IDA) among children, and non-pregnant and pregnant women (Smith and Macgillivray, 2000). Zinc deficiency was only recently recognized as a public health problem. Zinc is essential for normal growth, appetite and normal immunity function. It is an essential component of more than 100 enzymes involved in digestion, metabolism and wound healing (Guzmán-Maldonado et al., 2002). A recent national survey in Kenya showed that zinc deficiency is widespread—at 50.8% among children under five, 52.2% among mothers and 46.1% in adult males—and requiring urgent attention (Mwaniki et al., 1999).

Intervention strategies: To alleviate micronutrient deficiency in Africa, a three-pronged approach has been followed: giving vulnerable groups micronutrient supplements, fortifying common foods and encouraging dietary improvement. Providing mineral supplements is effective where vulnerable groups are easy to reach and have access to medical facilities. A large capital input is often needed, together with an elaborate and costly distribution network and patience. The supplements must be supplied on a regular basis. This approach, however, leaves out those at-risk groups who are hard to reach or practically unreachable and other household and community members who are not targeted to receive supplements. In Africa, these groups constitute most of those who are located in rural communities with almost no access to medical facilities.

The approach of fortifying common foods has had limited success in Africa because of the underdeveloped food industry and lack of effective legislation. At present, food fortification programmes are operating in Botswana (vitamin A in 'Tsabana' weaning food), Kenya (vitamin A and iron in wheat or maize flour, millet porridge and cooking oil), Malawi (vitamin A in cooking oil), Namibia (vitamin A and iron in maize meal), Nigeria (iron in wheat flour), Rep. of South Africa (vitamin A in maize meal and margarine), Uganda (iron in wheat flour), Zambia (vitamin A and iron in maize meal, and vitamin A in sugar) and Zimbabwe (vitamin A and iron in maize meal). This approach is effective for small affluent communities found mostly in urban areas and households with a capacity to purchase fortified foods on a regular basis. Again, it leaves out most of the urban poor and rural communities.

Dietary improvement is probably the most effective and sustainable strategy for reducing micronutrient deficiencies in Africa. This approach aims to increase dietary availability, regular access and consumption of mineral-rich foods by at-risk and micronutrient-deficient communities. It involves developing and promoting enhanced consumption of culturally acceptable, mineral-rich grains, vegetables and root crops. In 1995, the Consultative Group on International Agricultural Research (CGIAR) started a micronutrient project (Bouis et al., 2000) to assemble the package of tools that plant breeders would need to produce cultivars with increased levels of minerals and vitamins. Targeted crops include wheat, rice, maize, common bean and cassava—all important staples in Africa. The micronutrients being studied are iron, zinc and vitamin A. The project also seeks to determine the range of genetic variability available for exploitation by future breeding programmes; the bio-availability of the micronutrients contained in the grain of the best selections; the genetics, physiology and biochemistry of selected traits; and screening protocols for use in subsequent breeding programmes.

While enhancing nutritional quality is still possible through conventional plant breeding, biotechnology opens the door to more opportunities (Wang et al., 2003). Examples of crops that have been modified (or are being modified) to include or increase health-promoting compounds are:

- A transgenic rice with yellow seeds and exhibiting increased production of beta-carotene, a precursor of vitamin A (Ye et al., 2000).
- Another transgenic rice with enhanced iron content, obtained through the expression of a soybean gene that helps produce an iron-binding protein (Goto et al., 1999).
- Engineered tomatoes with high levels of the antioxidant lycopene, encoded by a gene from yeast (Handa and Mattoo, 2002).
- Maize with enhanced levels of vitamin E (Rocheford et al., 2002).
- Tomatoes with high levels of flavonols (strong antioxidants that reduce damage to body cells), encoded by a gene from petunia (Muir et al., 2001).
- Sugar beet with high levels of fructan (Sévenier et al., 1998).
- Potatoes with enhanced lysine content (Sévenier et al., 2002).

Policy

Issues stemming from a socio-economic or policy perspective influence how biotechnology can best contribute to African agricultural development. Like all agricultural technologies, the socio-economic impact of biotechnology outputs must be taken into account. Understanding these benefits, compared with those of alternatives, is crucial in deciding when and where it is most appropriate to invest in biotechnology. The potential benefits of biotechnology depend on the crop, the specific trait that is being improved and the gains that could be made from solutions other than biotechnological. The more important the crop, the more important the constraint or opportunity and the less effective the alternatives, the more attractive, overall, will be investment in biotechnology.

Such impact, however, cannot be seen only in the aggregate. Like all agricultural technologies, the benefits of biotechnology will be distributed differentially between consumers and producers, and between consumers and producers of different wealth or income levels or different social groups such as small farmers, landless labourers and large farmers. Similarly, biotechnology will have a different impact on different agro-ecosystems, an impact that is not only socio-economic but also environmental.

When choosing a technology to develop or deciding on how best to develop it, research costs need to be considered, together with the potential impact or benefits. In some cases, biotechnology may produce faster results more cheaply than other research methods. In other cases, constraints of capital or specialized, highly qualified, scientific personnel could make biotechnology more expensive or even impractical. Understanding the relative costs of biotechnology versus other scientific options is therefore an important economics issue.

A policy issue of particular relevance in assessing the potential of biotechnology (e.g. to alleviate poverty) is the question of how intellectual property rights (IPR) can affect the distribution of benefits. Because much of biotechnology, from methods to gene constructs, is owned by someone, the owners of biotechnology IPR claim a share of the benefits. This has led to concern that powerful multinational corporations and other such entities will obtain a disproportionate share of the benefits. Potentially, this is a matter not only of fairness—important in its own right—but also of reducing incentives for other potential beneficiaries to use the biotechnology, or even encouraging them to set up barriers against its use and thus prevent the creation of additional socio-economic benefits. The complicated tangle that IPR restrictions can create may so reduce researchers' 'freedom to operate' that applying a biotechnology solution would not be feasible, even if it were otherwise attractive. The issue of IPR is of especially high concern to national agricultural research systems (NARS), which have a high demand for further research and better understanding of these issues.

Biotechnology can provide a variety of tools, including tissue culture for improved and more rapidly available planting material, and molecular markers to better understand genetic diversity in crops and their pests. But, in the minds of much of the public, biotechnology is exclusively associated with GMOs. Because they introduce substantial novelty into the environment and food system, the public is legitimately concerned about how safe GMOs are. Such concerns have led to the design of both international and national regulatory systems for ensuring the safe use of GMOs. Implementing such systems has raised several scientific issues that have yet to be fully addressed. Moreover, as in the case of benefits, the specific scientific issues will vary according to the crop, its production environment, the trait that has been genetically modified and other considerations. Thus, biosafety represents an ongoing research agenda.

Biosafety, however, is not just a scientific issue, but also a policy and socio-economic issue. Generally, biosafety decisions are, firstly, about risk. How much risk is acceptable is a value judgment or political decision rather than a purely scientific question. Attitudes towards risk are known to differ among individuals or groups, and this is evidenced by different national policy and implementation regimes to ensure biosafety. These are complex issues where scientific certainty does not prevail and choices must be made. Again, there is a strong demand from national systems in the developing countries for assistance in setting up systems that meet their needs for biosafety. It is worth noting that biosafety regulatory regimes have costs that need to be taken into account when investing in biotechnology.

Likewise, consumer acceptance issues affect whether biotechnology innovations are in fact used. Many socio-economic policy issues in this area also require considerably more research and debate.

EFFECTIVE AND EFFICIENT PARTNERSHIPS TO PROMOTE EDUCATION AND ACCESS TO INFORMATION

Capacity building

The importance of capacity building in sustainable development cannot be over emphasized. It is reflected in the many initiatives that have been put forward at national, regional and international levels. National and international donor organizations, governments in developing and industrial countries, non-governmental organizations (NGOs) and the private sector are increasingly building policies around capacity building, and including them in programmes and projects. Capacity building has many facets that can range from training and development of human resources only to addressing instrumental issues such as developing procedures, management and organizational structures, or strategy formulation.

Moreover, it is becoming increasingly clear that capacity building can contribute to sustainable development only if it is an integral part of a project and not just another extra activity. Neither is capacity building in biotechnology transferable; countries and organizations need to develop their own capacity in locally appropriate ways. In a biotechnology programme, capacity building should aim at fostering the interaction between producers (scientists) and end users (small farmers) of a technology. It becomes apparent, then, that capacity should be built up at all levels, from end users (farmers and consumers) to policy makers. Capacity building should be carried out to:

- Increase awareness among high-level policy and decision makers of the interrelated areas of biotechnology, and food quality and safety.
- Strengthen national capacities to identify, formulate and implement relevant policies.
- Promote sound governance and standard setting.
- Develop national and regional capacities for legal and regulatory frameworks.
- Strengthen human resources in related technical and regulatory matters.
- Strengthen related regional and national institutions, including the provision of training and scientific equipment.
- Enable scientists and policy makers to fully and effectively participate in negotiations in international fora where issues related to biotechnology and biosafety are discussed.
- Provide information on understanding available data, including for local and indigenous communities, and promote joint research and foster open dialogue at all levels, including the media (Martínez, 2001).

Past experience has clearly shown that human resources are ultimately a key factor behind any progress. Two major bottlenecks for development in Africa comprise shortages of trained personnel and ineffectual means for information dissemination. Information, education and training allow farmers to make use of new farming knowledge and technologies. Both formal and informal training substantially affect agricultural productivity. Capacity building should, therefore be directed towards:

- Country officials involved in negotiations in trade and agriculture fora, so they can analyse their needs and strengthen their position to defend their interests with respect to food security and poverty reduction. Availability of such personnel provides capacity for technical analysis, critical review of information, consultations and peer review of proposal applications for donor support or loans, and review of implications regarding materials protected by IPR.
- End users (farmers), so they may know of the technologies available to them, and can make informed decisions.
- Scientists or technical people, so they may undertake the development and/or transfer of technology.
- The public, so that they are correctly informed when making their own decisions.

Capacity in biotechnology among African NARS differs. For example, FAO (2001b) separates the NARS into three categories, namely:

- Group 1 (‘very strong’)—those NARS that have a strong capacity in molecular biology, including the capacity to develop new tools for their own specific needs (e.g. Rep. of South Africa and Egypt). This group invests, on average, 5% to 10% of their research expenditures on biotechnology.
- Group 2 (‘medium to strong’)—has considerable capacity in applied plant breeding research, and the capacity to apply molecular tools (markers and transformation protocols), but is dependent on tools being developed elsewhere (e.g. many African countries, including Zimbabwe, Kenya and Uganda).
- Group 3 (‘fragile or weak’)—weak capacity in plant breeding and virtually no capacity in molecular biology (e.g. Zambia and Mozambique).

Links for capacity building with institutions in developed countries should be used to transfer (when feasible) technology that is available so that this can be efficiently used in African research centres. The links should also be used to build an essential core of human capacity conversant in the area of biotechnology to represent different areas and needs.

Several universities in most countries offer training at BSc, MSc and PhD levels in biotechnology and related areas. Universities in the Republic of South Africa, such as the University of Cape Town, are among the centres of excellence in biotechnology, generating GM crops for disease resistance and other valuable traits relevant to African farmers. The new model for developing PhD graduates in Africa at the University of Natal and sponsored by the Rockefeller Foundation aims to train 50 students in plant breeding, at 5 cohorts of 10 PhD students per year. The Rockefeller, Ford and MacArthur Foundations, and the Carnegie Corporation of New York led an initiative on ‘Partnership for Strengthening African Universities’. The foundations agreed to a 10-year time span, and to spend US$100 million over the first 5 years to support universities pursuing reforms in Uganda, Tanzania, Mozambique, South Africa (Rep.), Ghana and Nigeria. During the first 2 years (2000 and 2001), the four foundations together contributed about $62.3 million to higher education in these African countries.

Numerous institutions and organizations offer training to developing country nationals. For example, the U.S.—

Egypt Science Technology Joint Board, which supports work by U.S. and Egyptian scientists on agricultural biotechnology, has been funding about 40 collaborative biotechnology projects since 1995. For IITA's Biotechnology Unit, training African scientists is a major activity. Training is also offered by BIO-EARN, which goes by the long name of "East African Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development". Its programmes include:

- Short courses (1 or 2 weeks) at the African Centre for Technology Studies (ACTS). The courses are designed to strengthen the capacities of a core group of people from the BIO-EARN countries to analyse, formulate and implement biotechnology policies.
- International training programmes for graduate students and visiting scientists.
- Regional workshops to assist countries in the region to gain enough knowledge and confidence to make regulatory decisions.
- Training courses for policy makers from East Africa (organized by ACTS).
- Training in biosafety assessment and field evaluations of transgenic crops, including 'hands-on' training of members of national biosafety committees.
- Internships for researchers, students and policy makers from the region at selected institutions in Africa and overseas.
- Training on risk assessment and other scientific and technical expertise.
- Regional workshops to stimulate awareness of policy issues related to biotechnology among policy makers, practitioners and the public.
- Graduate studies. Since its inception in 1999, BIO-EARN has trained 3 PhD students in ecological risk assessment of GMOs and 6 MSc students in various fields of GMOs (Magoya, 1999).

To students from developing countries, UNESCO actively provides fellowships and courses through its Microbial Resources Centres (MIRCENs) and Biotechnology Education and Training Centers (BETCENs). The International Atomic Energy Agency (IAEA) and the African Regional Co-operative Agreement (AFRA) also support regional training initiatives in Africa.

Capacity in gene discovery needs to be built up. Africa has an abundance of untapped, indigenous knowledge and genetic wealth. Here, the CGIAR centres can play a major role by forming strong research partnerships to be led by African national programmes. The key to successful capacity building is following up and effectively deploying the trained manpower. Success should be measured, not in the number of researchers trained in a new technology at a given time, but in terms of what happens after the trained researchers return to work in their respective home countries. Do they have the infrastructure, facilities and resources to apply some of the new tools and methods they had acquired? Capacity building courses or workshops must be followed up by constructing the necessary facilities and acquiring funds from donors to conduct biotechnology that will benefit African farmers.

Partnerships and linkages

Biotechnology 'coalitions' should be promoted at local, national, regional and international levels (Kameri-Mbote et al., 2001). For such partnerships to succeed, two aspects must be recognized: (1) that needs vary from country to country and should, therefore, be dealt with on a country basis, taking into account the specific problems of their agricultural sectors; and (2) that similar agroecological zones exist, thus facilitating and accelerating the transfer of technologies among countries and regions. Partnerships should also be used:

- As platforms to launch collaborative work among participating countries and/or institutions
- To increase the capacity of African countries in specific policy areas, including IPR
- To increase African policy makers' awareness of important policy issues in agricultural biotechnology.

Through concerted efforts, creation of electronic distribution lists for disseminating information on policy and regulatory issues of interest can be established to benefit member countries. Capacity building through training courses for national officials on specific policy issues can be fostered at a regional level and such fora can be used to develop specific project proposals to address identified gaps and needs of participating countries.

Partnerships and networks. Several partnerships and networking programmes have been set up at a regional level in Africa. They are beginning to create capacities and shape the direction of the development and use of biotechnology. These programmes include:

- Scientific and technical training courses such as those run by BIO-EARN (Mugoya, 2003)
- Agricultural research and development programmes such as those of the African Agency of Biotechnology (AAB) and the Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA) biotechnology initiative.
- Regional biosafety approaches such as that of the Eastern and Central African Biosafety Focal Point.
- Awareness creation networks on biotechnology, which include the African Biotechnology Stakeholders Forum (ABSF) and AfricaBio (the Biotechnology Association for Food, Feed and Fibre) (Wafula, 2001).

The African Agency of Biotechnology (AAB) began in 1997 as an instrument of African scientists, bringing together 16 African member states: Algeria, Burkina Faso, Burundi, Cameroon, Côte d'Ivoire, Egypt, Ethiopia, Gabon, Ghana, Kenya, Mauritius, Morocco, Nigeria, Senegal, Tunisia and Zimbabwe. Its mission, focusing on biosafety and bio-policy, aims to:

- Reinforce the national capacities of member states in biotechnology training, research, equipment and infrastructures.
- Coordinate and promote cooperative research programmes in areas of priority biotechnology applications.
- Enhance dissemination of scientific and technical information at regional and sub-regional levels.
- Encourage the production, distribution and commercialization of biotechnology products for sustainable development in Africa.
- Develop and harmonize regulations pertaining to bio-ethics, and intellectual property and patent rights.

The ASARECA Biotechnology Program. ASARECA is a sub-regional organization for the national agricultural research systems (NARS) of 10 African member countries: Burundi, Democratic Republic of Congo, Eritrea, Ethiopia, Kenya, Madagascar, Rwanda, Sudan, Tanzania and Uganda. The association began as an initiative to establish a biotechnology and biosafety programme for its members.

***The Southern African Regional Biosafety Program* (SARB)**, sponsored by USAID and established in September 2000, aims to build biosafety capacity to permit the safe and responsible introduction of GMOs and their products into the region. The programme focuses on seven countries that are most likely to make decisions on GMOs in the near future: Malawi, Mauritius, Mozambique, Namibia, South Africa (Rep.), Zambia and Zimbabwe. In addition, SARB conducts activities for all countries in the region. The Agricultural Research Council (ARC) of South Africa (Rep.) coordinates the programme.

***The African Agricultural Technology Foundation* (AATF)** is a new initiative that was launched in 2002 with funds from the Rockefeller Foundation and USAID. Its unique public-private partnership is designed to resolve many of the barriers that have prevented smallholder farmers in sub-Saharan Africa from gaining access to existing agricultural technologies, materials and know-how that would help relieve food insecurity and poverty. The Foundation also aims to help other public-private partnerships to also provide smallholders with access to improved agricultural technologies (AATF, 2002).

Linking with advanced research institutes. To accelerate capacity building in biotechnology, African NARS, out of necessity, must forge collaborative links with their counterparts in developed countries, international organizations and/or other developing countries with advanced technologies. Alliances can be formed around joint biotechnology R&D projects, with emphasis on scientific and technical aspects of risk assessment and management.

The Kenya Agricultural Research Institute (KARI), for example:

- Collaborates with the John Innes Centre in UK and CIMMYT to study maize streak virus resistance. The collaboration is funded by the Rockefeller Foundation and the Dutch Directorate-General for International Co-operation (DGIS). Five scientists have been trained in marker-assisted selection (MAS) technologies.
- Has, in response to its training requirements in gene construction and crop transformation, formed links with Monsanto Company and U.S. universities such as Michigan State, Missouri and Texas A&M. Collaborative programmes on sweet potato and pest-resistant maize were set up with funding from USAID's Agricultural Biosafety Support Project (ABSP) and the Kenyan Government. Three students were trained in crop genetic engineering and biosafety development.
- Has trained as many as 10 of its animal-health scientists in recombinant DNA techniques for animal disease diagnostics. Their training was carried out through an international programme on animal health research in collaboration with U.S., UK and Kenyan research institutions and universities and with support from USAID, DGIS and Department for International Developments (DFID).

The CGIAR plays a role in raising awareness and capacity building in issues of biosafety, risk assessment and patents. It also provides links between advanced research institutes (ARIs) and NARS. The CGIAR sister centres IITA, International Livestock Research Institute (ILRI, Ethiopia and Kenya), ICRAF (Kenya) and West Africa Rice Development Association (WARDA, Côte d'Ivoire) have their headquarters in Africa. Other regional programmes in various parts of Africa are being conducted by other CGIAR centres: CIAT (Colombia), International Potato Center (CIP, Peru), CIMMYT (Mexico), International Center for Agricultural Research in the Dry Areas (ICARDA, Syria) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, India). CIAT has recently strengthened its African programme by acquiring the Tropical Soil Biology and Fertility Programme (TSBF, Kenya) and creating the TSBF Institute within CIAT.

THE WAY FORWARD

Although enough reasons exist to believe that biotechnology will help find solutions to medical, agricultural and environmental problems, the ethical, environmental, socio-economic and food safety issues that underlie the public's concerns must be addressed effectively and responsibly. Public awareness remains the key to narrowing the gap between the public's understanding of basic biotechnologies and the rapidly advancing science.

To find a common ground for the use of technologies that will benefit humanity, groups such as environmentalists, farmers, consumers, the media and religious leaders must be included. Some GM crops provide environmental benefits and, thus, are compatible with the agendas of groups concerned about environmental pollution through heavy pesticide use, or the use of GM microbes for bioremediation. Other benefits include prolonged shelf life of perishable fruits and vegetables (thus reducing post-harvest yield losses), and resistance to fungal, bacterial and viral diseases when the plant gene pool has inadequate sources of resistance.

Strong opponents of biotechnology need to realize that the technology is here to stay and, thus, must focus their opposition on those applications whose risks truly outweigh the sought-after benefits. No technology is risk-free. On the other hand, strong proponents of biotechnology should not dismiss the concerns raised by opponents. Who can really forecast with certainty the long-term consequences of a potpourri of genes from animals, bacteria, viruses or humans in a plant genome?

Africa still has a long way to go if it is to fully exploit its crop production capacity by using available conventional methods at the levels achieved in other continents. Even so, where genetic engineering is the best or only way to achieve a certain agricultural benefit that will make a difference in peoples' lives to significantly outweigh the perceived risks, then Africa should use this technology.

Many biotechnology products are being developed in various countries for different uses. These include modified plants for food, animal feed, medical care and bioremediation. Africans themselves need to examine and balance the potential risks of the technologies against the confirmed or potential benefits. International agricultural research centres should play an active role in working together with African scientists and policy makers to responsibly deploy those technologies that will benefit African farmers and consumers, and develop national biotechnology policies. Multinationals and other research institutions should fully recognize the valuable contributions and free donations made by African farmers who conserved priceless genetic resources through thick and thin. To return the value of these contributions, such entities should make every effort to ensure that at least some of their agricultural technologies and products are available to these poor farmers free of charge. Private commercial companies should realize that investing in the future of poor farmers and giving them a helping hand out of subsistence farming is not only good public relations strategy, but will also eventually create new markets for them.

To benefit from biotechnology, Africans must be willing to take some potential risks to gain substantial immediate and future benefits. The bottom line is that they themselves must decide on the future of their agriculture, using the best available scientific data and, hopefully, taking politics out of the equation.

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