



## Crop biotechnology and the African farmer

Carl K. Eicher<sup>a</sup>, Karim Maredia<sup>b,\*</sup>, Idah Sithole-Niang<sup>c</sup>

<sup>a</sup> *Department of Agricultural Economics, Michigan State University, East Lansing, MI 48824, USA*

<sup>b</sup> *Institute of International Agriculture, Michigan State University, 416 Plant and Soil Science, East Lansing, MI 48824, USA*

<sup>c</sup> *Departmental of Biochemistry, University of Zimbabwe, P.O. Box MP167, Harare, Zimbabwe*

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### Abstract

Recent reports, workshops and meetings on GM (Genetically Modified) crops tend to characterize GM food production as a solution to Africa's food crisis. However, GM crops are currently grown commercially in only one country in Africa – South Africa. Biotechnology tools range from tissue culture to molecular breeding and genetic engineering. This paper focuses on GM crop improvement and analyzes the development of seven GM crops (six food staples and cotton) over the past 15 years in Africa. The case studies reveal a number of unexpected scientific, legal, economic and political barriers to the development of GM crops and long delays in developing and implementing national biosafety regulations and guidelines. We conclude that most GM crops are at least 10–15 years or longer from reaching smallholder farmers in Africa. During this time special attention should be given to strengthening conventional plant breeding programs in NARS (National Agricultural Research Systems), African universities and the CGIAR. Biotechnology approaches must be nested and integrated into plant breeding programs. Special attention should also be given to raising public awareness of biotechnology, mobilizing political support and commitment to strengthening African capacity in biotechnology, biosafety, food safety and IPR (Intellectual Property Rights) and mounting long-term training programs to train the next generation of African plant breeders and GM crop specialists.

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\* Corresponding author. Tel.: +1 517 353 5262; fax: +1 517 432 1982.  
*E-mail address:* [kmaredia@msu.edu](mailto:kmaredia@msu.edu) (K. Maredia).

## Introduction

Africa is a hungry continent and the poorest, most food insecure region of the world. Africa's bleak prospects for improving food security have been addressed by a number of study teams that point to increased GM food production as a solution to Africa's food crisis. However, simple facts tell the story. Commercialization of genetically modified (GM) or transgenic crops, was first approved for use by farmers in the United States, Mexico and Australia in 1995.<sup>1</sup> However, after a decade of rapid growth of GM crops, South Africa is the only one of the 53 countries on the African continent that is currently growing GM crops.

Closer examination reveals that many African governments are skeptical of GM foods. Also there are a number of complex barriers to the development and testing of new GM crops in Africa. The origins of African policy makers' concern over biotechnology are partially a spillover from concerns in Europe about food safety, the environment and generalized public mistrust of multi national seed companies as being manipulative and unscrupulous (Bodulovic, 2005). The transplanting of European consumer concerns coincided with a regional drought in Southern Africa in 2002/03/04 that required a large amount of food aid. The main supplier of food aid was the United States, which did not have "identity-preserved supply chains"<sup>2</sup> for most of the GM and non-GM maize. Hence African governments become concerned about the potential health, environmental and trade effects of importing food aid. The lack of biosafety regulations and the capacity to evaluate GM and non-GM maize was heightened by the slowness of international organizations to come out and say that GM maize food aid was safe. In the absence of authoritative information, the debate over technical issues turned into sovereignty issues and become a fertile ground for anti-GM activists to fuel the fears of policy makers and general public. Zambia's experience captures the GM debate in Southern Africa. In 2002, the government of Zambia rejected GM food aid from the United States even as the country was facing drought while intense debate ensued over whether the food aid was GM grain and whether it contained possible health, environment and trade concerns (Bodulovic, 2005). Recently, the Zambian government developed a National Biosafety and Biotechnology Strategy Plan (Zambia, 2005), which aims to build biosafety capability and ensure GM crops are appropriately regulated.<sup>3</sup>

Food aid fears surfaced in Angola in December 2004 and the government now requires food-aid grain to be milled before it is distributed. Namibia cut off all corn trade with South Africa in 2004 because the latter grows GM corn. The way forward is clearly a need for an exchange of technical information about GM products, training African scientists, creating a public awareness of biotechnology issues, and helping African nations develop their own policies to guide regulatory, legal and technology transfer issues.

Looking ahead to future sources of food production and agricultural growth, the overarching challenge in African agriculture is to lift the cereal yield ceiling which has been flat in Africa since the 1960s (Fig. 1).

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<sup>1</sup> We have adopted FAO's definition of agricultural biotechnology: Agricultural biotechnology encompasses a range of research tools scientists use to understand and manipulate the genetic make-up of organisms for use in agriculture: crops, livestock, forestry and fisheries. Biotechnology is much broader than genetic engineering and includes tissue culture, genomics and bioinformatics, marker-assisted selection, micro-propagation, cloning, artificial insemination, embryo transfers and other technologies (FAO, 2004, p. 4). We assume most countries in Africa are using tissue culture in their research. This paper focuses on crop biotechnology in Africa.

<sup>2</sup> Johnson (2002) points out the difficulty of tracking grain movements from millions of farmers to consumers.

<sup>3</sup> For a discussion of the Zambia's experience with food aid see Zerbe (2004) and Bodulovic (2005).

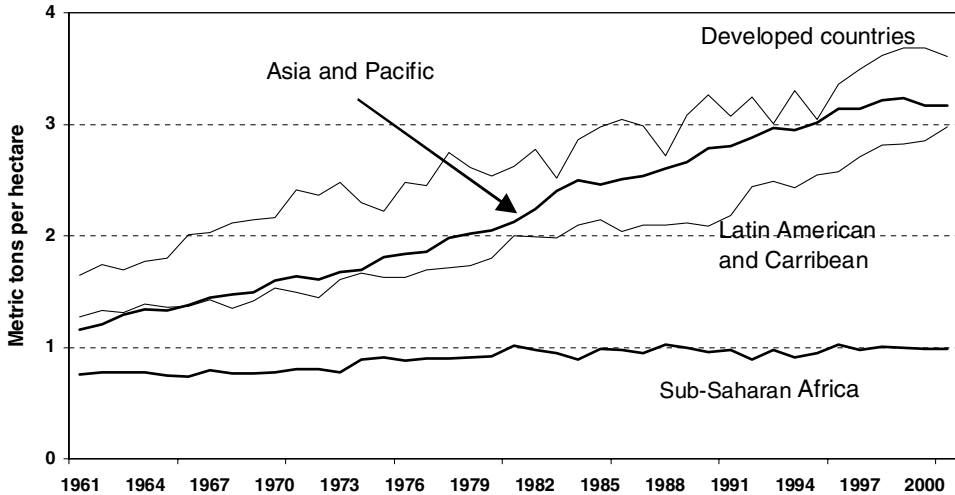


Fig. 1. Annual cereal yields by region, 1961–2000.

This challenge poses the question: can agricultural extension agents, conventional plant breeding or biotechnology-driven crop improvement lift cereal yields? There is abundant evidence that an army of extension workers, NGOs and Peace Corps volunteers have been unable to develop high yielding crop varieties and bring Green Revolutions to Africa. Although extension workers and NGOs can play a useful role in speeding up the adoption of improved agricultural, health and nutrition practices, the bottom line is that long-term investments in research are needed to develop high yielding crop varieties and improved crop and livestock practices for smallholders (Gemo et al., 2005). And because of the risk and time involved, most of the needed investments in agricultural research will have to be financed by African governments – not the private sector. Since increasing cereal yields is an overarching agricultural challenge facing Africa, this raises several key questions: what priority should be given to future investments in plant breeding and in GM crop improvement? What can be done to promote combined conventional/transgenic research partnerships?

This paper is divided into five parts. The first part provides the background to the skepticism about GM crops and highlights the slow pace of GM crop improvement in Africa. The second presents the results of seven case studies that document the problems in developing GM crops, and getting them cleared by national biosafety committees and ready to release to smallholders in Africa. The third part draws lessons from the seven case studies. The fourth part discusses the need to maintain large investments in conventional plant breeding programs in Africa over the coming 10–15 years while simultaneously investing in strengthening Africa's capacity in biotechnology and biosafety. The eventual goal is to help African scientists become "intelligent borrowers" of biotechnology products and eventually develop their own biotechnology products for use in Africa or for sale in global markets.

### Agricultural biotechnology: overview

In addressing the role of agricultural biotechnology in African development, we begin with a discussion of population growth and then consider estimates of the rate of growth

of food and livestock production over the coming 25 years. Although global population growth has slowed, the FAO (Food and Agriculture Organization) estimates that Africa's projected annual rate of population growth of 2.8 percent will lead to a doubling of the size of Africa's population in 25 years (FAO, 2005). This leads to the question: What is the potential role of crop biotechnology in meeting Africa's future food security needs?

Donors joined the biotechnology movement in the early nineties amid a spirit of optimism and dreams of agricultural biotechnology producing quick success and impact. This optimism was captured in the title of the report of the *World Bank Agricultural Biotechnology – “The Next Green Revolution”?* (1991). Today, the Gene Revolution is divided into two camps. Proponents include Erbsich and Maredia (1998), Ndiritu (2000), Borlaug (2003), Chetsanga (2000), Wambugu (2001), Persley and Lantin (2000), Thomson (2002), Sithole-Niang (2005), DeGregori (2001) and Omamo and von Grubmer (2005) and many others. These proponents are reinforced by Bt impact assessments by Huang and Wang (2003) and Qaim and Matuschke (2005) that have contributed to the optimistic view of agricultural biotechnology in developing countries. The unabashed leader of the optimistic view of the potential of biotech crops is Nobel Laureate Norman Borlaug who describes anti-GM critics as engaged in “hysteria” and “in need of a better education in biological science” (2003). Without question, there is considerable skepticism in Europe about GM food.<sup>4</sup>

The critics of biotech crops include Altieri (2001), Greenpeace, Oxfam, Global Justice Ecology Project, Vandana Shiva, GRAIN (2004), Zerbu (2004) Tewolde Berhan, and many African governments. Critics emphasize the potential health and environmental risks and the dominance of multi-national corporations in research and decision making in developing countries. However, the unexpected environmental benefits of Bt cotton are helping some African policy makers change their position on GM crops and food aid. Because of the favorable health effects of reduced spraying of cotton, it is clear that reducing pesticide use and protecting the health of cotton farmers are important rejoinders to the anti-GM critics (Maumbe and Swinton, 2003).

Today, global trends reveal an optimistic picture of the growth of biotech crops. In 2004, the global area of biotech crops grew by 20 percent (James, 2005). Eight million farmers in 17 countries grew biotech crops in 2004. South Africa is the eighth largest country in the world in terms of biotech crops (maize and cotton) grown commercially. Most African GM researchers are using tissue culture and many countries have active GM crop research programs.<sup>5</sup> However, despite the outpouring of global literature on GM crops, there is a dearth of information on the arduous and time consuming process of developing GM crops and biosafety regulations in Africa. The following analysis of the process of developing seven GM crops (six food crops and one export crop-cotton) will shed light on the role of the technical, managerial, financial and institutional factors that shape the scientific discovery process and the lengthy period of time to develop biosafety frameworks and regulations (Sithole-Niang et al., 2004) and North–South research partnerships (Tollens et al., 2004).

<sup>4</sup> For more information on GMOs in Europe see Questions and Answers on the Regulations of GMOs in the European Union May 20, 2005. [http://europa.eu.int/comm/food/food/biotechnology/gmfood/qanda\\_en.htm](http://europa.eu.int/comm/food/food/biotechnology/gmfood/qanda_en.htm).

<sup>5</sup> Wambugu (2001) describes tissue culture “as a relatively simple and inexpensive set of technologies that allows whole plants to be propagated from minute amounts of plant tissue even just a single cell of the plant”. Tissue culture represents a necessary first step in building and managing a varietal improvement system that is linked to seed distribution and upstream biotechnology (Lynam, 1995).

## Case studies of seven GM crops

Since donors are discussing various proposals to increase aid to Africa, it is an appropriate time to step back and analyze investment priorities in plant breeding and GM crop development in Africa. First we start with conceptual issues in understanding the pathway of biotech crop development. Ruttan (1999) has developed a simple three-stage classification of the goals of agricultural biotechnology development starting with stage one where the goal is lifting the yield ceiling of cereals (Fig. 1). The second stage focuses on enhancing the nutritive value of cereals such as golden rice, which increases the Vitamin A intake, and reduces child blindness. The third stage focuses on the development of plants as nutrient factories to supply food, feed and fiber. Byerlee and Fischer (2002) have laid out a three-stage model of the process of developing and diffusing biotechnology. Type I countries are weak NARS (National Agricultural Research Systems) using tissue culture and have little private sector activity. Type II countries have medium to strong NARS with strong national commodity research programs and have some capacity in molecular biology. Type III countries have very strong NARS with considerable research on transgenics.

FAO's *State of Food and Agriculture 2003/2004* includes a valuable global assessment of agricultural biotechnology. The FAO (2004) urges caution in drawing "strong conclusions" from surveys because the GM crops have often been grown for only a few years and the sample size of farmers may be small. The discussion of smallholder GM cotton in South Africa below is a sobering reminder of the risks involved in speculating on future adoption rates.

What can Africa learn from the global GM experience to date? Cohen and Paarlberg (2004) surveyed six developing countries (including Kenya) and concluded that biosafety procedures for GM crops were not working well. They report that it is time consuming to make and enforce regulatory decisions because decisions must be applied at three points: approval for confined trials; approval for larger location trials, and finally approval for commercial use. More recently, Cohen (2005) and researchers on three continents studied the role of the public sector in the transformation process in 15 developing countries and concluded, "The public sector is a competent but largely unproven player for GM leadership in developing countries". One of the surprising findings of the survey was the high cost of compliance for the regulatory approval of a single transformation event, ranging from US \$700,000 for virus-resistance papaya to US \$4 million for herbicide-resistant soybeans. In India one private firm spent \$2 million and the other spent \$3 million to obtain regulatory approval for Bt cotton hybrids (Pray et al., 2005). However, since no government agencies have yet commercialized a GM crop in India, it is not known what the cost will be for government GM crops. India scientists do not expect the financial cost of meeting regulatory requirements to be more than \$50,000–\$100,000 per event but the years of delay are probably a larger concern than cost.<sup>6</sup> These global insights point out the barriers and time lags in gaining biosafety regulatory approval, and the high cost of compliance for regulatory approval.

The results of the following case studies of the development of seven GM crops will help answer two central questions. First, what are the political, scientific, technical and institutional barriers that have delayed the development and biosafety regulatory approval for testing and release of biotech crops in Africa? Second, what are the challenges and

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<sup>6</sup> The low cost is because government research programs do not separately budget for salaries as they are already paid for and because much of the biosafety testing is done at other public sector institutions at normal cost (Pray et al., 2005).

priorities in building public awareness of biotechnology and biosafety and building African scientific, technical, legal and managerial capacity to develop, test and diffuse GM crop technology to smallholder farmers in Africa?

### *Insect and virus resistant sweet potato*

Sweet potato, is an important food staple grown in Kenya and other parts of the continent.<sup>7</sup> It is appealing to donors because it is predominately grown by resource-poor women farmers and it yields more food energy and micronutrients per hectare than any other crop (Qaim, 2001). The sweet potato area under cultivation is expanding in Kenya because of rapid population growth. But yields have declined in recent years because of virus diseases; the average sweet potato yield in Kenya is around 6 ton/ha as compared with 18 ton/ha in China.

GM sweet potato research is designed to develop varieties that are resistant to potato weevils and virus diseases, especially the sweet potato feathery mottle virus. In 1991, the Monsanto Company offered to transfer a virus resistant GM sweet potato from the United States to KARI (Kenya Agricultural Research Institute) on a royalty-free basis as a means of improving the food security of Kenya. In 1996, Kenya, the government of Kenya formed a National Biosafety Committee (NBC). In 1998, the NBC published a set of Regulations and Guidelines for Biosafety in Kenya (Cohen and Paarlberg, 2004). Since some of the basic research functions in crossing Kenya sweet potatoes with the Monsanto lines were to be performed in Monsanto laboratories in the United States, Kenyan scientists were invited to the United States to carry out the experiments in cooperation with Monsanto scientists (Wambugu, 1999). However, technical problems were encountered in the Kenyan cultivars that were taken to the United States to be transformed and a sweet potato variety from Papua New Guinea had to be used at Monsanto in place of Kenyan material (Paarlberg, 2001).

In 1998, KARI requested its National Biosafety Committee (NBC) to allow it to import its GM sweet potato materials from Monsanto in the United States into Kenya. However, it took the NBC 2 years to approve the importation of the material. Field trials of transgenic sweet potatoes have been ongoing since 2001. It now appears that some basic science and research priority issues are hanging over the sweet potato experiment.<sup>8</sup> Some scientists believe that the construct for virus resistance was not well tested and it did not hold up in the field trials. One might explore whether there was a need to link biotech research with a well-developed conventional sweet potato breeding program. The International Potato Center (CIP) and Auburn University in the United States are now working on a transgenic approach to weevil protection, but researchers are still far away from a product to release to farmers. To summarize the transgenic sweet potato is still making its way through the regulatory approval process in Kenya.

### *Insect resistant Bt potato*

This case study is a progress report of an ongoing collaborative research program to develop and commercialize Bt Potatoes to control the Potato Tuber Moth (PTM)

<sup>7</sup> This case study draws on Wambugu (1999, 2001), Wambugu and Kiome (2001), Odame et al. (2002), Qaim (1999, 2001, 2005), Qaim and Matuschke (2005), Wafula et al. (2004), Paarlberg (2001) and Cohen and Paarlberg (2004).

<sup>8</sup> Two years ago KARI sub licensed the virus resistance technology to the Danforth Center (USA).

(*Phthorimaea operculella* Zeller) in Egypt and South Africa. In 1993, Michigan State University (MSU), secured funding from the USAID mission in Cairo to form a partnership with the Agricultural Genetic Engineering Research Institute (AGERI) in Egypt to develop transgenic Bt potatoes to reduce the losses from PTM and the use of pesticides. The MSU team secured a license for the codon-modified *cryIIa1*Bt gene from the ICI Seeds in October 1994 to develop transgenic potatoes resistance to PTM. MSU currently has a license to use this gene in potato research. The MSU team in collaboration with the AGERI scientists in Egypt developed Bt potato lines using the *cryIIa1* gene. The transgenic Bt potato lines were transferred to Egypt under a material transfer agreement (MTA) and field-tested at two locations from 1997 to 2001. The Bt Spunta lines performed well in Egypt and provided excellent control of PTM both in the field and storage. However, Egypt regularly exports potatoes and other agricultural commodities to the European Union (EU). In 2001, after 8 years of research, the government of Egypt decided not to commercialize Bt potatoes at this time because of trade concerns with the EU over GMs crops.

The MSU potato research team turned to South Africa in 2001 and developed a joint research project with the Agricultural Research Council (ARC) with an initial goal to commercialize PTM resistant Bt potatoes for resource-poor farmers. The Spunta Bt potato lines were transferred to the ARC's Vegetable and Ornamental Plant Institute (VOPI) in Roodeplaat under a material transfer agreement for a field trial in South Africa. VOPI has excellent infrastructure and a national potato-breeding program. The first field trial was conducted at VOPI in 2001 and repeated in 2002 and 2003 at two locations. In 2004, field trials were planted at five locations. The field and storage trials in South Africa have produced excellent results in terms of PTM control and have generated interest among both resource-poor and commercial farmers in growing the Bt variety.

As a result of corporate mergers and acquisitions, the ownership of *cryIIa1*Bt gene now resides with the Syngenta Company. In addition, the Spunta Bt potato lines contain intellectual properties that are owned by the Monsanto Company (promoter and a marker gene). The MSU Technology Transfer team has started negotiations with Syngenta to obtain a license to commercialize the Spunta G2 Bt line in South Africa. Syngenta is willing to grant the license but it has requested a full regulatory approval of the South Africa government before granting a commercial license. The company is also concerned about the liability and stewardship issues, especially the potential *trans*-boundary movement of Bt potatoes into neighboring countries that do not have biosafety regulatory policies and regimes/systems in place. Hence there is a need for a regional dialogue on regulatory issues. The MSU team is also developing a regulatory file to submit to the South African government. As a part of this effort, MSU and VOPI are gathering environmental biosafety, food safety and toxicology data in collaboration with local and international experts. A South African Team is also conducting an *ex-ante* socio-economic assessment.

In summary, there are two major barriers to the commercialization of Bt potatoes in Egypt and South Africa. First, Egypt fears the loss of its future potato export market to Europe if the Bt potato is commercialized. Second, progress has been delayed in South Africa because of a concern over liability issues arising from the potential cross-boundary movement of Bt potatoes from South Africa to neighboring countries that do not have functional biosafety policies and regulatory regimes/systems or where the Bt technology is not registered. Brenner (2004) reviewed the potato project and concluded that Bt potato lines have been field-tested in Michigan, Egypt, and South Africa and they have performed well agronomically and expressed excellent resistance to PTM both in the field and in

storage. However, because of a number of legal and regulatory issues, the Spunta G2 Bt transgenic potato variety is still not grown by smallholders in Africa despite 12 years of research and more than \$3 million of donor funding for the potato research project (1993–2005). It is estimated that it will take another 4 years of research, regulatory data collection and technology negotiations before the Bt potato is ready for release to farmers in South Africa.

### *Insect resistant Bt maize*

It is predicted that by 2020, maize will surpass both wheat and rice as the number one cereal in the world. Nine of the top 25 maize-producing countries are from Africa. Globally, maize is severely constrained by insect pests. Half of these losses are due to lepidopteran insects that can be controlled by the Bt toxin protein gene. Other production constraints include drought, low N, soil acidity, insect pests, infestation by parasitic weeds (*Striga* sp.), viral and fungal diseases.

To date, several GM maize products that have been developed by the private and public sectors (De villiers and Ferguson, 2004). The Universities of Cape Town and KwaZulu Natal in South Africa are developing new products in drought tolerance. Maize engineered for drought tolerance using an antioxidant gene from the resurrection plant, *Xerophyta viscosa*, has been transferred to the African Center for Crop Improvement (ACCI) of the University of KwaZulu Natal for further evaluation. The University of Cape Town is also developing a maize streak virus resistant maize line which, if found effective, will be back crossed into locally preferred and adaptable germplasm. This development fits in nicely with existing policy developments in South Africa, where GM maize, both yellow and white maize varieties have been commercialized. South Africa is the first country in the world to commercialize a GM crop that is also a staple food, white maize (Gouse et al., 2005a,b).

In collaboration with CIMMYT, the Kenya Agriculture Research Institute (KARI) embarked in 1999 on the development of insect resistant transgenic maize in a project popularly known as Insect Resistant Maize for Africa (IRMA). The maize was transformed with *cry1Ab* and *cry2A* and backcrossed into African-adapted varieties in Mexico. Leaf assays were conducted in Kenya followed by trials in a newly established biosafety level 2 greenhouse facility and confined field trials. IRMA Phase 2 aims at distributing two types of maize, one developed through conventional means and the other by genetic engineering using *Bt*-technology. The conventionally bred material that uses leaf toughness as the main attribute to insect tolerance is currently undergoing performance trials within the national program. The transgenic plants are devoid of marker genes, and continue to be backcrossed into Kenya varieties. Impact assessments of gene flow, socio-economic and base line studies have already been conducted (Mugo et al., 2005). On May 27, 2005, confined field trials of Bt maize were planted in Kenya.<sup>9</sup> It is estimated that it will take another 4 or 5 years of field trials before the GM maize can be approved and released to farmers. The IRMA project will ensure that smallholders in sub-Saharan Africa have access to maize resistant to stem borers. The Syngenta and Rockefeller Foundations are providing funding.

In April 2005, a biosafety level 2 Facility for Plant Genetic Transformation was established at Kenyatta University in Kenya. The Facility will be used primarily for maize genetic

<sup>9</sup> See <http://www.cimmyt.org/english/wps/news/2005/may/kenyaTransgenic.htm>.

transformation to generate maize that is resistance to *Striga* as well as drought tolerant varieties. This facility will train students from Kenya, Ethiopia, Sudan, and Tanzania at masters and doctoral levels. The Kenyatta University researchers are working closely with the private sector as well as the Rockefeller Foundation, USAID, and the USDA.

### *Disease and insect resistant banana*

The East African highland banana is an important food and cash crop for many resource poor smallholders in Eastern and Central Africa, including Uganda, Kenya, Tanzania, and Rwanda. In Uganda, more than one third of the cultivated land is planted to banana and per capita consumption is the highest in the world, estimated at 250 kg per capita/year or, roughly seventy kilograms per person per day (ABSP II, 2004). Most bananas are locally consumed as cooking or beer bananas. The East African highland banana is susceptible to pests (nematodes, banana weevils) and diseases (Black Sigatoka, Banana Streak virus, Bacterial wilt), and host resistance was identified as one of the most feasible alternatives to control the pest and disease problem. The national banana research programme adopted both short term and long-term approaches to address this problem. The short term approach included assembling of local and foreign germplasm for evaluation and selection of resistant or tolerant cultivars, propagation of superior, clean planting materials through tissue culture, and importation of hybrids from other breeding centers including *Fundacion Hondurena De Investigacion Agricola* (FHIA) and the International Institute of Tropical Agriculture (IITA), Ibadan-Nigeria for evaluation against local pests and diseases. The long-term strategy includes breeding for resistance with genetic transformation (Kikulwe et al., 2005).

Since 2000, the government of Uganda has annually contributed funds to the International Network for the Improvement of Banana (INIBAP) to carry out research on the major banana diseases in cooperation with Uganda's National Agricultural Research Organization (NARO), the KUL (The Catholic University of Leuven), CIRAD, IITA, the University of Pretoria, Leeds University and other institutions. In 2003, a biotechnology laboratory for genetically modifying bananas was opened at the National Agricultural Research Organization (NARO). The KUL, in Belgium, houses the world's largest collection of banana and germplasm is sent around the world as tissue culture material. The goal of the NARO/KUL partnership is to insert genes into bananas that will enhance resistance to Black Sigatoka and banana weevils. NARO scientists have identified several varieties for initial transformation assays in order to represent the range of genomic and use group diversity found among clone sets in Uganda (Karamura and Karamura, 1994). Edmeades and Smale (2005) demonstrate the pro-poor potential of transgenic East African highland cooking bananas and predict the sensitivity of farmer demand for transgenic planting material to research and other investments.<sup>10</sup>

Looking ahead, what is the time-line for getting transgenic bananas into the hands of smallholders in Uganda? A recent assessment of on-going transgenic research for solving major pest and disease problems (fungal, nematode, bacterial, weevil, and viral) concluded that, in the medium-term, the approach that is most likely to deliver improved transgenic

<sup>10</sup> The problems encountered with the recent introduction of banana hybrids illustrates the need for research by social scientists on locally important variety attributes from a consumer's perspective. Although the banana hybrids have large bunches, consumers report they are inferior in terms of cooking quality.

material to smallholder farmers will take 7–10 years of further technology development, and building NARO's capacity in biosafety for contained and ultimately field trials of transgenic plants (Quemada and Johanson, 2004).

To summarize, the development and use of tissue culture in banana research is an important achievement. However, GM research has been slow in combating Black Sigatoka and banana weevil because of many complex scientific and biosafety issues. More time is needed to deliver GM bananas to smallholder farmers in Uganda.

### *Insect resistant Bt cowpea*

Cowpea is a low cost vegetable protein generally grown by women. The crop is consumed as fresh green leaves, soft pod, as well as dry grain. The crop is a rich source of vegetable protein. The stover of cowpea is used as fodder, especially during the dry season. Cowpea is drought tolerant and it can be used to enrich the soil through nitrogen fixation. But cowpea suffers from severe insect pest and disease pressure during vegetative growth and the cowpea weevil during post harvest storage (De villiers and Fergusson, 2004). Production constraints include: insect pests, storage weevils, fungal diseases, bacterial blight, viruses and the parasitic weed *Striga gesneroides*.

The Network for the Genetic Improvement of Cowpea for Africa (NGICA) was established in 2001 to focus research attention on cowpea, an "orphan" crop in terms of research funding. Larry Murdock of Purdue University, and Idah Sithole-Niang of the University of Zimbabwe, manage the network. In 2001, Murdock convened a meeting of cowpea researchers in Dakar to assess the state-of-the-art of cowpea research and devise plans and new research initiatives to address constraints on cowpea production and storage in Africa. The assembled researchers concluded that pests were by far the largest single challenge the crop faced and that *Maruca vitrata* was the most damaging and that genetic engineering tools might be useful in reducing smallholder losses from pests in the field and in storage.

Murdock and Sithole-Niang urged donors to continue funding the following cowpea research groups:

- T.J. Higgins group, CSIRO, Australia.
- George Bruening, UC/Davis and Ivan Inglebrecht, IITA.
- Ray Bressan, Purdue University.
- Richard Allison, Michigan State University and Idah Sithole-Niang, University of Zimbabwe.

The research groups also met with the private sector and discussed the acquisition of proprietary technology, namely the Bt gene. These discussions reached an advanced stage, but when the African Agricultural Technology Foundation (AATF) was formed, it included the Cowpea Productivity and Utilization project as one of the five pilot projects in its portfolio.<sup>11</sup>

In October 2004, the T.J. Higgins group introduced a foreign gene (the GUS marker gene) into cowpea cotyledonary nodes using *Agrobacterium tumefaciens* and identified

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<sup>11</sup> The AATF plans to assist in cowpea research and utilization by launching a pilot AATF/NGICA project to address IP negotiations to access existing technologies, liability protection, license for distribution, licensor/ licensee for cowpea network activities, and link producers, traders and consumers.

three preferred cowpea lines, worked out the modalities of replicating the system, obtained fertile seeds, and had molecular data (Southern blots) to show that the gene was indeed in the plant/seed and could be passed on to the next generation. Now Higgins' group has to work on scale up and ensure that other people reproduced their experiments in different locales (Higgins, 2004). There is excitement among cowpea researchers and researchers who are now busy replicating the Higgins protocol in their laboratories.

The management of the NGICA has relied on donated time by key individuals. The network *per se* has no legal status, thus limiting its ability to compete for technical, intellectual as well as budget support. Discussions are underway to formalize the network and select an individual to lead the cowpea research community. The Secretariat will be located at an existing organization in Africa. Lobbying, collaboration with key stakeholders and advocacy for cowpea in all areas, and capacity building will continue (Sithole-Niang and Murdock, 2004). There is close cooperation between NGICA, IITA and the Bean and Cowpea CRSP managed by Michigan State University.

To summarize, the cowpea case study illustrates how difficult it is to mobilize donor support to carry out research on cowpea, an orphan crop. The first step in resource mobilization is to seek support from African governments to finance targeted research on orphan crops. The insect resistant GM cowpea varieties are many years away from release to smallholders in Africa.

#### *Virus resistant cassava*

Cassava is the second most important food crop in sub-Saharan Africa and it has unrealized potential for industrial exploitation. Cassava Mosaic Disease (CMD), a viral disease transmitted by white flies and vegetative propagation destroys one-third of the harvest each year. Scientists at the Donald Danforth Plant Science Center (USA) have succeeded in introducing a gene into cassava through genetic engineering that imparts resistance to the viruses that cause CMD.<sup>12</sup> These viruses include the African cassava mosaic virus (ACMV) and the East African cassava mosaic virus (EACMV). Three seasons of testing these transgenic plants in greenhouses in the United States have demonstrated high levels of resistance to CMD. Given these promising greenhouse results, the Danforth scientists decided to test the plants in the field where the disease pressure is high. Kenya was selected as the priority site for this trial because (a) it permits field trials of GM crops, and (b) CMD is a severe problem. In April 2003, USAID/Washington made a 1-year grant to the Danforth Center to prepare for a field trial in Kenya. The Danforth Center signed a MoU with the Kenyan Agricultural Research Institute (KARI). The Danforth Center and KARI are in the process of obtaining regulatory approval for conducting a field trial in Kenya. KARI and the Danforth Center have jointly identified local cultivars for transformation.

The short-term goals of the Danforth–KARI collaboration project is to conduct a field trial of GM cassava plants in KARI's Alupe field station, and initiate the development of product commercialization package (PCP) for regulatory approvals. This PCP will focus on East Africa and Kenya in particular. As additional funding becomes available, the PCPs will be expanded to include Nigeria and Malawi. The tentative timeline for the

<sup>12</sup> For a discussion of cassava in Africa see Nweke et al. (2002). Also see Fregene and Puonti-Kaerlas (2002) for an overview of cassava biotechnology research.

development and commercialization of CMD resistant transgenic cassava lines in Kenya is outlined below:

- Production of a Large Number of Plants (year 2006).
- Selecting the Best Plant Lines for Phase II Field Trials (year 2007).
- Implementation of Phase II Field Trials (year 2008).
- Final Field Trials and Selection of Two Best Transgenic Lines as Proposed Products (year 2009).
- Development of Full Biosafety Packages for Commercialization (2010).
- Licensing and Public Outreach (year 2011).
- Multiplication of Planting Materials by KARI and others (year 2012).
- Monitoring and Measuring Impact (year 2013).

In summary, biotechnology offers a promising approach to addressing the problem of cassava mosaic disease (CMD). Transgenic cassava plants developed at the Danforth center have demonstrated resistance to CMD in greenhouse trials, and progress is being made to test this resistance in field trials in Kenya. Improved genetic constructs have been produced and efficacy tested in a new generation of transgenic cassava plants. Genetic transformation protocols are also being developed for high-priority local cassava varieties in order to develop a product adapted to East African farmer needs. Integration of optimized genetic constructs into East African germplasm will commence in late 2005 followed by screening for CMD resistance both in the greenhouse and the field. The best performing cassava lines will become the subject of further study to generate required data on food and environmental safety. These data will form the basis for regulatory review and approval, which will be followed by licensing, multiplication, and general release to farmers of the improved, transgenic planting materials by the year 2012. GM cassava technology has potential to improve farmers' productivity and livelihoods, but it is seven to eight years away from reaching the fields of smallholders in Africa.

### *Insect resistant Bt cotton*

Cotton is the second most important global GM crop (after soybeans) in terms of area planted. Smallholder cotton production has increased in China,<sup>13</sup> South Africa and more recently, in India. Spurred by these success stories, Bt cotton field trials are now underway in Tanzania and Burkina Faso and Mali will soon initiate testing.

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<sup>13</sup> Bt cotton in China is the global GM success story in developing countries (Huang and Wang, 2003). Cotton is an important source of income for smallholders and also an important export crop. Biotechnology research began in the mid eighties with large public investments and the Chinese Academy of Agricultural Sciences secured patents, plant varieties, trademark protection and developed Bt cotton. The original 22 transgenic lines were sublicensed to provincial seed companies, which backcrossed the *trans* genes into well-adapted local varieties to ensure that appropriate local Bt varieties would be available to smallholders throughout the country (Pray et al., 2002 and Shirong et al., 2004). The Chinese experience demonstrates the payoff to staying the course and sustaining the commitment of public investments in Bt cotton research for over two decades. The Chinese experience also sends a political message to policy makers in Africa about the importance of government investment in agricultural research. Huang and Wang (2003) report, "Chinese policymakers consider agricultural biotechnology as a strategically significant tool for improving national food security, raising agricultural productivity and creating a competitive position in international agricultural markets".

The anti-GM critics have a hard time criticizing GM cotton because it requires substantially less pesticides than conventional cotton varieties, produces higher yields and incomes for poor farmers and is better for the health of smallholders by reducing the number of insecticide sprays. The major fear associated with the use of Bt cotton is the possibility that pests may develop a resistance to it as they have done with chemical pesticides.<sup>14</sup> Currently, another international policy issue surrounding cotton is the subsidies being paid to farmers producing cotton in industrial counties.<sup>15</sup>

What is Bt cotton? The genes from the common soil bacterium *Bacillus thuringiensis* (Bt) can be inserted into the cotton plants to produce a protein that is toxic to caterpillar pests such as the pink bollworm and cotton bollworm (Traxler, 2004). In 1996, the first Bt cotton varieties were introduced commercially in the United States, Mexico and Australia through a licensing agreement between Monsanto, the gene discoverer, and Delta and Pine Land, an international seed company. The Delta seeds are sold under the trade name Bollgard®. Farmers wanting to use Bollgard® must pay for the seed and a technology fee. New Bollgard® seed must be planted every year according to the company's agreement with the growers.

In examining the reasons for the rapid growth of transgenic cotton, we begin with South Africa because it is the African leader in terms of developing public sector biotech research capacity and it has both large scale and smallholder farmers producing GM cotton.

#### *Bt cotton in South Africa*

South Africa is the pacesetter for GM research and GM crop production in Africa.<sup>16</sup> Cotton is grown by smallholders on rainfed land and by large-scale farms on irrigated land. Smallholders generally have 1–3 hectare farms and plant about one half hectare to rainfed cotton. Bt cotton was commercially introduced in the Makhatini Flats in the Kwa-Zulu Natal region in 1999 (Kirsten and Gouse, 2003). Two years later, around 90 percent of the 3500 smallholders had adopted Bt cotton (Gouse et al., 2003). The early adopters of the Bt varieties reported higher incomes because of the reduced cost of pesticides and slightly higher yields. Thirtle et al. (2003) found that higher yields and lower chemical costs outweighed seed costs, giving higher gross margins to adopters.

However, in 2002/2003, “things started to fall apart” when a new cotton company installed a gin next to the original gin that had provided credit to smallholders growing cotton since the inception of the project in 1999. Unfortunately, some of the smallholders sold their cotton to the new gin and the original gin lost money and discontinued the provision of credit to smallholders. As a result, over the past 2 years, cotton production has been drastically reduced due to a lack of credit, declining world cotton prices and drought (Gouse, 2005). Several researchers recently concluded that smallholder Bt cotton in the KwaZulu Natal represents a “technological triumph but an institutional failure” (Gouse

<sup>14</sup> Tabashnik et al. (2005) monitored pink bowl worm resistance to Bt toxin for 8 years with laboratory bioassays of strains derived annually from 10 to 17 cotton fields statewide in Arizona. Bioassay results revealed no net increase from 1997 to 2004 in the mean frequency of pink bowl worm resistance to Bt toxin.

<sup>15</sup> See Minot and Daniels (2005) for a study of the impact of cotton subsidies on cotton production in Benin.

<sup>16</sup> South Africa's journey into biotech crops started in 1978 when a government committee, SAGENE, drafted biosafety guidelines. The government field tested Bt cotton in 1990 and commercialized it in 1997 followed by soybeans in 2000 (James, 2005).

et al., 2005b).<sup>17</sup> The South African experience adds evidence to the proposition that research is urgently needed on what Tripp (2003) has called the “enabling environment”, including how to develop efficient input markets to facilitate the adoption of biotech crops.<sup>18</sup> But keep in mind that developing efficient input markets is one of the oldest and toughest institutional problems to be solved in African agriculture.

#### *Bt cotton in Tanzania*

The bollworm attack was so severe in the Mbeya, Rukwa and Iringa regions in 1968 that the government ordered farmers to stop growing cotton because of the fear that it would spread to the entire country (Balile, 2005). In April 2005, Tanzania became the seventh African country to launch field trials of Bt cotton. Researchers at Sokoine University of Agriculture will supervise the government-managed trials. Tanzania’s Ministry of Agriculture recently reported, “Tanzania cannot afford to be left behind by technologies that increase yields, reduce farm costs and increase profits” (Balile, 2005).

#### *Bt cotton in West Africa*

Cotton is one of the most important agricultural exports for many countries in West Africa.<sup>19</sup> Burkina Faso’s, national agricultural research organization – INERA – and Monsanto signed a partnership agreement and launched field trials of Bt cotton in 2003/2004. The trials reduced Bollworms by 92 percent and increased yields by 15–20 percent (Greenplate, 2004).

#### *Summary of Bt cotton*

The adoption of smallholder Bt cotton in China and India has reduced the use of pesticides, and increased yields and farm incomes. The Asian experience has captured the attention of many African policy makers and stimulated GM cotton trials in a number of countries in Africa. But the recent rise and decline in smallholder production of Bt cotton in South Africa because of credit problems, drought and low world prices illustrates the urgent need for research on input delivery reforms and a number of complex institutional and capacity-building issues.

### **Lessons and challenges**

Biotech crops have been grown commercially for a decade and they are now well established in Latin America and Asia but not in Africa, except for South Africa. We now turn to our seven case studies and pose the question: What lessons can be drawn from the case studies about why Africa is being left behind in the GM movement?

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<sup>17</sup> Gouse (2005) points out that smallholders lost their access to credit because the two cotton gins could not co-exist nor cooperate. This failure has been exacerbated by the low world price of cotton and drought.

<sup>18</sup> See Kherallah et al. (2002) and Kelly et al. (2003) for a discussion of the difficulties in reforming agricultural markets in Africa.

<sup>19</sup> See Alhassan (2003).

Table 1

Seven case studies: projections of the timeline for the release of GM crops to smallholder farmers in Africa<sup>a</sup>

Crop	Target country/region	Problem addressed	Research started (year)	Projected time of delivering GM crops to smallholder farmers
Sweet potato	Kenya	Feathery Mottle Virus	1991	8 or more years
Potato	Egypt <sup>b</sup> South Africa	Potato Tuber Moth	1993	4 or more years
Maize	Kenya	Maize Stem Borers	1999	4 or more years
Banana	Uganda	Banana Weevil and Diseases	2000	7 or more years
Cowpea	West Africa	Pod Borer	2001	8 or more years
Cassava	Kenya, Nigeria, Malawi	Cassava Mosaic Virus	2001	8 or more years
Cotton	Major cotton growing countries	Cotton Bollworms	2000	5 or more years

<sup>a</sup> Excluding South Africa where GM crops are grown commercially.

<sup>b</sup> Michigan State University Bt potato research with Egyptian scientists was discontinued in 2001.

### Lessons

1. *Time and cost:* The case studies have provided insights into the longer period of time than it originally envisaged for the development of GM crops and gain biosafety approval. In the early nineties it was believed that it would only take 3–5 years for developing countries to carry out the GM transformation research phase and gain biosafety approval (Brenner, 2004). The seven case studies summarized in Table 1 suggest that a working time frame of 10 to 15 years should be used in planning new GM crop research and development programs.<sup>20</sup> The cost of the development of a GM variety has also been higher than anticipated and it is expected to increase because of the cost of lengthy field trials. The total cost of Bt potato research in Egypt and South Africa is \$3 million to date. The global experience reveals that it cost \$700,000 to develop virus-resistant papaya, \$4 million for herbicide resistant soyabeans and \$2–\$4 million for private companies developing several Bt cotton hybrids in India. The costs of GM crop improvement are high for many small countries in Africa and need to be addressed through regional and international cooperation (Herdt, 1991).<sup>21</sup>
2. *Biosafety:* A common theme cutting across the seven case studies is the delays in preparing national biosafety regulations and guidelines and getting them approved through the political process. It took Kenya five years from the time of signing the KARI/Monsanto agreement in 1991 to set up a National Biosafety Committee, and an additional 2 years to develop biosafety regulations. The case studies also reveal the need to develop and maintain a strong national capacity to deal with new problems as they emerge. In the potato case study in South Africa, biosafety clearance was near completion when a new issue emerged: how to deal with the legal responsibility in case

<sup>20</sup> But a 10–15 year GM time frame should come at no surprise when it is compared with conventional plant breeding programs. It took Zimbabwe 28 years (1932–1960) of public sector-financed research before it hit the jackpot and produced the famous SR 52 maize hybrid that increased smallholder yields around 40 percent (Eicher, 1995). Likewise it took Norman Borlaug 20 years of research on wheat in Mexico (1943–1963) before his high yielding wheat varieties were transferred to India in 1963 to form the foundation for the Green Revolution. And it took 14 years (1950–1964) for Plowright to develop the famous Rinderpest cattle vaccine in Kenya.

<sup>21</sup> One example of cost savings is for a group of countries in a sub-region is to share the cost of food safety tests.

of environmental and health damage arising from the cross border movement of GM crops. The bottom line is the need to help Africa build its biosafety and regulatory capacity (Maredia et al., 1999).

3. *Stages of GM development*: The case studies display the different capacities of national GM research programs and the need to tailor government and donor assistance to the stage of institutional development of each country and sub-region (Horstkotte-Wesseler and Byerlee, 2000). The case studies reveal the diversity of agroecologies and the complexities of African diets, and call for research by social scientists on a range of topics, including consumer food preferences to guide GM research priorities and diagnostic research to understand farmer adoption of GM crops (Smale and De Groot, 2003). For example, in Uganda there are more than 200 banana clones to satisfy local food preferences. Which local clones do plant breeders choose to use in their GM research programs?
4. *Public and private sector cooperation*: Although a number of African nations have requested donor aid for GM capacity building, donors have allocated relatively small budgets to support GM research, infrastructure and training as compared with the estimated \$1.5 billion spent each year by private global plant science research companies. The CGIAR is only spending around \$40 million of its \$450 million budget on biotechnology research for crops and livestock in 2005.<sup>22</sup> The World Bank assistance for biotechnology is embedded in agricultural technology and research projects. The cowpea case study is a classic example of the difficulty of mobilizing national and donor support for orphan crops such as cowpea, mung beans, teff, cucurbits and others. Fortunately, the AATF has agreed to facilitate the development of partnerships between cowpea researchers and companies owning some of the genes used in cowpea research. But despite the technological and marketing savvy of private multi-national firms, the private sector will thrive only if the public sector trains African scientists, conducts local plant breeding research, builds research laboratories, and develops input markets and favorable economic policies. Both public and private investments are needed in GM R&D; the payoff to either public or private investments will be higher if they are coordinated as complementary activities (De Vries and Toenniessen, 2001).
5. *Capacity building*: Cutting across all seven case studies are the problems of the brain drain, turnover of scientific staff, HIV/AIDS (Yamano and Jayne, 2003) and other forms of human capital degradation (Ndulu, 2004). For example, the University of Zimbabwe was a front-runner in setting up an MS program in biotechnology in the 1990s. A total of 63 students were trained over a 10-year period but the program has been terminated. Capacity building is a critical problem on the biotechnology agenda in Africa but the knowledge base on how to build and retain scientific, technical, and managerial capacity is disturbingly limited in Africa (World Bank, 2005). Each of the seven case studies encountered setbacks due to the turnover of biotech scientists. There is a need to develop a plan to train the next generation of African scientists and figure out how to expand GM research and post graduate courses in Africa's universities. Unfortunately donors are investing heavily in workshops, and networks and ignoring

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<sup>22</sup> Lele (2003) contends, "The CGIAR lacks a *system* level policy, strategy or capacity for biotechnology and IPRs or public-private partnerships" (p. 1123). See Morris and Hoisington (2000), CGIAR (1997) and Persley and Lantin (2000) and for a discussion of the evolution of CGIAR thinking on research on GM crops and livestock.

long term training in biotechnology and biosafety. For example, USAID's budget for GM activities in Africa does not include funds for long term (Phd) training. CORAF's \$25 million proposal for biotech/biosafety capacity building from 2005 to 2010 includes only \$1 million for training or only \$200,000 per year (CORAF/WECARD, 2004).

6. *Enabling policies and institutional environment*: Recent events in South Africa point up the importance of enabling policies (elimination of credit to smallholders to grow cotton, side selling, drought and lower world cotton prices) in reducing smallholder Bt cotton production over the past 2 years. A research team that studied smallholder Bt cotton in South Africa and initially declared it a success story now describe it as "a technological success and an institutional failure". Research is urgently needed on how to develop institutions to address the seed, credit and marketing problems of smallholders (Rukuni et al., 1998). These are the same issues that have slowed the adoption of hybrid maize production by smallholders in Africa in the seventies and eighties (Byerlee and Eicher, 1997).

### Challenges

1. *Raising public awareness of biotechnology, mobilizing political support and Fostering Regional Cooperation*: Without question, there is confusion among the general public and decision makers in Africa about potential applications, benefits and risks of biotechnology products. There is a lot of misinformation, miscommunication and misperception about biotechnology products. This has caused fear among the general public and policy makers and has made the decision process unduly slow and complex. There is an urgent need for each country to be able to tap global information sources to enable decision makers to analyze their own situation and make science-based policy decisions. Regional networks and international cooperation are effective in sharing information, scientific and regulatory data, and expertise within specific geographic regions (FANRPAN, 2005; Omamo and von Grubmer, 2005). For example, since environmental and food safety risk assessments are expensive, some countries may benefit by jointly financing food safety studies and using the findings in their requests for donor assistance. The advances in Internet technology now enable rapid delivery of information. One way to promote the culture of partnership and collaboration is to make it a requirement in the bidding for competitive sub-regional biotechnology research grants.
2. *Building a national biotechnology strategy*: The governments of Africa need to develop a national biotechnology strategy that outlines a clear vision, priorities, commitment and various pathways to biotechnology R&D and human resource development. This strategy should define how biotechnology fits into the overall national agricultural research strategy, agricultural development strategy and target farmers and sectors where biotechnology tools will be applied based on the needs and priorities identified by various stakeholders. We have stressed the need to target biotechnology to increase the average cereal grain yields in Africa but recognize that the GM strategy for a particular country may give priority to increasing the production of Bt cotton, coffee or livestock.
3. *Developing policies to guide regulatory, legal and technology transfer framework*: In spite of numerous studies and reports that document the safety of GM products developed through genetic engineering, a number of environmental and food safety issues have been raised. The environmental safety issues surrounding the use of biotechnology

include gene flow/gene transfer, pest/pathogen effects, impacts on non-target and beneficial organisms, and development of pest resistance. The food safety issues encompass toxicity, allergenicity, and altered nutritional content of the genetically modified food products and their impact on human, and animal health.

As biotechnology products move forward from laboratory to marketplace, they will require biosafety and food safety regulatory approvals from the national governments. Food safety and biosafety assessments are expensive and require extensive laboratory and field studies/experiments. The high costs of regulatory approvals have been the major factor hindering the commercialization of biotechnology products developed through the public sector. The tools of modern biotechnology and genetic engineering are mostly proprietary and held by the private sector and laboratories in industrial countries. Access to these proprietary technologies will require a capacity to negotiate and develop agreements. The private sector increasingly wants to ensure that regulatory approvals are granted by the national governments before issuing a license to target a recipient country. Thus regulatory issues and IPR issues are closely tied together. Therefore, public private sector partnerships are of paramount importance for moving biotechnology forward in Africa.

4. The African Agricultural Technology Foundation (AATF) was launched in June 2004 to broker royalty-free proprietary technologies for use in sub-Saharan Africa (AATF, 2005). Initial activity has focused on five pilot projects of which three are focused on maize: Striga, insect resistant maize for Africa (IRMA) and pro-vitamin A enhancement in maize. The other two pilot projects are cowpea and banana. The AATF has developed a business plan for the cowpea project and participating institutions have been identified. The challenge is to develop innovative ways to secure funding for the long term sustainability of the AATF or similar programs.

## Conclusions

We have argued that agricultural biotechnology has the potential to help African smallholders and also confer benefits to consumers, the environment and health of farmers and farm workers. However, many African decision makers are requesting more information on potential environmental and food safety issues related to GM products. There is a need to develop national capacity and regional dialogues to monitor potential health, environmental, distributive, and food safety risks and cross-border movement of GM cultivars, especially when neighboring countries do not have functional regulatory systems in place. Nine major points summarize our conclusions:

1. GM crops have now been commercialized for a decade and they are producing benefits to farmers, consumers and the environment, especially in Asia, Latin America, Canada and the United States. The global area under GM crops grew by 20 percent in 2004, illustrating growing farmer acceptance in these regions and countries. Although, many countries in Africa are utilizing tissue culture in their biotechnology research and have GM products in the pipeline, South Africa is the only country in Africa that is currently growing GM crops commercially.
2. The seven case studies have revealed a dramatic underestimation of the time required and the cost of developing and field testing a GM crop and securing regulatory approval for moving it from the laboratory to the fields of farmers. Instead of taking 3–5 years

(a common estimate in the early nineties), the seven case studies show that it might take a total of 10–15 years or longer to develop GM crops, create regulatory systems and field test, and deliver GM cultivars to smallholders. The seven case studies have revealed a variety of reasons and barriers responsible for the delay in developing GM crops in Africa. These include a number of scientific, technical, political and institutional factors and a limited pool of scientific, managerial, legal, regulatory and entrepreneurial talent in Africa. Also, food aid and trade fears are common in southern Africa because of drought from 2002 to 2005 and the need to rely on food aid or commercial grain imports.

3. Bt cotton is a success story, especially in China and India, in terms of reducing the amount of pesticides and labor inputs and increases in yields and farm incomes. The new knowledge embodied in the Bt gene has substituted for resources (labor and the capital cost of pesticides) to control the cotton bollworm. The positive environmental effects of Bt cotton have moderated the voices of the anti-GM lobbies and spurred African Heads of State and Ministers of Agriculture to allow Bt cotton trials to be grown in seven countries in Africa. However, there is now an air of uncertainty surrounding Bt cotton in South Africa. In 1999, Bt cotton was rapidly adopted by smallholders but after a few years the curtailment of credit to smallholders, drought and declining world cotton prices contributed to a decline in smallholder cotton production. Smallholder Bt cotton in South Africa has recently been described as a technological triumph and an “institutional failure”. The rise and decline of smallholder Bt cotton in South Africa should be carefully studied by African nations where cotton field trials are underway.
4. Capacity building is basically an accretionary (step by step) process that unfolds slowly and almost invisibly over time. Because of the shortage of well-trained human resources in Africa, especially in legal and regulatory matters, trade, and biosafety, donors should invest in long term training of African scientists (World Bank, 2005).
5. There is a growing number of optimistic scenarios of the projected growth of GM crops. However, in some cases these are based on a small sample of farmers covering two to three years of field trials. The early reports on the “success” of smallholder Bt cotton in South Africa illustrates the need for caution in drawing conclusion from a small sample of farmers covering a few years of experience. Likewise, some African countries have been over enthusiastic about when GM crops would be ready for release. In some cases these predictions have been followed by years of delay in getting a functioning regulatory system in place.
6. Since GM crop development in Africa is in its infancy, donors and foundations can play a strategic role in supporting long term public sector investments in capacity building (human capital and infrastructure), carrying out risk/benefit assessments and supporting institutional innovations such as the AATF and sub-regional GM networks. Special attention should be given to the “small country” problem.
7. Donors should refrain from encouraging organizations such as NEPAD, FARA, the AATF or the CGIAR to develop an African GM strategy. Because of the sharp differences in agroecologies and stage of development, the logical place for developing GM strategies and partnerships is at the national and sub-regional levels. The regional sub-committees on GMOs should be charged with developing partnerships and pool resources to finance such activities as food safety assessments for a sub-region.
8. GM crop research should be embedded into African plant improvement programs that facilitate interaction and cooperation between plant breeders and GM specialists. However, since donor support is increasingly targeted to GM crop research rather than

conventional plant breeding programs, it is proving difficult to attract African students to pursue postgraduate training in crop science and plant breeding in African universities. Without question, African universities need donor support to finance the training of future plant breeders and helping government researchers carry out research on orphan crops such as teff, mung beans, cowpea and other crops.

9. We end with the critical question of investment priorities. We have argued that raising the average cereal yield is the overarching problem to be addressed by agricultural researchers in Africa over the next 10–20 years. This is especially urgent in a continent with an average rate of population growth of 2.8 percent, which implies a doubling of population in 25 years. The policy question that flows from rapid population growth and stagnant cereal yields is whether African governments and private seed companies should invest in plant breeding or GM research or both to raise cereal yields. The facile answer points to expanded investment in GM research in Africa because the global area under GM crops grew by 20 percent in 2004 alone and donors are underwriting the cost of sub regional meetings and workshops on biotechnology and biosafety in Africa. But the seven case studies summarized in [Table 1](#) reveal an underestimation of the time, cost, risks and unforeseen political and policy problems associated with the development of GM food crops at this early stage of African's economic history and institutional maturity.

Without doubt, the results of the seven case studies focus the attention of policy makers, economists and donors on the key question: what is the cheapest source of new cereal crop technology in Africa in the medium term (10–15 years): modern plant breeding or GM research? The past rate of return on plant breeding research by the CGIAR in Africa is around 20–30 percent per year ([Evenson and Gollin, 2003](#)).<sup>23</sup> Because of the delays in GM development pointed out in the seven case studies, African governments should pursue three mutually supporting scientific pathways to crop improvement and raising crop yields: (1) give immediate attention to mobilizing African political and financial support for the long term development of biotechnology and investing in strengthening both plant breeding and GM research in NARS, universities and the CGIAR, (2) strengthen African capacity in biosafety, IPR, regulatory procedures, WTO, and research on institutional innovations to develop efficient seed and fertilizer input delivery systems and (3) invest in long term training programs for African scientists to enable them to become efficient borrowers of GM research from other countries in the world and progressively build their own scientific capacity to develop GM products for African farmers. Although GM research is promising, the evidence suggests that plant breeding research in national breeding programs, universities, private seed companies and the CGIAR will be the primary source of increased cereal yields in Africa in the foreseeable future, i.e. until 2015–2020.

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<sup>23</sup> There is still not enough evidence to generalize about the returns to GM crop improvement research. See the following for some insights: [Maredia et al. \(1999\)](#) and [Marra et al. \(2002\)](#).

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