Staff Paper

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Staff Paper 2005-08 June 2005

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52 pages

No Abstract

June 28, 2005

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[*] Invited paper presented at the Third EAF – EARO International Symposium on Development Studies in Ethiopia, June 18-19, 2005, Addis Ababa, Ethiopia. The authors are grateful for financial support from the W.K. Kellogg Foundation.

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Final 6/28/05

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BIOTECHNOLOGY AND THE AFRICAN FARMER

"Those who reject biotechnology do so on full stomachs."
-Romano M. Kiome, Director, KARI, Kenya, 2003

I. INTRODUCTION

Africa is a hungry continent and the poorest, most food insecure region of the world. Its bleak prospects for improving food security raise two critical political economy questions: why are most African governments underinvesting in the essentials for a modern and productive agriculture, failing to build scientific capacity, roads, dams, schools, and universities of agriculture and ignoring such essential micro details as security of tenure and efficient input and product markets? In stark contrast to Africa, why are Asian governments such as China, India and the Philippines investing heavily in agricultural biotechnology[1] when they have grain surpluses (India has 50 million tons of grain in storage), while most food deficient countries in Africa are fearful of supporting and investing in the gene revolution?

Simple facts tell the story. Commercialization of genetically modified (GM) or transgenic crops, now often called biotech crops, was first approved for use in 1995 by farmers in the United States, Mexico and Australia. However, after a decade of rapid growth of GM crops, most governments in Africa are watching the gene revolution pass it by. Currently, South Africa is the only one of the 53 countries on the African continent that is growing GM crops (James 2004).[2]

Two examples show that biotech crops are facing a number of

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[1] We have adopted FAO's definition of agricultural biotechnology as follows: 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.

[2] 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 2004).

complex and unforeseen barriers to adoption in Africa. In 1991 the Monsanto Company offered to transfer GM sweet potato technology to the government of Kenya on a royalty-free basis. After fourteen years of research this public – private partnership has been unable to develop GM sweet potatoes and secure biosafety regulatory approval to release them to smallholders. The second example is potato research, in Egypt and subsequently in South Africa. In 1993, Michigan State University and Egyptian researchers formed a partnership to develop Bt potatoes for smallholders in Egypt. After eight years of research, the government of Egypt terminated the research agreement for fear that the planting of the Bt potato (Spunta1) might jeopardize its future potato exports to Europe (because of the EU's positon on GM crops). In 2001 the Michigan State potato researchers then shifted their effort to South Africa, but after four years of joint research, some new regulatory concerns still need to be addressed. To summarize, 12 years of time and $3 million of donor support have been unable to deliver GM potatoes to smallholder farmers in either Egypt or South Africa. These and other examples highlighted in the seven case studies in this paper illustrate the unexpected barriers and the time required to develop and release GM crops and get them approved for release to farmers in Africa. It is easy to understand why multinational firms are not investing in biotech research on crops with small markets such as teff, cowpea and millet (deVries and Toenniessen 2001). But why have public scientists in NARS and the CGIAR been unable to develop GM maize, cassava, sorghum (Africa's main food staples)? Why does the CGIAR only allocate around 10 percent of its global budget to GM crop and animal vaccine research?

Ten years ago, farmers in the United States, Mexico and Australia were authorized by their governments to grow GM crops. [3] Since then the growth of GM crops has mushroomed, growing by 20 percent in 2004 alone (James 2004). However, the historical record on the growth and expansion of biotech crops highlights one startling statistic: GM crop growth has taken root in many regions of the world except in Europe and Africa.

The origins of African policy makers' concern over biotechnology are

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[3] See James (2004) for a global report on GM crops; Trigo et al (2002) for a discussion of GM growth in Latin America; Qaim and Matusche (2004) for a global survey and Kelemu et al (2004) for an up to date inventory of biotech research in Africa.

partially a spillover from concerns in Europe about food safety, the environment and generalized public mistrust of multi national as being manipulative and unscrupulous. The transplanting of European consumer concerns coincided with a regional drought in Southern Africa in 2002/3/4 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"[4] 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. The way forward is clearly a need for an open 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.

This paper is divided into five parts. The first part discusses the problem. The second presents the rationale for using case studies to gain insight into the barriers to the development of GM crops in Africa. The third presents the results of seven cases studies and the challenge in developing biotech crops, getting them cleared by national biosafety committees and into the hands of smallholders in Africa. The fourth part draws lessons from the case studies. The fifth part discusses what financial resources, infrastructure and expertise (scientific, technical, political, institutional and financial) are needed to help Africa overcome these barriers and join the global biotech revolution. Since biotechnology is multidisciplinary, a comprehensive approach to capacity building should include capacity in science, regulatory, legal, ethical, communication, business management and entrepreneurship (Figure 1). Figure 1 depicts the need for a comprehensive approach to biotechnology capacity building.

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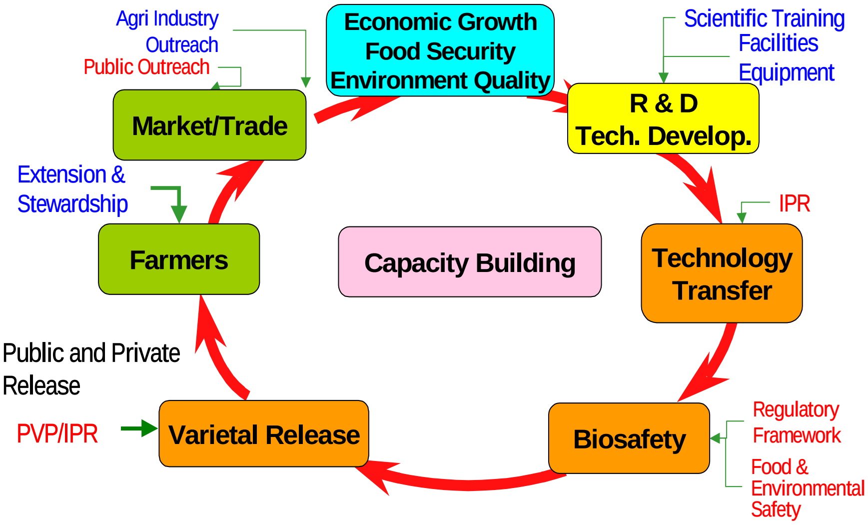
[4] Johnson (2002) points out the difficulty of tracking grain movements from millions of farmers to consumers.

Figure 1. Comprehensive Approach to Embedding Biotechnology into Crop Improvement Programs



Source:ABSP-I Project, Michigan State University

II. AGRICULTURAL BIOTECHNOLOGY

Without question, getting agriculture moving is the central challenge for African political leaders and the donor community. But four decades ago, many agriculturalists were debating the same type of problem: what to do to solve Asia's food crisis[5]. Asia's political leaders responded to the food crisis with massive investments in roads, irrigation and building research capacity. India, for example, built a chain of 33 state agricultural universities and sent 1,000 agricultural scientists overseas for advanced training, as well as importing modern varieties of wheat and rice. India's slow but steady 16-year march from near famine in 1965 to food self-sufficiency in 1981 has many lessons for African nations today. India's Green Revolution demonstrated that investment in agriculture was not only necessary, but also profitable, and that generating new knowledge through research could drive down the real cost of food production and indirectly combat poverty through lower food prices.

Doubling aid to Africa is now being promoted as a strategy to "buy" rapid development. Jeffrey Sachs (2005) and the recent Blair report (Commission for Africa 2005) both call for a doubling of aid to Africa. But there is abundant evidence that-aid by itself cannot buy development. The political commitment to get agriculture moving must start in State Houses across Africa.

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 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: How will Ethiopia feed 120 to 140 million people in 2030?

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 (Figure 2).

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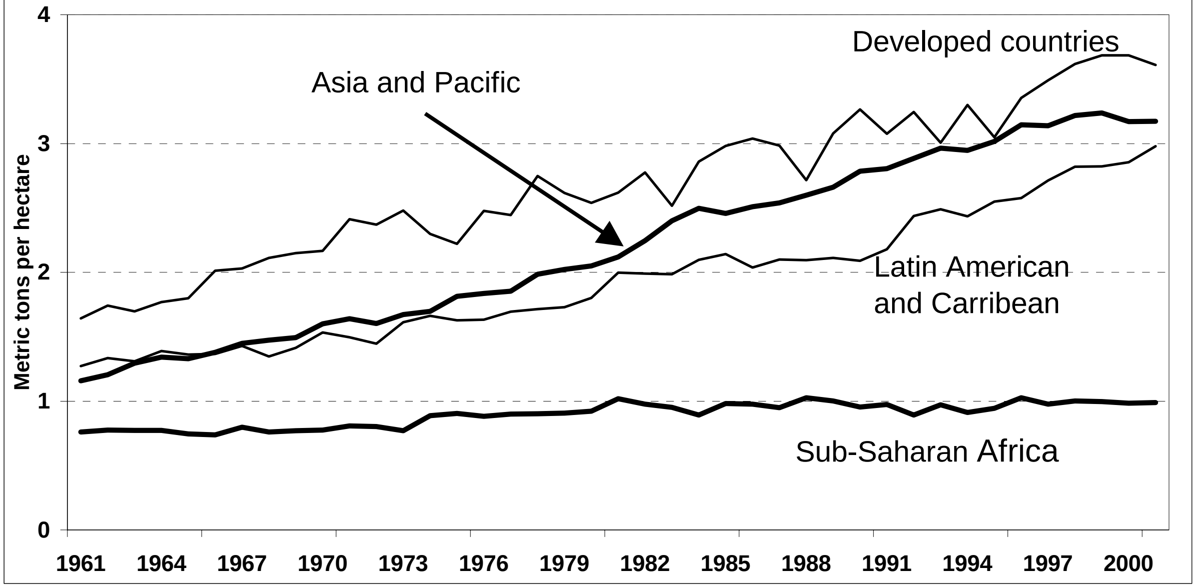
[5] For a discussion of major issues in Asian agricultural development in the 1960s, see Eicher and Witt (1964); Mellor(1976); and Lele and Goldsmith (1989).

Figure 2. Annual cereal yields by region, 1961-2000



Source: World Bank 2005.

This poses the question: can agricultural extension agents or 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, Eicher and Teclemariam 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 the agricultural challenge facing Africa, this raises a key question: what priority should be given to future investments in plant breeding and in GM crops?[6]

Donors joined the biotechnology race in the early nineties amid a spirit of optimism and dreams of agricultural biotechnology producing quick success

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[6] Biotechnology is an outgrowth of a U.S. ruling in 1980 that microorganism could be patented under existing law and a l985 ruling that patent protection could be extended to genetically engineered plants. These critical events sparked a surge in private, public and university investments in medical biotechnology research and later in agricultural biotechnology.

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 Ndiritu (2000), Borlaug (2000), Chetsanga (2002), Wambugu (2001) Persley and Lantin (2000), Thomson (2002), Sithole-Niang (2005) DeGregori (2001) and many others. These proponents are reinforced by Bt impact assessments by Huang and Wang (2003) and Qaim and Matuschke (forthcoming) 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 skepticism in Europe about GM food.[7]

The critics of biotech crops include Altieri (2001), Greenpeace, Oxfam, Global Justice Ecology Project, Vandana Shiva, GRAIN (2004) and many African governments." Critics emphasize the potential health and environmental risks and the dominance of multi-national corporations in research and development 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, the facts paint an optimistic picture of the growth of biotech crops. In 2004, the global area of biotech crops grew by 20 percent (James 2004). 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. Despite the outpouring of global literature on GM crops, there is a dearth of information on the long and arduous process of developing GM commodities and biosafety regulations.[8]

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[7] 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. Tollens (2002) reports that the Government of Flanders founded VIB, an autonomous biotech research institution in Belgium in 1995. VIB has 750 researchers and technicians engaged in biotech research.

[8] For example, Zambia's decision in 2002 to reject GM food aid from the United States even as the country was facing drought was followed by intense debate over whether the food aid was GM grain and whether it contained possible health, environment and trade concerns. Recently, the Zambian government developed a National Biosafety and Biotechnology Strategy Plan (Zambia 2005), which aim to build biosafety capability and ensure GM crops are appropriately regulated. Zambia is now facing is third drought since 2000 and it now needs 200,000 tons of maize to

The results of our analysis of seven commodities (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 development of biosafety regulatory frameworks in Africa (Sithole-Niang et al 2004).

The case studies will show that GM crops are facing an unexpected set of scientific and regulatory issues and even if these are resolved the rise and decline of smallholder Bt cotton in South Africa shows that sustainable adoption of Bt crops requires a number of institutional problems to be solved such as seed and fertilizer input systems, access to markets and favorable economic and trade policies. These are the same problems that constrained the adoption of hybrid maize in Eastern and Southern Africa in the 1970s and 1980s (Byerlee and Eicher 1997).

III. AFRICA'S EXPERIENCE IN DEVELOPING GM CROPS: SEVEN CASE STUDIES

Introduction

Tissue culture research, the first stage of biotechnology research, was launched in several CGIAR centers in the late seventies followed by the governments of South Africa and China in the mid 1980s. In the late eighties, Kenya developed tissue culture capacity to reinvigorate its pyrethrum research program.[9] Many other countries in Eastern Africa have developed impressive tissue culture facilities.

Since donors are discussing various proposals to increase aid to African agriculture, it is an appropriate time to step back and analyze investment priorities in plant breeding verses 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 I where the goal is lifting the yield ceiling of cereals (Figure 2).

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avert a crisis in 2005. But Zambia has reaffirmed its ban on GM products until it is satisfied they pose no threat to health or the environment. 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.

[9] Florence 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).

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 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) recently surveyed six developing countries (including Kenya) and concluded that biosafety procedures for GM crops were not working well. They report that it is difficult 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) teamed up with researchers on three continents and 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.”[10] One of the surprising findings of the 15-nation 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. These global insights point out the barriers and time lags in gaining biosafety regulatory approval, the high cost of compliance for regulatory approval and the growing number of ex ante

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[10] See also Sithole-Niang et. al. 2004)

studies showing favorable results of GM crops for farmers, consumers and the environment.

The results of the following seven case studies will help answer two central questions. First, what are the 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 priorities in building public awareness of biotechnology and biosafety and the African scientific technical, legal and managerial capacity to develop, test and diffuse GM crop technology to smallholder farmers in Africa?

1. Insect and Virus Resistant Sweet Potato

Sweet potato, an important food staple grown in Kenya and other parts of the continent.[11] 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 sweet potato 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.

Transgenic 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.[12]

During the early nineties, a variety of Kenyan organizations and donors pulled KARI's evolving biotech program in many different directions. The development of national biosafety regulations is a case in point. In 1996, five years after Monsanto's offer to transfer a virus resistant sweet potato to Kenya, the government of Kenya formed a National Biosafety Committee (NBC) under the National Council of Science and Technology. Two years later, the NBC published a set of Regulations and Guidelines for Biosafety in Kenya (Cohen and Paarlberg 2004). The fact that it took seven years (1991-1998) to set up a biosafety committee and develop and publish national biosafety guidelines, illustrates how time passes when the drafting process is supported by a variety of donors without proper coordination of various activities and projects.

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

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[11] This case study draws on Wambugu (1999,2001); Wambugu and Kiome 2001; Odame et al (2002); Qaim (1999,2001); Qaim and Matusche 2004; Wafulu et al (2004); Paarlberg (2001) and Cohen and Paarlberg (2004).

[12] Kenya would then be able to pass on the GM sweet potatoes to any other African country on a royalty –free basis.

transforming 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 a 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 two years to approve the importation of the material and field trials of transgenic sweet potatoes have been ongoing since 2001. A total of four seasons of trials and final NBC approval will be needed before release to smallholders. It now appears that some basic science and research priority issues are hanging over the sweet potato experiment.[13] 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 question whether there was a need to link biotech research with a well-developed conventional 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.

2. 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 Potato Tuber Moth in Egypt and South Africa. The potato (*Solanum tuberosum* L.) is an important food crop in Africa. The Potato Tuber Moth (PTM) (*Phthorimaea operculella* Zeller) is a serious pest of potato in Egypt, South Africa, Ethiopia, and other countries in Africa. The tuber moth mines leaves and feeds on tubers in the field and in storage. Losses of up to 100 percent have been reported in storage.

Michigan State University (MSU) has maintained a conventional breeding program for potato improvement for many decades and biotechnology has been integrated into the breeding program to address insects, pests, disease and other constraints. In 1993, the MSU potato team[14] secured funding from

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[13] Two years ago KARI sub licensed the virus resistance technology to the Danforth Center (USA).

[14] The Bt potato research team at Michigan State University includes Johan Brink, David Douches, Walter Pett, Edward Grafius, Karim Maredia, Hector Quemada. South African researchers include Muffy Koch, Kobie de Rone, Diedrich Visser and Ben Pieterse.

the USAID mission in Cairo to form a partnership with the Agricultural Genetic Engineering Research Institute (AGERI) in Egypt. The goal was to develop transgenic Bt potatoes with PTM resistance and reduce the losses from PTM and the use of pesticides. The Egypt project started as a collaborative program under the Agricultural Biotechnology Support Project (ABSP) that was managed by MSU and funded by USAID. The ABSP Project licensed the codon-modified *cry1Ia1*Bt gene from the ICI Seeds Company in October 1994. This gene was licensed for research purposes to develop transgenic potatoes resistance to PTM. MSU currently has a license to use this gene in potato research.

The MSU potato team in collaboration with the AGERI scientists in Egypt developed Bt potato lines using the *cry1Ia1* gene. The potato variety "Spunta" was one of many lines or varieties transformed by using this gene. The Spunta is a Dutch variety that has been widely grown in Egypt for local markets. The transgenic Bt potato lines were transferred to Egypt under a material transfer agreement (MTA) and field-tested at two locations from 1997 – 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). After eight years of potato research in Egypt, the government decided not to commercialize the Bt potatoes at this time because of trade concerns with the EU over GMs crops. Even though the Bt potatoes have not been commercialized in Egypt, the project helped build biotechnology research and policy capacity in Egypt over the 1993 – 2001 period.

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 *cry1Ia1* 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, specially the potential trans-boundary movement of Bt potatoes into neighboring countries that do not have biosafety regulatory policies and regimes/systems in place. The MSU technology transfer team has also initiated discussions with Monsanto because it owns two of the intellectual properties used in this project (promoter and marker gene). Hence there is a need for a regional regulatory framework.

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.

The MSU potato team, in collaboration with VOPI scientists, is currently transforming three additional potato varieties that are important to smallholder and commercial farmers in South Africa (BP1, Mnandi and Darius). VOPI, Potatoes South Africa, and local companies are discussing the development of a road map for seed production, commercialization and distribution of this technology to farmers in South Africa. It is expected that it will take at least three to four more years to commercialize this technology in South Africa, provided a commercial license and regulatory approvals are granted for this technology. The expected outcome of the application of Bt technology in potato in South Africa will be to reduce the losses from PTM damage in the field and in storage and reduce the use of chemical pesticides. The project has enhanced biotechnology and management capacity in South Africa and it can serve as an excellent technology bridge to other countries in southern Africa.

In summary, two major barriers to commercialization have emerged for the same crop in two countries on the same continent. First, Egypt fears the loss of its potato export market to Europe if the Bt technology is commercialized. Second, in South Africa, progress has been delayed because of the unexpected 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) recently reviewed the potato project and concluded “Bt potato lines have been field-tested in Michigan, Egypt, and South Africa over the life of the ABSP project. Not only have they performed well agronomically, they have also expressed excellent resistance to PTM both in the field and in storage.” However, the Spunta G2 Bt transgenic potato variety is still not grown by the smallholders in Africa despite 12 years of research and more than $3 million of donor funding for the Potato Tuber Moth project (1993 – 2005). The projected time of GM release to farmers is around four years.

3. 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. Developing countries plant two thirds of the global maize production while industrialized countries plant one third. 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.

The International Maize and Wheat Improvement Center (CIMMYT) and the International Institute for Tropical Agriculture (IITA) have the CGIAR mandate for maize improvement in Africa, with the former being responsible for eastern, central and southern Africa and the latter for West Africa. Drought tolerance, nitrogen use efficiency, Striga tolerance, stemborer and post harvest pest resistance, several leaf and grain diseases, and grain quality characteristics are priority traits for improvement.

To date several GM products that have been developed (De Villiers and Ferguson, 2004) by the private and public sectors. 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 viscose*, 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*., 2005).

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 *cry*1Ab and *cry*2A 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 gene flow, socio-economic and base line studies have already been conducted (Mugo *et al*., 2005). On May 27, 2005 the government of Kenya planted confined field trials of Bt maize.[15] It is estimated that it will take another four or five 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 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 donors, notably the Rockefeller Foundation, USAID, and the USDA.

4. Insect Resistant Bt Cotton

Cotton is the second most important global GM crop (after soybeans) in terms of area planted. African policy makers are well aware of the expansion of smallholder cotton production in China,[16] 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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[15] See http://www.cimmyt.org/english/wps/news/2005/may/kenyaTransgenic.htm

[16] 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 (Conway, Toenniessen and de Vries 2003; 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. 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. Currently, another international policy issue surrounding cotton are the subsidies being paid to farmers producing cotton in industrial counties.[17]

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 et al 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 smallholders producing GM crops.

South Africa

South Africa is the pacesetter for GM research and GM crop production in Africa. 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.

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[17] See Minot and Daniels (forthcoming) for a study of the impact of cotton subsidies on cotton production in Benin.

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 two 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 KwaZula Natal represents a "technological triumph but an institutional failure" (Gouse et al 2005).[18] The South African experience adds evidence to the proposition that "institutions matter" (Eicher 1999) and 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. [19] But keep in mind that developing efficient input markets is one of the oldest and toughest institutional problems to be solved in African agriculture.

Tanzania

Tanzania's smallholder cotton experience in the Mbeya, Rukwa and Iringa regions in the 1960s illustrates the devastating impact of insects on cotton. In fact, the bollworm attack was so severe in 1968 that the government ordered farmers to stop growing cotton in the three regions because of the fear that it would spread to the entire country (Balile 2005). Recently, Tanzania took a political decision to increase its domestic budget for strengthening its science capacity and 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).

West Africa

Cotton is one of the most important agricultural exports for many countries in West Africa.[20] In Burkina Faso, cotton is the lifeblood of 2.5 million farmers. Burkina's national agricultural research organization - INERA - and Monsanto signed a partnership agreement and launched field trials of Bt

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[18] 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.

[19] See Kherralah et al (2002) and Kelly, Adesina and Gordon (2003) for a discussion of the difficulties in reforming agricultural markets in Africa.

cotton in 2003/2004. The trials reduced Bollworms by 92 percent and increased yields by 15 to 20 percent (Greenplate 2004).

Summary of Bt Cotton

The commercialization of biotech crops is now a decade old. The adoption of smallholder Bt cotton in China and India has reduced the use of pesticides, and increased yields and farm incomes. The expansion of Bt cotton has captured the attention of many African policy makers and has stimulated GM cotton trials 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 seed marketing reforms and a number of complex institutional and capacity-building issues.

5. 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 .70 kg per person per day (ASBP 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 *Foundacion 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).

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[20] See Alassan 2003.

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, CIRAD, IITA, the University of Pretoria and other institutions such as Leeds University on an informal basis. The goal of the joint project is to contribute to food and income security of smallholders in Uganda through improved banana production by introducing genes, which result in enhanced tolerance to Black Sigatoka and nematodes using genetic transformation technologies. In 2003, a new biotechnology laboratory for genetically modifying bananas was opened at the National Agricultural Research Organization (NARO). 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 Sigtoka 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.[21]

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 material to smallholder farmers will take seven to ten 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, transgenic 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 transgenic bananas to smallholder farmers in Uganda.

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[21] The problems encountered with the recent introduction of banana hybrids illustrated 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.

6. 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 Ferguson, 2004). Production constraints include: insect pests, storage weevils, fungal diseases, bacterial blight, viruses and the parasitic weed *Striga gesneroides*. The IITA has been breeding cowpea for years, while scientists in the USAID funded Bean Cowpea Collaborative Research Support Program (B/C CRSP) have been breeding cowpea varieties for West African ecologies for two decades. Some success has been achieved for breeding against bacterial, fungal and viral diseases, but unfortunately, not much success has been achieved for insect pests (Singh, 2004).

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 attracting research funding. Larry Murdock of Purdue University, and Idah Sithole-Niang of the University of Zimbabwe, Harare, 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. The researchers also concluded that genetic engineering tools might be useful in reducing smallholder losses from pests in the field and in storage.

The Dakar meeting launched the NGICA and the membership was drawn from the scientists, administrators, business people, non-governmental organizations (NGOs) and individuals committed to the genetic improvement of cowpea. The group decided that resource poor farmers in Africa should be the ultimate beneficiaries and a coordinated international effort was needed to introduce new traits into the cowpea by using marker-assisted breeding, genetic mapping and molecular genetic transformation. The group also decided that new tools of biotechnology and genetic engineering should be integrated into traditional breeding programs, regulatory constraints should be addressed and a Steering Committee was needed to coordinate the work of the Network.

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 & 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.[22] NGICA organized a meeting of Cowpea Molecular Biologists in Italy in 2002 to discuss the progress of the research groups and issues of ownership, recognition and technology transfer in the event that a particular research group succeeded in developing transgenic cowpea varieties.

Pursuant to the 2004 Accra meeting, a joint proposal was sent to the Global Diversity Alliance (GDA) and funding was obtained to assist with the transformation effort. Satisfied that enough effort was being devoted to genetic transformation, the Network turned to issues relating to marker-assisted selection (MAS) because it was reasoned that if a Bt cowpea became available, the trait would need to be introgressed into locally adapted and preferred varieties. It was agreed that MAS would accelerate this process, and that discussions on MAS should begin immediately. The Kirkhouse Trust co-sponsored a second Cowpea Meeting in Accra in November. Discussions centered on specific technology transfer activities for both MAS and the genetic transformation of cowpea.

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 3 preferred cowpea lines, worked out the modalities of replicating the system, obtained fertile seeds, and had

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[22] 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.

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.

Murdock has developed a comprehensive flow chart spanning 14 years that outlines activities and tasks that had to be undertaken to develop a Bt cowpea. The issues that emerged from the flow chart were:

1. Use of molecular tools was a small part of a much broader long-term research agenda
2. Some activities must be anticipated and initiated in a timely fashion
3. IPR issues must be addressed sooner
4. We must foster a community effort to succeed
5. Africans must be involved at all stages
6. Implementation and deployment of transgenic cowpea will first occur in a single African country, and that country was to be identified early
7. We must ensure sustainable deployment of transgenic cowpea
8. Genetic improvement must not be pursued in isolation, but must be viewed as part of the whole package

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. This suggests that 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 developed through biotechnology are many years away from release to smallholder farmers in Africa.

7. Virus Resistant Cassava

Cassava is the second most important food crop in Africa and it has unrealized potential for industrial exploitation.[23] 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.[24] 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 one-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 Danforth Center have jointly identified local cultivars for transformation.

In the fall of 2003, USAID awarded a one-year grant to the Danforth Center to try to initiate Nigeria’s first field trial of a GM crop. The Danforth Center along with the International Institute for Tropical Agriculture (IITA), the National Biotechnology Development Agency (NABDA) and the National Root Crops Research Institute (NRCRI) have designed a field trial and completed the biosafety dossier/application required by the Nigerian government. The application has been reviewed and approved by the biosafety committees at IITA and NRCRI; the final approval of NBC is awaited.

Malawi has also expressed interest in accessing the CMD resistant cassava technology. The discussions are underway between researchers in Malawi and Danforth to collaborate on this activity. Malawi has been designated as

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[23] Donald Danforth Plant Science Center: Team Members - Dr. Claude Fauquet, Dr. Nigel Taylor, Mr. Lawrence Kent, Dr. Elizabeth Vancil. Scientists from, KARI, CIAT and IITA are cooperating with Danforth scientists.

[24] For a discussion of cassava in Africa see Nweke, Spencer and Lynam (2002). Also see Fregene and Puoenti and Kaerlas (2002) for an overview of research on cassava biotechnology.

the lead country in the Southern Africa Region for a regional cassava biotechnology program funded by the USAID and coordinated by CIAT and Michigan State University.

The short-term goals of the Danforth – KARI collaboration project is to conduct a field trial of transgenic 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 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) – a serious production constraint that devastates one of Africa's most important food staples. Transgenic cassava plants developed at the Danforth Center have demonstrated strong 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.

IV. LESSONS FROM THE CASE STUDIES AND FUTURE 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.

The evidence reveals that some transgenic crops have delivered increased profits to farmers, reduced health problems and generated positive environmental effects in Latin America, Asia and 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?

LESSONS

1. Time and cost. The case studies have provided insights into the amount of time that it takes to develop GM crops, gain biosafety approvals and develop input delivery systems to get these products into the hands of smallholder farmers in Africa. A historical footnote is instructive on the time question. In 1991 USAID signed a contract with Michigan State University to administer the Agricultural Biotech Support Project (ASBP). At that time, the managers of ASBP believed that two commodities—potato and cucurbits-could be commercialized in about six years of the life of the first ASBP contract. In a recent evaluation of ASBP I covering 1991-2004 life, Brenner (2004) concluded that instead of adopting a three to six year time frame, at least 10 to 15 years "should have been used as the norm" for the GM transformation research phase, biosafety approval and release of a GM product to farmers. Brenner concluded that the delay in getting the potato and cucurbit technology in the hands of farmers was mainly because of problems with the broad enabling environment, including policy and regulatory obstacles and weaknesses in input markets. The seven case studies in this paper support Brenner's position that a working time frame of

10 to 15 years should be used in planning new GM research and development programs.[25]

The cost of the development of a GM variety has been higher than anticipated and expected to increase further because of the cost of lengthy field trials. The total cost ranges from \$3 million to date for Bt potato to \$700,000 for virus-resistant papaya, \$4 million for herbicide resistance soyabeans and \$2 million for Bt cotton in India. The costs of GM crop improvement are high for many small countries and need to be addressed through regional and international cooperation (Herdt 1991).

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 two years to develop biosafety regulations. The case studies also reveal the need to 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 obstacle emerged: how to deal with the legal responsibility in case 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 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 diagnostic research to understand farmer adoption of GM crops (Smale and DeGroot 2003) and consumer food preferences to guide GM research priorities. 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 GM research programs?

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[25] But a 10 to 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 to 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 twenty 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.

4. Public Sector. Although African nations have requested donor aid for GM capacity building, donors have small budgets to support GM research 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 $430 million budget on biotechnology research for crops and livestock in 2005.[26] 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. The cowpea researchers have set up an unpaid Secretariat but progress has been slow in mobilizing donor support. Fortunately, the AATF has agreed to facilitate the development of partnerships between cowpea research 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, infrastructure, develops input markets and favorable economic policies. Both public and private investments are needed in GM R&D and the payoff to either public or private investments will be higher if they are coordinated as complementary activities.

5. Capacity Building. Cutting across all seven case studies are the problems of the brain drain, civil war, 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 ten-year period but the program was terminated. Capacity building is a critical problem on the biotechnology agenda in African but the knowledge base on how to build and retain scientific, technical, and managerial capacity is disturbingly limited in Africa (World Bank 2005a). One of the critical capacity building problems is developing a plan to train the next generation of African scientists and figuring out how to expand GM research in Africa's universities. 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).

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[26] 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) for a discussion of the evolution of CGIAR thinking on research on GM crops and livestock.

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 two 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". The most important lesson from the South African experience is that "institutions matter". 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 smallholder hybrid maize in Africa (Byerlee and Eicher 1997).

7. Synthesis of Case Studies. Table 1 summarizes the seven case studies, the years of GM research to date and the anticipated years of additional research required to reach a stage where GM varieties will be available to smallholders.

Table 1. Seven case studies: Projections of the timeline for the release of GM crops to smallholder farmers in Africa[1]

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[2] South Africa	Potato Tuber Moth	1993	4 or more years
Maize	Kenya	Maize Stem Borers	1999	4 or more years
Cotton	Major cotton growing countries	Cotton Bollworms	2000	5 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

1. Excluding South Africa where GM crops are now commercially grown by farmers.
2. Michigan State University Bt potato research with Egyptian scientists was discontinued in 2001.

CHALLENGES

1. Raising Public Awareness of Biotechnology in Africa

In many parts of Africa, there is confusion among the general public and decision makers 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. Therefore, 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, make science-based decisions and capture the benefits from this new technology.

Capacities will need to be developed to access, disseminate and communicate information related to biotechnology for agriculture. For example, Zambia has established a Biotechnology Outreach Society of Zambia (BOSZ) to serve as a platform for an open dialogue among stakeholders on all issues related to biotechnology. The Public Understanding of Biotechnology (PUB) program of the Department of Science and Technology in South Africa is another example of effective communication with the public and various stakeholders (http://www.pub.ac.za/). Organizing learning events such as the workshops organized by the AfricaBio and the Africa Biotechnology Stakeholders Forum (ABSF) are good models for educating journalists and the media.

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 Issues

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, 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.

Further, 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. Capacity Building

Biotechnology applications, utilization and management requires a diverse pool of well trained human resources, infrastructure/facilities for R&D, regulatory and legal policy framework, communication/outreach programs, and technology transfer/management support systems. Capacity building encompasses both institutional and human capacity building. To take advantage of the wide spectrum of biotechnology tools, a country must pursue an integrated and comprehensive approach to capacity building (Figure 1).

5. Fostering Regional Cooperation in Biotechnology in Africa

Institutions in Africa and around the world are accumulating a wealth of experience and an information base on the use and management of biotechnology. African scientists and policy makers can gain from the experiences of other countries and regions. Regional networks and international cooperation are effective in sharing information, scientific and regulatory data, and expertise within specific geographic regions. For example, environmental and food safety risk assessments are expensive, and countries may benefit from each other by sharing regulatory data and information. The advances in Internet technology now enable rapid and free delivery of information. One way to promote the culture of partnership and collaboration is to make it a requirement in the bidding for competitive biotechnology research grants. For example, ASARECA, a sub-regional network in East Africa, is promoting regional collaboration and partnerships through its competitive research grant program.

6. The African Agricultural Technology Foundation (AATF) was launched in June 2004 to broker royalty-free proprietary technologies for use in sub-Saharan Africa. 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. It is estimated that the damage caused by *Striga* on maize annually is $1 billion and affects more than 100 million people in sub-Saharan Africa.

V. 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. Ten 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 and South Africa. The global area under GM crops grew by 20 percent in 2004, illustrating widespread farmer acceptance. However, South Africa is the only country in Africa that is growing GM crops commercially. However, many countries in Africa are utilizing tissue culture in their research and others have GM products in the pipeline.

2. Fifty two of the 53 countries in Africa are not growing GM crops commercially. The seven case studies have revealed a variety of reasons and barriers responsible for Africa's delayed response, including scientific, technical, political and institutional factors and a limited pool of scientific, managerial, legal, regulatory and entrepreneurial talent. Food aid and trade fears are common in southern Africa because of drought from 2002 to 2005 and the need to import food aid or commercial grain imports.

3. The seven case studies have revealed an 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 5 to 7 years (a common estimate in the early nineties), the seven case studies show that it might take a total of 10 to 15 years to develop GM crops, create regulatory systems and field test, and deliver GM cultivars to smallholders.

4. There is a need to develop a national and regional capacity to monitor potential health, environmental, distributive, food safety risks and cross border movement of GM cultivars, especially when neighboring countries do not have functional regulatory systems in place.

5. Bt cotton is a global success story 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 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.

6. GM research should be embedded into African plant and animal 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. While the private sector is increasingly taking over breeding internationally, African universities will have to play a key role not only in training future plant breeders but also in helping government researchers carry out research on orphan crops such as teff, mung beans, cowpea and other crops.

7. 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 heavily in long term training of scientists.

8. Premature success stories. There is a growing number of optimistic scenarios of the projected of GM crops. However, in some cases these are based on a small sample of farmers covering a 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.

9. 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 assessments and supporting institutional innovations such as the AATF and sub-regional GM networks. Special attention should be given to the “small country” problem. 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 such as regional sub-committees on GMOs.

10. 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 ten to twenty 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 logical 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 to raise cereal yields. The quick answer points to expanded investment in GM research in Africa because the global area under GM crops grew by 20 percent in 2004 alone. This is reinforced by increasing donor support for 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 question, the results of the 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 to 15 years): old fashioned plant breeding or GM research? The data show that the past rate of return on plant breeding research by the CGIAR and NARS in Africa is around 20 to 30 percent or higher per year, an impressive statistic (Evenson and Gollin 2003).[27]

The results of the case studies and global experience suggest that African governments should pursue three mutually supporting scientific pathways to crop improvement and raising food crop yields:(1) give immediate and sustained priority to investing in strengthening plant breeding research in African 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 counties in the world and progressively build their own scientific capacity to eventually carry out GM research in Africa. But the evidence suggests that old-fashioned plant breeding research from 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 to 2020

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[27] There is still not enough evidence to generalize about the returns to GM crop improvement research. See the following for some insights:Maredia, Byerlee and Maredia (1999) and Marra, Pardey and Alston(2002).

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ANNEX 1. Biotech Websites

International Resources in Biotechnology

I. General Resources

USAID – Agricultural Biotechnology Support Project II (ABSP II):
http://www.absp2.cornell.edu/

USAID – Program for Biosafety Systems (PBS):
http://www.ifpri.org/themes/pbs/pbs.htm

The Biosafety Information Network and Advisory Service (BINAS),
United Nations Industrial Development Organization (UNIDO):
http://binas.unido.org/binas/

CAMBIA (Australia): http://www.cambia.org/

AfricaBio: http://www.africabio.com

International Service for the Acquisition of Agri-biotech Applications (ISAAA):
http://www.isaaa.org/

The Consultative Group on International Agricultural Research (CGIAR):
http://www.cgiar.org

The Food and Agriculture Organization (FAO): http://www.fao.org/biotech/act.asp

African Biotechnology Stakeholders Forum (ABSF): http://www.absfafrica.org/

African Agricultural Technology Foundation (AATF): http://www.aftechfound.org/

African Journal of Biotechnology: http://www.academicjournals.org/AJB

Biotechnology Trust Africa (BTA): http://www.africabio.com/status/bta.htm

Biosciences Eastern and Central Africa (BECA): http://www.biosciencesafrica.org

USDA – FAS (Biotechnology Group): http://www.fas.usda.gov/itp/biotech/index.html

The World Bank: http://www.worldbank.org/

CABI AgBioechNet: http://www.agbiotechnet.com

The Donald Danforth Plant Science Center, St. Louis, USA:
http://www.danforthcenter.org/

Technical Cooperation Network on Plant Biotechnology in Latin American and the Caribbean
(RedBio-FAO): http://www.redbio.org/

World Technology Access Program (WorldTAP), Michigan State University:
www.iia.msu.edu/worldtap.html

BIO-EARN - http://www.bio-earn.org/why-bioearn.html

Plant Biotechnology Institute for Developing Countries (IPBO), University of Ghent, Belgium: http://www.ipbo.rug.ac.be

Information Systems for Biotechnology: http://www.isb.vt.edu/

International Center for Genetic Engineering and Biotechnology (ICGEB – Biosafety):
www.icgeb.trieste.it/biosafety

AgBioWorld: www.agbioworld.org

AGBIOS: http://www.agbios.com/main.php

II. Biosafety Resources

USAID Program for Biosafety Systems - http://www.ifpri.org/themes/pbs/pbs.htm

AGBIOS - http://www.agbios.com/main.php

ICGEB (International Center for Genetic Engineering and Biotechnology) -
http://www.icgeb.trieste.it/

European Biosafety Association (EBSA) - http://www.ebsa.be/

General Biosafety Resources -
http://www.jiwlp.com/contents/biosafety_resources_net.html

Pew Initiative in Food and Biotechnology - http://pewagbiotech.org/

UNEP-GEF Biosafety Program - http://www.unep.ch/biosafety/

USDA-APHIS – Biotechnology Regulatory Service (BRS) -
http://www.aphis.usda.gov/brs/

NIH guidelines for Research Involving Recombinant DNA Molecules - http://www4.od.nih.gov/oba/rac/guidelines/guidelines.html

University of Tennessee Biosafety website - http://biosafety.utk.edu/plant.htm

Biosafety News - http://www.biosafetynews.com/

Information Systems for Biotechnology – http://gophisb.biochem.vt.edu/

Biosafety Workbook (MSU/IIA web site) ABSP I - http://www.iia.msu.edu/absp/biosafety_workbook.html

Environmental Biosafety Research - http://www.edpsciences.org/journal/index.cfm?edpsname=ebr

Biosafety Journal - http://www.bioline.org.br/by

Essential Biosafety - http://www.essentialbiosafety.info/main.php

The Biosafety Information Network and Advisory Service (BINAS) - http://binas.unido.org/binas/

Cartagena Protocol in Biosafety - http://www.biodiv.org/biosafety/

III. Intellectual Property Rights and Technology Transfer Resources

International Union for the Protection of New Varieties of Plants (UPOV): http://www.upov.int

World Intellectual Property Organization (WIPO): http://www.wipo.int

World Trade Organization (WTO): http://www.wto.org

The International Association for the Protection of Intellectual Property (AIPPI): http://www.aippi.org/aims.html

Association of University Technology Managers (AUTM): http://www.autm.net

Licensing Executive Society (LES): http://les.org

PIPERS Virtual Intellectual Property Library: Gateway to IP offices across the world: http://www.piperpat.co.nz

World Technology Access Program (WorldTAP), Michigan State University: http://www.iia.msu.edu/worldtap.htm

Franklin Pierce Law Center: http://www.fplc.edu

Strategic World Initiative for Technology Transfer: http://www.swiftt.cornell.edu

Intellectual Property Rights in Agricultural Biotechnology – Biotechnology in Agriculture Series, No.28: http://www.cabi-publishing.org/

Intellectual Property Rights in Animal Breeding and Genetics: http://www.cabi-publishing.org/

USDA Plant Variety Protection Office: http://www.ams.usda.gov/science/pvpo/pvp.htm

U.S. Patent and Trademark Office: http://www.uspto.gov

USDA Office of Technology Transfer:
http://www.ars.usda.gov/business/docs.htm?docid=763

IV. Food Safety Resource List

World Health organization – Biotechnology (GM Food) -
http://www.who.int/foodsafety/biotech/en/

FAO/WHO Biotechnology and Food Safety –
http://fao.org/es/esn/food/risk_biotech_en.stm

Codex Task Force on Food Derived from Biotechnology
http://fao.org/codex/ALINORM01/al01_34e.pdf

Organization for Economic co-operation and Development (OECD) Biotechnology –
http://www.oecd.org

Pew Initiative on Food & Biotechnology: http://www.pewagbiotech.org

Royal Society (London). Genetically Modified Plants for Food Use and Human Health – an update. Policy Document 4/02: http://www.royalsoc.ac.uk

National Food Safety and Toxicology Center, Michigan State University –
www.foodsafe.msu.edu

International Food Information Council (IFIC): www.ific.org

Asian Food Information Center (AFIC) - www.afic.org

Gateway to U.S. Government Food Safety Information -

http://www.foodsafety.gov/~fsg/biotech.html

Institute of Food Science and Technology (IFST) - http://www.ifst.org/hottop10.htm

International Food Information Council/FDA. Food Risks: Perception vs. Reality.
http://vm.cfsan.fda.gov/~dms/risk-toc.html

USDA Food Safety Research Information Office
http://www.nal.usda.gov/fsrio/

U.S. Food and Drug Administration - http://www.fda.gov/

USDA Food and Nutrition Information Center
http://www.nal.usda.gov/fnic/

The Pan American Health Organization (PAHO) - http://www.paho.org/

World Organization for Animal Health - Office International des Epizooties (OIE) -
http://www.oie.int/eng/en_index.htm

AgBiosafety - University of Nebraska - http://agbiosafety.unl.edu/

V. Biotechnology Communication Resources

CropBiotech Net – Weekly summary of world developments in agri-biotech for developing countries – http://www.isaaa.org/kc

International Service for the Acquisition of Agri-Biotech Applications (ISAAA) – Knowledge Center - http://www.isaaa.org/kc

Biotechnology Technical Information Services – http://www.tiskmutt.org

AfricaBio - http://www.africabio.org

SEAMEO SEARCA Biotechnology Information Center (Philippines) -
http://www.searca.org/~bic

Public Understand if Biotechnology (PUB) – South Africa. http://www.pub.ac.za/