# Debunking the myths of GM crops for Africa:

# The case of Bt maize in Kenya

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**Summary. --** Empirical evidence from research on *Bt* maize in Kenya puts to rest most concerns raised against GMOs, most importantly that the technology would not respond to the needs of poor farmers, but would be expensive and benefit only agro-business, and that it might decrease biodiversity. However, research results indicate that contamination of local varieties is likely through farmers' seed selection practices and dissemination. Moreover, possible buildup of insect resistance requires careful monitoring and evaluation after release.

*Key words* **--** Africa, Kenya, GMO, *Bt,* maize, risk

## 1. INTRODUCTION

The genetic modification (GM) of plants involves transferring genetic material from a plant or bacterium into a different species, in order to transfer desired traits such as insect resistance or herbicide resistance. GM crops are highly successful in the US, Canada and several other countries, with the area planted to GM crops rapidly increasing, especially for maize (James, 2003a). This unprecedented rapid adoption has been attributed to increased yield, reduced labor and cultivation costs and reduced chemical inputs into the environment. However, GM crops have generally not been well received in Europe, mostly because of consumers' concerns about possible harm to human health, damage to the environment and unease about the 'unnatural' status of the technology (Nuffield Council on Bioethics, 1999). Moreover, Europe has already surplus production, so yield enhancing technologies are not that interesting and a strong farmers' lobby would rather protect its markets from external competition. Expected benefits to the European consumer are also small (Demont and Tollens, 2001). Europe has accepted the precautionary principle (also included into the Cartagena protocol): where the possibility of harmful effects on health is identified but scientific uncertainty persists, provisional risk management measures necessary to ensure the desired high level of health protection may be adopted (McMahon, 2003). Although many GM products are now accepted in food and pharmaceuticals in Europe, because of high risk perceptions and low expected benefits associated with GM crops, the interpretation of the precautionary principle has in practice led to a *de facto* moratorium on producing them,

Africa is caught in between: should it embrace the technology to help feed its hungry people, or rather protect them from its possible dangers? The potential benefits of the technology are substantial. The technology is likely to increase yields and this for a continent that has benefited little from the green revolution (Evenson and Gollin, 2003). Moreover, it could increase food security by increasing yields of food crops but also by reducing yield variability and risk, and this for the only region in the world where the number of malnourished children has been increasing since 1970 (Rosegrant *et al.* 2001, p. 4), and is expected to rise even over the next 20 years (*ibid.,* p.76). Finally, the technology is embedded in the seed and is easy to disseminate, and this for a region where extension services have collapsed and market liberalization is emphasizing an increased role for the private sector (De Groote *et al.*, 2003b).

Despite these potential benefits, deployment of GM crops in Africa is controversial, and many concerns have been raised (Orton, 2003; Nuffield Council on Bioethics, 1999; Pinstrup-Andersen and Schiøler, 2000). Some of these concerns are general, including food safety and ethical concerns, and negative effects on trade with countries opposed to GM crops. Others are specific to developing countries, especially Africa, in particular that they are not in the interest of the small-scale farmer, that they are dangerous to the environment, and that the institutional framework is not in place for their deployment (Table 1). GM crops would not be in the interest of small-scale farmers because they do not respond to the farmers' priorities, their traits would not respond to a particular demand, and their seed would be expensive. On the contrary, GM technology would only be beneficial to the agro-business and seed companies, who can protect their interests through Intellectual Property Rights (IPR) and terminator genes.

Farmers would increasingly depend on the use of extra inputs such as herbicide and purchased seed of the new varieties, while loosing the biodiversity of their landraces. Moreover, GM crops are thought to pose serious environmental risks through gene flow into related weeds and local varieties, and from negative effects on non-target organisms. Institutionally, African countries might not be adequately equipped with the appropriate bio-safety regulations to make an informed choice, and lack democratic procedures through which poor consumers can express their choice.

## 2. ENHANCING THE DEBATE THROUGH SCIENCE AND PARTICIPATORY RESEARCH: THE IRMA PROJECT

### *(a) Principles*

In this paper, we argue for a more balanced view and a science-based discussion starting from following principles. First, biotechnology, and GM crops in particular, have high potential in improving crop productivity and actual production, yield stability, and the nutritional quality of major crops in Africa in ways that would not be possible using conventional technology (Nuffield Council on Bioethics, 1999). Second, these benefits should be carefully evaluated against the concerns formulated above. Third, African farmers and consumers have the right to choose their own technologies, based on the best available knowledge (Pinstrup-Andersen and Schiøler, 2000). Finally, to make informed choices possible, scientists need to experiment, adapt and test GM technologies in Africa, with all precautions in place and using participatory methods, so poor farmers and consumers are not denied a chance to improve their livelihood due to an academic debate in which they cannot participate. Through careful experimentation, the necessary capacity and expertise will gradually be developed in the areas of environmental impact assessment, bio-safety protocols, regulations and legislation to handle GM crops, and to assess impact. This hands-on experience makes it possible to communicate with farmers, consumers and policy makers, to raise awareness, and to equip farmers to make an informed choice by letting them evaluate the technology and, if appreciated, trying and adapting it in their fields.

Based on these principles, the International Maize and Wheat Improvement Center (CIMMYT) and the Kenya Agricultural Research Institute (KARI), with financial support from the Syngenta (previously Novartis) Foundation for Sustainable Agriculture, launched the Insect Resistant Maize for Africa (IRMA) project in 1999. This project aims to develop maize varieties resistant to stem borers, a major maize pest in Africa, using both conventional breeding and biotechnology, and combining the best available science, bio-physical as well as social.

*(b) Development of the IRMA project*

When CIMMYT approached the (then) Novartis Foundation, several elements were agreed upon: transformed plants would only carry the gene of interest but no selectable marker genes such as herbicide or antibiotic resistance, CIMMYT would only test and deliver transgenic crops in countries that have appropriate biosafety legislation or regulations, and only genes in the public domain would be used. The project is being implemented initially in Kenya, from where the results and experiences will be available to other interested African countries. Kenya was selected because of the importance of maize and stem borers in the country, the decline per capita maize production, and the existence of a regulatory and policy environment with respect to GM crops.

Formally, the objectives of the IRMA project are to (1) develop insect resistant maize varieties for the major stem borer species associated with the major maize cropping systems, (2) establish procedures for providing insect resistant maize to resource poor farmers, (3) assess the impact of insect resistant maize varieties in maize farming communities, (4) transfer technologies to develop, evaluate, disseminate, and monitor insect resistant maize varieties, and (5) plan, monitor, and document processes and achievements for dissemination to the Kenyan public and other interested developing countries.

Kenya is well positioned and prepared to utilize the novel technology involving genetically modified organisms (GMOs). Kenya has the necessary biosafety policies in place and has experiences with other genetically modified crops. A transgenic sweet potato developed for resistance to sweet potato feathery mottle virus (SPFMV) was field tested at four locations; a cassava with resistance to the white fly is being tested at KARI Kakamega, while an approval for Bt cotton was recently granted. Kenya also has facilities like biosafety laboratories, a biosafety greenhouse and an open quarantine field site, all run by Kenyan scientists trained in biotechnology and in place to position Kenya at the forefront of research in eastern Africa. After the principal agreement, a first meeting between the different organizations was held in Nairobi in June 1999, followed by a planning workshop in August 1999 that brought together scientists from KARI, CIMMYT and the Novartis Foundation for Sustainable Development. They consulted, shared information and planned the development and deployment of insect resistant maize in Kenya, using both conventional breeding techniques as well as biotechnology and genetic transformation (Siambi *et al.*, 2000), and produced a strategic work plan for the first five-year phase of the project (KARI and CIMMYT, 2000). At the end of this phase, a preliminary assessment of the technology can be made, based on the available research, including biotechnology, breeding, entomology, diagnostic research and impact assessment. In this paper, the research on supply of and demand for Bt maize will be synthesized, together with an analysis of the enabling socioeconomic environment as well as the natural environment for which it is intended. We will show that most objections to GM crops are not supported by the available evidence, although some concerns still remain, in particular the development of insect resistance and gene flow into local varieties.

## 3. THE DEMAND FOR INSECT RESISTANT VARIETIES

### *(a) Maize in Kenya*

All available data and research results indicate that the demand for *Bt* maize in Kenya is likely to be high. Maize is by far the most important food crop in Kenya, being grown as both a subsistence and a commercial crop. It is planted on 1.5 million ha, or 30% of the arable land. The average annual production over the past 5 years was 2.4 million tons (FAOSTAT), or, for a population of 31 million, 79 kg/person. Over the last forty years, agriculture in Kenya has undergone major changes. After major progress in productivity during the 1960s and 1970s, maize yields and production has stagnated at 1.5 ton/ha, so production per capita is decreased. Since per capita consumption in Kenya is estimated at 103 kg/person (Pingali, 2001), increasing quantities of maize need to be imported. Heavy government involvement was partly blamed for this deficit, and agriculture went through an ambitious, donor-driven liberalization process, in particular of maize marketing (prices and movements), seed production (with an end to government monopoly), and fertilizer markets (removal of import taxes and restrictions). However, the effect of liberalization was limited (De Groote *et al*., 2003b). Factors include the limitations of maize marketing (with government interference and high price volatility), the *de facto* oligopoly in maize seed production (Nambiro *et al.,* 2004), and the poor state of infrastructure, in particular roads and communications. To solve the threatening food crisis, markets still need improvement, but at the same time new, adapted technology is urgently needed.

In Kenya, six major agro-ecological zones can be distinguished for maize production. Going from East to West, we first have the Lowland Tropics (LT) at the coast, followed by the Dry Mid-altitudes and the Dry Transitional (between mid- and highland) zone. These three zones are characterized by low yields (below 1.5 ton/ha) and, although they cover 29% of maize area in Kenya, they only produce 11% of the maize. In Central and Western Kenya we find the Highland Tropics (HT), bordered at the West and East by the Moist Transitional (MT) zone. These zones have high yields (more than 2.5 t/ha) and produce 80% of the maize in Kenya on 30% of the country's maize area. Finally, around Lake Victoria, we find the Moist Mid-altitude (MM) zone with an average yield of 1.44 ton/ha that covers 22% of the maize area and accounts for 9% of the national maize production.

*(b) Farmers, maize and stem borers*

To judge if insect resistant maize varieties would respond to a need of small-scale farmers, the

IRMA project organized participatory rural appraisals (PRAs) in 43 villages spread over the different agro-ecological zones. More than 900 farmers participated in group interviews and documented which varieties they grow and why, and expressed the constraints and pest problems they faced (De Groote *et al.*, 2001). Most farmers grow local varieties, except for the high potential zones. The two major criteria for variety selection are early maturity and yield. Three other traits are generally important: tolerance to drought, field pests and storage pests. Constraints in maize production experienced by the farmers differ substantially between zones. Pests problems rank high in the low-potential zones (between first and third constraint), but are only of medium importance in the high potential zones (ranking fifth or sixth), after cash constraints, lack of technical know-how and extension, and expensive seed, often hard to obtain and of poor quality. The two major pest problems maize farmers encounter are stem borers and weevils (storage pests), which rank in the top three in all the agroecological zones.

After establishing that stem borers are a major constraint to maize production, an attempt was made to quantify the crop losses they cause. Based on estimates obtained from 1400 farmers in a 1992 nation-wide survey (Hassan, 1998), maize yield losses due to stem borers could be estimated at 12.9% of the potential yield (De Groote, 2002). Crop losses were also measured in 150 farmers' fields during four seasons starting in 2000, using a simple experimental design in which half of each field was protected with a systemic insecticide, and the other half was left unprotected (De Groote *et al.*, 2004). The weighted average yield loss for all zones was calculated at 13.5% of the potential, ranging from 11% in the highlands to 21% in the dry areas. Total losses were estimated at 0.41 million tons, valued at US$ 79 million. These results were combined with data on stem borer species prevalence in a GIS based model to calculate losses per zone per species (Figure 1) (De Groote *et al.,* 2003a). The results show that three quarters of the losses occur in the high-potential zones. Three species are responsible for 98.9% of the losses: *Busseola fusca* (63%, dominant in the highlands), *Chilo partellus* (29%, dominant in the lowlands), and *Sesamia calamistis* (7%).

Based on the importance of maize as a food and cash crop, farmers' perceptions on the importance of stem borer, and crop loss assessment, we can conclude that there is a large demand for the insect resistant maize, in particular against the three major stem borer species and against storage pests.

## 4. THE SUPPLY SIDE

### *(a) Development of Bt technology*

Conventional breeding against stem borers in maize has proven to be quite complex, but biotechnology has produced a very important alternative: Bt maize. Bt maize is the common term for maize that is genetically engineered to contain a gene from the soil dwelling *Bacillus thuringiensis (Bt)* that is responsible for the production of delta-endotoxins. These toxins have a crystalline form, hence the terms *cry* gene. Several of these *cry* genes have been found to offer a high level of control against specific leptidopteran pests. Using modern molecular biology tools, these genes are modified to enable their stable expression in plants following their introduction using either the gene gun (Koziel *et al.* 1993) or *Agrobacteruim tumefasciens* (Ishige *et al.* 1996). Upon ingestion by susceptible stem borers, proteins are released from the crystal. These protoxins are then activated by the insect's gut proteases to generate an active protein (Gill *et al*., 1992). The Bt toxins are active against lepidopteran pests but are not toxic to mammals, in particular humans nor livestock. Therefore, Bt maize offers farmers an effective and practical option for reducing stem borer damage in maize. Studies elsewhere have demonstrated the high effectiveness of *Bt-maize* in controlling damage by temperate stem borers (Koziel *et al.*, 1993). The use of *Bt-maize* could reduce the heavy reliance on pesticides for stem borer control.

*(b) International developments*

The first commercially available Bt gene, was *cry1Ab*, which was introduced into the commercial maize market in 1996 and has provided effective control against several of the primary pests of maize, principally the stem borers (James, 2003a). The successful performance of Bt maize and other GM crops (in particular herbicide resistant maize and soybeans) has resulted a rapid adoption. By 2003, 67.7 million hectares were planted with GM crops (21% in maize), and an increasing proportion (now 30%) is being grown in developing countries. In Africa, South Africa is the only country where Bt maize is commercially grown, including 87,000 ha planted to white maize used for food in 2003 (James, 2003b). Different studies by national and international organizations show no demonstrated toxic or nutritionally deleterious effects resulting from the consumptions of foods derived from GMOs, although the long-term effects still need to be studied (FAO, 2004).

*(c) Development of Bt technology for Kenya*

CIMMYT's Applied Biotechnology Centre (ABC) in Mexico, started transforming maize (in particular a line developed in Africa, CML 216) in the early 1990s using the biolistic method. In this method, a "gene gun" is used to bombard gold particles coated with plasmids containing a modified version of one of four *cry* genes. The modification facilitates stable expression of these genes in maize plants. Earlier transformation events contained selectable markers such as herbicide or antibiotic resistance to identify putative transformation events. A successful transfer of a gene, with or without markers, is called an "event". Products are now available that do not contain selectable markers and are referred to as "clean events", and it is these products that are being proposed for release in Kenya following appropriate testing. (KARI and CIMMYT, 2001).

The placement of *cry* genes into the maize genome is random, so molecular characterization, including mapping, is required to determine the location of the insertion and the number of copies of the gene that were inserted. Based on evaluations in a biosafety greenhouse, the events are planted to ensure they follow expected inheritance pattern, as well as to quantify protein expression levels in various tissues and to ensure that the insertion has not adversely affected the agronomic performance of the maize line. Most events developed at CIMMYT were found to express Bt toxins only in the embryo and not the endosperm (the part usually consumed, accounting for 70% of the grain weight) and toxin levels there were only 20% of levels observed in leaf tissue (KARI and CIMMYT, 2001; KARI and CIMMYT, 2002). Food safety studies by US government agencies have shown that Bt toxins do not bind to human intestines and are digested readily in humans and livestock. Therefore, the low levels of toxin expressed in whole grain does not represent any food safety hazard for humans or livestock.

At the outset of the project, the biosafety framework in Kenya was sufficiently developed to process the application to import leaf tissue from Bt maize, after inspection of the research facilities by the National Biosafety Committee (NBC) an the Kenyan Plant Health Inspectorate (KEPHIS). After the necessary permits were obtained, two batches of Bt maize leaves were imported from CIMMYT's biosafety greenhouse in Mexico. The first trail took place in January 2001, with maize leaves containing several single gene events, one per leaf. In leaf bioassays, larvae of the different stem borer species were put on Bt maize leaves. The efficacy of the Bt toxins in controlling the different stem borer species was determined based on larval mortality and leaf area consumed by the larvae. Both showed that *cry* 1Ab and *cry*1Ba genes are very effective against the *Chilo* species (almost 100% mortality after 5 days), but not as good against *Busseola fusca* (60%) (Figure 2). In the second trial, which took place in December 2002, different events were combined in the same plant. The results showed that combining either the *cry1Ac* or *cry1Ba* gene with *cry1Ab* in the same plant enhanced the level of control for *Busseola fusca* without decreasing the effect on *Chilo partellus* and other species, although complete control of *B. fusca* was not achieved (Figure 3) (Mugo *et al.*, 2004b).

The promising genes were further developed into "clean events" that do not contain genes for antibiotic resistance. An open quarantine site was constructed and an application was filed to bring in maize seed of clean events to be tested in the open quarantine field site. The National Biosafety Committee, however, requested that the tests first be held in a Biosafety Level II Greenhouse (BSGH) facility. Biosafety levels range from 1 (1= very low level, to work for example with common bacteria) to 4 = very high (for working with highly contagious diseases like the Ebola virus). Bt maize in Kenya is thus placed at a medium-low category of biosafety. Key features of the level II greenhouse are the pollen screen that prevents pollen from escaping and crossing into nearby maize, and the security. This biosafety II greenhouse (BSH) was built at KARI's Biotechnology Centre, and inspected and approved by the Kenya Standing Committee on Imports and Exports (KSTCIE) in May 2004. The application to import maize seed containing the Bt genes *cry*1Ab and *cry*1Ba and was approved by the NBC in May 2004, the permit to introduce the seeds was approved by KEPHIS in late May, and the seeds from eight events were planted and screened in the BSGH during June 2004. The next stage of testing will involve Bt-maize plants being grown in the open quarantine site where additional testing will be conducted to produce the documentation required for on-farm testing and commercial release.

*(d) Impact assessment*

The results from the supply side indicate that an efficient Bt gene against the major tropical stem borers (*Chilo spp*. and *Sesamia*) can be found but additional genes will be required to control *B. fusca.* This information was incorporated into an economic surplus model to calculate the potential benefits of the technology, based on geo-referenced data from different sources, including the production data and crop loss data from Figure 1. It was further assumed that farmers would adopt the *Bt* maize varieties proportionate to the current adopt rates of improved varieties, which range from 40% in the low potential to 90% in the high potential areas (Hassan, 1998), depending on the effectiveness of the *Bt* genes to the stem borer species in their zone.

Two scenarios were considered. First, assuming the new *Bt* maize varieties are efficient against all stem borers, and two-thirds of farmers who previously adopted improved varieties will also adopt *Bt* maize varieties. Annual production is expected to increase by 250,000 ton (+9.4%), at a value of US$ 48 million. Second, if no resistance against *B. fusca* is found, farmers in the high potential areas are unlikely to adopt the new varieties. In this scenario, production would only increase by 29,000 tons (+1.1%), valued at US$ 5.4 million.

Total benefits of the projects can be calculated using the conventional economic surplus model, which takes into account that prices and demand adjust to the extra production, so that part of the benefits goes to the consumers. (Alston *et al.*, 1998). Benefits are compared to the project's costs, about US$ 1 million per year over 10 years (a discounted total of 6.76 million in 1999 dollars. In the first scenario, compete control of all stem borers, the yearly benefits reach $49 million per year, of which two thirds go to the consumers (Table 2). Discounted benefits over 25 years reach $ 208 million, compared to discounted costs of $ 6.76 million, or a very good benefit/cost ratio of 31. In this scenario, higher impact is expected from the high production moist-transitional zone. In the second scenario, with no resistance to *B. fusca,* the technology would only be effective in the low potential areas, and adoption rates would be fairly low. Yearly benefits only reach $ 5 million, or $24 million over 25 years, with a modest benefits/cost ratio of three, although these benefits would be concentrated in the low potential areas, and benefit the poorer farmers.

## 5. THE ENABLING ENVIRONMENT:

The above results strongly indicate that there is a potentially large demand for, as well as an expected supply of good and efficient Bt maize varieties. However, supply and demand still need to find each other in the market within the existing regulatory framework. For the market to function properly, it is important that an enabling environment is fostered (Tripp, 2003), including socioeconomic and political factors (Smale and De Groote, 2003). The most important factors in this environment are the regulatory system, the distribution or seed system, and the attitude of the different stakeholders towards this new technology.

### *(a) The regulatory system*

A first analysis of the regulatory system (Ely *et al.*, 2002) found that it is becoming increasingly efficient in handling biosafety applications, partially due to the experience gained through the IRMA project. The development of biosafety regulations started in 1987 when the then Minister of Research Science and Technology set up a committee under the National Council for Science and Technology to determine the priorities for research in biotechnology. This committee, then named the National Advisory Committee on Biotechnology Advances and their Applications (NACBAA) and consisted of directors from different research institutes (such as KARI, the Kenya Intellectual Property Institute, and the Kenyan Bureau of Standards), recommended to the government that the NCST develop a policy on biohazards and ethics in biotechnology (Thitai *et al.*, 1999).

In 1994, the Kenya National Environment and Action Plan, developed by the Ministry of Environment and approved by the Cabinet, made the following recommendations: i) to establish a National Commission on biotechnology and biosafety, ii) to formulate a scientific criteria for the safe use of GMOs including methods or hazard identification and exposure assessment before they are released into the environment to monitor the organism, genetic material and processes exposed to GMOs, iii) to make prior informed consent a pre-requisite for all field testing, and iv) to formulate a biosafety policy and regulations.

In 1997, KARI produced draft guidelines for biotechnology and biosafety research within the institution, and established an Institutional Biosafety Committee accordingly. In 1998, the National Council for Science and Technology (NCST) produced a draft of "Regulations and Guidelines for Biosafety in Biotechnology for Kenya" (National Council for Science and Technology, 1998) which identified the NCST as the competent authority in biosafety matters. The guidelines provided a base for the establishment, under the NCST umbrella, of the National Biosafety Committee (NBC), in which different ministries, research institutes and farmer organizations are represented. The NBC encourages the establishment of Institutional Biosafety Committees (IBCs) within the relevant institutions. The NBC also has power to appoint task forces and to co-opt any individual it considers necessary for more efficient performance of its functions. In 1999, with the support of the UNEP/GEF Biosafety Enabling Activity, the NCST produced the "Kenya Biosafety Framework" (Thitai *et al.*, 1999) based on an assessment of the status of biotechnology and biosafety in the country. In 2000, the National Biosafety Strategies and Action Plan (NBSAP), published by the Ministry of Environment and Natural Resources, that identified biosafety as an important area that required support for its advancement. On $15^{th}$ May, 2000, during the Fifth Conference of Parties to the CBD, the President of Kenya signed the Cartagena protocol on Biosafety. Kenya took part in the round table conference of Ministries held in May 2000 during the Conference of Parties 5 (COP) and supported the need for providing assistance to developing countries for biosafety capacity building activities. Also in 2000, the National Environment Co-ordination and Management Act was enacted by parliament. This Act also emphasized the need to set regulatory framework for biosafety issues.

Within those acts and preparatory work, Kenya is now implementing the biosafety framework under the UNEP/GEF support project. To this end, a draft Biotechnology and Biosafety Policy, draft Biosafety Bill, and draft Biosafety Regulations have been developed, and the draft Biosafety Bill is currently (mid-2004) under review by the office of the Attorney General to be tabled at Parliament later this year. The Biosafety Regulations cover areas of research and development involving the release of GMOs and all aspects of recombinant DNA technology and use of biological products derived through genetic modification. They specify that NBC may allow the importation of biotechnology products, including GMOs, under the national quarantine system, after assessing the adequacy of the tests done on the products in the country of origin. Containment facilities and other safeguards are required when carrying out work on GMOs. The guidelines are implemented by the different key regulatory agencies: the Kenya Plant Health Inspection Services (KEPHIS), the Department of Veterinary Services, the Kenya Bureau of Standards and the Public Health department.

In the case of Bt maize, as mentioned above, the applicants (KARI and CIMMYT) first needed to make an application to KARI's IBC, to introduce Bt leaves or seed into Kenya. This application detailed the materials to be introduced, the research being proposed, the facilities to be used, the personnel to be involved, and the biosafety measures that will be taken during the introduction and the research. Assuming all information provided is adequate for risk assessment, the committee submits the application to the NBC, who sends out the application to a team of experts for review. If that is satisfactory, the NBC approves the application, and stipulates the conditions under which the research is to be carried out, in particular biosafety facilities, guidelines, and appropriate skills of all personnel involved. If all conditions are satisfactorily addressed, including certification of the biosafety facilities by KEPHIS, the applicants can then apply for a plant importation permit from KEPHIS. KEPHIS also oversees the research activities on a regular basis, including the entry of the GM material into the country, accompanying the material from the port of entry to the research site, and appropriate disposal of all GM material at the end of the evaluation.

*(b) Other factors in the enabling environment: seed systems, IPRs and rural finance*

The seed sector is of particular importance to bring biotechnology products to the farmers (Tripp, 2001). An analysis of the sector, after visiting all seed companies and regulatory agencies, found that the liberalization of the seed sector (starting in the 1990s) had increased the number of companies and varieties dramatically, but that the overall market was still dominated by one company and a few varieties. Moreover, the amount of improved maize seed sold has not increased over the years. This was also confirmed by the PRA results, a survey of seed distributors and a seed sector study in Transnzoia district (Nambiro *et al.*, 2004). From the PRAs we know that farmers commonly recycle their own seed, including hybrids. Farmers often mark selected plants in the field for seed recycling, in particular in drought-prone areas for early maturity. Therefore, they are likely to lead select for plants containing the Bt gene, since plants affected by stem borers are easily recognized, and thus preserve the trait on-farm.

Several seed companies, through the annual stakeholders' meetings, have expressed strong interest in producing and distributing *Bt* maize seed. They would, however, prefer to transform and develop their own varieties. They are particularly concerned with how much it would cost to transform their varieties, and which Intellectual Property Rights (IPRs) are involved. IPRs, designed to provide and to protect economic returns to research to stimulate innovations, also increase the cost of using a new technology by other firms, in fees as well as in increased transaction costs for obtaining information and settling disputes. To assure that the technology developed will be accessible to farmers without excessive costs, the IRMA project commissioned a review of IPRs, including a Freedom to Operate (FTO) review. The study concluded that no patents had been filed in Kenya concerning the Bt technology, and therefore no patent restrictions are expected in that country (SwiftReviews, 2001). Moreover, when a company files for a patent in one country, it only has a limited number of months to file for this patent in another country. Since all patented technologies under consideration by the IRMA project have been patented for longer periods, patents can no longer be filed in Kenya.

During the PRAs, farmers also identified the lack of cash and of access to credit as one of the major constraints to using improved seed or other inputs A study of the credit sector in Western Kenya showed that small scale farmers no longer have access to formal agricultural credit, but are increasingly turning to indigenous informal finance groups (Owuor *et al.*, 2004). Half of the credit obtained from these groups is used in agriculture, and it doubles the use of improved seed and fertilizer. Improving the credit situation of small-scale farmers, through support of the informal finance sector, is likely to substantially improve adoption of new varieties, including Bt maize.

*(c) Consulting with consumers and other stakeholders*

To gauge the awareness and attitudes of the consumers towards GMOs, 604 consumers were interviewed at different points of sale (in supermarkets, posho mills, and kiosks) concerning their awareness and attitudes toward GMOs. Almost half of the respondents were aware of GM crops; people were appreciative of their benefits, but many worried about potential negative effects on human health and the environment, especially on local plant varieties (Kimenju *et al*., 2004).

Regular discussions with farmers, consumers and institutions during annual stakeholders meetings, group discussions and other forums, reveal that farmers are generally very enthusiastic about Bt maize, while scientists, consumers and the general audience are cautiously optimistic (Mugo *et al.,* 2001; Mugo *et al*., 2004a). Interestingly, upon learning that the Bt gene is dominant (and can therefore be recycled) farmers requested that the project also consider transformation of their local varieties.

To bring the technology to farmers in the low-potential areas, where adoption rates are low and where the supporting institutions are weak, a substantial effort through agricultural extension, farmer associations and NGOs active in rural development, would be needed. Once the farmer has access to the technology through improved OPVs or transformation of local varieties, farmers will be able to reproduce it on-farm in a sustainable way. Given the high relative crop loss levels and the high levels of poverty in this zone, the impact of *Bt* technology can be high here, even without genes against *Busseola fusca*.

## 6. THE NATURAL ENVIRONMENT

Concerns of the potential effect of *Bt-maize* on the environment need to be addressed by carefully designed studies and experiments. In particular, these studies need to address the effect of *Bt* maize on non-target organisms and on the development of insect resistance, as well as the extent and effect of gene flow, especially on bio-diversity.

To study the potential effects of the *Bt-maize* technology on target and non-target arthropods in maize-based cropping systems in Kenya, field collections of these organisms were established, using different trap types to determine the diversity and relative abundance of target and non-target organisms in the five major maize agroecologies. Bi-weekly collections from farmers' fields were made and all insects within each sample were classified to genus and a dry collection of specimens for each family of insects was established. In addition, a digital database for the specimens was developed, including a digital photograph and the coordinates of the location, to enable researchers in other research stations to classify specimens in the future to at least family to facilitate monitoring to document the impactof  Bt-maize on arthropod diversity and abundance.  This information is now being used to identify groups of arthropods that my be adversely affected by Bt maize, to quantify the impact of Bt maize on these non-target species in the greenhouse, prior to field testing, and serve as a baseline for impact assessment studies to ensure the technology is not adversely affecting arthropod diversity while at the same time providing stem borer control (Songa *et al.* 2002).

Another major concern regarding the use of Bt-maize is the development of insect resistance.  The strategy currently being used in developed countries is the concept of refugia whereby a non-Bt host crop is within close proximity (<800m) of the Bt-crop to ensure that if a moth emerges from a Bt-maize field that it will intermate with a wild-type moth from a non-Bt crop. This strategy is designed to prolong the development of highly resistant biotypes of the target pest by ensuring resistance alleles are maintained in a heterozygous state. In the USA, the area planted to a refuge should be 20%, but it is not reasonable to expect farmers in developing countries will plant a refuge given the amount of extension required to communicate the concept of refuge and the potential loss in production by planting a refuge. For these reasons, the IRMA project established research plots to determine the effectiveness of different alternate hosts that are commonly found in farmers' fields and their effectiveness in providing and adequate refugia in each of the two main maize cropping seasons. Farmer surveys conducted from 2001 to 2003 revealed that in most maize-growing districts of Kenya an adequate natural refuge was available within the mixed cropping system in order to delay the development of stem borer resistance to *Bt* toxins. In some commercial maize areas, however, this is not the case and therefore additional extension effort must be made to train farmers on the importance of refugia so as to impede the development of resistant biotypes.

Gene flow is the third major environmental concern associated with the use of GM crops and is particularly important for centers of origin, such as Mexico, the center of origin for maize. In Kenya, maize was introduced fairly recently so biodiversity, although not to be ignored, is less important. Moreover, no wild relatives of maize are found here, so the Bt gene cannot cross into wild species. However, since the Bt gene is dominant and maize is a cross pollinating crop, gene flow can be a problem for farmers who do not wish to use Bt maize. To better understand how to manage gene movement, gene flow studies were conducted in Kenya using yellow maize, since yellow grain color is a dominant trait, as is the Bt gene. A square plot of 1 $m^2$ was planted in a field of white maize and the rate of crossing was established in the different directions.

Although there is a strong directional effect associated with the predominate wind direction, 75% of the maize pollen was found to fall within 10m of the source plant and less than 0.2% of crossing is found at 50m from the source, due to the weight of maize pollen.

Farm surveys and PRAs also indicate that intra-specific biodiversity in maize does not generally decrease with agricultural intensification (De Groote *et al.*, 2002). In the high-potential areas, farmers have adopted more improved varieties at the cost of local varieties, but the number of varieties has not decreased, a result confirmed by the calculation and analysis of different biodiversity indices.

## 7. CONCLUSIONS

The results of the different studies conducted by the IRMA project clearly show that most objections to Bt technology are based on misconceptions due to the absence of sound scientific studies. The results reported here allow us to systematically discuss the concerns that were presented in Table 1. On the general issues, consumers in Kenya do not have undue concerns about food safety or ethical concerns about scientific procedures perceived to be unnatural, and that trade would not be a problem. It has, however, become very clear that Bt maize responds to a problem perceived by farmers as very serious, and farmers are likely to adopt it. Without patents in Kenya, and the project's policy on IPR, local seed companies are likely to embrace the technology and benefit from the project's research, while international companies have no apparent comparative advantage. The price of Bt maize seed is not expected to be much higher than conventional maize seed. Although total benefits per farm would be higher in the high-potential areas, the benefit per unit area would be substantially higher for the low-potential areas. Although adoption rates for improved maize varieties are lower for low-potential areas, the dominance of the *Bt* gene would allow for its recycling and its incorporation into local varieties.

With respect to the environment, there are no wild relatives of maize in the country, so no gene flow into weeds is expected. No effect on non-target organisms can be measured so far, but the project is putting substantial effort in cataloguing and analyzing arthropod diversity for monitoring purposes in the future. Preliminary results suggest that the impact of Bt maize will likely be favorable as it will reduce the application of broad-spectrum insecticides. Insect resistance can be managed through the availability of existing refugia due to the mixed-cropping system employed by most farmers in Kenya. Regions where refugia are not adequate will be the focal point for training of extension and farmers alike. Since the development of maize agriculture has not led to a decrease in biodiversity, the development of Bt maize is also unlikely to decrease biodiversity. Moreover, farmers' recycling methods are likely to lead to a recycling of these plants which have the gene, leading to transformation of local varieties, an actual increase in biodiversity.

Institutionally, Kenya has demonstrated that it can develop a biosafety regulatory network and is capable of handling complicated applications. Although no formal systems exist to incorporate the opinion of the general consumer, the project has demonstrated that it can use participatory methods to work with farmers as well as consumers, and with the stakeholders at large. So far, these first efforts indicate enthusiasm from farmers and acceptance of consumers and other stakeholders, although with some reservations. These reservations concern the potential damage to the environment and local varieties, and need to be addressed through providing scientific information of the pros and cons and raising public awareness.

However, three major concerns remain. First, the Bt gene can easily flow into local varieties, in particular since it is a dominant gene, a process that would be very difficult to stop.

However, local varieties should not be seen as museum pieces, since farmers are continuingly modifying them to incorporate new desired traits. The "irreversibility" of the technology is an important consideration and for that reason this project has been very thorough in characterizing potentially adverse environmental effects. The project has also established a collection of local varieties in the national gene bank before any *Bt* material is released. Second, resistance may develop in stem borer species such as *Busseola fusca* that are not completely controlled with existing Bt genes and events. Therefore, monitoring for insect resistance is now being started to determine the rate of resistance development for *Busseola fusca* using existing events within the BSGH. The third concern is the potential for adverse affects on non-target organisms. Baseline studies to characterize non-target arthropods have been completed in the major agroecological zones, and studies to investigate the effects of Bt maize on non-target organisms will soon start to characterize the impact on arthropods that face the greatest risk of being adversely affected by Bt maize. Monitoring of farmers fields once Bt maize is introduced will be important for both resistance management and impact studies for non-target organisms.

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Table 1. *Concerns regarding the deployment of GM crops in Africa*

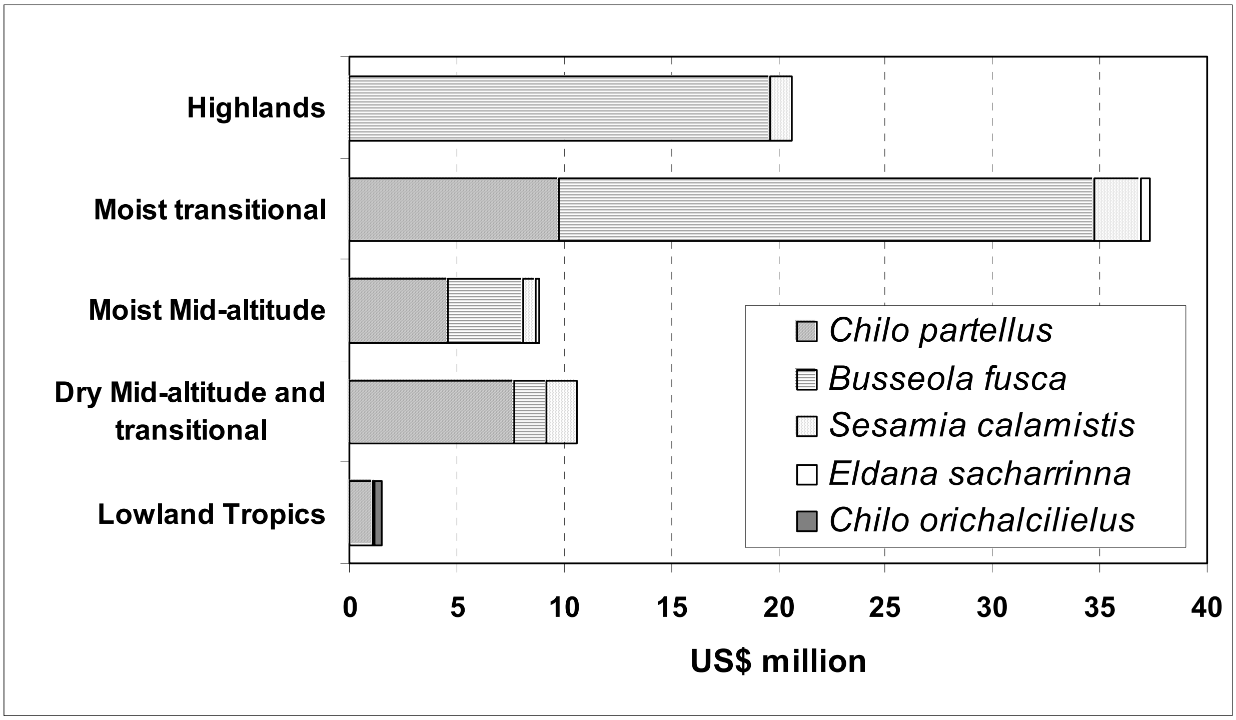
| Specificity | Category | Concerns about GM food and crops |
|---|---|---|
| General | Food safety | - GM food not safe for human consumption |
| | Ethics | - Genetic engineering is tampering with nature |
| | Trade | - Negative effect on trade with countries opposed to GM crops |
| Developing countries and Africa | Benefit to farmers | - GM crops do not correspond to priorities set by African farmers<br>- there is no demand for GM traits expressed by farmers<br>- high cost of technology<br>- not beneficial to small farmers,<br>- beneficial to seed companies and multinationals |
| | Environment | - insect resistance can develop<br>- GM genes can flow into weeds and local varieties<br>- potential effect on non target organisms<br>- decreased biodiversity |
| | Institutional: | - African countries have insufficient biosafety regulations<br>- there is insufficient participation in decision making from poor farmers and consumers |

Table 2. Impact assessment - Economic Surplus Model

| | | | Elasticities | | Economic surplus (benefits) | | | Costs | Benefit/cost | Internal Rate of return |
|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | period | discount rate | supply | demand | producer | consumer | total | (discounted) | ratio | (IIR) |
| A | 1 year | 10 | 0.8 | -0.4 | 16.3 | 32.7 | 49 | | | |
| | 25 years | 10 | 0.8 | -0.4 | 69.5 | 139 | 208.5 | 6.76 | 31 | 83 |
| B | 1 year | 10 | 0.8 | -0.4 | 1.9 | 3.8 | 5.7 | | | |
| | 25 years | 10 | 0.8 | -0.4 | 8.1 | 16.1 | 24.2 | 6.76 | 3.6 | 30 |

Source: De Groote et al. (2003)

Figure 1. Value of crop loss in maize due to different stem borer species in Kenya, by agroecological zone (in US$ million)




Source: De Groote *et al.,* 2003.

Figure 2. Percent larval mortality for the three most important stem borers species in Kenya after feeding for five days on a leaves containing different events (combination of different *Cry* genes with promoters) and a non-GM control (variety H614).

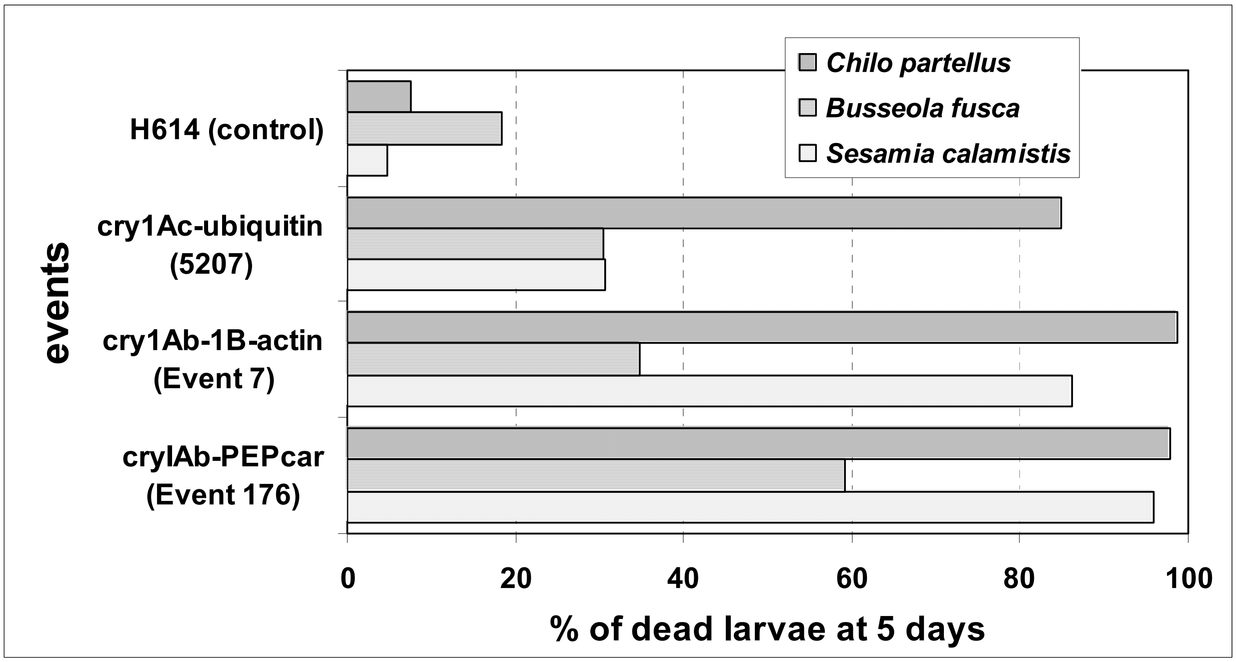


Figure 3. Percent larval mortality for the three most important stem borers species in Kenya after feeding for five days on a leaves containing non-GM control (variety CM216), one event (events 7, 176 or 5207), or a combination of two of these events.