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Insect Resistant Maize for Africa (IRMA) Project: An overview

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ABSTRACT

Developing countries, especially in Africa will continue to face the challenge of access to adequate food supply in the face of increased populations, reduced water, and arable land resources. Results of conventional breeding will not keep pace with the demand for food and the key to renewed growth in agriculture will be rapid technological change in food production. In recognition of the importance of maize in sub-Saharan Africa, the damage inflicted by stem borers, the difficulties in controlling these pests using traditional methods, and the availability of novel technology using the Bt endotoxins, three institutions came together to form the Insect Resistant Maize for Africa (IRMA) project. The IRMA project aims at increasing maize production and food security through the development and deployment of insect resistant maize to reduce losses due to stem borers. The objectives of the project are to: development of insect resistant maize varieties, establish procedures for deployment of the varieties to resource poor farmers, assess the impact of the varieties in the Kenyan agricultural systems, transfer technologies to participating countries through training and infrastructure development, document experiences and communicate on the technologies. Further successes are dependent on continued support by science, favorable policies, the involved institutions, and by other stakeholders. We are working to ensure that IRMA will serve the intended purpose, as a model of how major scientific and development projects will be carried out in future, through innovative partnerships and through institutional and disciplinary collaborations.

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INTRODUCTION

A major challenge facing developing countries is access to an adequate food supply. At the global level, in the next 50 years, world population will increase by 3 billion people mainly in urban areas in developing countries, water and arable land will become scarce and of lower quality, and results of conventional breeding will not be able to keep pace with increased demand for food production which must double in developing countries to meet the demand (Mugo et al. 2002). Any increase in food production, maize being the major crop, must be nutritious and be produced using environmentally friendly technologies.

In Africa, a large and growing population, expected to double from 600 million in 1995 to 1.2 billion by 2020, has led to increasing poverty, estimated at 40% (Eicher and Byerlee, 1997). Food production in sub-Saharan Africa grew at half (1.5% per year) the rate of population growth (3% per annum) from 1970–85. Since then, the situation has continued to deteriorate. For 1988–93, 33 African countries experienced a reduction in per capita food production (Rosegrant et al. 1997). Reduced food production has led to reduction in average caloric intake and malnutrition, estimated to affect 300 million people. Sustainable food production systems are essential for enhancing food security and for overall income and economic growth. The key to renewed growth in the agricultural sector is rapid technological change in food production.

Maize is the dominant food staple in Eastern and Southern Africa, accounting for 40% of the calories consumed, mainly the poor, most of whom are women and children. Governments and regional bodies like ASARECA and SADCC regional research networks recognize the importance of maize as food and for trade. Per capita maize consumption in the region averages more than a 100 kg per year [103 kg per year in Kenya, and as high as 182 kg per year in Malawi] (Pingali, 2001). Given the rapid population growth, the demand for maize in sub-Saharan Africa is expected to rise by 3.0–3.5% per annum over the next twenty years. IFPRI projects the annual maize demand in sub-Saharan Africa to be around 504 million tons by 2020, or twice that of today. Sub-Saharan Africa currently imports around 2–3 million tons of maize annually and that amount is likely to rise sharply, especially through food aid programs (IFPRI 200). Maize yields are low due to biotic and abiotic stresses such as drought, low soil fertility, pests and diseases.

There have been compelling success stories of increases in maize productivity in Eastern and Southern Africa through the application of modern technologies. However, the challenge remains for further increases in maize production. Arguably, the most important challenge is sustainable intensification of maize systems. Intensification of production has brought about dramatic changes in pest ecology and increased susceptibility of the maize crop to losses from insects and diseases. More than 60% of the maize area in Eastern and Southern Africa suffers from devastating pest infestations each year.

In Kenya, annual maize production is 2.3 million tons produced on 1.5 million hectares at an average grain yield of 1.5 t/ha (Pingali, 2001). Growth rate in agriculture is low. Growth rate in maize production is also low, and negative averaging –1.3% during the 1988-99 period (Pingali, 2001). Like in most countries, this is not adequate due to increase in population. The causes of low production are drought, low soil fertility, and losses due to weeds, stem borers and weevils in storage. Technologies have been developed to reduce the effects of drought, low soil fertility, and weed competition. However, damage by insect pests in the field and grain storage remains a challenging problem for resource poor farmers in Africa.

Insect pests, of which stem borers are the most widely distributed and most damaging, seriously affect a significant proportion of the 96 million hectares of maize in developing countries (Pingali 2001). In Kenya, stem borers cause 15% maize grain yield loss valued at US$90M annually (De Groote et al., 2001). In particularly bad years or in combination with drought stress, total crop loss can occur. The major stem borer species in Kenya are [*Chilo partellus* Swinhoe (Spotted stem borers), *Busseola fusca* Fuller (African stem borers), *Sesamia calamistis* Hampson (pink stem borers) and *Eldana saccharina* Walker (African sugarcane borer)]

The four general approaches to stem borer control are chemical, biological, cultural, and host plant resistance. The chemical control method is the most widely used, but this method exposes the farmer to health risks and can result in pesticide loading of the environment. Pesticides are expensive for poor subsistence farmers, while their application demands more labor inputs. Hence some farmers resign to not controlling stem borer damage. Biological control agents often require trained personnel for identification and deployment and the commitment of the farming community to enhance the establishment of biological control agents. Cultural control strategies, such as residue management, are best when used in combination with other control measures and rarely stand-alone. Host plant resistance is delivered to farmers as seed, a fact that ensures that the technology is safe and often does not require the purchase and application of insecticides in order to reduce yield losses from stem borer damage.

CIMMYT has followed conventional breeding methods to develop germplasm resistant to stem borers. A sub-tropical source population with multiple borer resistance (MBR population) was developed by recombination and recurrent selection under infestation with four stem borer species, however it is actually resistant to seven borer species (Mihm 1985, Smith et al. 1989). Stem borer resistance using conventional breeding methods has been elusive due to limited genetic variation, difficulty in maintaining a quantitative trait, and dealing with two organisms: pests and hosts. These challenges are especially felt in developing countries. Recently, CIMMYT has initiated development of insect resistant germplasm using molecular and transformation technologies, including the use of quantitative trait loci (QTL) to select for improved stem borer resistance in elite lines. Marker assisted selection (MAS) is being used by some African countries to promote the transfer of resistance into elite and adapted germplasm.

CIMMYT has also developed the capacity to produce transgenic maize. The resistance factor(s) in this maize is derived from genes that encode delta-endotoxins; proteins derived from the soil bacterium *Bacillus thuringiensis* (*Bt*). The protein binds to the brush border membrane vesicles of the peritrophic membrane resulting in pore formation and larval mortality of susceptible insects (Gill et al., 19921). Most Bt toxins are active against lepidopteran pests as well as some Coleopterans, but are not toxic to mammals. The rest of this paper will deal with an attempt to harness this technology to benefit resource poor farmers in Kenya initially and to other countries that are willing and capable of exploiting the technology, through the Insect Resistant Maize for Africa (IRMA) Project.

THE INSECT RESISTANT MAIZE FOR AFRICA (IRMA) PROJECT

The IRMA Project is a joint venture between the International Maize and Wheat Improvement Center (CIMMYT) and the Kenya Agricultural Research Institute (KARI), with financial support from the Syngenta Foundation for Sustainable Development. CIMMYT approached the Syngenta Foundation to assist in deploying Bt maize technology following the points below:

CIMMYT provides only transformed plants that carry "clean" events, meaning that only the gene of interest is inserted into the final product.

- No transformed plants that carry selectable markers, such as herbicide or antibiotic resistance, will be delivered to national programs for release.
- CIMMYT works only in countries that have biosafety legislation or regulations.

The project is being implemented initially in Kenya, from where the results and experiences will be available to other interested African countries. All activities with Kenyan institutions will be carefully documented so that other African countries can use lessons learned in the future, when insect resistant germplasm will become widely available to developing countries.

To formulate IRMA Project, a project concept meeting was held in Nairobi in June 1999 during which a planning workshop was organized for August 1999. The workshop 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 all available genetic tools (Siambi et al., 2000). A major output from that workshop was also a strategic work plan that includes broad objectives, logic log frames, timelines and responsibilities for each of the five identified project objective teams (KARI and CIMMYT, 2000).

GOAL OF IRMA PROJECT

The IRMA project is to increase maize production and food security through the development and deployment of insect resistant maize.

SPECIFIC OBJECTIVES:

1) *Product Development:* Develop Bt maize source lines using suitable genes and gene constructs that will control stem borers without undue effects on non-target organisms, farmers and the environment. Maize varieties with insect resistance and adapted to Kenyan maize production systems will be developed,
2) *Product Dissemination:* Establish procedures for providing insect resistant maize to resource poor farmers in Kenya,
3) *Impact Assessment:* Assess the impact of insect resistant maize varieties in Kenyan agricultural systems,
4) *Technology Transfer:* Transfer technologies to KARI and Kenya to develop, evaluate, disseminate, manage and monitor insect resistant maize varieties, and
5) *Project Documentation and Communication:* Plan, monitor, and document processes and achievements for dissemination to the Kenyan public and neighboring countries.

PROJECT ORGANIZATION

To implement these objectives, the IRMA project established teams along the five major objectives. Each objective team consists of a scientific team including entomologists, socio-economists, molecular biologists, and maize breeders. These teams meet regularly under a KARI and CIMMYT co-conveners to plan and budget for research and to review research results. IRMA project has an overall coordinator from CIMMYT and a KARI contact person. The CIMMYT Director of Applied Biotechnology Center and Bioinformatics is the oversight director of the IRMA project. The five project objective teams meet annually in at the IRMA Project annual review and planning session to develop the project wide annual work plan. This is the main forum where results from each research activity are discussed and reviewed. The work plan includes specific activities with monthly activities, responsible scientist and an annual budget. This work plan is then referred to the IRMA project steering committee for deliberation and approval. The steering committee has broad membership including KARI, CIMMYT, Syngenta Foundation for Sustainable Development, and the Ministry of Agriculture and Rural Development of Kenya. The status and progress of IRMA project are presented to the annual stakeholders' meeting. This includes all those who stand to be affected by implementation of IRMA project activities as well as use of the products from the activities. This includes farmers, government ministries, NGOs, research institutions, processors, and consumers among others.

APPROACHES AND ACTIVITIES

I. Product Development: Development of insect resistant maize varieties for Kenya will involve:

1. *Development and or procurement of appropriate genes and gene constructs*. Various gene constructs have been developed and tested against stem borers in Mexico and in Kenya. Molecular characterization of the first generation events has been accomplished. Crosses have been made among the first generation events. Development of second-generation "clean" gene events continued and we now have six new events showing negative for bar gene and positive for cry genes. These are the most desirable events, as they would involve only the gene of interest.
2. *Development of the infrastructure for screening insect resistant maize germplasm*. An operational biosafety level 2 laboratory has been developed; a biocontainment greenhouse and an open quarantine field site are nearly complete to enable screening of leaves and plants of Bt maize.
3. *Identification of genes active against Kenyan stem borers*: Screening cry proteins available at CIMMYT (*cryIAb, cryIAc, cryIB, and cryIE*) against Kenyan stem borers was done and the effective ones identified under laboratory conditions. These results will be verified under field conditions when approval and permits to import Bt maize seeds will be granted by the NBC and by KEPHIS, respectively.

4. *Development of improved insect resistant maize germplasm that combines conventional and Bt-based resistance into locally adapted germplasm*. Incorporation of Bt into adapted germplasm will wait for regulations to allow crossing such maize in fields within Kenya. However, in the process to identify suitable varieties to cross to Bt maize, we are identifying germplasm that farmers can utilize to reduce stem borer damage. This germplasm is from KARI and CIMMYT, developed from sources of conventional resistance as well as elite germplasm. These are being developed into varieties for farmer use as well as pyramiding into sources of stem borer resistance.

II. ***Product Dissemination:***

Establishment of procedures to provide insect resistant maize germplasm to resource poor farmers in Kenya will involve:

1. *Development of insect resistant management (IRM) strategies*. The unique farming systems among small scale resource poor farmers call for innovative ways to develop insect resistance management that utilizes crop mix, alternative crop species, fodder and forage species, and farm management options. To be accepted by farmers, IRM strategies must conform to existing cropping systems, and the refugia crops must be economically viable and socially acceptable to those making the management decisions at the farm level. Surveys to establish the acreage under wild and alternative crop hosts of stem borers and screening of selected species for their suitability for use as refugia are on going.
2. *Assessment of potential impacts of Bt maize on non-target organisms.* Extensive work is underway to establish the diversity of non-target organism (pollinators, decomposers and parasitoids) in maize growing environments in Kenya. This involves identifying, quantifying and characterizing arthropods in maize growing systems. The information will be used as baseline data during monitoring and evaluation phases of the project. This has been done in four of the five maize growing zones in Kenya.
3. *Gene flow between transgenic maize and local germplasm.* Experimental plots have been planted on experimental stations to look at contamination rates using

yellow maize in white maize plantings. This research has been extended on-farm. Socioeconomic surveys will assess the expected rate of incorporation into recycled seed – a practice common to small-scale farmers.

4. *Agronomic studies and seed production strategies for insect-resistant Bt maize.* These studies will await the availability of Bt maize in Kenya.

III. Impact assessment and socio-economic analysis

1. *Assessing the demand for insect resistant maize varieties*. This has been achieved through the study of different maize-based farming systems, survey of farmers' perceptions and preferences, and of consumers' preferences.
2. *Ensuring that the technology fits within the country's institutional framework*
3. *Assuring the safety of the technology.* This through dialogue with environmental groups and local research institutes, and private or public seed companies.
4. *Assessing intellectual property rights' (IPR) implications and costs.*
5. *Ensuring that the technology is appropriate and acceptable to farmers through farmer participatory trials.*
6. *Comparing the costs of the new technology to the benefits at different levels.* The levels are the seed company, the maize producer, the consumer, and society as a whole.
7. *Assessing the impact of the research and comparing the benefits to the costs*.

IV. Technology transfer

Transfer of technologies to KARI to develop, evaluate, disseminate, and monitor insect resistant maize varieties will include:

1. *Establishment of facilities.* These include an appropriate laboratory, an insectary, a greenhouse, and a field trial location in KARI to develop and evaluate transgenic germplasm. These have been developed to various extents as indicated above.
2. *Training*. Training has been in the areas of genetic engineering, handling Bt maize, evaluation of insect resistant germplasm; and experience in drafting, submitting, and defending applications for the introduction of Bt maize tissues

and seeds for use in insect bioassays and for evaluations in a biosafety greenhouse and field testing. Several KARI scientists have visited the CIMMYT ABC laboratories and Biosafety greenhouses in CIMMYT and elsewhere. A freedom-to-operate review of the IRMA Bt-Maize was made in order to ascertain what intellectual property considerations might come into play with the introduction of Bt maize, developed by the IRMA project, into Kenya. The report reflected the view that the IP issues related to the release of IRMA Bt maize in Kenya appear to be "relatively uncomplicated".

V. Documentation and Communication

Plan, monitor, and document processes and achievements for dissemination to the Kenyan public and neighboring countries. Considerable effort has been given to creating dialogue and raising public awareness about Bt and insect resistant maize, and about biotechnology in general. Communication has been emphasized through stakeholders meetings, positive media relations, creation of print and electronic materials, working closely with local press to achieve objective coverage, and participation and documentation of IRMA-related seminars and conferences. In 2002 emphasis will be laid on creating awareness among extension staff and developing strategies to reach farmers.

PARTNERS AND THEIR ROLES IN IRMA PROJECT

Partnerships and innovative institutional arrangements will continue to be the way research and development will continue to be done. This will be mainly to exploit the comparative advantages that exist among institutions be they public/public, public/private, or private/private partnerships including technology ownership and facilities (physical, human, and financial. The IRMA project has benefited from partnerships among the three institutions. IRMA project also works with other institutions involved in biotechnology in Kenya.

1. The Kenya Agricultural Research Institute (KARI)

KARI's mission is to increase sustainable agricultural production in Kenya by generating appropriate technologies through research, and disseminating these to the farming community. KARI has an extensive history of productive collaborators with national and international institutes and universities, as well as with the private sector. KARI expressed the need for insect resistant maize to solve the problem of stem borer damage in maize, the most important food crop. Having had experience with transgenic sweet potato with resistance to the sweet potato feathery mottle virus, KARI had the human capacity to evaluate Bt maize. Kenya had also put in place biosafety regulations that were driven by the sweet potato project.

KARI brought good repute into the IRMA project and experiences in processing applications for the introduction of Bt maize into Kenya. KARI also brought with it a good testing system, with more than six research centers, laboratories in Katumani and in the KARI biotechnology Center in the National Agricultural Research Laboratories, Nairobi. KARI also has a network of farmers and farmer groups that help in scaling up technologies. KARI leadership (Dr. R. Kiome, the current Director of KARI and Dr. C. Ndiritu the former Director of KARI) has been a source of inspiration due to their outspoken stands on the potential for Bt maize in Kenya. KARI has also contributed germplasm for screening to develop insect resistant maize.

2. International Maize and Wheat Improvement Center (CIMMYT)

CIMMYT is an internationally funded, nonprofit scientific research and training organization. CIMMYT works with agricultural research institutions worldwide to improve the productivity, profitability, and sustainability of maize and wheat systems for poor farmers in developing countries. Financial support for CIMMYT's research agenda comes from the traditional CGIAR donors as well as from many other sources, including foundations, development banks, and public and private agencies. CIMMYT brought into IRMA the source lines with Bt genes, expertise in genetic engineering, entomology, IPR, biosafety, socio-economics, documentation and communication, and project management. Training of KARI scientists has been undertaken in CIMMYT laboratories and fields in Mexico and Kenya.

The critical roles for the CGIAR are: 1) protector of the interests of the poor and facilitator and bridge-builder in biotechnology partnerships, and 2) facilitator of public policy and innovative institutional arrangements (Persley 2000). In fulfilling these roles, CIMMYT has contributed through: 1) research in Bt maize and biotechnology in general 2) facilitating information sharing among partners, 3) identifying problems and priority setting with partners, 4) supporting capacity building, 5) assistance with development of biosafety standards and managing intellectual property, 6) fostering the public/private partnership, and 7) communicating and addressing public concerns (Mugo 2001). The experiences gained in dealing with large number of developing countries, the positive track record in developing and delivering germplasm based technologies, and the credibility cultivated in working in Africa are important aspects that CIMMYT brought into the IRMA project. CIMMYT is the coordinating institution and is responsible for technical backstopping.

3. The Syngenta Foundation for Sustainable development

The Syngenta Foundation for Sustainable Development provides major funding for the project. The Foundation is dedicated to fostering sustainable development in poor countries of the South through its support of programs and projects in the areas of sustainable agriculture, health, and social development. It is also an active player in development of policy debate through its preparation and dissemination of research analysis. Like KARI and CIMMYT, the Syngenta Foundation was involved in the IRMA project from project formulation through implementation. Apart from funding, major inputs have been in training through seminars, contributions in steering committee deliberations, and through stakeholders meetings. As the private sector, Syngenta Foundation brings business culture and results and product orientation to the IRMA project.

4. Other Partners

The eventual deployment to farmers will rely on working with private sectors seed companies. The IRMA project will also have to work with the private sector to get the rights to use some of the components of Bt gene constructs.

At a more abstract level, IRMA has been working with other public sector organizations as well as the private sector in the efforts to educate the media and through the media, the public. IRMA project has benefited by working with the Kenya Industrial Property Institute (KIPI) from their information on IPR issues as well as the African Biotechnology Stakeholders' Forum (ABSF) as partners in raising awareness on biotechnology. The print and audio media have played a major role in bringing to fore the agenda for food through new technology development and adoption in Kenya. IRMA project has enhanced good relations with the media.

IRMA has interacted with the Ministry of Agriculture and Rural Development (MOARD), the National Council of Science and Technology (NCST), and the Kenya Plant Health Inspectorate Service (KEPHIS) through Biosafety issues as well as stakeholders meetings. These will continue to be important until society come to realize that food developed through biotechnology mediated processes do not necessarily carry more risks to humans and the environment than those produced using conventional technology.

To win public relations war, IRMA has cultivated these partnerships, supported grass root fora like ABSF and AfricaBio that disseminate balanced information, and strengthened regulatory and other related institutions that are related to capacity building. Support has been in technical instructions, participation in various events, and nominal financial support.

EXPECTED OUTPUTS

The expected outputs and impacts include:

1. Maize inbred lines, hybrids, and open pollinated varieties (OPVs) that combine the most effective conventional and biotechnology-based insect resistance, tested and available in Kenya;
2. Protocols developed and KARI scientists trained in (i) the development and evaluation of insect resistant maize cultivars at the experimental station level, (ii) the deployment and monitoring of insect resistant varieties in farmers' fields;

3. Insect resistance management strategies developed and implemented in all zones of Kenya where the insect resistant maize will be grown;
4. Documented impacts of *Bt*-gene based resistance in maize on non-target organisms associated with major maize production environments in Kenya;
5. An economic analyses to (i) determine likely farm-level profitability for different categories of farmers, (ii) assess farmers' willingness to pay for the technology, and (iii) assess the overall private and public benefits of the technology;
6. The accrual of practical experience for KARI in biosafety and IPR regulatory procedures in Kenya;
7. A thorough documentation of all lessons learned during the project, which will be availed to other developing countries interested in promoting similar technology; and
8. Kenyan scientists, farmers, officials, and stakeholders trained in the production, evaluations, and dissemination of insect resistant maize.

FACTORS IMPACTING ON SUCCESS

Factors impacting on the success of the IRMA project will include scientific, political, policy, financial, institutional, and individual factors. Bt technology has been perfected for several crops and in different environments and countries and we believe that the science is sound. Scientists and stakeholders have all indicated that good science will not be compromised in all of IRMA project activities. In this age of debates on the use of living modified organisms for food production, we hope that Kenya and other countries will only base their policy on informed points of view. It is hoped that the institutions charged with responsibilities for safe application of the technology, including issuance of import permits and inspection services will continue to discharge their services in timely manner and basing decisions on science. We also hope that the IRMA project agenda of raising awareness at all levels of society will help in filling any gaps in knowledge and awareness for the policy makers in Kenya. We also hope that financial and other support as well as commitment among the key institutions, KARI, Syngenta Foundation and CIMMYT will continue till we have insect resistant maize germplasm in the hands of farmers.

CONCLUDING REMARKS

The achievements made so far are encouraging. The delays in processing application include making decisions by Kenya authorities are understandable considering that Kenya has only recently developed Biosafety regulations and is still in the processes of perfecting the regulatory process. However, these delays are likely to postpone the time when Bt maize will be availed to farmers and the necessary deployment and monitoring and evaluation beyond the project period.

We are working to ensure that this project will serve the intended purpose as a positive example to other nations on how we can develop partnerships between projects and institutions in the region to safely and responsibly put this technology to work for the betterment of our people and our nations.

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