RESEARCH AT A GLANCE

Genetic Resource Policies

Promising Crop Biotechnologies for Smallholder Farmers in East Africa: Bananas and Maize

Brief 26

Biosafety and Biodiversity Risks

Melinda Smale, Hugo De Groote, and José Falck-Zepeda

What is Biosafety Risk?

The potential biosafety risks of transgenic varieties have generated controversy in the international community. According to the U.S. National Research Council (2002), these risks include (1) the flow of transgenes, (2) evolution of resistance in the targeted pest population, (3) plant escape and establishment of self-reproducing populations, (4) effects on nontarget species, and (5) health hazards (NRC 2002).A conceptual profile of biosafety risks for the two case studies is provided in Box 1.

Many experts consider that evolution of resistance is not a biosafety risk, per se, but a consequence of genetic uniformity. When many farmers grow varieties with the same sources of genetic resistance to a pest or disease—either because it is very popular among farmers or too few varieties are supplied by the seed industry—the probability of a mutation in the pest that overcomes the resistance increases. Once resistance has been overcome, the chances of epidemic-scale crop losses increase markedly. Developers of technologies and regulators tend to address this challenge by implementing strategies that reduce pressures for mutation, such as refuges where susceptible varieties or crops that host the targeted pest continue to be grown, thereby increasing the useful life of varieties in the hands of farmers.

Maize and Banana Case Studies

Maize has a considerable risk of gene flow through cross-pollination, particularly when landholdings are fragmented, varieties are planted contiguously, and farmers recycle, exchange, or mix maize seed. In addition, the dominance of the *Bt* genes augments the risk of genetic uniformity in the trait. Moreover, because *Bt* genes are single genes that cause heavy pest mortality, they augment the pressures for mutation. In the highland areas of Kenya, where the adoption rate for a single maize hybrid (H614) is very high, virtually all farmers will be growing the F1 or advanced-generation *Bt* hybrid within a few years—primarily because H614 already accounts for a dominant share of the maize area. In the zones where the productivity potential of maize is lower and improved maize varieties are less popular, farmers ascribe greater importance to losses to stemborers. They are also likely to recycle, mix, and select for stemborer resistance in their local materials, which could contribute to gene flow and uniformity in the *Bt* genes. The Insect-Resistant Maize for Africa (IRMA) program's 2002 baseline survey data demonstrated that the array of maize materials grown in many of the ecologies, as well as continuing crop diversification in response to economic opportunities, may provide sufficient natural refugia for the stemborers, delaying the evolution of resistant strains. In some commercial maize-

About the Authors

Melinda Smale *is a senior research fellow in the Environment and Production Technology Division of the International Food Policy Research Institute (IFPRI) and was also a senior economist with the International Plant Genetic Resources Institute (IPGRI) at the time this research was conducted.*

Hugo De Groote *is an economist in the Social Sciences Group of the International Maize and Wheat Improvement Center (CIMMYT), based in Mexico.*

José Falck-Zepeda *is a research fellow in the Environment and Production Technology Division of the International Food Policy Research Institute (IFPRI) and an associate director of the Program for Biosafety Systems (PBS).*

Box 1. Biosafety Risks Associated with Transgenic East African Highland Bananas and *Bt* Maize in Kenya

Pest and disease resistance in East African highland bananas	*Bt* maize in Kenya
1. FLOW OF TRANSGENES	
No flow of transgenes is possible among East African highland bananas because they are sterile triploids. Gene flow is possible among tetraploids, such as recently developed hybrids, although normally these reproduce through self-propagation.	Maize has a high risk of gene flow through cross-pollination, particularly when landholdings are fragmented; varieties are planted contiguously; and farmers recycle, exchange, or mix maize seed, as is the case in most of Sub-Saharan Africa.
2. EVOLUTION OF RESISTANCE	
Genetic uniformity in a trait increases the probability of a mutation in the pest population or disease pathogen that overcomes resistance and makes the crop more vulnerable to an epidemic if the mutation occurs. Ironically, it is clonal propagation and the system for disseminating plant material, rather than gene flow, that engender the risk of resistance evolution for transgenic bananas. The risk of resistance evolution in the targeted pest population may be great with the soil and root borne problems of banana, since mats move slowly with new roots in a given location and farmer propagation reproduces the same trait. Large-scale multiplication schemes, such as those envisaged for tissue culture systems, would contribute to genetic uniformity in the trait.	The dominance of the *Bt* genes augments the risk of genetic uniformity in the trait. However, this risk is also increased by a lack of variety diversification. For example, in the highland areas of Kenya, where the adoption rate for a single maize hybrid (H614) is very high and has been for some time, many farmers will be growing the F1 or advanced-generation H614 with *Bt*-resistance within a few years, simply through seed replacement. In zones where the productivity potential of maize is lower and improved maize varieties are less popular, farmers ascribe greater importance to losses from stemborers and would be keen to try stemborer-resistant varieties. They are also likely to recycle, mix and select for this resistance trait in their local materials, contributing to gene flow and genetic uniformity in the trait. *Bt* genes are single genes that cause heavy pest mortality, thereby augmenting the pressures for mutation. On the other hand, differences in genetic backgrounds among improved and unimproved materials in coastal areas should contribute to the continuing evolution of diversity. Higher levels of stemborer resistance in some of these materials might also act as a buffer against pressure for stemborers to mutate to overcome this resistance.
3. PLANT ESCAPE	
Wild diploid bananas have been found only in Asia. The diploid bananas known to exist in Tanzania and Uganda are not wild plants, but cultivated and edible types that have no female seeds and are sterile.	There are no wild relatives of maize in Africa.
4. EFFECTS ON NONTARGET SPECIES	
Nothing is known yet about the risks to nontarget species of transgenic banana varieties.	*Bt* genes are very specific, and preliminary evidence suggests the risks to nontarget arthropods in Kenya are negligible
5. HUMAN HEALTH	
Nothing is known yet about the risks to human health of transgenic banana varieties.	The potential risks of *Bt* genes to human health are associated with the genes themselves, as well as those genes used as constructions for insertion and markers. To date, no studies have found health risks associated with *Bt* maize that are not also associated with conventionally bred maize (GAO 2002). In any case, scientists working on *Bt* maize in Kenya now focus on "clean" events—that is, the insertion of the gene and the subsequent removal of the mechanism used to insert it, eliminating risk to consumers.

growing areas, although additional extension effort could be geared toward training farmers about the importance of refugia (De Groote et al. 2004), the enforceability of refugia, and the associated costs to producers in terms of annual yield losses and management time, are genuine concerns.

No flow of transgenes is possible among East African highland bananas because they are triploids that are generally sterile. Gene flow can occur among tetraploids, such as the recently developed hybrid bananas, though normally these reproduce through self-propagation. Ironically, it is clonal propagation and the system for disseminating plant material, rather than gene flow, that engender the risk of resistance evolution for transgenic bananas. Large-scale multiplication schemes, such as those envisaged with tissue culture, would contribute to genetic uniformity in the resistance trait. The risk of resistance evolution in the targeted pest population may be great with the soil and root borne problems of banana, because banana plants are vegetatively propagated and are grown for long periods of time in the same grove.

Both the problem of genetic uniformity and its solutions, however, are well known to conventional plant breeders. Solutions include pyramiding genes with various resistance mechanisms, combining genetic resistance and crop management practices, and ensuring that a wide range of varieties with differing resistance levels and mechanisms are available to farmers. Aside from the physical characteristics of the surrounding agroecosystem, resistance evolution is influenced by seed policy and other factors that determine the varieties farmers choose to grow.

Neither maize nor bananas have wild relatives in Africa; hence there is no risk of gene flow to wild relatives from transgenic varieties of these plants. It is often said that the spread of transgenic crop varieties will cause farmers to abandon potentially valuable landraces. However, the risk that transgenic varieties will replace landraces is no greater than that of conventionally bred varieties replacing landraces. Rather than destroying diversity, genetic transformation could potentially maintain the diversity of types that farmers recognize and find useful, because it adds desired traits while leaving other characteristics unchanged (Ságí, Remy, and Swennen 1997).

The East African highlands is a secondary center of diversity for banana. Findings in Uganda suggest that farmers diversify among varieties as a means of combating pests and disease and satisfying multiple end-uses, including consumption and sales (see Brief 24). Farmers may also maintain many banana varieties simultaneously because they serve as living stocks, reducing farmer reliance on cumbersome, long-distance exchanges of planting material (see Brief 20). The propagation and growth cycle of bananas also contributes to farmers having higher numbers of varieties per grove than would be the case for an annual crop like maize.

Although maize is not endemic to Africa, maize breeders in Kenya do recognize some local maize varieties as distinctive and as potential sources of valuable traits for crop improvement. Surveys conducted in Kenya suggest that farmers continue to grow local maize varieties as a result of consumption preferences, agronomic attributes, or the subsistence orientation of production (see Brief 25). Concern regarding the "irreversibility" of *Bt* gene flow into local varieties has led the IRMA project in Kenya to establish a collection of such varieties in the national gene bank.

Nothing is known about the risks to nontarget species or human health of transgenic banana varieties, since the technology is still in its developmental stages. *Bt* genes are very specific, and preliminary evidence suggests the risks to nontarget arthropods in Kenya are negligible. The perceived risk of *Bt* genes to human health are associated with the genes themselves, as well as those used as constructs for insertion and markers. *Bt* genes were isolated in 1901 by a Japanese biologist and were rediscovered in 1911 by a German scientist. *Bt* toxin has been applied by French organic farmers since 1920. To date the only health risks identified as being associated with *Bt* maize are the same as those associated with conventionally bred maize (GAO 2002). IRMA scientists working on *Bt* maize in Kenya now focus on "clean" events—that is, the insertion of the gene and the subsequent removal of the mechanism used to insert it, eliminating potential risks to consumers.

Regular discussions with Kenyan farmers, consumers, and institutions at annual stakeholder meetings, group discussions, and other forums, reveal that farmers are generally very enthusiastic about *Bt* maize, while scientists, consumers, and the general public are cautiously optimistic. A survey in Nairobi showed that consumers generally trust the regulatory agencies, and relatively few consumers object to the use of genetically modified crops for food (Kimenju et al. 2005). Interestingly, upon learning that the *Bt* gene is dominant (and can therefore be recycled), farmers requested that the IRMA project also consider transformation of their local varieties

(De Groote et al. 2004). Ultimately, Kenyan farmers and consumers will decide whether the benefits outweigh the costs when they accept or reject transgenic varieties. The Kenyan government has the responsibility to ensure that they are well informed.

Biosafety Regulations

Biosafety frameworks, laws, and regulations in developing countries have been developed in response to the implementation of the Cartagena Protocol on Biosafety. The Cartagena Protocol, a supplement to the Convention on Biological Diversity, addresses the safe transfer, handling, and use of living modified organisms (LMOs), especially those that may have an adverse effect on biodiversity, taking into account risks to human and animal health. Biosafety processes inspired by this protocol focus specifically on transboundary movements of materials. The aim of these international agreements is to ensure that countries have the capacity to assess risks involving modern biotechnology.

In Kenya and Uganda, biosafety (and biotechnology) policies, acts, and regulations are in different degrees of development and implementation. Initial applications in Kenya for conducting confined field trials of genetically modified maize and cassava have been submitted to the National Biosafety Committee. Only the maize trial has been approved so far. In Uganda, an application to conduct confined field trials of genetically modified bananas is expected to be submitted soon.

All biosafety regulatory processes are precautionary by definition. As such, the process of evaluation of a particular technology goes beyond demonstrating effectiveness to demonstrating reasonable safety. There are costs associated with the additional testing needed to demonstrate food/feed and environmental safety. If regulations are too stringent or uncertain, the cost of generating additional information will be high, and possibly prohibitive, ultimately stalling further development of products. Alternatively, meeting stringent regulatory requirements may delay the release of a product, increasing the length of time required for the biotechnology to reach producers, reducing their expected benefits of the technology.

References

De Groote, H., S. Mugo, D. Bergvinson, and B. Odhiambo. 2004. Debunking the myths of GM crops for Africa: The case of *Bt* maize in Kenya. Selected paper, Annual Meetings of the American Association of Agricultural Economists, August 1–4, Denver, Colorado.

GAO (United States General Accounting Office). 2002. *Genetically modified foods: Experts view regimen of safety tests as adequate, but FDA's evaluation process could be enhanced*. Report to Congressional Requesters GAO-02-566. Washington, D.C.: U.S. General Accounting Office.

Kimenju, S. C., H. De Groote, J. Karugia, S. Mbogoh, and D. Poland. 2005. Consumer awareness and attitudes toward GM foods in Kenya. *African Journal of Biotechnology* 4 (10): 1066–1075.

NRC (National Research Council). 2002. *Environmental effects of transgenic plants: The scope and adequacy of regulation*. Washington, D.C.: National Academy Press.

Sági L., S. Remy, and R. Swennen. 1997. *Genetic transformation for the improvement of bananas: A critical assessment*. Annual Report, Focus Paper II. Montpellier, France: International Network for the Improvement of Banana and Plantain, International Plant Genetic Resources Institute.

For further information, please contact Melinda Smale (m.smale@cgiar.org).

THIS WORK WAS MADE POSSIBLE IN PART BY SUPPORT FROM THE SWEDISH INTERNATIONAL DEVELOPMENT AGENCY (SIDA), SYSTEM-WIDE GENETIC RESOURCES PROGRAM OF THE CGIAR, EUROPEAN COMMISSION, AND THE U. S. AGENCY FOR INTERNATIONAL DEVELOPMENT (USAID).

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

2033 K STREET, NW, WASHINGTON, DC 20006-1002 USA
TEL +1.202.862.5600 FAX +1.202.467.4439 EMAIL ifpri@cgiar.org WEB www.ifpri.org

Copyright © January 2006 International Food Policy Research Institute and the International Plant Genetic Resources Institute. All rights reserved. Sections of this material may be reproduced for personal and not-for-profit use without the express written permission of but with acknowledgment to IFPRI and IPGRI. To reproduce the material contained herein for profit or commercial use requires express written permission. To obtain permission, contact the Communications Division <ifpri-copyright@cgiar.org>.

Any opinions expressed herein are those of the author(s) and do not necessarily reflect those of IFPRI or IPGRI.