RESEARCH AT A GLANCE

Genetic Resource Policies

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

Brief 19

Assessing the Impact of Crop Genetic Improvement in Sub-Saharan Africa: Research Context and Highlights

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Genetic improvement of planting material (in a broad sense) is an important component of agricultural growth for nations and regions in the process of economic development. Asia's Green Revolutions in rice and wheat are perhaps the best-known examples of dramatic agricultural growth associated with crop genetic improvement. Most experts agree that no such seed-based revolution has occurred in Sub-Saharan Africa, despite frequent, though scattered, episodes of success. Such change is crucial, however, given that an estimated 200 million people in Africa can now be classed as undernourished—almost 20 percent more than in the early 1990s (Benson 2004). Many of these individuals are smallholder producers of food crops.

Smallholder farmers are the subject of two parallel case studies that explore the potential for integrating transgenic varieties of cooking bananas and maize into smallholder agriculture in East Africa. Both bananas and maize are devastated by pests and diseases in this region, particularly in the lowland tropical environments. Since chemical treatment of these crops is not economically viable for most smallholder farm families, varieties with genetic resistance could play a vital role in reducing their vulnerability to crop failure. Hence, national research programs have targeted bananas and maize for genetic transformation.

Crop Biotechnology for African Smallholders

A recent State of the World report authored by a panel of experts concludes that genetic engineering and other biotechnologies should form part of an integrated agricultural research and development program that gives priority to the problems of the poor, complementing rather than substituting research in other areas, such as plant breeding and disease management (FAO 2004). The public sector must continue to play a prominent role in this research, supported by governments, public–private partnerships, and other innovative strategies to mobilize research and technology delivery. The international community should also lend priority to capacity building to rationalize regulatory procedures and conduct related agricultural research.

So far, few genetically transformed varieties have been released to farmers in less industrialized agricultural economies, and most are of cash crops, such as cotton and soybeans. Little can be gleaned from study of these cases regarding the potential for use of transgenic varieties of food crops by smallholder farmers in Sub-Saharan Africa. Smallholder producers of food crops in Sub-Saharan Africa are typically semi-commercial

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producers who face costly and uncertain market transactions for seed and harvested products. A recent expert survey revealed 40 biotechnology products in the public research pipeline for Kenya, South Africa, and Zimbabwe alone (Cohen 2005), but only in South Africa have transgenic crop varieties actually been released to farmers.

Given the above circumstances, any technology assessment is by definition ex ante, or based on prediction. The two case studies undertaken in East Africa were selected from a range of biotechnology products currently in the research pipelines, based on several criteria. First, these technologies tackle economically important, biotic constraints that are not easily addressed through conventional plant breeding or other methods of control. Second, they pose little risk of endangering trade through exports to countries that do not accept transgenic products. Third, each could make a substantial difference in the welfare of smallholder farmers by serving as a source of either food or cash. A fourth consideration is the crop reproduction system, which has implications for the risk profile of the crop once it is genetically transformed. Banana and maize plants have distinctive properties that affect their breeding history, the probabilities of success of new varieties, and the type of investments needed to support their widespread adoption by smallholder farmers. These properties, along with other essential points of contrast between the two case studies, are summarized in Box 1.

In both studies, data were collected from geo-referenced, stratified random samples of farm households across the major producing zones for the crops. For banana, the sample consisted of 800 households (540 in Uganda and 260 in Tanzania) located in a continuous area around Lake Victoria, where East African highland bananas are the dominant genomic group. In Kenya, 1,200 households were sampled in the five major agroecological zones defined by the Kenya Agricultural Research Institute (KARI). Analysis of data from field interviews with farmers reveals their perceptions and the impediments that must be overcome for widespread adoption to occur. Analysis of national databases and geographical information systems serve as a basis for estimating the overall magnitude of the economic benefits generated by the research investment. Both approaches are used to illustrate how benefits are likely to be distributed among social groups.

Can Past Experience Be Used to Predict the Future?

Ex ante assessments must be made to some extent based on past, or ex post, experiences. However, past economic assessments of the national impact of crop genetic improvement in Sub-Saharan Africa are inconclusive. Identifying localized or episodic successes in terms of yield or farm family well-being is simpler than measuring longer term impacts on national yields and the economy. One reason is the methodological difficulty of separating the effects of seed from other inputs and intervening factors, especially when the focus of breeding efforts is to support yield levels against pest and disease pressure. Another is that broader social, political, and economic contexts mediate the impacts of seed technical change. These contexts vary over time, in some cases abruptly.

For example, the state-based public research and delivery systems that supported the diffusion of modern technologies during the decades following the independence of many African nations later proved to be fiscally unsustainable. Once dismantled, these state-based systems have been partially replaced by a patchy mosaic of firms and nongovernmental organizations. Over the same time period, the relative importance of agricultural earnings in the income of poor households has declined, so that the effects of seed technical change on employment and poverty may have diminished (Meinzen-Dick et al. 2003). Encouraged by donors, governments have sometimes pursued a crisis-to-crisis approach to agricultural policy, particularly in food crops, leading to fluctuating input–output price ratios faced by smallholders and inconsistent technology recommendations. In the meantime, the number of institutional actors has grown and the configuration of institutions involved in agricultural research and development, as well as technology provision to farmers, has changed. Supply-driven, commodity focused research is often viewed as detrimental to crop and income diversification. The need to work through civil society and other institutions to enable the successful integration of technological innovations in African agriculture has become increasingly evident (Haggblade 2004).

Despite these changes, the paucity of public funds in Africa, and its implications, cannot be understated. Africa received only 6 percent of public agricultural research expenditures in 1976 and 6 percent in 1995;

Box 1. Points of Contrast in the Two Case Studies

Pest and disease resistance in East African highland bananas

East Africa is the largest banana-producing and consuming region in Africa. Most production is by smallholder farmers who grow bananas mainly for food, selling any surplus in local markets. Banana exports are negligible at present. Growing urban markets contribute to the importance of the crop as a source of cash. Although the origin and center of diversity for banana is believed to be Southeast Asia, the East African highlands is recognized as a secondary center of diversity.

East African highland bananas are difficult to improve through cross-breeding because they are all triploids (that is, they possess three complete sets of chromosomes). Plants with three genomes, rather than two or four, produce no pollen and are sterile. Farmers reproduce banana varieties through vegetative propagation. Although professional breeding of bananas began during the 1920s, it was not until recently that a major breakthrough was achieved through the development of a hybridization technique by the Fundación Hondureña de Investigación Agrícola (FHIA). Genetic transformation is an attractive option for enhancing bananas compared with cross-breeding.

Major national breeding efforts began in Uganda only 11 years ago. Elite lines are selected from local and foreign germplasm (both natural and recent hybrids from breeding centers) and new genotypes are developed using both conventional and genetic engineering methods. The best yielding highland bananas have proved sterile and hence not amenable to conventional breeding. Efforts to establish a cell suspension and plant regeneration system are progressing well. Suspension culture methods are now being optimized for a wide range of varieties and arrangements to initiate gene insertions are in their final stages.

Various pests and diseases affect banana production. Weevils are the major banana pest in the East African highlands. They prolong the maturation period, decrease yields, and cause crop failure through the death of young banana plants. Major losses also occur due to Black Sigatoka, a recently introduced airborne fungal disease that reduces the number of fruit per bunch and fruit weight. Another fungal disease affecting bananas is Fusarium Wilt (Panama Disease), which attacks the roots and persists in the soil. Nematodes are also pests that affect banana roots. These pests and diseases affect genomic and use groups differentially. For example, East African highland cooking bananas are more susceptible to black Sigatoka and weevils than are exotic beer bananas, whereas exotic beer bananas appear to be more susceptible to Fusarium Wilt than highland bananas.

Bt maize in Kenya

Kenya is one of the largest producers of maize in eastern and southern Africa, and maize is by far the most important food staple in Kenya. Average annual per capita consumption of maize is one of the highest in the continent (FAO 2005). Portuguese traders likely brought maize to Africa centuries ago. By the 1930s maize was a major crop, its popularity fueled by poor millet harvests and export markets for starch. In most years, Kenya is self-sufficient in maize but does not export it. Maize is both a food staple and a cash crop for smallholder Kenyan farmers.

Adoption rates for improved maize in Kenya are among the highest in Africa, varying by production environment. The spectacular maize breeding successes accomplished in the early 1960s and 1970s through varietal hybrids bred from local materials and unimproved, center-of-origin materials are well documented (Gerhart 1975). Some have contended that the yield potential of successive maize seed releases in Kenya continued to rise since the 1970s but the rate of increase declined; others have argued that smallholder farmers are far from realizing the yield potential because genetic advances have not been matched by improved agronomic practices and efficient support services for smallholders located in marginal areas. As improved maize diffuses into more marginal areas, the effects on national yield levels are also numerically marginal. The secular decline in soil fertility in the intensive maize systems of this region has been worsened by reduced application of fertilizer and the abandonment of traditional methods of soil regeneration. The removal of subsidies, in combination with high transportation costs, has eroded the profitability of using fertilizers, while pest and disease problems have worsened with intensification and continuous maize planting (for detailed documentation of these points, and references, see Smale and Jayne 2003).

Experts consider that the most appropriate means for enhancing the maize productivity of smallholder farmers in East Africa is to improve yield maintenance or yield stability through better combinations of resistance and tolerance traits. Estimated national crop losses from stemborers are 12–14 percent, depending on the measurement technique (De Groote 2002; De Groote et al. 2003). Participatory rural appraisals (PRAs) indicate that stemborers are the most critical insect problem perceived by farmers (De Groote et al. 2004). The effect on yield of enhanced resistance obtained through genetic engineering is likely to be greater than that achieved through conventional crossing since the former method does not risk introducing other, less desirable genes.

its overall rate of increase, at 1.5 percent per year, was the lowest among all regions for the two decades. Africa is the only region in the world where per capita research spending (in terms of both total population and agricultural workers) declined over that time period (Pardey and Beintema 2001).

Role of Social Science Research in Technology Development

Given these challenges, social science research can help identify ways to create an enabling environment for improved crop varieties and practices before their release. By diagnosing potential and existing impediments to adoption during variety development rather than after variety release, we can increase the chances that the variety will be successful in farmers' fields.

For example, effective, demand-driven provision of planting material is a critical ingredient to any successful seed innovation—an issue explored in Brief 20. The formal agricultural research and development institutions that constitute the commercial seed system in high-income countries deliver final products to dispersed clients who demand them on a regular basis. In contrast, farmers in marginal environments of poorer countries in Sub-Saharan Africa often rely on their own saved seed or village connections since seed supplies through more formal market channels can be unreliable. Another challenge common to any new technology is that farmers must perceive its benefits in their fields, and not just on the experiment station. Not all new seed varieties are "popular" or widely grown—especially in semi-commercial, smallholder production in Africa, where farmers have multiple objectives and work with combinations of biophysical and economic constraints. Farmers may not discern the benefits of inserting a particular trait, or may view them as less important than some other disadvantageous traits of the new variety relative to those of the varieties currently grown. Findings from the application of a trait-based model of farmer demand for planting material are explored in Brief 22.

For crop biotechnology, as with any introduced technology, knowing the social determinants and social consequences of its adoption is important for designing policies to support its use. Although planting material may be neutral to the scale of the farm operation (that is, there is nothing inherent in the technology that implies large-scale farmers will have a greater ability to use it than smallholder farmers), a technology typically has an aspect that favors its adoption by certain social groups. In the case studies summarized here, the potential social impacts of crop biotechnologies in farming communities and among regions have been emphasized (see Briefs 21–23).

An aspect of the enabling environment for technological intervention, which is also inherent in the biology of the crops, is the broad taxonomic base for host selection. A large number of farmer varieties, as well as introduced varieties, are grown in banana groves and on maize farms. The biological diversity of maize and bananas in these environments is explored in Briefs 24 and 25.

As compared with conventional genetic technologies,[1] genetically transformed seed presents a number of unique challenges, such as the need to develop appropriate regulatory frameworks for biosafety. Governments have a public responsibility to invest in assisting farmers to make informed choices regarding genetically transformed seed and to take full advantage of the technology if they choose to use it (Tripp 2001). Biosafety considerations in the context of the two case studies are discussed in Brief 26.

Research Highlights and Contrasts

Research findings from the two case studies reveal the continued semi-subsistence orientation of many smallholder producers of bananas and maize, confirming the need for improved commercialization of planting material and products. In Uganda, nearly a quarter of the banana-producing households in the sample do not participate in banana markets. The rate of commercial sales appears to be much higher in the highlands of

[1] Here, conventional genetic technologies refer to any type of hybrid (for example, varietal, top-cross, three-way, or single- or double-cross), improved open-pollinated variety (such as a synthetic or composite) or pure line selection developed in a crossing or selection program, in contrast to those developed through gene insertion.

Tanzania (90 percent) than in the highlands of Uganda (63 percent), and in both countries the highlands are much more commercially oriented than the lowlands. In Kenya, baseline data confirm that 59 percent of households sold no maize during the survey season (2002). Despite the orientation of farmers toward subsistence production, analyses demonstrate that farmer demand for planting material, use of recommended practices, and supply of produce are responsive to changes in prices and marketing costs. These results indicate the potential of these food crops to generate rural income in local markets. Investment in market infrastructure would likely result in large payoffs for both crops and countries, as would investment in human capital and education.

Findings confirm that smallholder farmers value the crop traits targeted by national researchers for genetic transformation, and that the envisaged crop genetic improvements are demand-driven. High adoption rates for recently introduced banana varieties, particularly in Kagera region of Tanzania, underscore the willingness of farmers to experiment with new varieties in an effort to avoid the devastation they have experienced from banana pests and diseases. Farmers continually search for resistant banana types, sometimes traversing great distances. Evidence also confirms that use of the Fundación Hondureña de Investigación Agrícola (FHIA) hybrids reduces the vulnerability of Tanzanian households to yield losses from pests and disease. Differences in the severity of biotic pressures, the relative importance of cooking quality, and dissemination strategies for improved planting material contribute to the differences in adoption rates between Uganda and Tanzania. Although use rates for new banana types are much lower in Uganda, exposure to new banana varieties and practices appears to have reduced inefficiency in the production system. Further analysis is needed over time, to see if rates of diffusion increase, benefits are sustained, and income effects are observable.

Private seed companies play a much larger role in the planting material system for maize than is the case for cooking bananas. There are examples of private or public–private provision of tissue-cultured banana planting material, particularly among commercial growers marketing dessert bananas to urban consumers in Kenya (Qaim 1999). Investment in innovative means of transferring seed, growing practices, and information dissemination through village associations and social networks will expand farmers' use of improved banana technologies, particularly for cooking bananas. The farmer-based dissemination programs that have already been implemented in Uganda, though limited in their impact in terms of numbers of farmers and communities, warrant closer examination as models for structured, yet decentralized, mechanisms of information diffusion.

Maize hybrids currently account for over 90 percent of the maize area in the high-potential zones of Kenya, although there is substantial variation in the proportion of farmers growing hybrids, improved open-pollinated varieties, and local varieties across the nation's heterogeneous maize-producing environments. In the decade since the last nationally representative survey was conducted, changes have occurred in the use of maize hybrids, particularly in the lowland tropics, where adoption rates have nearly doubled. Nevertheless, maize landraces that are recognized as potentially important by both breeders and farmers continue to be grown in some locations.

Findings demonstrate the potentially pro-poor application of transgenic technology to bananas, particularly if a cooking variety is used as a host for trait insertion. Decisions regarding which variety to use as the host variety are likely to have social consequences. For example, inserting resistance to black Sigatoka into the variety Nakitembe would effectively target larger households with more dependents, who are poorer in cash transfers, livestock, and housing. These households are concentrated in the central region of Uganda, the historical locus of banana production, where disease pressures are high but urban markets are more developed. In the context of maize, inserting *Bt* genes into a maize landrace like Mdzihana would target poorer farmers in a marginalized zone of Kenya, with potentially important effects on their household food security. In general, however, delays in crop genetic improvement are likely to generate greater social costs due to benefits foregone.

Farmer demand for improved banana planting material will increase when insertion and expression of more than one resistance trait is achieved, in part because of the difficulties farmers have in distinguishing yield effects of different pests and diseases. This has research cost implications in terms of technical constraints and time delays, and targeting too many traits simultaneously could substantially curb net benefits.

Application of the economic surplus approach shows that in the case of maize, the marginal (per hectare) value of inserting *Bt* into improved varieties would be the same in the high and low potential zones of Kenya. The high potential zone would generate most of the total value of benefits from *Bt*, even though a gene effective against the dominant stemborer species in that zone has not been identified (De Groote et al. 2003). In the case of bananas, findings show that both farmers and consumers stand to benefit greatly from improvements in banana technologies (Kalyebara, Wood, and Abodi 2006, forthcoming). The research team formulated a number of scenarios in collaboration with scientific experts. Results indicate that the option of accelerating adoption of current best cultural practices and multi-use hybrids may have the highest payoffs and present the fewest implementation challenges, largely because with technical constraints and the lack of a biosafety regulatory framework lead to long estimated time lags before new varieties can be made available to farmers. Yet, authors conclude that more needs to be done urgently to raise the productivity of the banana sector given its importance in the diet of Ugandans, the large amount of agricultural land currently planted to relatively unproductive banana systems, and the biotic stresses that cause large economic losses. From a scientific perspective, maintaining existing productivity levels already poses a challenge. Emphasizing a combined biotechnology and conventionally based strategy has several advantages, not least of which is time.

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