International Scholars Journals

Frontiers of Agriculture and Food Technology ISSN 7295-2849 Vol. 9 (7), pp. 001-010, July, 2019. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Review

Diagnostic research to enable adoption of transgenic crop varieties by smallholder farmers in Sub-Saharan Africa

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Accepted 24 April 2019

Diagnostic research is important in helping to create an enabling environment for promising biotechnology products in smallholder agriculture, *before* rather than *after* release. The biotechnology products that now hold promise for poor people in Sub-Saharan Africa are those that tackle economically important, biotic or abiotic problems not easily addressed through conventional plant breeding or pest control, in crops that serve for food as well as cash, while posing little risk of endangering trade. Two biotechnology products we have selected for social science research in East Africa, *Bt* maize in Kenya and pest and disease resistance in the East African highland banana, meet these criteria. Preliminary research suggests that the expression of the trait is much more visible to farmers in maize than in bananas; for either crop, for different reasons, bottlenecks will be encountered in planting materials systems; and despite differing crop reproduction systems, transgenic varieties of either share the same environmental hazard of heightened genetic uniformity in the inserted trait relative to conventionally bred varieties. Aside from the performance of the technology, many factors that have incidence at national, regional, and farm levels will affect the likelihood that farmers will adopt transgenic varieties. Social science research can help pinpoint necessary complementary investments.

Key words: Bananas, maize, adoption, smallholder farmers, transgenic crop varieties.

INTRODUCTION

Much public debate has revolved around the term “biotechnology.” Some contend that agricultural biotechnologies offer a better chance than conventional breeding to overcome challenges faced by smallholder farmers in Africa, including tolerance to drought or devastating pests. Yet transgenic methods in particular have raised concerns about environmental and health hazards. Ethical issues, and skepticism about the social benefits and costs of transgenic crops, have led consumers and advocacy groups to resist biotechnology products.

A recent expert survey revealed 40 biotechnology products in the public research pipeline for South Africa, Kenya and Zimbabwe alone (Cohen et al., 2003), though across Sub-Saharan African countries, transgenic crop varieties have only been released to farmers in South Africa. In our view, diagnostic research is important in helping to create an enabling environment for promising biotechnology products in smallholder agriculture, *before* rather than *after* their release [Diagnostic research as defined here refers simply to the investigation of potential problems and their solution]. Past lessons from conventional breeding demonstrate clearly that social and economic constraints can impede the adoption of promising new crop varieties (Tripp, 2003). Poorly developed markets for planting material, weak institutions

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for diffusing it, or the extreme poverty and cash flow problems faced by many smallholder farmers in Sub-Saharan Africa have often thwarted their ability to benefit from varieties that perform well in their fields. The history of maize research and diffusion in Eastern and Southern Africa illustrates this point succinctly (Smale and Jayne, 2003).

Furthermore, not all technologies are "right;" nor are all released varieties popular. Farmers may not discern the benefits from inserting the trait, or may view these as less important than some other disadvantageous traits of the new variety relative to those they currently grow. A third lesson from past experience is that though planting material may be neutral to the scale of the farm operation (meaning that there is nothing inherent in the technology that implies large-scale farmers will have greater ability to use it than smallholder farmers), there is typically an aspect of the technology that favors its adoption by certain social groups. Those who fund research need to think about which investments provide the best payoffs in terms of the priorities as they have defined them, and success in the future must be gauged against a baseline. Priorities may include equity considerations.

Finally, the economic, social, and political environment into which transgenic varieties will be released differs in important ways from that of many past, conventionally-bred varieties. From case studies published so far, relatively little can be gleaned about farm-level bottlenecks to the adoption of transgenic varieties of staple food crops in Sub-Saharan Africa, however. Few biotechnology products have been released to farmers in less industrialized agricultural economies until recently, and most economic analyses of impacts have been conducted primarily on experiences in the U.S. with commercial crops. Empirical evidence is now accumulating for Bt cotton in Argentina, China, India, Mexico and South Africa (Pray et al., 2001; Thirtle et al., 2003; Qaim, 2003; Qaim and de Janvry, 2002; Traxler et al., 2003), although cotton is a commercial, fiber crop. Cotton seed cannot be easily saved by smallholder farmers, and the requirements of ginning and de-linting processes favors the vertical integration of cotton production and marketing.

Three questions concern us here. First, which agricultural biotechnology products hold promise for improving the welfare of poor people in Sub-Saharan Africa? Second, what are the constraints to their use by farmers? Third, how do these differ from those associated with conventional technologies? Some bottlenecks to farmer adoption can be addressed by complementary investments during the process of the development and release of transgenic varieties. Our working hypotheses are based on research projects recently initiated by the national agricultural research programs in Uganda, Tanzania, and Kenya with other local and international stakeholders, including several international agricultural research centers.

PROMISING CANDIDATES

Selection criteria

At present, the biotechnology innovations that hold greatest promise for poor people in Sub-Saharan Africa are those that: 1) tackle economically important, biotic or abiotic problems that are not easily addressed through conventional plant breeding or pest control methods; 2) pose little risk of endangering trade through exports to countries that do not accept transgenic products; and 3) can make a difference in the welfare of smallholder farmers as sources of both food and cash.

The first criterion asserts that to be cost-effective, biotechnology tools should demonstrate a comparative advantage relative to other tools or tool combinations. To target traits effectively and result in popular crops, genes must be inserted into well-adapted genetic backgrounds that are either conventionally bred or farmer -selected. The second criterion acknowledges that genetic engineering of important export crops makes them vulnerable to trade disputes, regulations, and political lobbies outside their borders (Nielsen et al., 2001).

The third criterion recognizes that the vast majority of smallholder farmers in Sub-Saharan Africa consume part of their food crops and many are net consumers. Market liberalization has progressed unevenly and eventfully in a number of Sub-Saharan African countries. Farm families in these countries often face high and variable input as well as output prices, scrambling to meet their cash needs through numerous sources (Bryceson, 2002). Because food occupies a large proportion of their budget and they respond relatively more to price changes in terms of quantities demanded, both urban and rural consumers in these countries will benefit many times more from the price decreases that accompany technological change than will those of richer countries (Pinstrup-Andersen and Cohen, 2001). Reduction of crop loss and yield increase can therefore lead to a significant income increase.

The two agricultural biotechnology products we have selected for social science research meet the three criteria we have advanced for "promising candidates." They are described next.

Two promising examples from East Africa: bananas and maize

Pest and disease resistance in East African highland banana. East Africa (most notably the Great Lakes region covering portions of Rwanda, Burundi, Tanzania, Kenya and Congo) is the largest banana producing and consuming region in Africa. The geographical focus of our research is an area around the shores of Lake Victoria in Uganda and Kagera District of Tanzania. Estimates of average daily per capita consumption in

Uganda range from 0.61 to over 1.6 kgs (FAOSTAT, 2001; Karamura et al., 1999) and most production is by smallholder farmers who grow bananas mainly for subsistence. Though the origin and center of diversity for banana is believed to be Southeast Asia (Simmonds, 1959) the East African highlands is recognized as a secondary center of diversity for an endemic genomic group (AAA-EA) that consists of several clone sets and two use-determined types: cooking bananas (matooke) and beer bananas (mbidde). Other bananas grown in Uganda include beer or dessert bananas that originated in Southeast Asia (AB, ABB, or AAA) and roasting bananas or plantains (AAB genomic group) [*M. acuminata* (A genome) and M. *balbisiana* (B genome)]. Some newly developed, tetraploid hybrids (AAAB, AAAA, AABB) also grown, and used for cooking and beer.

The Banana Research Programme of the National Agricultural Research Organization (NARO) has targeted several pests and diseases that cause yield losses of economic importance in highland bananas. The major insect pest is weevils, which prolong the maturation period and reduce yields, or cause crop failure through the death of young banana plants. Black Sigatoka, an airborne fungal disease, reduces the number of fruit per bunch and fruit weight. Fusarium Wilt (Panama Disease) is a fungus that attachs to the roots of banana plants and persists in the soil. Nematodes also affect the roots.

All East African highland bananas (referring here to the AAA-EA genomic group) are triploids and therefore difficult to improve through cross-breeding. With three genomes, as compared to two or four, no pollen is produced and plants are sterile. Though 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 advanced by the Fundacion Hondurena de Investigacion Agricola (FHIA) and employed by breeders at the International Institute for Tropical Agriculture (IITA) in Uganda. Male fertile diploids are used to pollinate triploid varieties to produce tetraploid hybrids, which can then be crossed. The hybrid tetraploid expresses the traits of both parents.

Genetic transformation is an attractive option for enhancing bananas relative to cross-breeding. In the case of some pests and diseases that afflict banana plants, sources of resistance have been identified in landrace and wild bananas (Sági et al., 1997). Landraces are sterile, and wild bananas (diploids that are not sterile) have many other undesirable traits. Genes are likely to be inserted from one sterile banana plant into another, rather than from other species (Rutherford, cited by Clarke, 2003). A biotechnology laboratory has recently opened in Kawanda, a research station of NARO, backed by a commitment from the Ugandan government.

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. Average annual per capita consumption of maize is 94 kg, one of the highest in the continent (FAOSTAT, 2001). Portuguese traders probably brought maize to Africa (Miracle, 1966). By the 1930s it was a major crop, its popularity spurred by poor millet harvests and export markets for starch.

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; Harrison, 1970; Hassan, 1998). Some have contended that the yield potential of successive maize seed releases in Kenya continued to rise but the rate of increase declined (Karanja, 1990); others argue that smallholder farmers are far from realizing yield potential because genetic advances have not been matched by improved agronomic practices and efficient support services for smallholders located in marginal areas (Hassan, 1998). As improved maize diffuses into more marginal areas the effects on national yield levels are also numerically marginal (Byerlee and Heisey, 1996). The secular decline in soil fertility in the intensive maize systems of this region has been aggravated by reduced application of fertilizer and the abandonment of traditional methods of soil regeneration as populations rise (Lynam and Hassan, 1998). The removal of subsidies, in combination with high transportation costs, have eroded the profitability of using fertilizers (Heisey and Mwangi, 1996), while pest and disease problems have worsened with intensification and continuous maize planting.

The most appropriate means for enhancing the maize productivity of smallholder farmers in the region is to improve yield maintenance or yield stability through better combinations of resistance and tolerance traits (Lynam and Hassan, 1998; De Vries and Toenniessen, 2001). De Groote (2002) estimated an aggregate maize crop loss of 12% based on farmers' estimates from a geo-referenced, national statistical survey of 1200 farmers (Hassan, 1998). Direct estimation with a sub-sample of fields drawn from the same sampling frame generated a figure of 14% (De Groote et al., 2002). Moreover, the yield effect of resistance obtained from genetic engineering is likely to be greater than that achieved through conventional crossing since it is not linked to other, less desirable genes.

Since 2000, Kenya Agricultural Research Institute (KARI) and International Maize and Wheat Improvement Center (CIMMYT), supported by the Syngenta Foundation for Sustainable Development have sought to develop *Bt*-resistant, adapted Kenyan maize materials. Genes with resistance to 4 of the 5 major stemborers have been successfully inserted and the leaves of transformed varieties have been brought into the country to test *Bt* genes against different stemborer species. If the available genes were inserted in current improved varieties the expected benefit would amount to US$ 6 million. If appropriate genes were found against the 5th stem borer species, this would increase to US$ 48 million.

ENABLING ADOPTION BY SMALLHOLDER FARMERS

Conceptual approach

The performance of a technology (crop and trait) is only one consideration among many in its adoption. Once a technology has been developed and tested, factors that have incidence at national, regional, and local levels influence whether or not smallholder farmers will choose to use it, the geographical extent of use, its continuity and duration. The economic impact or "success" of the technology is determined in the first instance by these outcomes.

As a wave of liberalization swept Sub-Saharan Africa during the late 1980s and 1990s, government support to agriculture was reduced drastically. Though the aim was to encourage the supply of seed and fertilizers by private enterprise, most national governments were reluctant to release controls, instead imposing costly regulations on companies in order to protect consumers and farmers. With any regulatory system, there is a trade-off between cost and feasibility and the protection achieved. Perhaps the most pressing problem to resolve before transgenic varieties can be released to farmers is the design of appropriate biosafety systems. A conceptual framework to assist developing countries in the formulation of biosafety regulatory frameworks has now been created (McLean et al., 2002).

Once a crop variety has been released, factors that vary among regions but are constant for farmers within regions condition their choices. Farmers' choices are influenced by market conditions for seed, related inputs, and the crop, as well as their surrounding agroecosystem (soils, pests and plant disease pressures, moisture, elevation, and environmental heterogeneity). Social capital and social networks may substitute for institutions such as extension services as sources of the information that is critical for farmers to perceive benefits and earn them (Katungi, 2003).

Explanatory factors that vary among farmers are documented in the literature on adoption of agricultural innovations in developing countries (reviews include Feder et al., 1985; Feder and Umali, 1993). Our work involves the application of econometric models that draw on both Lancaster's (1966) theory of consumer choice and the theory of agricultural household (Singh et al., 1986) . We view varieties as bundles of attributes from which farmers derive utility, each variety supplying its own expected levels of attributes given its genotype and interactions with the environment. In our framework, the production attributes of a variety include input traits such as increased resistance to pests and diseases or tolerance to abiotic stresses such as drought, while the consumption attributes include taste as food or beverage, or suitability as fodder (Edmeades, 2003). Transgenic varieties consist of targeted traits inserted into a background that provides other attributes of interest to farmers. Relatively few adoption models have treated variety attributes other than crop yield explicitly (for example, Adesina and Zinnah, 1993).

The theoretic framework of agricultural household predicts that when all markets function perfectly and farmers maximize profits, only prices, agronomic attributes, the technology of the farm, and the agroecology of the region in which the farm is located, shape variety choices. This is seldom the case, however. When markets do not function perfectly, consumption and production decisions cannot be separated and effective prices are determined within each household based on its characteristics and market access. Household characteristics include the human and physical capital endowments of the farm household, and income that is external to farming decisions. These factors then explain variety choices in addition to the other genetic and physical determinants (Van Dusen, 2003).

The next section explores some working hypotheses from our ongoing research, which focuses on factors that vary at the farm level and highlights those that are distinct for transgenic as compared to conventionally-bred varieties. We close with some hypotheses concerning the risk profile for transgenic varieties. Risk has incidence at the farm level but influences, and is influenced by, biosafety systems.

FACTORS ENABLING ADOPTION OF TRANSGENIC VARIETIES OF MAIZE AND BANANA IN KENYA, UGANDA AND TANZANIA

Following the lower section of Figure 1, we begin by summarizing the seed system factors for maize and bananas as these reflect fundamental differences in plant reproduction. We then discuss the targeted traits and background materials for gene insertion, which influence whether or not farmers will perceive the advantages of adopting transgenic varieties relative to those they currently grow. Finally, the risk profile of transgenic varieties most sharply distinguishes the social and economic environment into which they are introduced from that of conventionally-bred varieties.

Plant reproduction and markets for planting material

Maize. Morris (1998) has aptly summarized the properties of maize as a crop species that influence the nature of seed genetic change and its impact on smallholder farmers. Maize seed is compact and easy to

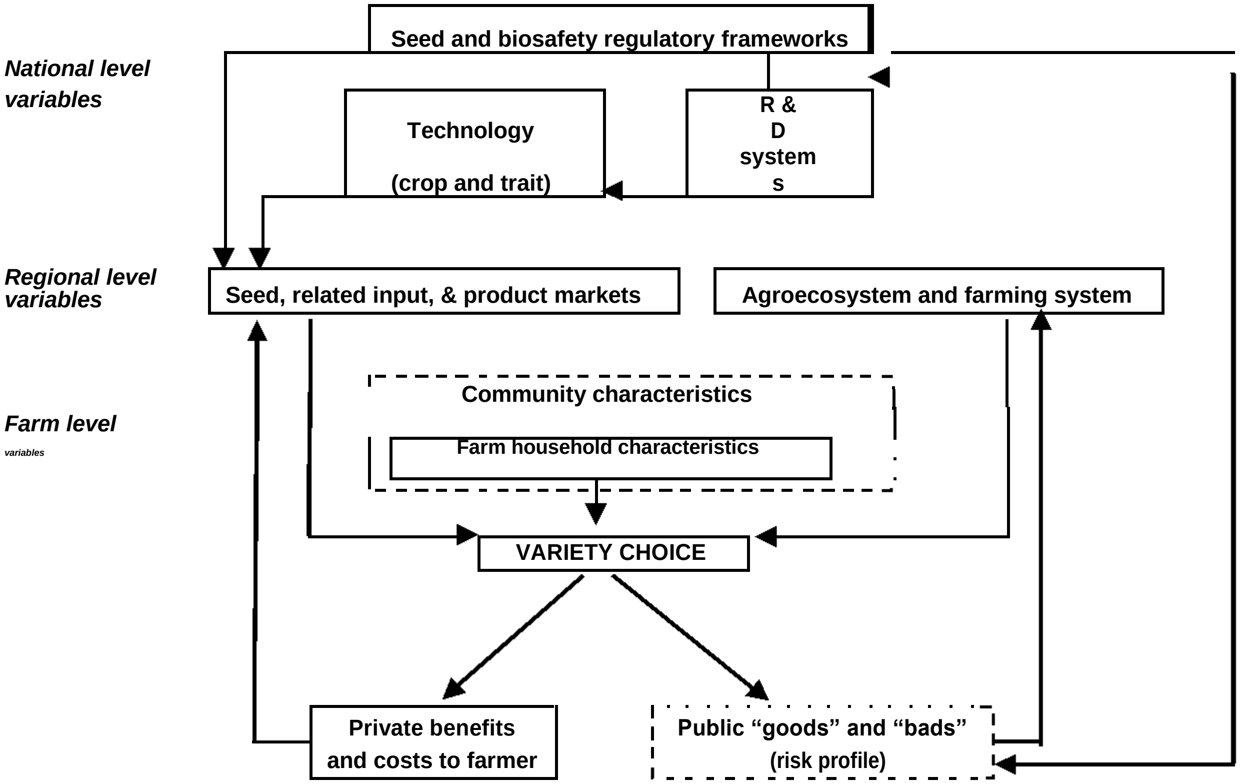

Figure 1. Schematic diagram of factors affecting adoption of transgenic varieties by smallholder farmers in Sub-Saharan Africa.

store and transport. Maize is predominantly a cross-pollinating crop, with high rates of exchange of pollen among neighboring plants. Unless carefully controlled, all of the maize plants in a given field will differ from the preceding generation and from each other. When maize self-fertilizes, the progeny often have undesirable traits, but when it cross -fertilizes, some demonstrate significant yield advantages relative to their parents ("hybrid vigor").

To maintain the significant yield advantages offered by maize hybrids, farmers are reliant on a commercial seed industry to purchase their seed annually. Most maize farmers in Sub- Saharan Africa grow local varieties and reproduce their own seed, though many more have grown hybrids at one time or another. A hybrid-based maize sector requires large-scale commercial seed enterprises, whose profits can be sustained only by strong seasonal demand by farmers to renew their seed (Tripp, 2001a). Though improved open-pollinated varieties are popular, farmers must also renew their seed periodically—yet there are limited incentives for commercial seed enterprises to produce them.

Due to market imperfections and cash constraints, smallholder farmers in Sub-Saharan Africa often save the harvest from F1 seed, "recycling" it through planting advanced generations. Survey data collected intermittently from 1989 to 1997 among 420 smallholder farmers in the major maize-producing zones of Malawi revealed that during the process of market liberalization only 7% were able to purchase F1 hybrid seed every year (Smale and Phiri, 1998). In 1997, an estimated 30% of all maize area represented in the survey was planted to advanced-generations of maize hybrids. Such practices are widely reported for other countries in Sub-Saharan Africa.

High rates of cross-pollination mean that the advantages of F1 seed of maize hybrids can degenerate rapidly when farmers save the seed and replant it, though evidence suggests that in some cases advanced-generation hybrids significantly outperform the variety that the farmer was growing previously—depending on the type of hybrid (single-, three -way, or top-cross) and the control that serves as the basis for comparison (Morris et al., 1999). Maize is one of the most highly bred crops in the world, and in industrialized countries, its seed industry is one of the most highly concentrated in terms of the share of seed sales held by leading private companies (Heisey et al., 2001). While the maize seed industry functions well compared to that of other grains and legumes in Eastern and Southern Africa (Tripp, 2001a), seed supply problems have accompanied the patchy, incomplete process of seed market liberalization. For example, growth in seed sales in Kenya slowed in the 1980s and has recently declined (Karanja, 1990), apparently provoked by inefficiencies and seed quality problems with some private companies. More recent, publicly-bred varieties released in Kenya have diffused more slowly than did their predecessors (Karanja, 1990; Hassan, 1998).

***Bananas*.** In contrast to maize, the planting material of a banana is not a seed but a “sucker” that grows from and is a clone of the mother plant. The sucker must be uprooted from an existing mat to reproduce the variety, and because of its bulk, transports poorly. We know comparatively little about the mechanisms by which banana planting material circulates among farmers and communities. At present, there is scant evidence of markets for banana planting material—presumably due to the related costs of transactions.

Once farmers have acquired a new type, if it thrives and the seed is clean, they can propagate it themselves and maintain its yield advantages for many years. The sheer bulk of the planting material, and clonal propagation, limits opportunities for small-scale seed enterprises, and some public resources are always likely to be necessary to diffuse new banana varieties (De Vries and Toenniessen, 2001). One approach is to maintain large planting stock nurseries in the project area for direct sale to farmers and wholesaling to stockists; another is to establish nurseries managed by “expert” farmers through community organizations. Diffusion mechanisms are one focus of the social research conducted on this project.

Farmer propagation of bananas takes nearly 2 years. Three of the four major pests and diseases (nematodes, weevils, and Fusarium wilt) are transmitted through planting material. Other biotechnology applications in banana have involved micro-propagation techniques (tissue culture) for the purpose of multiplying “clean” banana planting material. Yet even if high standards can be maintained, long-term use of clonal propagation through tissue culture results in cell (somaclonal) variations that may have deleterious consequences (Crouch et al., 1998).

Farmer perceptions of new traits

Even if planting material is available and they can afford to purchase it, farmers will not adopt a variety unless they can *see* the benefits. Assuring the physical quality of the planting material is one problem, but its genetic quality is another; seed has to be grown by farmers or trustworthy neighbors for the genetic quality to be *credible* to them (Morris, 1998; Tripp, 2001b). Empirical research suggests that while farmers are knowledgeable about pests that they can see and touch (weeds, insect, vertebrate pests), they know much less about plant diseases and insect reproduction (Orr, 2003: 834; Bentley, 1994), which scientists observe with the assistance of laboratories and controlled experiments.

Farmers recognize stem borers and the losses they cause to the maize crop (De Groote et al., 2003). Stemborers feed on the leaf tissue, tunneling and feeding into the stem and sometimes the cobs. Nematode infestation of banana roots is not observable. Fusarium Wilt persists in the soil, but its visible effects on the banana plant do not. Black Sigatoka and Fusarium Wilt are imported diseases of banana, with Black Sigatoka only emerging in importance during the 1990s. Farmers often attribute the visible damages caused by these diseases, as well as nematodes, to weevils (Gold et al., 1993).

Backgrounds for gene insertion

Too often, social scientists conducting adoption studies have simply juxtaposed “modern” with “traditional,” or “new” with “old,” assuming that one would replace the other. Plant breeders and farmers recognize that any single variety is a bundle of traits. Social scientists have long observed that farmers often grow more than one variety at once. Sometimes they grow many side by side, as in the case of bananas in Uganda.

Despite the restricted genetic structure of banana as a crop, the literature suggests, and preliminary survey results confirm, that farmers’ themselves recognize a tremendous diversity in morphological traits. Karamura and Karamura (1994) estimate that there are 233 locally distinguishable clones of East African highland banana. Preliminary estimates from our sample survey of 800 farm households reveal an average and mode of 8 distinct cultivars per farm.

Since insertion into multiple backgrounds has cost implications, choices will need to be made about the cultivar(s) into which the transgene will be inserted. For example, East African highland cooking bananas are more highly susceptible to Black Sigatoka and weevils than are exotic beer bananas, while exotic beer bananas appear relatively more susceptible to Fusarium Wilt than highland bananas (Gold et al., 1994). Choice of background will affect the distribution of benefits among communities, farmers within communities, and members of farm families.

On farm diversity also has implications for adoption of transgenic banana. Even if many farmers adopt a new variety, the variety may constitute a small share of their total banana population because no single cultivar dominates with respect to all uses or attributes. On the other hand, uneven, spatially discontinuous adoption could be beneficial in terms of managing pest and disease evolution, extending the usefulness of the trait and the economic advantage farmers earn from adopting transgenic varieties.

In Kenyan maize, as in the highland bananas of Uganda and Tanzania, there are many genetic backgrounds into which *Bt* transgenes may be inserted.

In Kenya, however, most are hybrids and improved open-pollinated varieties (IOPVs). The choice among them will have economic efficiency, social equity, and genetic diversity implications. The percentage of the crop lost to stem borers and its value varies among the six maize producing environments of the country. About 80% of the estimated value crop losses to stem borers in Kenya accrue in the moist transitional and highlands zones, where adoption rates for maize hybrids (including advanced generations) are 90-95 percent of farmers. The highlands zone is dominated by one single maize hybrid, while a wider range of maize hybrids produced by KARI and private companies are purchased by farmers in the moist transitional zone. Only 12.5% of the national value of crop losses to stem borer occurs in the dry and lowland tropics zones, where IOPVs and some distinctive maize landraces, rather than hybrids, dominate. Farmers in the high potential zones are gradually diversifying into other crops and income-earning activities; in the drier and the coastal lowlands areas where farmers are economically marginalized, reducing crop losses may have a greater incremental impact on welfare. Furthermore, the distribution of stem borer species indicates that the dominant species in the moist and transitional zones is *Busseola fusca*, for which the effective *Bt* gene has not yet been identified. The dominant species in the other zones is *Chilo partellus*, against which Cry proteins were found to be very efficient (De Groote et al., 2003).

Risk profile

Perceived biosafety risks of transgenic varieties are hotly debated in the international community. These include the (1) flow of transgenes; (2) resistance evolution in the targeted pest population (3) plant escape and establishment of self-reproducing populations; (4) effects on non-target species; and (5) health hazards (NRC, 2002).

No flow of transgenes is possible among East African highland bananas because they are sterile triploids. Geneflow can occur among tetraploids, such as the recently developed hybrids, though 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. The dominance of the *Bt* genes augments the risk of genetic uniformity in the trait. In the highland areas of Kenya where the adoption rate for a single maize hybrid (H614) is very high, virtually all farmers would be growing the F1 or advanced-generation hybrid with *Bt*-resistance within a few years. In the zones where the productivity potential of maize is lower and improved maize varieties are less popular, farmers ascribe greater importance to losses from stemborer and would be keen to try resistant varieties. They are also likely to recycle, mix and select for the trait in their local materials, which would contribute to gene flow and genetic uniformity in the trait.

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. *Bt* genes are single genes that cause heavy pest mortality, augmenting the pressures for mutation. 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 banana. 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 with tissue culture, would contribute to genetic uniformity in the trait.

However, both the problem of genetic uniformity and its solutions 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 wide range of varieties with differing resistance levels and mechanisms are available to farmers.

There is no risk of gene flow to wild relatives or plant escape in either case. Wild diploid bananas have been found only in Asia. The diploid bananas known to exist in Uganda and Tanzania are not wild plants, but cultivated and edible types that have no female seeds and are sterile (D. Karamura, pers. comm.). There are no wild relatives of maize in Africa.

It is often said that the rapid spread of new varieties, and in particular transgenic crop varieties, will cause farmers to abandon potentially valuable landraces. Despite the fact that maize is not endemic to Africa, maize breeders in Kenya do recognize some old, regional maize varieties still grown in the drylands, along the Coast or Lake Victoria as distinctive and potential sources of valuable traits for crop improvement. The East African Highlands banana is a secondary center of diversity.

We argue that there is no greater risk of replacing these types with transgenic than with conventionally-bred varieties. On the coast, the adoption of improved maize remains low. Preliminary survey research suggests that farmers' preferences for maize landraces in these communities are related to a combination of consumption preferences, agronomic attributes, and market imperfections that are likely to persist. In the case of banana, we might hypothesize that one reason farmers maintain so many cultivars simultaneously is that they serve as living stocks, reducing their reliance on cumbersome, longer-distance exchanges of planting material for the range of types they demand. Genetic transformation is one way to maintain the diversity of types that farmers recognize and find useful, since when this technique is applied, each cultivar can retains its characteristics while the desired trait is added (Sági et al., 1997).

Nothing is known about the risks to non-target 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 non-target 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 constructions for insertion and markers. Purported health risks of the *Bt* maize that are different from those of conventionally-bred maize have not been substantiated (GAO, 2002). 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.

So far, surveys conducted by the *Bt* maize project in Kenya reveal that farmers and consumers in Kenya are largely unaware of the issues. Ultimately, they themselves will decide whether benefits outweigh costs when they accept or reject transgenic varieties. Governments have a public responsibility to invest in enabling farmers to make informed choices, and to take full advantage of the technology if they choose to use it (Tripp, 2001b). The evidence must be assembled and presented in a manner that the general public can follow.

CONCLUSIONS

Aside from the performance of the technology, many factors that have incidence at national, regional, and farm levels will affect the likelihood that farmers will adopt transgenic varieties of banana and maize in East Africa. At this early stage, only preliminary conclusions about farm-level factors can be drawn from the evidence and research.

First, though evidence demonstrates the economic importance of the targeted traits and crops to the welfare of smallholder farmers in this region, the expression of the trait is much more visible for maize than for bananas. For farmers to perceive the benefits from adopting transgenic banana, publicly-funded educational efforts are likely to be required unless traits are stacked.

Second, for either crop, though for different reasons, bottlenecks may be encountered in the seed systems that will deliver transgenic varieties. Commercial seed systems for maize are well established in Kenya, but small companies need assistance in research to transform their own lines, as well as public awareness. Since these companies expect to earn few profits from sales of IOPVs in marginal areas, public funds will be needed to bring IOPVs with *Bt*-resistance within the reach of the farmers who can reproduce them. A commercial seed industry is unlikely to develop for the East African highland banana. Farmers' systems for exchanging planting material must be better understood before appropriate diffusion strategies can be formulated, and these are likely to require public funds.

Third, though banana is clonally propagated and maize is a highly cross-pollinating species, we hypothesize that transgenic varieties of either crop share the same environmental hazard of heightened genetic uniformity in the inserted trait relative to conventionally bred varieties. Genetic uniformity in the inserted trait may lead to more rapid evolution of resistance in the target population. The problem can be addressed through plant breeding strategies, promoting the cultivation of multiple varieties with diverse resistance mechanisms, or control through *refugia*. In the production systems of East Africa, where monitoring and inspection systems do not seem feasible or would be prohibitively costly, the only viable option for *refugia* is natural. Investments designed to support crop diversification by farmers would be critical for maize. Other options such as seed mixtures may also be considered, though these might exacerbate seed sales problems that have resulted from lack of credibility. Public investments will be needed to support the generation of farmer knowledge about the environmental risks of transgenic varieties of banana and maize and how to manage them.

Finally, as promising biotechnology products near release, research aimed at understanding the context in which smallholder farmers make their variety choices will help pinpoint constraints to adoption. Social science research can be help in a more systematic understanding of farmers' preferences and perceptions, supporting the development of a fuller basket of options for them to choose from and adapt. Social science can also help to generate more realistic expectations about the likely impacts of adoption on the welfare of smallholder farmers in Sub-Saharan Africa. Today, any single agricultural activity, and agriculture itself, plays a diminishing role in the income-generating strategies of rural Africans.

ACKNOWLEDGEMENTS

The research we refer to here is conducted with numerous partners whose substantive contributions to the points expressed are gratefully acknowledged. In Uganda and Tanzania, the social science research is led by the Banana Research Programme of the National Agricultural Resource Organization (Uganda) and the Agricultural Research and Development Institute, Lake Shore-Maruku District (Tanzania), with the International Network for Improvement of Banana and Plantains (INIBAP) and the International Food Policy Research Institute (IFPRI). Doctoral students and professors participate from the University of Makerere, Uganda, University of Sokoine, Tanzania, University of Pretoria, South Africa, University of Wageningen, the Netherlands, and University of North Carolina, USA. In Kenya, the social science research is led by the Kenya Agricultural Research Institute (KARI) and the International Maize and Wheat Improvement Center, with participation by the International Food Policy Research Institute. Social science research in these projects is supported by the Syngenta Foundation for Sustainable Development, the U.S. Agency for International Development, and the Rockefeller Foundation.

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