AgBioForum, 10(3): 135-143. ©2007 AgBioForum.

Patterns of Political Response to Biofortified Varieties of Crops Produced with Different Breeding Techniques and Agronomic Traits

Carl Pray
Rutgers University

Robert Paarlberg
Wellesley College

Laurian Unnevehr
University of Illinois at Urbana-Champaign

This article first examines the political response to two crops that were nutritionally enhanced through conventional breeding—Quality Protein Maize (QPM) and orange-fleshed sweet potatoes. In the next section, the political response to food crops—maize, potato, and papaya—which have improved agronomic traits through genetic engineering is described. Finally, we mention briefly the initial political responses to biofortified GMO rice, potatoes, cassava, and sorghum. To gain political support as well as extensive adoption by farmers, biofortification needs to be combined with attractive agronomic traits. These case studies also show that only GMOs have elicited a strong negative political response and that the consumer trait, biofortification, is not likely to make GMOs more appealing to activists and politicians. However, political opposition to GMOs can be outweighed by well-organized, politically powerful interest groups.

Key words: QPM, maize, sweet potatoes, papaya, potatoes, Africa, Mexico.

Political responses to novel foods and crops can be specific to the new traits of those crops (agronomic versus enhanced nutrients), to the intended uses of those crops (food for people versus feed for animals), and also to the methods used to introduced those traits (conventional breeding versus genetic engineering). This article describes variations in observed political responses to three different categories of novel foods and crops: conventionally bred crops with enhanced nutrient traits; genetically engineered/modified organisms (GMOs), in this case, plant varieties with enhanced agronomic traits; and GMOs with enhanced nutrient traits. The pattern that emerges from these case studies is that both conventional and GMO crops must have superior agronomic traits in order to spread rapidly. A second pattern is that GMO crops encounter significantly more political resistance than conventionally bred crops. A third pattern is the importance of some influential interest groups, such as farmers or agribusiness, in generating political support for these new technologies.

Conventionally Bred Food Crops with Enhanced Nutrient Traits

Quality Protein Maize

We have only a limited amount of political experience so far with biofortified food crops bred conventionally to contain enhanced nutrient traits. The single most important example is Quality Protein Maize (QPM), a conventionally bred variety of maize with roughly double the available protein of ordinary maize due to higher levels of various amino acids, principally lysine and tryptophan. When first discovered by scientists at Purdue University in 1963, QPM appeared to address a widespread and serious nutritional problem around the world (Mertz, 1994). Feeding studies with human populations, and also with animals, confirmed that QPM could deliver more protein than normal maize. Yet this higher level of protein unfortunately was combined with lower yields and with a soft, chalky kernel, which changed the taste and left the maize susceptible to disease and pest damage both in the field and during storage. In addition, the gene controlling for the high protein levels was recessive, and therefore, protein levels could be reduced if new seeds were not purchased every two or three seasons or if proper seed selection was not carried out. These factors made QPM unattractive for farmers to produce (Lauderdale, 2000). Also, in 1973 the United Nations and the World Health Organization (WHO) issued new nutritional guidelines with substantially lower recommended levels of protein intake (Food and Agricultural Organization of the United Nations [FAO] & WHO, 1973), after which the main focus of nutritional concerns shifted from protein deficiency to overall energy consumption. By the mid-1980s the International Maize and Wheat Improvement Center (CIMMYT) board decided to stop funding QPM research. However, protein deficiency remained a real concern, protein enhancement for weaning foods remained an accepted targeted intervention for child malnutrition, and emerging evidence suggests it may also be important for extending survival of HIV-positive adults. Thus, technologies such as QPM can still play a valuable role.

In the 1990s, researchers at CIMMYT started working on QPM again. Scientists there developed QPM with hard kernels and a taste that was similar to traditional varieties. Then, they concentrated on improving the production qualities of QPM to increase its yield. The first improved varieties of QPM were introduced into developing countries in the 1990s, and hybrids have been released since 2000. It is estimated that there are now roughly 800,000 hectares of QPM varieties being grown in Africa (300,000 ha in Ghana alone and 100,000 ha in Uganda) according to Sasakawa-Global 2000 (Sasakawa Africa Association, 2006). CIMMYT reports that there are 318,500 hectares in Asia (nearly all in India and China), and 45,700 hectares in Latin America. As a general rule, QPM is grown for *human* consumption in Africa and for *animal* consumption in Asia and Latin America.

CIMMYT has worked with national agricultural research organizations as well as other local partners and stakeholders to promote and develop QPM. CIMMYT, sometimes partnering with the International Institute of Tropical Agriculture (IITA), develops the germplasm and then works with national agricultural research organizations or regional networks of maize breeders to develop varieties well-adapted to the region. The variety that has been most successful is the Ghanaian open-pollinated variety Obatanpa, which is planted on about 700,000 ha of the 800,000 ha of QPM in Africa (Sasakawa Africa Association, 2006). It has good grain quality, agronomic advantages like higher yield, and nutritional advantages for people, pigs, and poultry. CIMMYT and Sasakawa believe that a distinct agronomic advantage—particularly yield—is a requirement for reasonable levels of uptake. Governments negotiate with seed companies to produce the seed, usually for sale but sometimes for distribution through national agricultural programs. In Ghana, the President of the country became interested personally in the Obatanpa variety. His enthusiasm ensured that it was well publicized, and its spread was encouraged through government extension.

Many countries, particularly in Asia and Latin America, are currently funding and carrying out their own work on QPM. In addition, CIMMYT receives QPM funding from the Nippon Foundation for work in Africa, CIDA-Canada for work in Central America and eastern Africa, and the Rockefeller Foundation for work in East Africa. They also receive some funding from the Suri Sehgal Foundation for work in India. Sasakawa-Global 2000 remains a supporter of QPM. It has QPM projects in Uganda and Ethiopia.

With more than a million hectares of QPM now grown worldwide, these varieties and hybrids deserve to be considered both a technical and a commercial success, particularly in Ghana and Uganda. Yet it took many decades of research improving and promoting QPM varieties to reach this point, suggesting that rates of return from this research may not be high. In addition, we could find no studies confirming a significant improvement in nutritional outcomes or even documenting how much QPM is consumed by people rather than animals. Poor farmers with dietary deficits might be more interested in planting QPM if the nutritional benefits were more visible and immediately apparent (Lauderdale, 2000). Poor farmers who save rather than purchase seed may lose some of the nutrient advantage of QPM if they do not buy new seed every two or three years. Their QPM will cross pollinate with the other popular maize cultivars in the area and produce grain which has the quality of the popular cultivars, not the QPM. Although saving seed from the center of the field before the crop is harvested will greatly reduce the chances of losing the protein advantage, farmers more traditionally select seeds after the harvest, at which time it is not possible to tell in which part of the field the seed originated, thus increasing the chances of loss of the desired characteristic. Such farmers will then have no way of knowing if the gene has been lost (Lauderdale, 2000). The consumer purchasing QPM in the market also has no way of knowing the quality of their maize. Overcoming this limitation could require an expensive certification process or the introduction of color or appearance differences. There is currently no available data showing who is purchasing QPM varieties in the marketplace or whether they are consuming it in large enough quantities to have any impact.

The situation might be different if the goal was to produce for urban areas for use in commercially produced products. Producers of commercially produced foods could contract with farmers to grow certified QPM seed, thus ensuring that the producers are actually receiving a QPM grain. It also may be possible for governments to contract with farmers to grow QPM for targeted selling or distribution to high-risk populations. Use in supplemental feeding programs is another possible option. It was demonstrated in Mali that protein-enhanced weaning foods might command a premium in the market if they could be reliably certified (Masters & Sanogo, 2002). Although the Mali study is related to cowpea flour enhancement, it suggests that certified QPM weaning foods could have a commercial market.

What we see in the case of QPM is that it has been adopted extensively in some countries, but the nutritional benefits to poor farmers and consumers have not yet been documented in the field. The greatest barriers to uptake have not included political opposition. Indeed, this is a technology that has enjoyed surprisingly strong international and local political support for decades. The greatest barrier to uptake has been a lack of interest by farmers in most QPM varieties which—with the exception of Obatanpa—have not had improved agronomic traits over farmers' traditional varieties or non-QPM commercial varieties.

Orange-fleshed Sweet Potato

A more recent effort to deliver to farmers a biofortified crop developed through conventional breeding is the case of orange-fleshed sweet potato (OFSP) in Africa (Low et al., 2005). In the Western Hemisphere, OFSP is not a new crop; in Africa, most traditional sweet potato varieties have been white- or yellow-fleshed and have contained little provitamin-A. To encourage Africans to grow orange-fleshed varieties, plant breeders have been developing OFSPs that conform to Africa's distinct preference for other traits, including sensory traits and high dry-matter content. Currently, about 40 varieties of sweet potato high in both provitamin-A and dry matter have been introduced into Sub-Saharan Africa. In Uganda, two OFSP cultivars, Ejumula and Kakamega, were officially released in April 2004 and by 2006 had spread into more than 40 districts in the country. In Kenya since the mid-1990s, the Kenya Agricultural Research Institute (KARI) has been participating in OFSP pilot projects with the support of the International Potato Center (CIP), Care International, and the International Centre for Research on Women (ICRW), with results that have led to the spread of OFSP to Mozambique, Tanzania, Malawi, Rwanda, Burundi, and elsewhere.

A current leader in this effort has been the HarvestPlus program of the Consultative Group on International Agricultural Research (CGIAR), which has been facilitating the introduction of high dry-matter OFSPs from CIP in Peru into Uganda, Kenya, Ethiopia, Rwanda, Madagascar, and Tanzania. More than 10 varieties have been tested in national and regional evaluation trials across different agro-ecological zones to identify promising traits, and pilot dissemination projects using these varieties are underway, led by CIP partnering with African agricultural researchers. Participatory breeding with local farmers has helped identify appropriate varieties, encourage local ownership and acceptance of the technology.

As of 2006, HarvestPlus was adding an additional implementation program to its breeding and nutrition research activities for OFSP, which is designed to disseminate biofortified sweet potato to end users. This program will include extension efforts plus active behavioral change and health communication efforts to ensure demand creation, focusing on target populations in Mozambique and Uganda (HarvestPlus, 2006). In Kenya as well, in Kwale District, CIP is partnering with KARI to promote production, dissemination, and marketing of OFSP. The health communication techniques employed include poems and skits that primary school students can read and perform and even a rap song extolling the virtues of OFSP (CGIAR, 2006).

Data collected in 2005 from a multi-donor-funded two-year pilot intervention research project in Mozambique confirm the beneficial potential of OFSP. The new cultivars have been well received by farm households, especially mothers of small children, leading to changes in food consumption patterns. Comparing results from 498 households with access to new OFSP varieties to 243 *control* households without access, this study showed that median intake of Vitamin A was 8.3 times higher among children in the intervention households versus the control households, and median energy intake in the intervention areas exceeded control areas by 14.2%. Vitamin A deficiency (VAD) was reduced by 24% among healthy children in the study. Part of the success of these OFSP varieties was the higher yield they promised under normal rainfall conditions, compared to local white-fleshed varieties (Low et al., 2005).

The efforts of HarvestPlus to push OFSPs in Mozambique have so far faced one consumer concern and one technical problem. The consumer concern is that some people thought the varieties were GM varieties, and they worried about safety for consumption. As a result HarvestPlus launched a public relations campaign to convince officials and consumers that the OFSPs were not GM. The technical constraint was that it has been difficult to keep the current OFSP varieties alive during the dry off-season in Mozambique, which means that vines, which are cut up to make the planting material, are not available to produce the next year's crop (Fuglie & Yanggen, 2006).

Table 1. South Africa: Transgenic maize area (acres) and as percentage of maize planted.

Crop	1999/2000	2000/2001	2001/2002	2002/2003	2003/2004	2004/2005	2005/2006
Bt yellow maize %	3%	5%	14%	20%	27%	22.4%	18.7%
Area	50,000	75,000	160,000	197,000	250,000	249,000	106,967
RR yellow maize %	0	0	0	0	0	1.3%	11.8%
Area	0	0	0	0	0	14,000	67,629
Bt white maize %	0	0	0.4%	2.8%	8%	8.3%	22.7%
Area	0	0	6,000	55,000	175,000	142,000	220,691
RR white maize %	0	0	0	0	0	0.3%	6.2%
Area	0	0	0	0	0	5,000	60,000

Notes. Areas are measured in hectares. Bt=Bacillus thuringiensis; RR=Roundup Ready.
Data from Van der Walt (2007).

Efforts are now underway to extend OFSP to West Africa as well, beginning with work in Burkina Faso under a project called VitABurkina funded by Helen Keller International (HKI) and the McKnight Foundation for four years, 2005-08. The challenge once again is to develop orange-fleshed varieties with enough dry matter to be locally acceptable. In 2005-06, agronomic tests were conducted on 22 varieties introduced from CIP in Uganda into a controlled environment, with varying results for dry versus rainy season conditions. Promotion activities have included introductions into 11 villages in Komondjari province, with schools hosting the nurseries and supplying interested farmers in the village. An organizational workshop in September 2005 resulted in the development of a "national action plan for OFSP production, dissemination and promotion" (HKI, 2006, p. 11). The results of this project may be used to inform other Sahelian countries with similar cultural practices and agro-climatic conditions (HKI, 2006).

These gratifying results for OFSP in Africa suggest that the rural poor are willing to consume biofortified versions of food staples even if the color of the food has been changed. The poor will consume these foods if they are educated as to the benefit. In fact, education programs to boost acceptance can work best when the biofortified food is visibly different.

Genetically Engineered Food Crops with Enhanced Agronomic Traits

The first generation of GMO crops was engineered to carry improved *agronomic* traits rather than improved *nutrient* traits. The most frequent use of these first generation GMOs has been either in industry (cotton) or for oil, starch, and animal feed (soybeans and yellow maize). GMO food staple crops are not yet in wide use anywhere. Yet, we do have several experiences to draw upon that suggest a wide variation in political responses to such crops: *Bacillus thuringiensis* (Bt) white maize in South Africa has been taken up readily, GMO potato in Mexico has not, and GMO papaya in Asia remains at least partially blocked.

GMO Maize[1]

In South Africa white maize is the major food grain. About half of the maize planted in South Africa is white maize for food, while the other half is yellow maize primarily used for animal feed and industrial processing. Insect-resistant and herbicide-tolerant white maize in South Africa is the lone example so far of a basic food grain genetically engineered to help farmers that has been successfully commercialized in the developing world.

In 1997, South Africa approved yellow maize hybrids containing a Monsanto Bt maize event. Monsanto sold this Bt maize seed and also licensed the Bt to Pioneer and Pannar, who used the Bt in their own yellow maize hybrids. In 2001, Bt white maize hybrids were marketed and planted for the first time, and in 2004 both yellow and white GMO maize hybrids resistant to the Roundup herbicide were first planted. In total, 30% of the yellow maize and 29% of the white maize in South Africa is now GM (Table 1).

GM maize in South Africa has been promoted by biotech corporations—Monsanto, DuPont, and Syngenta—which see South Africa as both a substantial market on its own and also as a stepping stone to other countries in Africa. South Africa offers these companies the advantage of strong intellectual property rights (IPRs), large modern farms, clear regulations, and a less

---

[1] *See the South Africa case study by Wolson (2007), elsewhere in this special issue, for more details.*

politicized regulation process. The other important supporters of GM technology in South Africa have been large commercial farmers who like the management convenience and lower costs of production provided by the technology. South African farmers have been able to segregate their maize and continue exporting non-GM white maize to those neighboring countries such as Zimbabwe and Zambia that do not want the GMO varieties. In South Africa, GMO technologies have also been supported by university-based scientists who are outspoken and quite effective at countering the myths about GM technology propagated by non-governmental organizations (NGOs).

For small farmers in regions with reliable rainfall, Bt white maize not only has *agronomic* advantages but also *quality* advantages. There is less fungus disease on the kernels, and when not mixed with local colored varieties, the flour made from the Bt maize is whiter and preferred to flour from conventional hybrids or landraces. Small farmers have adopted the technology in areas where they were already growing maize hybrids and where government extension services helped provide advice and helped local farmer co-ops buy seed produced by the private sector. It is not adopted in drier areas where regular drought makes maize production more risky; here, maize farmers use open pollinated varieties and rely mostly on saved seed for planting.

Opposition to GMOs within South Africa is confined mostly to a few NGOs. Their most effective tactic for slowing the spread of GM crops has been to pressure supermarkets to become non-GM. They have succeeded in convincing Woolworths, which is the more expensive supermarket chain with less than 10% of the retail market, to pledge that where possible, they will remove or replace products containing GM ingredients with non-GM equivalents, and where this cannot be done, to label accordingly.

White GM maize has been produced and consumed in South Africa since 2002, and so far it has faced little direct political opposition. This is because commercial farmers already had experience with yellow GM maize and appreciated the savings of costs and management time that it brought and were capable of segregating GM from non-GM well enough to reduce commercial export risks. Some African governments such as Zimbabwe and Zambia will only allow importation of non-GM white maize, but most other African countries continue to import mixed GM and non-GM white maize. As a result there has been virtually no difference in prices between GM and non-GM white maize, freeing farmers to make planting decisions based on the agronomic advantages of the new GMO varieties. With no mandatory labeling for GMO foods in South Africa, consumers have for the most part remained unaware of the new technology. The arguments of anti-GM forces about food safety have been countered by local scientists, and approvals have come through a reassuring and effective regulatory system.

GMO Potatoes in Mexico

GMO potatoes in Mexico never had the strong commercial sector backing that GMO maize has enjoyed in South Africa. In Mexico, GMO potatoes were promoted not by private companies but by public research institutes working in partnership with a foundation-funded (Rockefeller Foundation) private-sector technology provider. In Mexico, 17% of the potato harvest is used as seed potatoes, 10% is processed by the food industry, and 73% is used for direct consumption. Potato in Mexico is the third-most significant vegetable in terms of acreage and production volume, after tomato and pepper. It is grown in the highlands of the central region primarily by small-scale farmers that use various local colored varieties (yields are around 3-10 tons/ha) and in the northern states by farmers that pursue a more capital-intensive potato production and use the white variety called Alpha (yields around 40 tons/he) (Aerni, 2006).

Disease-resistant GMO potato varieties for use in Mexico were developed in a joint program between Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional (CINVESTAV) scientists and Monsanto starting early in the 1990s, financed by the Rockefeller Foundation, which was also funding a parallel program to develop a biosafety regulatory system in Mexico. Virus-resistant potatoes were chosen by the Mexican government as the focus of this program because viruses were a major problem for small farmers in Mexico and because there were no effective protection methods available through chemical or cultural controls (Aerni, 2006). The spread of a crop virus could only be attacked indirectly by using chemicals to control the insects that carried the virus. Ten colored GMO potato varieties with resistance to all of the main viruses were developed for use in the highlands by small farmers. The main commercial white variety, Alpha, was transformed but did not contain the gene for resistance to one of the main virus diseases.

These varieties were working their way through the government's regulatory system when two events took place that killed the program. First, in the late 1990s, McDonalds, McClain's (which supplies McDonalds with potatoes), and Frito-Lay announced that they would not purchase GM potatoes in the United States. In response, in 2000, Monsanto abandoned its GM potato program. This led the Mexican government and public sector scientists to wonder if there might really be some health problems associated with this product. Second, in 2001, Quist and Chapela, publishing in *Nature* (2001), found landraces of maize in Oaxaca which contained evidence of "genetic pollution" with genes from US varieties of GMO maize. This article created a firestorm of controversy in Mexico that spilled over from maize to potato. Potato scientists knew that Mexican highlands were the second major center of biodiversity in potatoes after Peru, with many wild varieties, and they became concerned—albeit without any clear scientific foundation—that GM potato varieties might somehow contaminate or affect Mexico's potato biodiversity. As a result, the Mexican government decided not to continue the CINVESTAV-Monsanto program (Aerni, 2006).

This project did not stop because of problems with the potato technology, with regulators, or because of protesters concerned about potatoes. The barriers instead were food company anxieties about consumer acceptance in the United States, plus spillover from the maize biodiversity controversy. While there was little or no active political opposition to the potato technology inside Mexico, it is also the case that there was little active support. The genes for resistance to the most important virus disease were not available for the main commercial variety, Alpha, so commercial farmers never had an interest, and the chance for support from commercial farmers disappeared completely after 2000 when it became clear there would be no chance to sell GMO potatoes to food companies like McDonalds.

Technologies of interest only to small scale farmers often die an early death. The GM colored potato varieties grown by small scale producers did have resistance to all important virus diseases and this might have been a significant agronomic benefit. Some social scientists (Massieu, Gonzalez, Chauvet, Castaneda, & Barajas, 2000) have questioned the overall importance of viruses for small farmers, but the consensus of Mexican scientists was that it was a major problem, even though it was a hard problem for anyone except a trained virologist to detect. The small farmers who could benefit from the project simply did not have the political clout to keep the program going, as they were poor and not well organized. In addition, since potatoes can be propagated clonally, and since the government was going to produce the basic seed and then distribute the foundation seed to farmers groups, there was no continuing role for private commercial seed companies to play, again narrowing the coalition of interests that might have supported the project. In addition, those at CINVESTAV doing the research were basic research scientists, not applied agricultural scientists, so they had no strong incentive to push the project all the way to commercialization. Even Monsanto had lost interest in potato. Under these circumstances those with the most to gain from the project—small farmers—lacked the power to keep it alive.

GMO Papaya

GMO papaya is a third food crop with improved agronomic traits developed through genetic engineering. This is a technology that has been taken up with spectacular success in the United States (Hawaii), but not yet at all in Southeast Asia. Papaya is a rich source of Vitamins A and C. It is widely grown in backyard gardens in Southeast Asia and serves to diversify rural diets. Thus, enhancement of its yield could contribute indirectly to dietary fortification. Papaya is also a cash crop for urban markets, and an increasingly important export crop. Both Thailand and the Philippines produce and export papaya, with the highest-value market for both being Japan—where consumers are reluctant to consume GM foods. Both countries have research on-going for adaptation of GM papaya from Hawaii, but neither has approved the crop.

In Hawaii, papaya production on Oahu had been wiped out in the 1960s by papaya ringspot virus (PRSV), forcing growers to relocate production to the Island of Hawaii. In the 1970s, PRSV was discovered in backyard papaya plants on that island as well, and in 1992 it was discovered in commercial fields. Production was cut by more than half between 1992 and 1998 (Gonzales, 2004). Research to develop a GMO PRSV-resistant variety of papaya started in the 1980s, led by a team of researchers from Cornell University, University of Hawaii at Manoa, and the Upjohn Company. The first field trial was carried out in 1992 and varieties were approved for official release in 1998. These proved to be very effective and popular with farmers. Production rebounded on the Island of Hawaii and papaya is now being planted again in Oahu as well. Non-transgenic and organic papaya can now be grown as well and segregated for export to markets that want to buy non-transgenic papaya. There has been little consumer resistance in the United States and Canada to GM papaya, in part because labeling is not required.

The political environment is different in Southeast Asia. Papaya is grown extensively in Thailand, much of it around homesteads and in small fields, making total production difficult to measure. About 90% of this papaya production is consumed in Thailand, with the other 10% exported to the Middle East, Europe, and Asia. It is the second-most important fruit in Thailand after bananas. In recent years, the most important problem with papaya production in Thailand has been the same PRSV that plagued Hawaii. Thai scientists from the Ministry of Agriculture, funded by USAID and working in partnership with Cornell University in the United States and with the cooperation of Monsanto, were able to develop for Thailand a parallel GMO technology against PRSV. In field trials, the benefits were obvious and the technology came with a full dossier of reassuring biosafety data developed from its use in the United States.

This promising program was ended in Thailand in 2004 when Greenpeace partially destroyed GM papaya trials in Khon Kaen and launched a media campaign claiming genetic pollution of local papaya in surrounding fields. This campaign was both an attack on the GM papaya plants and also part of a larger effort to stop the government from lifting a *de facto* ban on field trials for other GMO crops. Government scientists, a Biotechnology Alliance Association of scientists, private companies, and government institutions fought back with support from papaya farmers organizations in the Northeast that wanted the GM papaya. However, Greenpeace was successful in both stopping papaya field trials and preventing field trials of other GM crops. Greenhouse research continues on GM papaya, but not field trials.

Parallel to the Mexican potato case, there were few groups in Thailand with large commercial gains to be made from this technology. Public sector scientists would have enjoyed seeing their technology adopted, but otherwise had little financial incentive to push this technology, particularly since it would bring down on them criticism from Greenpeace and the press. No multinational or local private company could hope for large profits from the sale of papaya seed. The main beneficiaries would be small farmers who grow and eat substantial amounts of papaya and some commercial papaya growers who were serving local markets. Small producers may not have known the value of the GM technology and in any case did not have the power to pressure to the government to continue the program. Large producers lost interest when they saw this potential product being labeled a “Frankenfood.”

The experiences of some other countries with GMO food crops modified to provide an agronomic advantage show similar patterns of slow uptake. The Philippines has approved GMO yellow maize—primarily a feed crop for livestock—despite objections from consumer groups, NGOs, and some in the church community. But, seed companies have not developed GMO white maize because the market is small and declining. The Philippines also has not approved GMO rice. China has been slowing down its approval of GM rice as well, despite years of large-scale field trials. In India, regulators delayed approval of GM hybrid mustard for several years until the private company that developed the technology withdrew its application; field trials of GMO rice have been burned by protesters, and in November 2006, new field trials of all GM crops were temporarily stopped by a Supreme Court decision following a controversy over GM eggplant.

A major political breakthrough for GMO varieties of food staple crops could come in China, where GM rice cultivars with resistance to insects and bacterial disease have been developed by that nation’s public sector research institutes. Some of the scientists who developed them continue to push for them and may even have a financial interest as share holders in the companies that could make money from selling hybrid GM rice. However, the same Greenpeace tactics that worked well against papaya in Thailand and elsewhere have now been deployed against GM rice in China: the discovery of “genetic pollution” in farmers’ fields followed by discoveries of “illegal” sales in seed markets and in supermarkets, then contamination in baby foods along with comments about the possible food safety and biodiversity dangers (China is a center of diversity for rice). Critics are able to point out that no other major country (other than Iran) has commercialized GM rice, implying that there must be problems. The small farmers in China who could benefit from GM rice are not allowed to organize other than through the Communist Party, which makes it difficult to voice their demand for the technology. The agriculture ministry feels no sense of urgency so long as consumers are not complaining about high rice prices. In addition, there are worries about problems of selling GM rice-based products to Europe, Japan, and Korea. Weighing all these concerns, China’s political leadership has so far chosen to hold back on commercializing GMO rice.

These patterns suggest that when developing-country governments make regulatory decisions on GMO food crops, the nutritional status of their citizens and the welfare of their small farmers is seldom a high priority.

Even in South Africa, the only developing country to have approved a GMO food staple crop so far, these issues were secondary. In South Africa, the dominating factors appear to have been the interests of commercial farmers in using GMO technology, the commercial interests of multinationals and local private companies in selling GM seeds, an articulate defense of the technology from local university and public institute scientists, and the ability to segregate GMO and non-GMO grain as needed to protect export sales.

Genetically Engineered Food Crops with Enhanced Nutrient Traits

Three kinds of food staples are currently the focus of biofortification using genetic modification: rice, cassava, and sorghum. These modifications include

- GM rice that contains beta-carotene, widely known under the name "Golden Rice" (GR); further research is underway to stack other nutrient traits into GR, as well as to adapt it for release in different Asian countries (Dawe & Unnevehr, 2007, in this issue);
- GM potato that contains an amaranth gene for additional protein (Ramaswami, 2007, in this issue);
- GM cassava that contains stacked traits for increased iron and zinc content, improved protein, and Vitamins A and E, along with agronomic traits for virus resistance and enhanced storability (Donald Danforth Plant Science Center website);
- and GM sorghum, which will be more easily digestible, and will contain increased levels of provitamin A, Vitamin E, iron, zinc, amino acids, and protein. A prototype containing increased levels of the amino acid lysine has been developed (African Biofortified Sorghum Consortium website).

None of these biofortified GMO food crops is yet being grown commercially, and all will need more development and testing before they can be introduced into farmers' fields or consumers' diets. The responses to these crops have been shaped by early publicity surrounding GR. It has been the most controversial and by far the most publicized biofortified GMO food crop developed to date, having been featured on the cover of Time magazine in 2000. It has served as a model, albeit a debated one, for GM-based biofortification. As discussed in detail in the Golden Rice case study elsewhere in this special issue (Dawe & Unnevehr, 2007), critics have objected to investments in GM biofortification for a variety of reasons, including the diversion of resources from traditional nutrition interventions and the promotion of a technology that would make poor consumers into "test subjects" for this new approach. Thus, the combination of GM technology with the relatively new concept of biofortification has not led to the success of the former, and may jeopardize the success of the latter.

Summary

Superior—or at least adequate—agronomic traits, acceptable eating quality, and consumer education have played a role in the success stories that this article has documented above for development of food crops that are either biofortified, GM, or both. Certainly, consumer education and adequate agronomic performance were essential to the current limited success of conventionally-bred biofortified crops: QPM in West Africa and OFSP in East Africa. For GM crops that are not biofortified, agronomic performance and political acceptance have been key variables. GMO maize in South Africa has been embraced due to its superior agronomic performance and strong support from commercial agriculture. The absence of demonstrably superior agronomic traits that contributed to the abandonment of GM potatoes in Mexico was as important as lack of political support arising from market resistance and doubts about environmental risks. The Thai papaya case shows that political resistance to a GM crop can be more powerful than the benefits from clearly superior agronomic traits.

There is evidence in these case studies that when powerful political and economic interest groups, such as large commercial farmers and agribusiness companies in South Africa, push a GMO technology it is much more likely to be developed and adopted than if the main beneficiaries will be small, politically weak farmers, such as the potato growers of Mexico and the papaya growers of Thailand. The combination of GM technology with biofortification has not led to greater acceptance of GM crops, at least so far, although no GM biofortified crops have yet been released for general use. Thus, it seems that a combination of crop qualities intersecting with local political forces will determine the ultimate success of a GM or biofortified crop. The use of GM technology raises significant additional barriers to the development and eventual success of any biofortified crop.

References

Aerni, P. (2006). *The political landscape of agricultural biotechnology: The case of transgenic potato in Mexico* (Working paper). Boston, MA: Harvard University.

African biofortified sorghum consortium (ABSC) project overview website. Retrieved October 22, 2006, from http://supersorghum.org/project.htm.

Consultative Group on International Agricultural Research (CGIAR). (2006, June). *Sweetpotato hip hop* (CGIAR News June 2006). Washington, DC: Author. Available on the World Wide Web: http://www.cgiar.org/enews/june2006/story_04.html.

Dawe, D., & Unnevehr, L. (2007). Crop case study: GMO Golden Rice in Asia with enhanced Vitamin A benefits for consumers. *AgBioForum*, *10*(3), 154-160. Available on the World Wide Web: http://www.agbioforum.org.

Donald Danforth Plant Science Center, International Programs, Cassava Projects. Retrieved October 22, 2006, from http://www.danforthcenter.org/international/2_Cassava%20Projects.htm.

Food and Agricultural Organization of the United Nations (FAO), & World Health Organization (WHO). (1973). *Energy and protein requirements: Report of a joint FAO/WHO ad hoc expert committee* (FAO Nutrition Meetings Report Series No. 52; WHO Technical Report Series No. 522). Geneva, Switzerland: Author.

Fuglie, K.O., & Yanggen, D.R. (2006, August). *Impact of sweetpotato biofortification on Vitamin A deficiency in developing countries: An ex ante economic assessment*. Lima, Peru: International Potato Center (CIP).

Gonzales, D. (2004). Transgenic papaya in Hawaii and beyond. *AgBioForum*, *7*(1&2), 36-40. Available on the World Wide Web: http://www.agbioforum.org.

HarvestPlus. (2006). *Biofortified sweetpotato*. Washington, DC: Author. Available on the World Wide Web: http://www.harvestplus.org/pdfs/sweetpotato.pdf.

Helen Keller International (HKI). (2006). *VitABurkina*. Minneapolis, MN: McKnight Foundation. Available on the World Wide Web: http://mcknight.ccrp.cornell.edu/program_docs/project_documents/WAF_05-009_spbf/05-009_spbf_yr1_05-06_vweb_E.pdf.

Lauderdale, J. (2000). *Issues regarding targeting and adoption of quality protein maize (QPM)* (CIMMYT Economics Working Paper 00-02). Mexico, DF: CIMMYT.

Low, J.W., Arimond, M., Osman, N., Kwame Osei, A., Zano, F., et al. (2005). *Towards sustainable nutrition improvement in rural Mozambique: Addressing macro- and micro-nutrient malnutrition through new cultivars and new behaviors: Key findings*. Quelimane, Zambezia: Michigan State University.

Massieu, Y., Gonzalez, R.L., Chauvet, M., Castaneda, Y., & Barajas, R.E. (2000). Transgenic potatoes for small-scale farmers: A case study in Mexico. *Biotechnology and Development Monitor*, *41*, 6-10. Available on the World Wide Web: http://www.biotech-monitor.nl/4103.htm.

Masters, W., & Sanogo, D. (2002). Welfare gains from quality certification of infant foods: Results from an experiment in Mali. *American Journal of Agricultural Economics*, *84*(4), 974-989.

Mertz, E.T. (1994). Thirty years of *opaque-2* maize. In B.Z. Larkins & E.T. Mertz (Eds.), *Quality protein maize 1964-1994*. West Lafayette, IN: Purdue University Press.

Quist, D., & Chapela, I.H. (2001). Transgenic DNA introgressed into traditional maize landraces in Oaxaca, Mexico. *Nature*, *414*, 541-543.

Ramaswami, B. (2007). Biofortified crops and biotechnology: A political economy landscape for India. *AgBioForum*, *10*(3), 170-177. Available on the World Wide Web: http://www.agbioforum.org.

Sasakawa Africa Association (SAA). (2006). *Sasakawa Africa Association 20th anniversary report*. Tokyo, Japan: Author.

Van der Walt, W. (2007, July 19). [Area of transgenic maize and transgenic maize as a percentage of area planted]. Unpublished raw data.

Wolson, R. (2007). Assessing the prospects for adoption of biofortified crops in South Africa. *AgBioForum*, *10*(3), 184-191. Available on the World Wide Web: http://www.agbioforum.org.