CAST Commentary
QTA 2005-2 October 2005

The Science Source for Food, Agricultural, and Environmental Issues

Crop Biotechnology and the Future of Food: A Scientific Assessment

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Introduction

The introduction of agriculture marked the beginning of modern civilization. Over the ensuing 10,000 years, agriculturalists have improved agricultural production to support a growing population. Increased production often resulted from breeding—that is, the genetic modification—of crop plants. The Green Revolution intensified agricultural production, prevented mass starvation, and saved millions of acres of wilderness from going under the plow (Evans 1998; Trewavas 2001), while at the same time permitting agricultural practices that degraded the quality of some agricultural lands. In recent years, transgenic plants—that is, genetically modified plants produced through modern biotechnology (see **Glossary**)—have made it possible to continue the benefits of the Green Revolution while at the same time diminishing the detrimental environmental impact of agriculture.

The introduction of transgenic plants has not been without controversy. Films such as *The Future of Food* and books/videos such as *Seeds of Deception* and *Hidden Dangers in Kids' Meals* are representative of an ideology that rejects what is seen as the industrialization of agriculture and its use of genetic modification. Despite a preponderance of scientific evidence to the contrary, these and other activist critics claim that these transgenic crops are not safe to eat, that they do not perform well, that natural resistances will soon arise making engineered plants useless, and that genes will escape and thereby "contaminate" other crops or produce "superweeds."

Yet over the last decade, 8.5 million farmers have grown transgenic varieties of crops on more than 1 billion acres of farmland in 17 countries (http://www.isaaa.org/). More than 7 million of these farmers are small-holders in developing countries. These crops have been consumed by humans and animals in most countries. Therefore, a prodigious amount of data and observation is available on which to judge the safety and usefulness of transgenic crops. This commentary weighs hypothetical hazards voiced by activist critics against the available evidence and experience with transgenic crops.

What Is the Definition of Biotechnology-derived Food? Traditionally, biotechnology means the use of living organisms to benefit mankind. Historically, products such as wine, cheese, yogurt, enzymes, and antibiotics have been considered to be the products of biotechnology because they require the use of yeasts and other microorganisms for their production.

In a more current sense, biotechnology is used to refer to genetically modified (GM) crops, and not just any type of genetically modified crops, but specifically, transgenic crops—that is, those crops modified by genetic engineering. Modification by genetic engineering differs from more traditional genetic modification in that it is done with genes that have previously been isolated and analyzed in a laboratory and then inserted into a crop plant.

Are Transgenic Crops Safe to Eat? Science does not take a broad position that GM crops are safe or unsafe; each GM crop presents potential risks and benefits that must be evaluated on a case-by-case basis. When early farmers began to change the appearance of crops by conventional breeding 10,000 years ago, they also directed changes in crop DNA (reviewed by Bradford et al. 2005). (*Photo, left:* Teosinte, a corn ancestor.) In some cases, the changes have been so great that only a well-trained botanist can identify the wild ancestor of a crop. The nature of these changes has become clearer as we have been able to sequence the genetic code of domesticated plants and their wild relatives. We know that practically all plants we eat are extensively genetically modified compared with their wild ancestors. Often these modifications have been achieved through human selection of traits introduced through interspecific hybridization or created by random mutation using radiation or mutagenic chemicals. Many crops clearly have DNA that has come from other species. These crops are not "natural" by any definition, but have been diverted from "natural" selection to meet human needs.

Potential hazards associated with transgenic crop technology have been studied by the U.S. National Academy of Sciences (NAS). The NAS repeatedly has concluded that biotechnology is no more likely to produce unintended effects than conventional technology—indeed the greater precision and more defined nature of the changes introduced may actually be safer (NAS 2004). European Union scientists addressed this same issue and concluded that conventional plant breeding produces more unintended changes than are introduced in the construction of a transgenic plant (Cellini et al. 2004). These studies found that there are no new risks associated with the transfer of genes across species barriers. They concluded that transgenic crops on the market today are as safe to eat as their conventional counterparts, and likely more so, given the greater regulatory scrutiny to which they are exposed (http://europa.eu.int/comm/research/quality-of-life/gmo/index.html). After 10 years of safe use, it is fair to conclude that the inherent safety of the technology and the premarket case-by-case safety assessments conducted by regulatory agencies around the world have ensured that foods from transgenic crops are as safe to eat as any food.

Do Transgenic Crops Provide Benefits? As noted previously, the number of acres of farmland planted with transgenic crops has increased steadily since their introduction 10 years ago (http://www.isaaa.org/). Farmers pay more for transgenic seeds than they do for conventional seeds; yet each year they buy more seeds produced through modern biotechnology than the less costly, non-GM varieties that also are available. The majority of farmers who have planted transgenic crops must therefore believe that these higher-priced seeds offer benefits.

Because it is impossible to review all the benefits of planting biotech crops in a short paper, a few representative cases have been selected as examples of achievable benefits. At an estimated $US 5 billion per year, China is the world's largest user of chemical pesticides. Cotton is the most pesticide-intensive major crop plant. Transgenic cotton initially was planted in China in 1998 and now represents 50% of the cotton acreage. Yields have improved 10–30%, pesticide usage has fallen 50–80%, and profitability for small farmers has been improved significantly—in fact, those farmers who planted biotech cotton in 2001 and 2002 were more likely to make a profit, whereas those who did not plant biotech varieties were more likely to lose money. Equally important, pesticide poisonings from insecticides used on cotton have been decreased by approximately 75% among farmers using biotech cotton (Pray et al. 2002). Before 1996, an estimated 10,000 insecticide poisonings and approximately 400 deaths occurred annually in Chinese cotton-growing regions (from sources in Huang et al. 2003).

Transgenic crops may even provide human health benefits independent of reductions of pesticide use. Strong evidence exists that the high incidence of throat cancer, liver problems, and neural tube defects in fetuses among people in southern Africa and Latin America results from ingestion of fungal toxins (fumonisins) produced on insect-damaged corn. These fumonisins also can be fatal to horses and

pigs (Wu, Miller, and Cassman 2004). Insect-resistant (Bt) corn has much lower amounts of fumonisins than conventional corn does, because there is less insect damage to corn kernels on which the fungi can grow (Shelton, Zhao, and Roush 2002). Therefore, a switch to Bt corn varieties would lower exposure to fumonisin and decrease the incidence of these birth defects (Wu, Miller, and Cassman 2004). (*Photo, left*: Modern corn.)

The use of herbicides is a vexing problem because there are few alternatives for weed control in broad-scale agriculture that do not have serious environmental problems. Although there have been some relatively small increases in the total weight of herbicide applied to herbicide-tolerant soybeans in the United States (where glyphosate often replaces other herbicides that are more persistent in the environment [www.ers.usda.gov/publications/aer810/]), studies on U.S. herbicide use across all transgenic crops show there has been an overall decrease in use (http://www.ncfap.org); internationally, the decrease is about 4% (Brookes and Barfoot 2005). Even with soybeans, higher use rates—when they happen—are more than compensated for by permitting no-till agriculture, resulting in an overall lower environmental impact.

Are Transgenic Crops Beneficial or Harmful to the Environment? After years of research and evaluation on potential hazards, the published scientific research demonstrates that transgenic crops pose no environmental hazards unique to them (http://europa.eu.int/comm/research/quality-of-life/gmo/index.html). The evolution of resistance in insects and weeds is a concern when using transgenic crops, but no more than for conventional cropping systems. Nevertheless, regulations are in place to ensure that transgenic crops will receive better stewardship than has been given conventional crops. Before any transgenic crop can be marketed, regulatory agencies must be satisfied that transgenic crops will not make existing agricultural problems worse or create new ones. For example, a plan to minimize resistance problems in insects to Bt transgenic crops must be designed prior to regulatory approval. Other significant points include:

- Potential impacts on beneficial species are evaluated before introduction of a transgenic variety. Extensive studies after commercial release have revealed that transgenic crops have positive effects on beneficial species compared with conventional agriculture as a result of less need for broad-spectrum insecticides (Naranjo, Head, and Dively 2005; Shelton, Zhao, and Roush 2002).

- Weed shifts and the evolution of herbicide-resistant weeds have been a problem for more than 30 years. Such issues are not different for transgenic crops; resistance has actually been slower to evolve for the key herbicide glyphosate than for many other herbicides (www.weedscience.org). The use of transgenic crops does not substitute for good land stewardship practices. Farmers who use GM crops are well aware that these practices include rotations and preclude the overreliance on only a few chemicals.

- Strategies to delay the evolution of resistance in insects to insect-resistant crops have been more extensively investigated and implemented for transgenic crops than for any class of insecticides ever developed, the use of refugia being an example. One measure of the success of this effort is that resistance has not been detected to Bt crops after some 8 years of intensive use (Tabashnik et al. 2003), which exceeds the historical average effective lifespan for chemical insecticides in cotton. Not only is one intensively targeted pest—the pink bollworm on cotton—not showing resistance, it actually is declining in density in Arizona as a result of Bt cotton use (Carrière et al. 2003).

- The advent of engineered crops has resulted in dramatic reductions in insecticide use in agriculture (www.ers.usda.gov/publications/aer810/). In 2003, the last year for which data are available, the use of transgenic cotton and corn resulted in a decrease of 3,238,000 and 3,864,000 pounds, respectively, in insecticide use (http://www.ncfap.org/whatwedo/biotech-us.php) (see also Heimlich et al. 2002).

- In 2003, transgenic crops increased agricultural yields by 5 billion pounds. After deducting the increased cost of seeds, the net value to farmers was $1.9 billion (http://www.ncfap.org). Much of the increased revenue could be attributed to decreased expenditures on agrochemicals.

There are other benefits as well. Traditionally, there have been no effective and environmentally sustainable management tools for many key pests and diseases. For example, without herbicides, weed management would depend on tactics such as burning, tillage, and manual labor, which are not environmentally, economically, or socially sustainable. Burning is an increasingly serious cause of air pollution. Tillage generates both erosion and dust pollution, decreases soil organic matter, and increases loss of soil carbon to the air as CO_2, thus contributing to the greenhouse effect. In addition, soil is heavy, and tilling it requires fossil fuels to power the tractors that pull the plows. Thus, along with the adoption of transgenic crops have come savings in fuel, decreases in erosion, and better habitat for wildlife; the United States, for example, was able to save 70 million gallons of fuel on no-till soybeans in 2001 (Fawcett and Towery 2002).

A recent paper by Brookes and Barfoot (2005) summarized the overall global impact of transgenic technology. The analysis shows that there have been substantial net economic benefits at the farm level amounting to a cumulative total of $27 billion. The technology has decreased pesticide spraying by 378 million pounds and has decreased the environmental “footprint” associated with pesticide use by 14%. The technology also has significantly reduced the release of greenhouse gas emissions from agriculture, which is equivalent to removing nearly five million cars from the roads.

Can Transgenic Crops Contribute to Increased Food Stability and Security? The realities of population growth over the next 50 years mean that the global food supply must be doubled (FAO 2000). This growth is a staggering challenge for agriculture because most of the world’s usable farmland is already in production. In 1991, 0.81 acres of farmland was available to feed each person. By 2050, only 0.37 acres of farmland will be available for each person. It means that the productivity of each unit of land must be increased. Failing that, the United Nations (UN) Millennium Report makes it clear that “the world faces a real threat to future global food security” (*Millenium Report* 2000).

The UN Millennium Project (www.unmillenniumproject.org/) estimates that 850 million people are undernourished and that many more suffer from micronutrient deficiency, a number that may have increased to 1 billion by now (http://www.ers.usda.gov/Publications/GFA16/). Some people argue that there are no food shortages—that hunger is a food distribution problem, not a food production problem. But according to the UN Millennium Project, 50% of the world’s population consists of small-holder farmers who produce the food their families eat (see Sanchez and Swaminanthan 2005 for a summary and analysis). These are people with the necessary land to grow their own food, but whose crops often fail through no fault of their own because of pests or unfavorable weather conditions. Thus, any strategy or technology that allows these small-holder farmers to more consistently produce larger amounts of food in a more sustainable way will help decrease hunger, promote rural economic development and self-esteem, decrease dependence on distribution systems, and lower the need for food aid. Transgenic crops alone will not solve hunger, but they can help.

At least as important, use of transgenic crops can decrease the amount of land needed for cultivation, allowing better conservation of soil and biodiversity (Trewavas 2001) and can allow local peoples to have more reliable control over their food supply with less use of pesticides. Traditionally, there have been no effective and environmentally sustainable management tools for many key pests and diseases. For example, in Africa, insect pests and viral diseases substantially decrease yields of key staple crops such as plantain, corn, sweet potato, and cassava (http://apsnet.org/Education/feature/FoodSecurity/ and http://www.ers.usda.gov/Publications/GFA16/). To grow enough food reliably, farmers must either cultivate more land to compensate for these losses or treat with risky pesticides to prevent the losses. It is in loss prevention that biotechnology can help.

Will Transgenic Crops Encourage Further Industrialization of Agriculture at the Expense of Biodiversity? Some of the most significant historical examples of land management and agricultural degradation predate so-called industrial agriculture; consider, for example, the deforestation of Easter Island, extinction of certain animals by hunting and land clearing, and the Dust Bowl of the Depression. Modern agriculture has taken advantage of chemical inputs and mechanization since the end of World War II. Transgenic crops do not increase the use of pesticides, fertilizers, and other chemicals as compared with conventional agriculture, but they do answer consumer demands for high quality and low prices, with efficiencies that decrease the need to clear land. Instead, for the first time since World War II, transgenic crops are now making it possible to decrease reliance on chemical agriculture.

In the end, not all increases in agricultural productivity are the result of increased chemical use. The other half comes from improved seed, obtained as the result of genetic modification. Corn farmers became dependent on having to buy their seed every year once hybrid corn became available in the 1920s and 1930s. The seed was more expensive, but the higher yields more than made up for it. With transgenic crops, farmers are dependent on private industry for seed, but at the same time they are increasingly less dependent on industry for agrochemicals. Furthermore, much of the worldwide research on transgenic crops is being done not by private industry but by ministries of agriculture, research institutes, and university laboratories (Cohen 2005), thus helping ensure this technology benefits farmers and crops around the world, even in the absence of private industry.

The rapid deployment and adoption of transgenic crops has not resulted in loss of crop genetic diversity (Sneller 2003), primarily because breeders have produced crop varieties adapted to every part of the country—a task that would be impossible if genetic diversity were eliminated. (*Photo, above left:* Genetic diversity in corn.) Furthermore, wildlife has increased in and around fields that once would have been sprayed with pesticides (Naranjo et al. 2005; Pimentel and Raven 2000), and field-study after field-study show that beneficial and nontarget species are not reduced.

While films such as *The Future of Food* distort the history and facts of agriculture, and some people may long for a view of the past that never was, what the world needs from modern agriculture is both an increase in productivity and a decrease in its environmental footprint. Transgenic crops already have achieved these needs and will continue to offer much more, as long as mankind is willing to apply technology to meet societal needs.

Glossary

Biotechnology. The use of living organisms for useful purposes. Industrial production of antibiotics, pharmaceuticals, enzymes, and chemicals; production of cheeses, fermented beverages, and yeast breads; tissue culture and micropropagation techniques; and the *in vitro* transfer of genes between organisms are different forms of biotechnology.

Modern biotechnology. DNA, RNA, and protein analysis, genomics, and bioinformatics applied to *in vitro* modification of living organisms, as, for example, the development of transgenic crop plants.

Genetic engineering. The process of isolating DNA in a laboratory, analyzing it, and then inserting it into another organism.

Genetic modification. Altering the genetic composition of plants, animals, and microbes by selecting types with desired characteristics.

GMO. Although GMO literally means genetically modified organism, it has taken on the more restricted definition of being a transgenic or genetically engineered organism.

Transgenic plant. A plant that has been genetically altered by genetic engineering to contain DNA from other sources.

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