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Use of Biotechnology in Agriculture—Benefits and Risks

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What is biotechnology, and how is it used in agriculture?

Biotechnology is the application of scientific techniques to modify and improve plants, animals, and microorganisms to enhance their value. *Agricultural biotechnology* is the area of biotechnology involving applications to agriculture. Agricultural biotechnology has been practiced for a long time, as people have sought to improve agriculturally important organisms by selection and breeding. An example of traditional agricultural biotechnology is the development of disease-resistant wheat varieties by cross-breeding different wheat types until the desired disease resistance was present in a resulting new variety.

In the 1970s, advances in the field of molecular biology provided scientists with the ability to manipulate DNA—the chemical building blocks that specify the characteristics of living organisms—at the molecular level. This technology is called *genetic engineering*. It also allows transfer of DNA between more distantly related organisms than was possible with traditional breeding techniques. Today, this technology has reached a stage where scientists can take one or more specific genes from nearly any organism, including plants, animals, bacteria, or viruses, and introduce those genes into another organism. An organism that has been transformed using genetic engineering techniques is referred to as a *transgenic* organism, or a genetically engineered organism.

Many other terms are in popular use to describe these aspects of today's biotechnology. The term "genetically modified organism" or "GMO" is widely used, although genetic modification has been around for hundreds if not thousands of years, since deliberate crosses of one variety or breed with another result in offspring that are genetically modified compared to the parents. Similarly, foods derived from transgenic plants have been called "GMO foods," "GMPs" (genetically modified products), and "biotech foods." While some refer to foods developed from genetic engineering technology as "biotechnology-enhanced foods," others call them "frankenfoods." For the reasons discussed later in this publication, controversy affects various issues related to the growing of genetically engineered organisms and their use as foods and feeds.

How does genetic engineering differ from traditional biotechnology?

In traditional breeding, crosses are made in a relatively uncontrolled manner. The breeder chooses the parents to cross, but at the genetic level, the results are unpredictable. DNA from the parents recombines randomly, and desirable traits such as pest resistance are bundled with undesirable traits, such as lower yield or poor quality.

Traditional breeding programs are time-consuming and labor-intensive. A great deal of effort is required to separate undesirable from desirable traits, and this is not always economically practical. For example, plants must be back-crossed again and again over many growing seasons to breed out undesirable characteristics produced by random mixing of genomes.

Current genetic engineering techniques allow segments of DNA that code genes for a specific characteristic to be selected and individually recombined in the new organism. Once the code of the gene that deter-

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mines the desirable trait is identified, it can be selected and transferred. Similarly, genes that code for unwanted traits can be removed. Through this technology, changes in a desirable variety may be achieved more rapidly than with traditional breeding techniques. The presence of the desired gene controlling the trait can be tested for at any stage of growth, such as in small seedlings in a greenhouse tray. The precision and versatility of today's biotechnology enable improvements in food quality and production to take place more rapidly than when using traditional breeding.

Transgenic crops on the U.S. market

Although genetically engineered organisms in agriculture have been available for only 10 years, their commercial use has expanded rapidly. Recent estimates are that more than 60–70 percent of food products on store shelves may contain at least a small quantity of crops produced with these new techniques.

Major crop plants produced by genetic engineering techniques have been so welcomed by farmers that currently a third of the corn and about three-quarters of the soybean and cotton grown in the USA are varieties developed through genetic engineering (see *http://usda.mannlib.cornell.edu/reports/nassr/field/pcp-bbp/pspl0302.pdf*). Twelve transgenic crops (corn, tomato, soybean, cotton, potato, rapeseed [canola], squash, beets, papaya, rice, flax, and chicory) have been approved for commercial production in the USA. The most widely grown are "*Bt*" corn and cotton and glyphosate-resistant soybeans. *Bt* corn and cotton have had DNA from a naturally occurring insecticidal organism, *Bacillus thurin-giensis*, incorporated into their genome; it kills some of the most serious insect pests of these crops (European and southwestern corn borers, and cotton budworms and bollworms) after they feed on the plant, while beneficial insects are left unaffected. Glyphosate-resistant soybeans are unharmed by the broad-spectrum herbicide glyphosate, a characteristic that allows farmers to kill yield-reducing weeds in soybean fields without harming the crop.

What are the benefits of genetic engineering in agriculture?

Everything in life has its benefits and risks, and genetic engineering is no exception. Much has been said about potential risks of genetic engineering technology, but so far there is little evidence from scientific studies that these risks are real. Transgenic organisms can offer a range of benefits above and beyond those that emerged from innovations in traditional agricultural biotechnology. Following are a few examples of benefits resulting from applying currently available genetic engineering techniques to agricultural biotechnology.

Increased crop productivity

Biotechnology has helped to increase crop productivity by introducing such qualities as disease resistance and increased drought tolerance to the crops. Now, researchers can select genes for disease resistance from other species and transfer them to important crops. For example, researchers from the University of Hawaii and Cornell University developed two varieties of papaya resistant to papaya ringspot virus by transferring one of the virus' genes to papaya to create resistance in the plants. Seeds of the two varieties, named 'SunUp' and 'Rainbow', have been distributed under licensing agreements to papaya growers since 1998.

Further examples come from dry climates, where crops must use water as efficiently as possible. Genes from naturally drought-resistant plants can be used to increase drought tolerance in many crop varieties.

Enhanced crop protection

Farmers use crop-protection technologies because they provide cost-effective solutions to pest problems which, if left uncontrolled, would severely lower yields. As mentioned above, crops such as corn, cotton, and potato have been successfully transformed through genetic engineering to make a protein that kills certain insects when they feed on the plants. The protein is from the soil bacterium *Bacillus thuringiensis*, which has been used for decades as the active ingredient of some "natural" insecticides.

In some cases, an effective transgenic crop-protection technology can control pests better and more cheaply than existing technologies. For example, with *Bt* engineered into a corn crop, the entire crop is resistant to certain pests, not just the part of the plant to which *Bt* insecticide has been applied. In these cases, yields increase as the new technology provides more effective control. In other cases, a new technology is adopted because it is less expensive than a current technology with equivalent control.

There are cases in which new technology is not adopted because for one reason or another it is not competitive with the existing technology. For example, organic farmers apply *Bt* as an insecticide to control insect pests in their crops, yet they may consider transgenic *Bt* crops to be unacceptable.

Improvements in food processing

The first food product resulting from genetic engineering technology to receive regulatory approval, in 1990, was *chymosin*, an enzyme produced by genetically engineered bacteria. It replaces calf rennet in cheese-making and is now used in 60 percent of all cheese manufactured. Its benefits include increased purity, a reliable supply, a 50 percent cost reduction, and high cheese-yield efficiency.

Improved nutritional value

Genetic engineering has allowed new options for improving the nutritional value, flavor, and texture of foods. Transgenic crops in development include soybeans with higher protein content, potatoes with more nutritionally available starch and an improved amino acid content, beans with more essential amino acids, and rice with the ability produce beta-carotene, a precursor of vitamin A, to help prevent blindness in people who have nutritionally inadequate diets.

Better flavor

Flavor can be altered by enhancing the activity of plant enzymes that transform aroma precursors into flavoring compounds. Transgenic peppers and melons with improved flavor are currently in field trials.

Fresher produce

Genetic engineering can result in improved keeping properties to make transport of fresh produce easier, giving consumers access to nutritionally valuable whole foods and preventing decay, damage, and loss of nutrients. Transgenic tomatoes with delayed softening can be vine-ripened and still be shipped without bruising. Research is under way to make similar modifications to broccoli, celery, carrots, melons, and raspberry. The shelf life of some processed foods such as peanuts has also been improved by using ingredients that have had their fatty acid profile modified.

Environmental benefits

When genetic engineering results in reduced pesticide dependence, we have less pesticide residues on foods, we reduce pesticide leaching into groundwater, and we minimize farm worker exposure to hazardous products. With *Bt* cotton's resistance to three major pests, the transgenic variety now represents half of the U.S. cotton crop and has thereby reduced total world insecticide use by 15 percent! Also, according to the U.S. Food and Drug Administration (FDA), "increases in adoption of herbicide-tolerant soybeans were associated with small increases in yields and variable profits but *significant decreases* in herbicide use" (our italics).

Benefits for developing countries

Genetic engineering technologies can help to improve health conditions in less developed countries. Researchers from the Swiss Federal Institute of Technology's Institute for Plant Sciences inserted genes from a daffodil and a bacterium into rice plants to produce "golden rice," which has sufficient beta-carotene to meet total vitamin A requirements in developing countries with rice-based diets. This crop has potential to significantly improve vitamin uptake in poverty-stricken areas where vitamin supplements are costly and difficult to distribute and vitamin A deficiency leads to blindness in children.

What are the possible risks associated with using transgenic crops in agriculture?

Some consumers and environmentalists feel that inadequate effort has been made to understand the dangers in the use of transgenic crops, including their potential long-term impacts. Some consumer-advocate and environmental groups have demanded the abandonment of genetic engineering research and development. Many individuals, when confronted with conflicting and confusing statements about the effect of genetic engineering on our environment and food supply, experience a "dread fear" that inspires great anxiety. This fear can be aroused by only a minimal amount of information or, in some cases, misinformation. With people thus concerned for their health and the well-being of our planetary ecology, the issues related to their concerns need to be addressed. These issues and fears can be divided into three groups: health, environmental, and social.

Health-related issues

Allergens and toxins

People with food allergies have an unusual immune reaction when they are exposed to specific proteins, called allergens, in food. About 2 percent of people across all age groups have a food allergy of some sort. The majority of foods do not cause any allergy in the majority of people. Food-allergic people usually react only to one or a few allergens in one or two specific foods. A major safety concern raised with regard to genetic engineering technology is the risk of introducing allergens and toxins into otherwise safe foods. The Food and Drug Administration (FDA) checks to ensure that the levels of naturally occurring allergens in foods made from transgenic organisms have not significantly increased above the natural range found in conventional foods. Transgenic technology is also being used to remove the allergens from peanuts, one of most serious causes of food allergy.

Antibiotic resistance

Antibiotic resistance genes are used to identify and trace a trait of interest that has been introduced into plant cells. This technique ensures that a gene transfer during the course of genetic modification was successful. Use of these markers has raised concerns that new antibiotic-resistant strains of bacteria will emerge. The rise of diseases that are resistant to treatment with common antibiotics is a serious medical concern of some opponents of genetic engineering technology.

The potential risk of transfer from plants to bacteria is substantially less than the risk of normal transfer between bacteria, or between us and the bacteria that naturally occur within our alimentary tracts. Nevertheless, to be on the safe side, FDA has advised food developers to avoid using marker genes that encode resistance to clinically important antibiotics.

Environmental and ecological issues

Potential gene escape and superweeds

There is a belief among some opponents of genetic engineering technology that transgenic crops might cross-pollinate with related weeds, possibly resulting in "superweeds" that become more difficult to control. One concern is that pollen transfer from glyphosate-resistant crops to related weeds can confer resistance to glyphosate. While the chance of this happening, although extremely small, is not inconceivable, resistance to a specific herbicide does not mean that the plant is resistant to other herbicides, so affected weeds could still be controlled with other products.

Some people are worried that genetic engineering could conceivably improve a plant's ability to "escape" into the wild and produce ecological imbalances or disasters. Most crop plants have significant limitations in their growth and seed dispersal habits that prevent them from surviving long without constant nurture by humans, and they are thus unlikely to thrive in the wild as weeds.

Impacts on "nontarget" species

Some environmentalists maintain that once transgenic crops have been released into the environment, they could have unforeseen and undesirable effects. Although transgenic crops are rigorously tested before being made commercially available, not every potential impact can be foreseen. *Bt* corn, for instance, produces a very specific pesticide intended to kill only pests that feed on the corn. In 1999, however, researchers at Cornell University found that pollen from *Bt* corn could kill caterpillars of the harmless Monarch butterfly. When they fed Monarch caterpillars milkweed dusted with *Bt* corn pollen in the laboratory, half of the larvae died. But follow-up field studies showed that under real-life conditions Monarch butterfly caterpillars are highly unlikely to come into contact with pollen from *Bt* corn that has drifted onto milkweed leaves—or to eat enough of it to harm them.

Insecticide resistance

Another concern related to the potential impact of agricultural biotechnology on the environment involves the question of whether insect pests could develop resistance to crop-protection features of transgenic crops.

There is fear that large-scale adoption of *Bt* crops will result in rapid build-up of resistance in pest populations. Insects possess a remarkable capacity to adapt to selective pressures, but to date, despite widespread planting of *Bt* crops, no *Bt* tolerance in targeted insect pests has been detected.

Loss of biodiversity

Many environmentalists, including farmers, are very concerned about the loss of biodiversity in our natural environment. Increased adoption of conventionally bred crops raised similar concerns in the past century, which led to extensive efforts to collect and store seeds of as many varieties as possible of all major crops. These "heritage" collections in the USA and elsewhere are maintained and used by plant breeders. Modern biotechnology has dramatically increased our knowledge of how genes express themselves and highlighted the importance of preserving genetic material, and agricultural biotechnologists also want to make sure that we maintain the pool of genetic diversity of crop plants needed for the future. While transgenic crops help ensure a reliable supply of basic foodstuffs, U.S. markets for specialty crop varieties and locally grown produce appear to be expanding rather than diminishing. Thus the use of genetically modified crops is unlikely to negatively impact biodiversity.

Social issues

Labeling

Some consumer groups argue that foods derived from genetically engineered crops should carry a special label. In the USA, these foods currently must be labeled only if they are nutritionally different from a conventional food.

"Terminator" technology

Most farmers in the USA and elsewhere buy fresh seeds each season, particularly of such crops as corn, green peppers, and tomatoes. Anyone growing hybrid varieties must buy new seeds annually, because seeds from last year's hybrids grown on the farm will not produce plants identical to the parent. For this same reason—to avoid random genetic diversity due to open pollination—farmers do not plant mango, avocado, or macadamia from seed; instead, they clone individual plants of known quality through techniques such as grafting.

In developing countries, many farmers who are not growing hybrids save harvested seeds for replanting the next year's crop. A technology has been developed that might be used to prevent purchasers of transgenic crop seeds from saving and replanting them. Such "terminator" seeds are genetically engineered, along with other improvements more acceptable to farmers, to produce plants with seeds that have poor germination. This forces farmers who otherwise save seed to purchase it if they wish to use these improved commercial varieties. And, in the USA, the crops engineered with various characters are sold alongside nontransgenic alternatives for which growers also typically purchase seeds annually.

Despite these mitigating circumstances, this is serious issue among organic growers and in developing countries, where the practice of saving seeds is the norm for farmers who are not growing hybrid crops. Inclusion of "terminator" genes means that these farmers cannot take advantage of improvements brought about by genetic engineering without being brought into the economic cycle that profits the seed companies. Without profit incentive, however, these companies are unlikely to invest in improving crops. This issue is analogous to that faced by pharmaceutical companies developing new medications against human diseases. Clearly, it is a difficult and divisive social issue.

Safety and regulations

Transgenic crops and their resulting foods in the United States are extensively researched and reviewed by three federal government agencies: the U.S. Department of Agriculture (USDA), the U.S. Environmental Protection Agency (EPA), and the U.S. Food and Drug Administration (FDA). Each agency is responsible for a different part of the review process.

USDA has primary responsibility for determining if a new product is safe to grow, while EPA reviews the product for potential impact on the environment. FDA is concerned with protecting the consumer and has final authority to declare if a product is safe to eat.

Considerations about food from genetically engineered crops have raised a host of questions about effects on the environment, economic impacts, and ethics. However, perhaps the most fundamental question about such food is whether it is safe and wholesome to eat. Before field testing any new transgenic crop, companies and research institutions must register with USDA for field testing permission. Researchers must ensure that pollen and plant parts of the tested plants are not released into the environment during this period. Transgenic crops must also pass scrutiny of the EPA, which has the authority to regulate all new pesticides and genetically engineered crops. EPA is concerned with potential impacts on nontarget species and endangered or threatened species. Finally, any foods derived from transgenic crops must pass FDA inspection. Current law requires that foods from transgenic organisms must be labeled as such if their nutritional content or composition differs significantly from their conventional counterparts or if they pose any health risks. Both the National Academy of Sciences and the FDA have determined that, in general, foods derived so far from genetically engineered organisms are as safe or safer than conventional counterparts. The main concern is remaining vigilant for potential allergens.

Summary

Responsible scientists, farmers, food manufacturers, and policy makers recognize that the use of transgenic organisms should be considered very carefully to ensure that they pose no environmental and health risks, or at least no more than the use of current crops and practices. Modern biotechnology represents unique applications of science that can be used for the betterment of society through development of crops with improved nutritional quality, resistance to pests and diseases, and reduced cost of production. Biotechnology, in the form of genetic engineering, is a facet of science that has the potential to provide important benefits if used carefully and ethically. Society should be provided with a balanced view of the fundamentals of biotechnology and genetic engineering, the processes used in developing transgenic organisms, the types of genetic material used, and the benefits and risks of the new technology.