

Opinion

Genetically engineered plants: greener than you think

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Healthy, productive farmland separates humans from famine, making wise agricultural practices crucial to everyone. Plant scientists at universities and companies throughout the world endeavour to improve the quality, quantity, safety and sustainability of agricultural production, and their efforts have proven highly successful. Despite the remarkable success of a number of genetically engineered crop plants that have been grown and consumed – without incident – in large quantities since 1996, this technology faces increasing opposition in the United States and Europe. This article will discuss the major crops currently cultivated and provide information necessary to make informed decisions about plant biotechnology. Each new genetically engineered plant variety raises unique issues that must be considered on a case-by-case basis. Rejection or acceptance of all genetically engineered plants is unreasonable and will likely harm both the environment and the human condition.

Nature's genetic engineer

Gene flow between species is a natural process. Humans were not the first to transfer foreign genes into plants. A common soil bacterium, *Agrobacterium tumefaciens*, created the first genetically engineered plant cells. *Agrobacterium tumefaciens* infects plants and inserts specific genes permanently into the plant's nuclear genome (Chilton *et al.*, 1977). *Agrobacterium tumefaciens* genes expressed by the plant cause the plant cells to produce unusual secondary metabolites (called opines) derived from amino acids and sugars, which the bacteria can use as a carbon and nitrogen source (Winans, 1992). Other *A. tumefaciens* genes cause overproduction of plant growth hormones (auxin and cytokinin), which causes transformed plant cells to grow rapidly, forming a tumour that

produces high levels of opines. Thus, *A. tumefaciens* has created an ecological niche for itself.

Microbiologists have removed the tumour-inducing genes from *A. tumefaciens* and replaced them with beneficial genes, which the bacteria can insert into the plant nuclear genome (Gelvin, 2003). Although there are other methods to deliver foreign genes to plants, transgenes delivered using *A. tumefaciens* have lower copy numbers and undergo fewer rearrangements than those in plants transformed by other technologies. Virtually all of the transgenic plants cultivated today were made using *Agrobacterium* to deliver the transgenes.

Why do we need genetically engineered plants?

This frequently asked question deserves an answer, and there are several. In the United States, average crop yields are only 20% of those produced during bumper crop seasons when conditions are 'ideal' (Boyer, 1982). In other words, during a typical growing season 80% of our food production is lost to pathogens and environmental stress. Additional shortcomings of traditional and organic agriculture are erosion-promoting cultivation practices and use of toxic chemicals that could be minimized or avoided altogether by prudent use of genetically engineered plants. Genetically engineered plants have already solved some of these problems in an environmentally friendly way.

Insecticidal plants

Both traditional and organic farmers use insecticidal chemicals that kill beneficial insects as well as pests, and most of these compounds are also toxic to humans and other animals. Organic farming regulations permit the use of chemical poisons, as long as they are natural products. Rotenone, a favourite insecticide used by organic growers, is 100 times more toxic (to rodents) than carbaryl (Sevin) and 50 times more toxic than Lorsban (Windholz *et al.*, 1983).

A number of genetically engineered crops – widely cultivated in the United States since 1996 – have provided highly effective and environmentally benign protection against several serious insect pests. Genetically

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engineered cotton that makes an insecticidal protein lethal to bollworms reduced insecticide use by over one million pounds and increased yields by 85 million pounds in 1998. Corn plants that produce this insecticidal protein have prevented billions of dollars of damage caused by the European corn borer and corn rootworm, pests poorly controlled by sprays. *Bacillus thuringiensis* (Bt), which produces this insecticide, is a favourite of organic growers, although it is not effective as a spray in many situations because the caterpillars do not ingest a sufficient number of bacteria. *Bacillus thuringiensis* protein affects only larvae of moths and butterflies; this protein has no effect on humans.

Critics of Bt-producing plants have asked two valid questions. How will Bt plants affect non-target butterflies and moths, and will Bt-resistant insects evolve? In a laboratory study, milkweed leaves covered with Bt-containing corn pollen killed monarch butterfly larvae (Losey *et al.*, 1999). The lab study tested only one corn variety, which produces significantly more Bt protein than other brands of Bt corn on the market. Because this high-producing Bt line accounted for only 2.5% of the US corn crop, the relevance of the lab study to Monarch butterflies in the real world is limited (Ferber, 1999). No harm to wild Monarch populations has been reported since cultivation of Bt corn became widespread in 1997, and field studies suggest that this risk is minimal (Ferber, 1999; Pimmentel and Raven, 2000; Oberhauser *et al.*, 2001; Pleasants *et al.*, 2001; Scriber, 2001; Sears *et al.*, 2001; Stanley-Horn *et al.*, 2001; Zangerl *et al.*, 2001). Does corn shed pollen when and where monarch larvae are feeding? Latitude, weather and the corn variety affect the timing of these events, but in general corn pollen and the larvae usually do not overlap. *Bacillus thuringiensis* corn has minimal (if any) effect on monarch larvae in comparison with other threats, such as insecticidal sprays and loss of habitat (milkweed) to cities, suburbs and cultivated fields; indeed, Bt corn is beneficial to the monarch in comparison with traditional insecticidal sprays (Pimmentel and Raven, 2000).

Will target insects develop resistance to Bt protein? Although this has not been a problem for yet (Fox, 2003), it may (or may not) occur in the future. The excellent track record of Bt crops thus far tells us that such events, if they occur, will be rare, which provides an opportunity to combat this potential problem. Farmers that plant Bt-producing crops are required to sow a certain percentage of their land with traditional varieties. These areas provide refuges where Bt-sensitive insects can thrive. In theory, rare Bt-resistant individuals will mate only with Bt-sensitive insects because there are many sensitive insects and few resistant ones. If the Bt-resistant insect has lost a gene that normally makes it sensitive to Bt protein, then the Bt-sensitive parent will

contribute a normal copy of that gene, which will make all the offspring sensitive to Bt. If the Bt-resistant insect carries an altered gene that is 'dominant' to the normal copy, the offspring will be resistant to Bt and the refuge strategy will fail. This has not happened to date, and it may never happen. However, if insects develop resistance, it will be an isolated event that affects one species of Bt plant and one insect species at one location. For example, a Bt-resistant bollworm in Mississippi would not affect the utility of Bt corn in Iowa (or anywhere). This will provide an opportunity to learn how the insect became resistant and to modify the Bt protein so that it works again.

Bacillus thuringiensis cotton plantations in China have had an unanticipated positive side effect on multiple non-transgenic crops grown in the same region. The cotton bollworm, despite its name, affects other crops, including corn, soybean, peanuts and vegetables. In provinces where these crops are grown in the vicinity of Bt-producing cotton plants, bollworm populations were significantly reduced on the non-transgenic crops as well as the Bt cotton (Wu *et al.*, 2008).

Virus-resistant plants

Virus infections can devastate plants. Papaya ringspot virus destroyed papaya orchards in Hawaii, until growers planted genetically engineered trees resistant to this virus (Gonsalves, 2006; Stokstad, 2008). The engineered trees produce virus coat protein, which make them resistant to the virus. A virus particle contains the viral genome inside a protective protein coat. When a virus infects, it injects its genome into the host cell where the virus genome is duplicated many times. Late in the virus life cycle, coat proteins are produced. These proteins package the duplicated genomes to make a large number of new virus particles. If coat proteins are present too early, they block viral genome replication, a key step in the virus life cycle. This is how genetically engineered plants protect themselves from viruses without any input from farmers. To consumers, the virus coat is simply another source of dietary protein. This strategy has proven highly effective against a wide variety of viruses in a number of plant species.

Virus-resistant sweet potatoes were developed for use in Kenya (Qaim, 1999). Farmers in Kenya rely on their crops for both food and income, so yield is doubly important to them. Sweet potatoes are a staple in Kenya, and the traditional varieties grown are susceptible to a virus that reduces yields 75%. The sweet potatoes they do harvest are of poor quality. A Kenyan scientist, while on sabbatical at Monsanto, developed a sweet potato variety resistant to this virus, allowing poor farmers in Kenya to quadruple their yields at no cost to themselves.

Recently, scientists developed an entirely different method to make plants resistant to viruses (Kruphachaya *et al.*, 2007). The next generation of virus-resistant plants will not contain even one intact virus gene. The new method, which uses only a fragment of a virus gene to trigger gene silencing, promises to be extremely effective. Gene silencing is also effective against *A. tumefaciens*, which causes crown gall disease in fruit and nut trees (Escobar *et al.*, 2001; 2002; 2003; Lee *et al.*, 2003; Viss *et al.*, 2003).

Herbicide-resistant plants

Weeds are a huge problem in agriculture. On large farms, there are only two practical ways to control weeds: cultivation or herbicides. Each practice has drawbacks. Tilling promotes soil erosion by wind and water. Herbicide sprays introduce chemicals into the environment, and each chemical has unique properties that we must consider case by case.

The most common herbicide-resistance trait in crop plants is glyphosate (Roundup) tolerance. Glyphosate is less toxic to mammals than sodium chloride (Windholz *et al.*, 1983) because it blocks an enzyme (5-enolpyruvulshikimate-3-phosphate synthase: EPSP synthase) that is absent in mammals and insects but essential for aromatic amino acid biosynthesis in plants. Within days after application, soil microbes convert glyphosate into plant nutrients (ammonia, carbon dioxide and phosphoric acid) (Grossbard and Atkinson, 1985). Because plants transport glyphosate to their shoot tips, scientists make plants glyphosate resistant by engineering them to produce large amounts of EPSP synthase in shoot tips. Glyphosate-resistant plants do not make a new protein; they simply make more of one they normally have. This environmentally friendly herbicide allows farmers to use low-till and no-till methods and save precious topsoil (Service, 2007).

Golden rice

Today, all widely cultivated transgenic crops increase the efficiency of production, but genetic engineering can also improve the nutritional value of crops. For example, rice has been engineered with genes encoding three enzymes (phytoene synthase, phytoene desaturase and lycopene β -cyclase) that cause production of provitamin A (β -carotene) in rice endosperm, giving the rice grains a golden colour (Guerinot, 2000; Ye *et al.*, 2000). Vitamin A deficiency affects an estimated 124 million children worldwide, particularly in areas where rice is a staple food, causing 250 000 cases of blindness and 1–2 million deaths annually (Nash, 2000; Ye *et al.*, 2000). In a humanitarian effort to alleviate the suffering caused by

vitamin A malnutrition, the ability to produce β -carotene was introduced into a widely cultivated variety of rice, and patent rights to the transgenes were waived so that the 'golden' rice could be made available without cost. However, opposition from activists opposed to genetically engineered crops, along with lack of funding for safety testing, has prevented release of 'golden' rice for cultivation. It seems unlikely that 'golden' rice poses human health or environmental risks comparable to the harm that continues to occur due to vitamin A malnutrition. 'Golden' rice may or may not solve this problem, but it seems a shame not to try.

Conclusions

By discussing the three major classes of genetically engineered crops on the market today, I hoped to draw your attention to the very real benefits that these plants offer. Are genetic engineers 'reinventing life', as some critics claim? Hardly. A plant contains about 25 500 genes. Most genetically engineered plants cultivated today contain one or two novel genes that function in plants. Although the newly introduced genes confer important novel traits to the plant, they represent an extremely small (~0.008%) addition to the plant's genetic makeup.

Critics complain that genetically engineered plants are untested. Nothing could be further from the truth. Extensive field trials precede release of any new variety, whether it is the product of genetic engineering or traditional breeding. Plants produced by classical breeding are not subject to review by federal agencies, even though some varieties produced by traditional methods have been spectacularly toxic. One conventional celery variety caused chemical burns on the arms of farm workers as they harvested it (Berkley *et al.*, 1986), and grocery workers have also suffered chemical burns from exposure to conventional celery varieties (Seligman *et al.*, 1987; Fleming, 1990; Finkelstein *et al.*, 1994). Genetically engineered plants are reviewed by the United States Department of Agriculture, the Environmental Protection Agency (for environmental safety) and the Food and Drug Administration (for human safety). Genetically engineered foods are the safest, most thoroughly tested foods in the world. Laboratory tests and field trials are important, but the real test happens in the real world. Widespread cultivation of genetically engineered crops began in 1996 and has increased steadily ever since. In 2007, ~90% of the soybeans, 60% of the cotton, and 50% of the corn grown in the United States was genetically engineered (USDA, 2007), and genetically engineered crops were planted on substantial areas in Argentina, Brazil, Canada, India, China, Paraguay and South Africa (ISAAA, 2007). These crops have performed exceptionally well in the field and in people's diets. Problems have not arisen, so genetically

engineered crops have passed their real world test with flying colours. I can't wait until labelling is required. I will buy engineered foods as much as possible because I believe they are safer to eat and better for the environment than foods produced by either traditional or organic methods.

Traditional breeding, a technology that is over 10 000 years old, has increased crop yields and quality tremendously. However, this is a hit-or-miss process in which breeders look for spontaneous variants with beneficial traits. Usually breeders do not understand why their new varieties have new traits, and this can lead to problems. For example, the celery is pest resistant, but it is also too toxic to touch, much less eat (Berkley *et al.*, 1986). Genetic engineering provides an opportunity to introduce new traits on a rational basis that allows us to estimate potential benefits and risks. This opportunity is too important to miss. Even if some Americans and Europeans reject genetically engineered foods, the technology will continue to develop on other continents where most people are not overfed. History is not kind to societies that reject important new technologies.

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