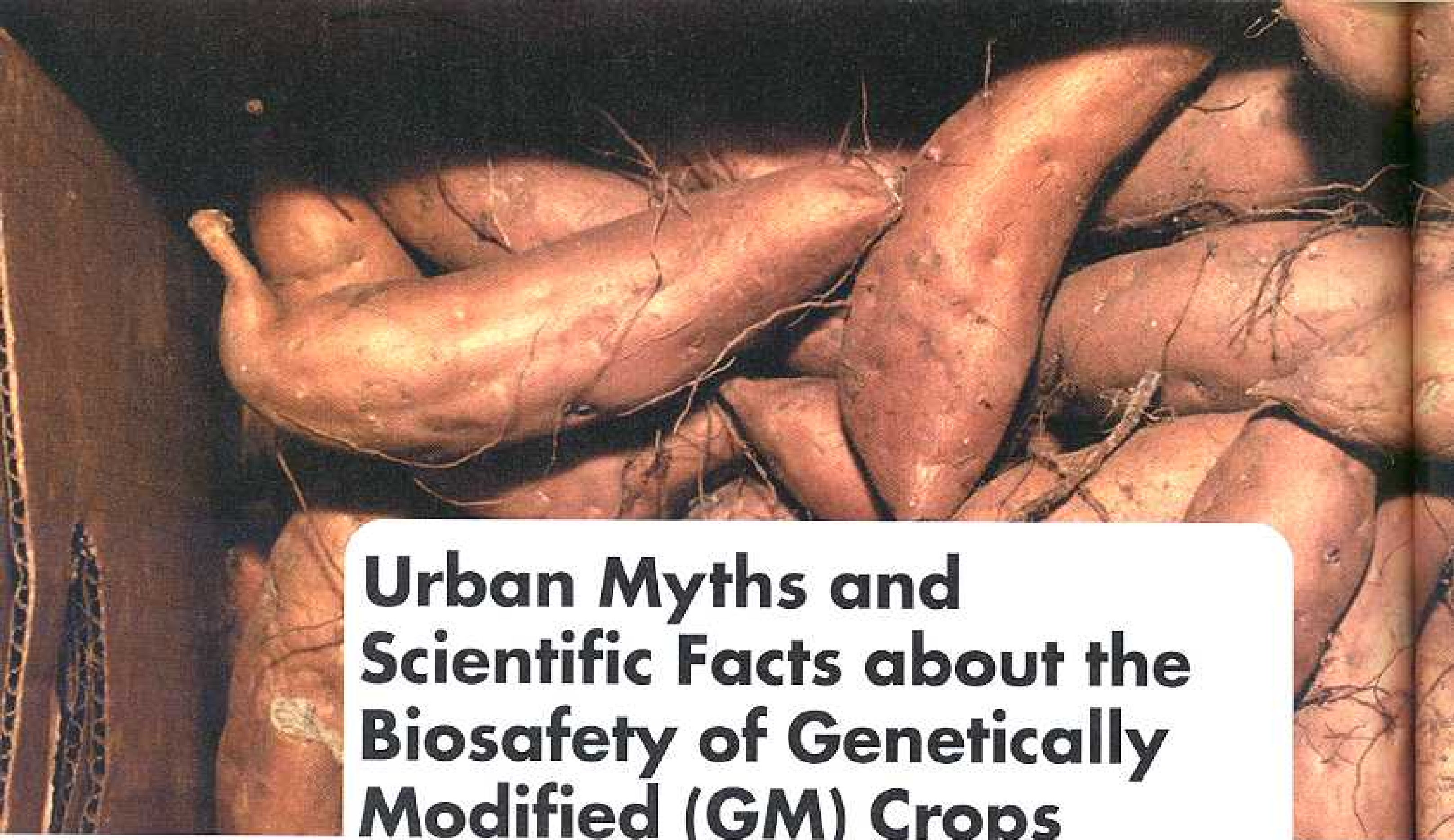

Urban Myths and Scientific Facts about the Biosafety of Genetically Modified (GM) Crops

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With the exceptions of western Europe, Japan, and parts of Latin America, genetically modified (GM) crops are fast joining agriculture throughout the world today and will play an increasingly important role in global food production. Both India and China have dramatically increased investment in molecular technologies, to increase their agricultural productivity. Molecular techniques, including gene transfer into crops, are the basis of the next logical development in agronomy and plant-breeding research (see Chapter 14). Although this technology can be viewed as an extension of traditional breeding (which also entails moving genes around), some people emphasize that transgenes are novel; that is, they do not originate from sexually compatible or closely related plants and instead can be derived from a range of organisms. For example, the *Bt* toxin genes from the bacterium *Bacillus thuringiensis* can and do function in plants after considerable modification of the nucleotide sequence of the gene. In fact, about half of the cotton and nearly one third of the maize grown in the United States in 2000 was genetically modified with *Bt* for insect resistance.

Because many transgenes are new to agriculture and might result in novel phenotypes, prudence dictates that people examine the risks before wide-scale deployment of transgenic crops. Some maintain that this breaking of the species barrier is so novel that the products (GM crops) pose uncertain risks to health and the environment. They want GM crops banned and maintain that people do not know enough about the consequences of introducing these foods in the human food chain and the plants into global environment (**Figure 20.1**).

Figure 20.1 Public protest in the streets of Oakland, California. Groups opposed to and in favor of GM crops hand out information at a peaceful rally. Activism and protests are part of every democracy. *Source:* Courtesy of P. Lemaux.

The development of agriculture as a science and its continual use and implementation of technology have clashed with a more idealized view in which a purity of purpose is considered on a par with scientific fact. We will examine some urban myths that have arisen during debates over GM crops and that have been propagated by activists,

CHAPTER

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the popular media, and even some scientists. We then discuss some of the real biosafety facts and concerns and how they are being handled.

Part I. Urban Myths about GM Crops and GM Foods

Urban myths arise because many people distrust new technologies that they do not understand and over which they have no control. The less control they can exert, the greater is their perception that it may be risky (see later, discussion of risk). Furthermore, distrust of large companies stems from the fact that people see such companies as less subject to national regulations (local control) and have not always been averse of putting financial gain ahead of public welfare. So there are sound reasons why urban myths about GM crops have developed. Furthermore, organizations that depend on voluntary donations to meet their large payrolls and entities that will secure a larger market share if GM technology fails (such as the organic food industry) are not averse to helping propagate such myths by ignoring some facts and emphasizing uncertainties.

The discussion of biotechnology risks in the media and by environmental organizations has not included the broader context of current agricultural practices. Problems ascribed to GM crops are often not unique to GM crops. Therefore, the consumer has increasing misperceptions about the dangers of GM crops and the role of biotechnology in agriculture. The discussions of GM crops have, in fact, added to urban people's mystification about how food is produced; no wonder the public feels a growing sense of alienation regarding food production. In this increasingly urban society, farming is romanticized, on the one hand, by the picture of the family farmer communing with the earth, and simultaneously demonized, on the other hand, by an image of giant agribusiness corporations treating livestock inhumanely and polluting pristine environments.

Today, only the smallest fraction of our population has any firsthand understanding of and appreciation for the strict constraints (biological, economical, and so on) of agriculture, information that was once considered familiar territory—literally in people's backyards. Many consumers want to be informed, but find unbiased information hard to come by. When distorted examples of research and development in biotechnology are added to the mix, it is not surprising that people feel threatened (see also the discussion of hazard and outrage in Chapter 7). In the course of the popularization of misconceptions about agricultural biotechnology, various myths have arisen.

Myth 1: The monarch butterfly is endangered by *Bt* corn.

The beautiful monarch butterfly (**Figure 20.2**) has become a powerful rallying symbol for the forces opposed to GM technology. They maintain that *Bt* maize threatens the butterfly population. This assertion is based on a study by J. Losey and colleagues of Cornell University, published in the prestigious journal *Nature*, that raised this possibility without providing evidence for it. The news that *Bt* maize pollen would kill larvae of the monarch butterfly (*Danaus plexippus*) circled the globe in days. Because milkweed (*Asclepias syriaca*), the only food for these larvae, grows in and around maize fields, and maize pollen could conceivably drift to, and land on, milkweed leaves, the Cornell researchers dusted milkweed plants with *Bt*-containing maize pollen, to look for toxicity to the larvae. They observed decreased feeding, growth, and survival rates in exposed larvae compared to larvae that ate leaves dusted with nontransgenic corn pollen. The authors concluded that *Bt* maize could endanger monarch populations feeding on milkweed near *Bt* maize. Several other scientists immediately questioned the validity of this study, arguing that its methods were not reproducible, that the "no choice" feeding strategy for the larvae did not represent true conditions, and that the pollen levels used were artificially high. Extensive follow-up studies by Mark Sears and colleagues have now shown that survival of monarch butterfly populations is not endangered by the planting of *Bt* maize in the United States, and that the impact of *Bt* maize is likely to be small (Sears et al., 2001).

Milkweed, the food of the monarch butterflies, is undesirable in both maize and soybean fields, and farmers try to eliminate it by the usual methods, including herbicides, which will always minimize monarch larva food supply in U.S. maize and soybean belts. Because milkweed patches are more frequent and larger on roadsides than in crop fields, perhaps scientists need to assess the impact of nonagricultural technologies, such as automobiles, on monarch populations. Although people are not going to stop using cars, having data about relative mortality rates to monarchs could be useful in the overall risk assessment to the species. One source (Monarch Watch, at the Web site www.monarchwatch.org) suggests that perhaps as much as 10% of the monarch butterfly

Figure 20.2 Monarch butterfly and larva. Activists opposed to GM technology and the media claimed that the beautiful monarch butterfly is threatened by extinction by *Bt* maize. The claims resulted from a misinterpretation of results published in the journal *Nature*. Extensive follow-up studies showed that *Bt* maize does not imperil the monarch population. *Sources:* Left photo, Iowa State University Entomology Image Gallery; right photo, Cornell University press release, photo by Kent Loeffler.

habitat in the U.S. maize belt is actually in maize fields. Would this habitat proportion be relevant to the monarch butterfly population levels?

Biotechnology currently represents a potential risk to monarchs, but how can people assess its relative importance to monarch butterfly survival? Although automobiles, tropical habitat loss, increasing exotic bird populations, and global climate change might have equivalent or greater actual effects, biotechnology risks are currently being assessed in a vacuum. The questions are simple, but the answers are complex.

Myth 2: GM plants will create superweeds.

Many people who feel generally unfavorable toward biotechnology have evoked the superweed idea, arguing that biotechnology will create weeds that are more invasive and damaging than our current weeds.

Weeds are the scourge of agriculture (see Chapter 17), and people have created plenty of superb weeds by moving weeds from one continent to another (such as the Russian thistle or tumbleweed) (**Figure 20.3**), by agricultural practices (monocultures; herbicide usage), and by hybridizing crops with native plants. The myth of the superweeds is best exemplified by the notion of genes for herbicide tolerance flowing from GM crops to related weedy plants. With only a few GM crops—namely, canola (usually *Brassica napus*)—engineered for herbicide tolerance, it is possible that transgenes could move from crop to weed in Canada and the United States. To minimize this occurrence, GM canola is not cultivated where its close relatives (such as field mustard, *Brassica rapa*) are dominant weeds. On a worldwide scale, there are other scenarios: Genes can flow from cultivated rice to wild rice, from cotton to wild cotton, from maize to teosinte.

Herbicide-tolerant weeds already exist as a result of natural selection after years of herbicide usage. Are these superweeds, or must a weed be transgenic to be a superweed? If herbicide-tolerant field mustard did arise, would it be worse for the farmer than it was before tolerant GM crops facilitated better weed control? These questions are in many ways rhetorical. Today there are no GM weeds, but in five or ten years, there will be. What novel traits will the transgenes confer to the host? How will they interact with the host plants' genetics, physiology, and ecology? This is a much more complex situation than can be addressed by the unilateral approach of equating the development and evolution of GM crops to the creation of superweeds. It is highly unlikely that GM crops will make weed control more difficult in the future or that transgenic weeds will invade pristine environments, any more than other crops have in the past.

Figure 20.3 Tumbleweed is a "superb" weed, if not a "superweed." Agricultural practices, and especially the movement of seeds from one continent to another, have contributed to the emergence of weeds that create serious difficulties for farmers. The tumbleweed or Russian thistle (*Salsola kali*) originally came from southern Russia and arrived in the United States as a contaminant of flax seed in 1877. Gene flow from crops to weeds will occur, but is very unlikely to create superweeds.

Figure 20.4 Are there genes in this food? Maize and soybeans were the main GM crops grown in the world in 2001. Because products derived from these two crops (for example, starch, protein, oil) are used in most processed foods, up to 70% of all products in U.S. supermarkets contain some GM ingredients. When the crops are processed, GM crops are not kept separate from traditionally bred varieties. Keeping separate production streams would add 10% to the cost of the ingredients. There are no good reasons for separating ingredients that come from GM crops; they are substantially equivalent.

Myth 3: GM foods have genes, whereas normal foods do not.

Opinion polls of people's attitudes toward GM crops in the late 1990s showed that many respondents believe that only GM crops have genes, whereas other crops do not. Plants vary quite dramatically (more than 50-fold) in the amount of DNA each cell contains; there is less variation in the number of genes and many plant species probably contain 25,000 to 40,000 genes (humans have 30,000 genes). Each cell has two copies of these genes. GM crops contain 2 to 3 additional genes (**Figure 20.4**).

Myth 4: There are fish genes in tomatoes and rat genes in lettuce; transgenes will change the fundamental vegetable nature of plants.

As part of exploratory research, scientists may perform experiments with particular crops, using many different genes to assess their performance. The media focused an inordinate amount of attention on one basic research project, in which an arctic fish gene was isolated and inserted into plants with the hope that it would confer freeze and frost protection. Such antifreeze properties would have great benefit to farmers who routinely lose crops to cold weather. In addition, antifreeze properties could extend the growing range of certain crops, such as tomatoes and citrus. However, when this particular fish gene was expressed in plants, it was ineffectual in providing frost/freeze protection. So, although there was, for a time, a fish gene in a tomato, it never made it into a jar of tomato sauce. Nevertheless, the distaste that people have for the smell of fish oil could be transposed to how they would feel about fruits with fish genes and has been cleverly exploited by people opposed to GM technology by creating the fish-shaped strawberry (**Figure 20.5**) as a symbol of their movement.

Figure 20.5 The hybrid fish-strawberry logo has become a powerful symbol of the anti-GM crop groups. This type of gene transfer is highly unlikely to ever be carried out commercially, but may be done by researchers to understand how genes function. Opinion surveys show that the public does not support using animal genes to improve crops, even though there is no scientific reason not to do so.

Another myth concerns plants with pig genes. No porcine genes are being evaluated by researchers for transfer into plants. The reason for the furor surrounding the subject and the reason why it will not happen are the same: Religious groups for whom pork products are forbidden make it economically unsound to transfer pig genes into crop plants. Even if scientists were to discover a pig gene that conferred salt tolerance or some other useful crop trait, it would not be commercialized because of economic considerations and the public's perception of what a gene from an animal does to the nature of a plant. This is an area where biotech companies are likely to follow public perceptions even though the religious authorities that have addressed the question agree that introducing a single animal gene does not alter the vegetable nature of a plant. A pig gene in a petunia does not a petunia pig make!

Myth 5: GM foods are not natural.

Human food plants do not occur in "nature" and generally cannot survive in natural environments, because their fitness has been changed by mutations, especially those that affect seed dispersal (see Chapter 13). Their continued existence depends on human intervention. Opponents of GM technology stress the idea that GM crops are unnatural because genes from any organism can be transferred through GM technology. This is indeed correct. Unfortunately, one cannot equate natural with good. HIV is just as natural as vitamin C. Mother's milk is as natural as cyanide. People need to examine, analyze, and regulate food products rather than determine if they are "natural." Gene transfer between organisms that are very distantly related does occur in nature as exemplified by the crown gall disease, in which a segment of bacterial DNA incorporates into plant DNA. Plant-breeding methods requiring embryo rescue or radiation are equally "unnatural," but have yielded more than 2,000 crop varieties that are generally accepted by traditional and organic farmers worldwide.

Myth 6: When you transform plants, you don't know what you are doing to the DNA.

Traditional breeding may introduce into a crop plant thousands of genes from wild relatives or related species. Even after many backcrosses, a couple of hundred genes will remain, and the breeders don't know which ones. With plant transformation, the genetic engineers know precisely which two or three genes they are introducing. With wide crosses (between species) and embryo rescue (see Chapter 14), one also does not quite know how the genes eventually rearrange and line up. With radiation breeding (see Chapter 14), the scientists expose the DNA to powerful radiation, causing many random chromosome breaks, point mutations, and deletions of DNA segments. They do not have a clue what has happened to the DNA. However, subsequent breeding and selection eliminate deleterious genetic accidents so that the resulting cultivars have the desirable properties the breeder seeks. Similarly, creation of GM crops involves years of breeding and selection after the initial transformation. In any case, the plant genome harbors a considerable number of transposons (mobile DNA) that can cause gene duplications and generally reshuffle a small number of genes in each generation. Thus DNA is not as stable as scientists thought 20 years ago, and this gene shuffling is a major driving force of evolution. GM crops, like other elite crops, need to be tested over and over again to make sure they retain their important characteristics.

Myth 7: This debate is not about economics but about food purity: Food suppliers will demand "GM free" foods.

Some prominent food handlers and processors have made public announcements that they will no longer use GM varieties in their food products, such as Gerber baby food, although most grain handlers accept without question those GM varieties and hybrids that are labeled for sale in both North America and Europe. Iceland Group, a large food distributor and processor in the United Kingdom, had a policy of carrying only organic vegetables. However, because of low sales, their policy has changed to sell both organic and traditionally grown foods, according to a BBC news story in December 2000. Although there have always been factions inclined toward one extreme or another, in today's market, consumers for the most part do not seem to respond strongly to food politics. Perceived value is what carries the most weight for consumers when they are considering the varieties, whether GM, organic, or something in between.

However, different sets of consumers have different priorities. Those with more disposable income may buy organic produce known to be GM free. Larger corporations—whether farms, food processors, or food retailers—that deal exclusively or largely in organic foods, realize they can increase their market share by supporting the notion that GM foods are probably unsafe or at the very least are not being adequately tested by government agencies. Thus, there is an important economic aspect to the many demonstrations and advertising campaigns. Similarly, the agricultural biotechnology companies that have invested billions of dollars in GM technology are defending their economic stake. Information to help consumers make informed decisions is presented by all parties to this debate (**Figure 20.6**).

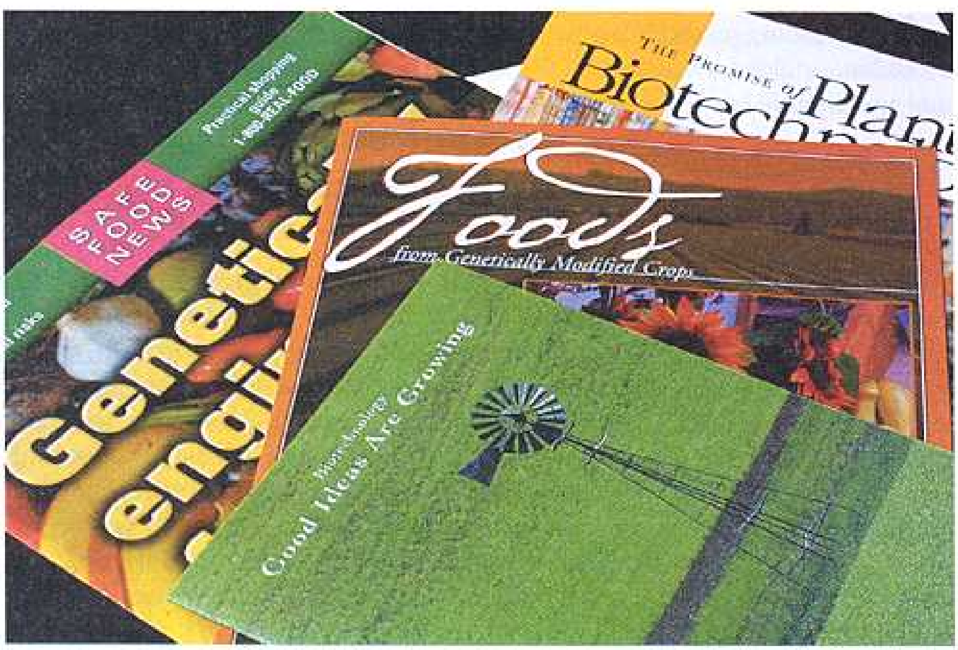

Figure 20.6 Informational brochures explaining the risks and benefits of GM crops are available to the public and produced by various organizations.

Myth 8: Low-resource farmers in developing countries will not benefit from biotechnology.

The first and second generations of GM crops were developed for industrialized societies, where the principals would be able to recoup their investments through high-value products. So far the major benefits have gone to the companies that developed the technologies and produced the products and to the farmers in the form of reduced production costs. Not to be ignored, however, are the benefits to farm workers, especially those who apply pesticides (**Figure 20.7**). *Bt* crops require less frequent pesticide applications (especially *Bt* cotton), and field workers who apply synthetic pesticides run considerable health risk in doing so. These risks are greatest in developing countries, where safety rules are frequently ignored.

Bringing biotechnology to developing countries has come about primarily through humanitarian efforts. Many multinational agricultural biotechnology companies have "noncommercial" projects aimed at the crops of the developing countries. Three examples of projects that will help poor farmers and consumers are the "Golden Rice" already discussed in Chapter 7, the virus-resistant potato lines being created in Mexico, and the virus resistant sweet potatoes now undergoing field trials in Kenya. The latter two projects are going forward with "donated" technology. Another effort that is underway is the development of GM plants to detect buried explosives (Neal Stewart, unpublished), in order to locate landmines in developing countries, in some of which (Afghanistan) they pose a substantial threat. Such humanitarian efforts targeted to the developing countries would not be possible without technology from the developed world and its subsequent global dissemination. Paradoxically, the same is true for the misinformation and melodrama that accompany the advent of any new technology; they are often exported in similar ways from the developed countries to the developing countries.

Whether people like it or not, the choices made in the developed world are crucial to the well-being and future of the developing world. Developing nations have bene-

Figure 20.7 Major health benefits could accrue from wider use of *Bt* crops to farm workers who spray insecticides in developing countries. The major problem with pesticide use is not pesticide residues on produce, but environmental damage and health problems for field workers. *Source:* Courtesy of Eugene Hettel, IRRI.

fited significantly from the students of their nations who trained in biotechnology fields in the United States, Europe, Japan, and Australia. These scientists returned home with the tools and information to convince leaders in their own countries that technology can play an important role in providing solutions to ever-increasing food production and environmental challenges. Many in the developing world see the efforts of organizations from the developed world (such as Greenpeace) to deny them the benefits of agricultural biotechnology as arrogant and misguided and as yet another expression of colonialism.

Myth 9: Antibiotic resistance genes used to produce transgenic crops will horizontally transfer into microbes and thus exacerbate problems of antibiotic resistance in human and animal pathogens. Transgenes will move from plants to gut microflora to humans.

This hot topic has grabbed public attention because it has married a real problem (antibiotic resistance in medicine) with the current controversy over GM crops. Although it is true that most GM crops have been produced using antibiotic resistance genes, that fact does not imply significant risk. Antibiotic resistance genes help protect transgenic plants in the presence of a drug that technologists administer to kill off untransformed cells. For example, the *nptII* (neomycin phosphotransferase) gene has been used for selection against the drug kanamycin. The FDA has approved *nptII* for this very practice, and no data suggest that *nptII* or any other gene can move intact from a plant into microbes such as those found in the human gut. In fact, scientists have performed numerous experiments to try to instigate that exact event, but have never succeeded. It is not surprising that this event does not occur, or over time gut microbes would become plants, or scientists would at least find in microbes genes that look like plant genes, which they do not. Genes can move between bacterial species (mainly via plasmids), and even from bacteria to plants (such as the case of *Agrobacterium tumefaciens*) (**Figure 20.8**), but movement in the other direction seems extremely unlikely. A compelling argument against the remote possibility of the movement of plant genes (or transgenes) into bacteria is the dissimilarity between bacterial genes and plant genes. Plant genes contain introns, whereas bacterial genes do not (although most transgenes are made from intronless cDNAs). The preferred genetic codon usage in plants is different from that of bacteria, and they use different kinds of regulatory sequences (promoters and terminators) as well. It is almost inconceivable that a large piece of DNA could withstand digestion in the human gut, but if it did, the intact DNA, including the promoter and terminator, would need to transfer to a microbial cell. That cell would then have to integrate the gene into its genome or plasmid, and the researchers would have to use kanamycin to select for the gene. Statistically, all this is so unlikely that one need not lose sleep over it! Although most scientists consider using antibiotic genes for plant transformation safe, all major biotechnology companies are now adopting technologies that remove those genes after the plants have been transformed and before they are released to the farmers as new crop lines.

Myth 10: GM crops are not adequately tested or regulated.

In all countries, government agencies regulate the products of technology that are sold to consumers. The reason is that technology is not inherently safe, and regulations are put

Figure 20.8 Crown gall disease caused by *Agrobacterium tumefaciens* is an example of unusual gene transfer between organisms. In this natural process, the bacterial pathogen transfers some of its genes to plant cells, which then grow out into a gall. Source: With the permission of the American Phytopathology Society.

in place to assess safety. These agencies all require that certain tests be done, and agency scientists then review the evidence and make decisions based on their understanding of the results. This procedure is followed for drugs, for example. Industry generally funds drug tests, which are often carried out by university scientists. For such research projects, strict conflict-of-interest guidelines are needed so that the scientists have no financial interests in the companies whose productivity they are testing. Government scientists then scrutinize the data and make recommendations. The situation for GM crops and GM foods is very similar. In the United States three agencies are involved: the U.S. Department of Agriculture, the Environmental Protection Agency, and the Food and Drug Administration. The amount of information submitted for approval of a single product is truly staggering. Large companies generally perform tens of thousands of analyses to show that GM products are compositionally and nutritionally equivalent to conventional plant varieties. Globally, tens of thousands of field tests have been conducted during the past 15 years to establish the safety of GM crops, and hundreds of food safety tests and animal feeding studies have been done during the past 10 years. For example, as of 2001 the data on Monsanto's herbicide-resistant soybeans have been examined by and approved by 31 regulatory agencies in 17 countries. Furthermore, leading national and international scientific authorities have concluded that biotech products are as safe for people and for the environment as conventional plant varieties. The real problem is actually the reverse: These crops are so highly regulated that small companies and nonindustrial entities (such as universities) that would like to develop GM crops lack the financial resources to do the tests required. In the past, noncommercial agencies released many improved plant varieties, but that is unlikely to be the way of the future for GM crops, because of required testing and the high degree of regulation.

Part II. Health and Environmental Risks of GM Crops and GM Foods

There are risks in growing and eating GM crops, as there are risks inherent in any human activity. These risks are not new or specific to GM crops, but derive from risks already existing in agriculture. Every year, new genes are expressed in novel crop varieties without being questioned; nor does the public hear much about the varieties that arise from random mutagenesis caused by chemicals or irradiation. These are accepted technologies with which people have achieved a certain level of comfort, and that were introduced at a time when technology was not scrutinized as it is today (**Table 20.1**) (see Chapter 14). Unknown factors exist in any new technology, and until a technology is thoroughly understood the risks cannot be completely characterized; so they are often misunderstood and overemphasized. The perception that special risks are associated with GM crops results from a combination of misinformation and fear (**Table 20.2**); true risk and perceived risk can be quite different from each other. **Figure 20.9** compares the actuarial risks of common activities that have been observed over time. There have been no documented injuries, illnesses, or deaths caused by the use of GM varieties in agriculture, from which one can infer that they are relatively low risk. However, GM foods are not specifically labeled in the United States, so it is not possible to conduct large epidemiological studies. All safety

Table 20.1 Examples of cultivars and/or species originating from spontaneous mutation, induced mutation, somaclonal variation, and interspecific hybridization

Species	Source	Trait
Capsicum annum (pepper)	Gametoclonal variation	Reduced seed number
Lycopersicum esculentum (tomato)	Somaclonal variation	*Fusarium* race 2
Nicotiana tabacum (tobacco)	Gametoclonal variation	Potato virus y resist
Zea mays (corn)	In vitro selection	Imidazilinone resistance
N. tabacum (tobacco)	Somatic interspecific hybridization	Nicotine content, blue mold, black root rot
Hordeum vulgare (barley)	Mutation	Proanthocyanidin free, beer stabilizing factor
Brassica napus, B. rapa (canola)	Spontaneous and induced mutation	Low erucic acid and glucosinolates, edible oil source
Triticale (×Triticosecale)	Interspecific hybridization	New cereal species (human made)
Triticum aestivum (wheat)	Interspecific hybridization	20+ disease-resistant cultivars

Table 20.2 Why some activities—in this case, eating GM food—have greater perceived risk perception than actual risk

Factor	Example
Coerced rather than voluntary	Everyone must eat GM food, if it is unlabeled
Industrial rather than natural	Big multinational hybrids versus landraces
Dreaded rather than not dreaded	Unknown risks (cancer?) stigma of dread
Unknowable rather than knowable	Only experts know risk, and they debate
Controlled others/controlled those at risk	Big multinational compared to individual
Untrustworthy rather than trustworthy	Multinational compared to small farmer
Unresponsive versus responsive management	Open versus arrogant and remote

Source: Adapted from Peter M. Sandman (1994), in Ruth A. Eblen and William R. Eblen, eds., *Encyclopedia of the Environment* (Boston: Houghton Mifflin), pp. 620–623.

studies are conducted in the laboratory with animals and with foods that are spiked with high levels of the proteins and genes that are novel to the GM food.

Since the first commercialized GM crop, the FlavrSavr® tomato (**Figure 20.10**), was introduced in 1994, people have learned a great deal about the real risks and the substantial benefits of GM crops. The benefits of growing GM crops far outweigh the few measurable risks discovered to date. The potential dangers that do exist are specific to particular crops and transgenes and are not associated with the process of plant transformation as a whole.

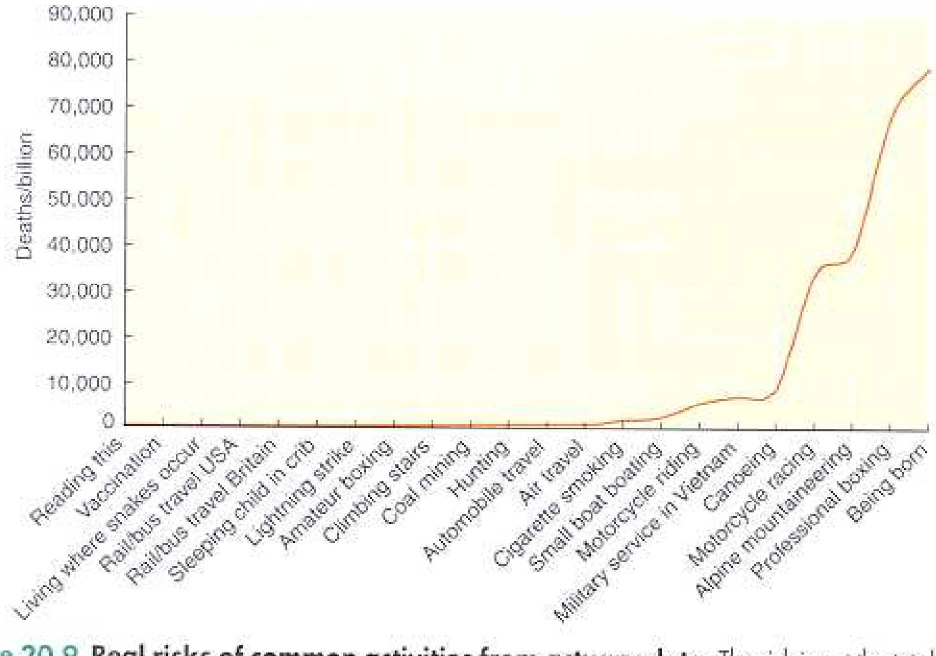

Figure 20.9 Real risks of common activities from actuary data. The risk is not the total number of deaths, but rather the total number divided by the number of people engaged in each activity. *Sources:* W. Stannard, *Insurance*, October 25, 1969; E. E. Pochin (1974), Occupational and other fatality rates, *Community Health* 6:2–13.

Figure 20.10 The first GM crop in the marketplace: FlavRSavR® tomatoes marketed under the MacGregor label. *Source:* Courtesy of William Hiatt, Calgene, Davis, California.

The risks of GM crops can be classified into two general categories: food safety risks and ecological risks. The food safety issues of GM food revolve around allergenicity and toxicity of the proteins to humans. There are several categories of ecological risks:

- Resistance management of insects to *Bt* and other plant-produced toxins
- Gene transfer and persistence
- Nontarget effects

Naturally, none of these risks exist in isolation; they must be viewed in the context of existing agricultural systems. Nature did not invent agriculture, people did; people should therefore analyze how one artificial construct (GM crops) affects and is affected by another existing and necessary artificial construct (agriculture), as well as how it might affect unmanaged ecosystems (nature).

20.1 The potential toxicity of new compounds entering the human food supply is thoroughly tested.

Any compound entering the food supply in the United States and many other countries is subject to specific regulatory scrutiny for food safety. A potentially toxic transgenic product such as *Bt* toxin must pass the same standards that are applied to any chemical pesticide product. Exceptions to this type of testing occur when the gene product (protein) expressed in a transgenic plant is found to be substantially equivalent to an ingredient or compound already existing in the food supply. Regulatory agencies such as the Federal Drug Administration use the doctrine of substantial equivalence to determine if a GM product is compositionally or nutritionally different from the original product. Synthesis of normal dietary components such as vitamins A and E would be exceptions to this rule; however, even these common dietary products would have to be tested for bioavailability and for any unexpected effects that could have occurred during crop transformation. When a plant overproduces innate compounds or when the transgene product has a known level of toxicity, it is necessary to conduct toxicity testing. An example of the former would be the overproduction of proteinase or amylase inhibitors for insect resistance. Plants already produce such inhibitors as part of their defense arsenal. Because they are endogenous to plants and could offer sublethal insect control, this class of proteins might be desirable to use in GM crops (see Chapter 16). However, because these compounds are natural antibiological agents, testing would be necessary to determine levels safe for human consumption. Toxicity testing also must be performed for all proteins not found in the human diet. For instance, green fluorescent protein (GFP) has numerous potential applications because of its visible fluorescence (**Figure 20.11**). It could be used to monitor the movement of transgenes to unintended weedy hosts, or track disease and stress responses with GFP that is produced using disease- or stress-inducible promoters. These would be valuable tools for agriculture, but would entail that GFP enter the human food chain, requiring that the potential toxicity of GFP be determined.

Some scientists have argued that protein products and the downstream metabolites are not the only potential source of toxicity in transgenic plants. They hypothesize that secondary pleiotropic or secondary mutagenic effects, resulting from gene expression or integration, could cause unforeseen hazards, including toxicity of secondary metabolites or lowering of important nutrients. In two documented cases, traditional crop improvement strategies have led to the appearance of unacceptable levels of toxic products: glycoalkaloids in potatoes and carcinogens in celery. These were detected only after breeders had released the new varieties to the public. Thus, the problem of unusual changes in some of the thousands of chemicals that crops contain is not specific to GM crops but is the consequence of genetic change, by whatever means. One method for assessing these potential problems would be quantitative measurement of thousands of metabolites—called *metabolic profiling*—to assure that any GM variety is materially equivalent to its nontransgenic counterpart.

The study that caused the European backlash against GM foods was initially introduced to the public in a British television interview with Arpad Pusztai, a well-known

Figure 20.11 Green fluorescent protein (GFP) expression in canola. The plant on the left expresses the jellyfish gene that encodes GFP, a protein that can be imaged with the proper equipment. This and other genes could be used to follow the spread of genes in plant populations. *Source:* Courtesy of Matt Halfhill.

biochemist/animal nutritionist from Aberdeen, Scotland. This study was subsequently published in the British medical journal, *The Lancet* (Ewen and Pusztai, 1999). Pusztai and his colleagues examined the effect of feeding rats transgenic potatoes that produced a lectin found in the bulbs of snowdrop (a nonfood plant). This lectin protein has insecticidal properties. The control feed included either wild type potatoes or wild type potatoes spiked with lectin. The researchers reported that only rats fed transgenic potatoes showed signs of intestinal damage and lowered immune response, and they concluded that the genetic transformation process itself caused the observed complications. This study has been heavily criticized for its lack of a control group fed transgenic potatoes that did not express the lectin gene, as well as for the imbalanced diet used overall. Because potatoes are protein deficient, they are a poor choice of food as the sole nutritional source; this kind of imbalanced diet could itself damage experimental subjects. Other reports have contradicted Pusztai's conclusion that transformation itself is a suspect technology. On the positive side, Pusztai emphasized the need for long-term nutritional studies with mammals in evaluating certain transgenes. In addition, the study showed the difficulty of evaluating GM crops. Spiking the food with a novel protein is relatively easy and requires only that the researchers know how to purify the protein, which is usually not too difficult. However, will such a study get the same results as one in which the protein is made by the crop itself and present in the cells? If the crop is a poor source of nutrition when fed by itself, and the level of the new protein is low—as it usually is—the experiment becomes even more difficult if not impossible to do.

20.2 Special testing ensures that novel proteins are not allergenic.

A major concern of people with food allergies is the possibility that genetically modified crops could introduce allergens into the food supply. Although food allergies are not completely understood, there is enough information about them to generate a limited list of common food allergens and standard characteristics that are used for defining food allergies (**Box 20.1**). Certain proteins have short stretches of amino acids on their surfaces that cause mammals to produce a special class of immunoglobulins called IgE, which are responsible for the allergic reactions. These short peptides can be identified, and researchers have determined the amino acid sequences of more than 200 food proteins with allergenic sites. No common amino acid motif or consensus sequence has been discovered. If a compound is known to be allergenic, then the process of evaluation is simplified; proteins that are not normally allergenic will not suddenly become allergenic when expressed in a transgenic plant. For instance, no known allergy to the iron-carrier-protein plant ferritin exists; therefore, transgenic iron-enriched rice that expresses ferritin poses no allergenicity risk. If a gene product is already an allergen, then it will remain an allergen when expressed in a transgenic plant. When researchers introduced the gene encoding brazil nut albumin into soybean to increase its methionine content, they found that serum from brazil nut–allergic people reacted with extracts of the transgenic soybean (**Figure 20.12**). This became apparent when Pioneer Hi-Bred International, the company that produced the transgenic soybean, tested it for food safety, because the same subjects were not allergic to soybean. The FDA and Pioneer came to the same conclusion: The transgenic soybean variety would carry a significant allergy risk and should not be commercialized.

Box 20.1

Some Facts About Food Allergies

Allergy (food allergy): Any adverse reaction to an otherwise harmless food or food component (a protein) that involves the body's immune system. To avoid confusion with other types of adverse reactions to foods, it is important to use the terms "food allergy" or "food hypersensitivity" only when the immune system is involved in causing the reaction.

Frequency: According to the U.S. National Institutes of Health, approximately 5 million people in the United States (5 to 8% of children and 1 to 2% of adults) have a true food allergy.

Most common food allergens: Eight foods account for 90% of human allergic reactions. They include peanuts, tree nuts (walnuts, pecans, Brazil nuts, cashews, and so forth), fish, shellfish, eggs, milk, soy, and wheat. Peanuts are the leading cause of severe allergic reactions, followed by shellfish, fish, tree nuts, and eggs.

Severe reaction (anaphylaxis): Medical researchers estimate that as many as 100 to 200 people die each year from food allergy–related reactions; approximately 50 people die from insect sting reactions. In highly allergic people even minuscule amounts of a food allergen (for example, 1/44,000 of a peanut kernel) can prompt an allergic reaction.

Naturally, risk assessment is considerably more complicated when the allergenicity of a transgenic protein is unknown. Once again, GFP is a good example. Although there are no known allergies to GFP, might it induce allergies if people routinely ingest GM foods expressing GFP over a long period of time?

One typical characteristic of food allergens is that they are not easily broken down in the gut. Testing a protein's stability during the digestive process is one way of identifying potential allergens; if a protein is degraded in the gut then it may not reach immune cells and cause a hypersensitivity response. For this reason, proteins that are stable in the human gut require extensive examination. The Aventis Starlink® *Bt* Cry9 maize variety found in Taco Bell taco shells in the summer of 2000 was a good example of a product that people feared could contain new allergens. *Bt* Cry9 is more stable in digestion than the other *Bt* toxin proteins in commercial crops, so the EPA took the precautionary measure of approving the Starlink® maize only as animal feed (pigs and cattle do not generally have food allergies). After discovering the maize in human foodstuffs because the farmers, grain elevator operators, and others down the food production line were either unable or unwilling to segregate the GM Starlink® maize, the EPA made the decision not to approve GM crops only for animal consumption in the future—once again, as a precaution against the recurrence of such problems.

One procedure that can be performed to assess whether a recombinant protein might be allergenic is to compare peptides of the recombinant protein to those of known allergens. Novel proteins with significant sequence similarities can be tested for reactivity with serum from subjects who are allergic to the homologous allergen. Although these tests may not be completely comprehensive in identifying potential allergens, the limited variety of allergenic foods (Box 20.1) suggests that the vast majority of transgene proteins will be safe for consumption. All those now in the marketplace have been thoroughly tested. It is interesting to note in this respect that traditional foods that contain known potent allergens, such as peanuts, and that are responsible for a number of deaths in the United States every year, are not labeled as being potentially life threatening.

Figure 20.12 Large Brazil nuts amid (much smaller) soybeans. To make soybeans more nutritionally complete, a gene from Brazil nut was transferred to soybean. Many people are allergic to Brazil nut, and it turned out that the chosen gene encoded a major allergen from Brazil nut. When it was discovered that people who are allergic to Brazil nuts, were now allergic to the GM soybeans, the project was stopped. This episode is always cited by opponents of GM technology as evidence of the dangers. It also clearly shows that the regulatory process works and that potential problems can be identified.

The other side of the coin is that GM technology can and will be used to eliminate allergenic proteins from some major crops by suppressing expression of genes that encode those proteins. Projects are under way to make hypoallergenic soybean and wheat.

20.3 Transgenic volunteer crop plants could become a nuisance in agriculture.

One important purpose of GM crop technology is to improve a crop's agricultural performance. Toward this end, it would be useful for some crops to acquire broader abiotic and biotic tolerances, allowing them to be grown in new geographic areas or under new conditions. Some people have argued that with crops such as alfalfa (*Medicago sativa*), canola (*Brassica napus* and *Brassica rapa*), sunflower (*Helianthus annuus*), and rice (*Oryza sativa*), all of which possess one or more weedlike characteristics, transgenic and novel traits could allow the crop itself to become more weedy and invasive. Generally, cultivated crop species contain few of the characteristics of weedy species (**Box 20.2**). In fact, most or all of the modifications associated with GM varieties are meant to enhance their productivity under intensive agricultural management. Such changes are not only less likely to make a crop species weedy but would tend to reduce its competitive capability in nonagricultural circumstances.

Weed volunteerism is an agricultural problem in which uncollected seeds from last year's crop germinate and grow within the crop currently being grown in the same location (see Chapter 17). Canola, to date, has been modified with at least three distinct herbicide resistance genes (two via genetic engineering and one through mutagenesis), and

Box 20.2

Characteristics of Weeds and/or Weedy Relatives of Economic Species

A weed is defined as an unwanted plant, especially a wild plant, growing where it is not desired by humans. In addition, weeds may be characterized by

- Seed production early in their life cycle
- High fecundity by seeds or vegetative structures
- Long-lived seeds, seed dormancy, and/or asynchronous germination
- Adaptation to coexist and be spread with crop seeds
- Production of allelochemicals that suppress the growth of other plants
- Adaptations such as prickles, spines, or thorns that aid dispersal or repel predators
- Parasitism of other plants
- Storage organs or seed reproduction that promote survival in harsh environments
- High photosynthetic growth rates and/or extensive root systems

Source: H. Baker (1965). Characteristics and modes of origin in weeds, in H. G. Baker and G. L. Stebbins, eds., *Genetics and Colonizing Species* (New York: Academic Press), pp. 147–168.

volunteers of these varieties could become a particular nuisance to agriculture. Individual plants combining all three herbicide resistance genes and expressing resistance to several herbicides did arise as a result of crossing in the field of one farmer in Canada who decided to grow all these varieties in close proximity. Such individual plants are at a selective advantage and will make weed control more difficult. More stringent regulatory requirements by the USDA have been applied to certain transgenic crops that have the potential for increased invasiveness and damaging volunteerism.

Figure 20.13 Weed beet. The weed beet is a hybrid between the sugar beet and a related wild species of the sugar beet. In this view, the weed beet has completely overtaken the crop. *Source:* Courtesy of Detlef Bartsch, Aachen University of Technology.

Once again, this problem is not unique to GM technology, because troublesome weeds have arisen in the past as a result of hybridization between crops and weeds. For example, the sugar beet industry in Europe was severely depressed at the end of the 20th century by the emergence of the weed beet, a cross between the sugar beet (*Beta vulgaris* subsp. *vulgaris*) and the sea beet (*Beta vulgaris* subsp. *maritima*) (**Figure 20.13**).

20.4 It is virtually certain that transgenes will flow from GM crops to other related plants.

Intraspecific hybridization occurs readily when wind- or insect-pollinated transgenic crops are grown in close proximity to nontransgenic varieties, and the agricultural practice of annually saving harvested seeds can unintentionally allow transgenic material to persist from one year to the next. Crops such as maize have the potential to pass genes to adjacent conspecifics (members of the same species) whether the crop is GM or a conventional variety, and many organic farmers worry about this possibility. Although in the United States a growing organic farming industry seems to coexist peacefully with conventional farmers using GM crops, organic farmers are opposed to the adoption of GM crops generally, either for their own use or use by conventional farmers. The term "genetic pollution" has been coined for the spread of transgenes from their home crops to the surrounding plants, whether crops or wild plants. Such spread worries producers of non-GM crops such as organic farmers. In the past the organic farming industry has had rigorous standards for pesticide overspray and trace "contaminants" in its products and seeds, and threshold limits for trace transgenes will also need to be established.

There is also concern that GM crops might rapidly accumulate several fitness-enhancing traits (transgene stacking) and that this could lead to new and unforeseen problems. This issue of unintended consequences will persist until scientists gain more first-hand knowledge about transgene stacks themselves. What would be the interactions, for example, among gene products that confer drought and aluminum tolerance, insect resistance, and increased nitrogen use efficiency? Scientists will have to assess ecology and physiology of such "superplants" individually, just as they do now. A related development in plant biotechnology is metabolic engineering—the ability to transform plants with several genes that make new metabolic pathways.

A more immediate problem is that of hybridization between closely related species. The most difficult problem would be if a weed species could receive transgenes directly from a related crop being grown nearby; these transgenes, if expressed, could then increase the fitness of the weed in nature. In a worst-case scenario, the weed could become more invasive and competitive, and in a relatively short time could damage natural ecosystems. People have to go back to the list of weedy traits and ask if it is likely that a transgene will exacerbate or promote weedy ability. Such evaluation is part of the government's regulatory system.

Interspecific hybridization depends on several concurrent circumstances to allow gene flow between related species. The crop must have some naturally occurring wild relatives growing near land under cultivation. Crops such as maize and soybean have no relatives in the United States and Canada; therefore, they represent no risk of interspecific gene flow. It is important to note that there may be unintentional movement of transgenic plants from the United States to other countries. Scientists can only speculate about the ramifications of transgenes introgressing from maize into teosinte, a wild relative of maize and a global treasure that originates and grows in Mexico (see Chapter 13). Sunflower (**Figure 20.14**), alfalfa, Brassica crops, and rice are all crop species that do have wild relatives near cultivation areas; these species complexes have all been the focus of gene flow studies in the United States. The wild and domesticated species involved must share a degree of sexual compatibility, and distantly related species do sometimes share enough genome similarity to produce viable progeny. They must occur in close enough proximity to allow transfer of viable pollen, and they must flower at the same time as well.

The variable homology of the genomes between related species leads to a wide range of possibilities for the introgression rate of a transgene, or any other gene, after the F_1 hybrid generation. Meiotic abnormalities caused by the distant relationship between parental genomes can decrease rates of introgression into new genotypes, so the production of initial hybrids does not at all guarantee that the transgenes will move into weeds. Unequal pairing during meiosis can cause chromosomes to be lost or disrupted, which results in higher rates of infertility and decreased rates of seed production. Recombination, an important process in the incorporation of foreign DNA, is diminished by the unstable chromosome configurations of hybrids produced by distant relatives. In contrast, hybrids produced by closely related species have been shown to combine fitness indices (seed production, pollen fertility, biomass, and so on) that parallel the parental species. In this situation, the hybridization barrier between species can be very low, and introgression of a transgene is likely.

Figure 20.14 Wild sunflowers in Nebraska. There is little doubt that gene flow from GM sunflowers to wild sunflowers is likely to occur in the future. The questions are, Is there likely to be ecosystem damage from such gene flow? And is this damage worse than present ecosystem damage from agriculture? *Source:* Courtesy of A. A. Snow, Ohio State University.

In particular crops, it is virtually certain that transgenes will flow from crop to weed. For example, canola, *Brassica napus*, hybridizes easily with birdseed rape or field mustard, *Brassica rapa*. Transgenic interspecific hybrids have been produced between transgenic canola modified with herbicide resistance and insect resistance genes, and wild *B. rapa*. After only one backcross, many of the progeny are morphologically and cytologically similar to the *B. rapa* parent. After another generation, the progeny are essentially *B. rapa* with a transgene; transgenic weeds in three generations! The transgenes have also been found expressed in the weedy genetic background. A *Bt* transgene in canola could have the same expression level when placed in the *B. rapa* genome through introgression. However, note that two types of herbicide-resistant canola are available: GM and bred by traditional means. The problem of herbicide-resistant weeds is not limited to GM canola but exists with the traditionally bred variety as well.

Just because transgenic weeds will arise does not mean that such weeds will be weedier or more invasive; the possibility for increased fitness of transgenic hybrids and backcrosses depends on the nature both of the transgene and of the environment. For example, weeds that contain a transgene conferring resistance to a herbicide would be a nuisance to agriculture, but would have little effect in a nonagricultural environment where the herbicide is absent. In contrast, an insecticidal *Bt* transgene in a weed host could alter natural ecology by giving transgenic weeds a selective advantage if a key insect had been historically critical to limiting the weed's survival. Transgenes that provide fitness-enhancing characteristics under natural conditions have the greatest potential to disrupt the balance of established ecosystems. However, most weeds already seem to have better insect resistance than their elite crop counterparts. Does insect herbivory presently limit weed populations? In gardens, insects seem to prefer tomato plants to weeds; will adding a *Bt* gene make a difference? How much weed fitness increase from transgenes should be tolerated? Norman Ellstrand and colleagues (Ellstrand, Hand, and Hancock, 1999) have suggested a 5% fitness increase, at which point they believe significant economic impacts might occur that would outweigh the benefits gained from the transgenic crop.

20.5 Effects on nontarget organisms are difficult to investigate.

Transgenic crops that express insecticidal transgenes to control agricultural pests may also affect nontarget organisms, and there are several different ways in which this could occur. An insect might eat a transgenic toxin in a food source it does not typically encounter. To use a much-touted example, the monarch butterfly could be impacted directly by feeding on parts of a crop plant that it does not usually eat, in this case, *Bt* maize pollen that has landed on milkweed plants (milkweed is the sole food of monarch larvae) adjacent to or in maize fields, as discussed earlier. A different nontarget effect involves interactions that occur through three trophic levels. A. Hilbeck and colleagues in Switzerland found that the lacewing (*Chrystoperla carnea*), an insect predator (**Figure 20.15**), suffered higher mortality rates from feeding on European corn borers (*Ostrinia nubilalis*) reared on *Bt* maize compared with those fed the non-*Bt* variety. However, no field studies on plant and insect population systems have been performed to determine if a GM plant (*Bt* maize, in this case) would have a significant impact on biodiversity in a farm setting. In another type of trophic interaction study—this one performed in Great Britain by T. Schuler, G. Poppy, and colleagues—insect behavior experiments using "choice" feeding (the insects can choose their food from a number of selections) showed that a parasitic wasp (*Cotesia plutellae*) preferentially selected *Bt* canola leaves as a food source habitat when the leaves had been damaged by *Bt*-resistant diamondback moths (*Plutella xylostella*). That is, the plant damage drew the wasp to the location of the moth larvae. If one were simply looking at whether the plant were transgenic (*Bt* canola versus non-*Bt* canola), the conclusion would have been that *Bt* decreased parasitism by the wasp. But the inclusion of *Bt*-tolerant larvae in the experiment uncovered the fact that the key factor was plant damage. The parasitic wasp experienced no reduction of reproductive success from exposure to *Bt* when it consumed *Bt*-resistant moth larvae, and could, in fact, help constrain the spread of *Bt*-resistant pests through natural predation.

Figure 20.15 Lacewings have a voracious appetite for insect larvae. Commercial insectaries breed lacewings and sell them to farmers for biocontrol of insect pests.
Source: Courtesy of Matthias Meier.

Another possible nontarget effect of *Bt* crops has to do with the *Bt* toxin contained in root exudates from *Bt* maize. Numerous studies have shown that soil organisms rapidly degrade *Bt* toxin. Nevertheless, G. Stotzky and colleagues of New York University have demonstrated that soils in which *Bt* transgenic maize was grown contain *Bt* protein that is not degraded. When tobacco hornworm (*Manduca sexta*) larvae were fed on this *Bt*-containing soil, the larvae suffered higher mortality rates than larvae that fed on control soil. Earlier studies demonstrated that the *Bt* protein, like many other proteins from root exudates, binds tightly to clay soil particles. The high sensitivity of tobacco hornworm to *Bt* permitted these low levels of *Bt* to be detected. The studies that show the rapid degradation do not eliminate the possibility that a fraction of *Bt* protein survives degradation when bound to clay particles. No one has examined the effect of this bound *Bt* on the soil ecosystem. Tobacco hornworm in the laboratory can be forced to eat soil particles, but whether insect larvae living in the soil ingest soil particles at similar levels is not known. The many questions raised by the various studies made to date demonstrate a clear need to analyze possible nontarget effects caused by genetically modified crops. However, for such research to be more relevant, researchers need to extend and examine the findings in the context of current agricultural practices.

Possible negative side effects must also be weighed against the positive effects of an insect control regime that uses insecticidal transgenic plants instead of chemical insecticides. For example, *Bt* cotton requires three or fewer insecticide treatments per year, a substantial reduction from the five to twelve annual sprays needed to control pests in nontransgenic cotton fields. Plantings of *Bt* cotton alone reduced pesticide use in the United States by over 900,000 kg during 1997. The overall reduction of pesticides results in lower costs (**Table 20.3**) and a safer working environment for the farmer, and a dramatic drop in amount of chemicals added to the environment. The decrease in broad-spectrum insecticides brought about by using specialized insecticidal transgenic plants also benefits

Table 20.3 Comparison of farmers' costs of growing traditional and *Bt* cotton in the United States in 1999

	Standard	*Bt*
Total insecticide cost (US$/acre)	178	109
Yield (lbs of lint/acre)	933	975
Return (US$/acre)	1081	1187

Note: Analysis of 17 different studies showed wide variation but an average of $106/acre net return. The United States has just over 6 million hectares of cotton, so the potential savings are substantial if this trend continues. In 2000 *Bt* cotton was grown on 2.2 million hectares.

nontarget insect populations. Insect biodiversity is encouraged, as is natural pest control through enhanced predator–prey interaction. Using fewer insecticides because of using GM crops can have many advantages for the environment, for the farmer, and especially for the farm workers, who currently deal with constant or repeated exposure to subtoxic levels of chemicals.

20.6 Careful management of GM crops is needed to avoid the emergence of resistant insect strains.

Obviously, evolved resistance to transgenic proteins by insect pests limits the usefulness and longevity of any insecticidal transgenic crop variety. The diamondback moth, an important pest of Brassica crops worldwide, was the first documented insect to develop resistance to *Bt* sprays in open-field populations. David Heckel (1994) has shown that *Bt* resistance in another insect, *Heliothis virescens* (tobacco budworm), is linked to several different genes on different chromosomes; resistance to *Bt* is not likely to result from a single recessive gene. Currently, no dominantly inherited *Bt* resistance genes have been documented, but they would severely limit the effectiveness of future *Bt* crops. Various resistance management strategies have been proposed to delay the onset of resistance, and the method commonly used at present is the deployment of a high *Bt* expression in transgenic plants coupled with a nontransgenic refuge planting; this is called the high-dose/refuge strategy. The high dose kills all *Bt*-susceptible insects, and the refuge allows *Bt*-susceptible pests to survive on the nontransgenic material and mate with *Bt*-resistant individuals that might arise out of the high-dose fields. The goal of this strategy is to keep the recessive *Bt* resistance genes at low levels, and thus limit the rate that the entire population will become *Bt* resistant. The effectiveness of this strategy depends on refuge size, refuge design (refuge plants mixed with transgenics or separate from them), the quantity of pesticides used for spraying the refuge, and the rate of migration of insect pests. Several scientists widely recognized for their sustained contributions to insect control strategies such as Fred Gould at North Carolina State University, Bruce Tabashnik of the University of Arizona, Tony Shelton at Cornell University, and David Andow at the University of Minnesota have contributed their expertise to formulate control strategies (Tabashnik, 1994; Shelton, Tang, Roush, Metz, and Earle, 2000) and to detect resistant insects when they arise (Andow and Alstad, 1998). Everyone agrees that *Bt* crops must be deployed with care to assure that the resource of unique *Bt* toxin proteins is not squandered. People have learned that the chemical insecticide treadmill, where insects become resistant to each insecticide in turn, so that every insecticide must be replaced by another, ad infinitum, is not the paradigm they want to follow with transgenic crops.

CONCLUSION

GM crops are fast becoming a part of agriculture throughout the world, but as with any new technology, opposition has surfaced that questions the safety and the appropriateness of this technology. Moreover, acceptance does not mean that there are no unresolved issues or that the technology is risk free. No technology is risk free. In the last few years, a number of "urban myths" about genetic engineering of plants have sprung up, and opposition groups have made effective use of powerful environmental symbols. The companies that developed this technology were caught by surprise that the technology, which has real potential benefits for farmers and consumers alike, was not more readily accepted. In Europe certainly, governments seemed to be more willing to listen to those perpetuating the urban myths than to the scientists who understood the technology. Much of the opposition stems from a general uneasiness that ordinary people lose out when there is general agreement between multinational companies, international organizations, and national governments on how society should develop and how new technologies should be applied. That some companies have knowingly harmed the public interest, and that governments have sometimes failed in their evaluation of what constitutes a public health or environmental danger, sustain this opposition.

Some technological scares have later proved to be nonissues for the public. For many years people thought that air flight would never be valid transportation, and when microwave ovens were first produced, people were afraid to use them for fear of radiation damage. Indeed, there are risks involved in using these and almost all tools. As people come to understand the real risks and benefits of a technology, and as they become educated and familiar with it, then they are in a position to judge it and accept it according to its merits. GM plants have an important role to play in developing an agricultural system that can serve ever-growing global food needs. When people move beyond urban myths, they will experience the fruits of this technology.

This does not mean that there are no unresolved issues. Every technology can be improved, and GM crop technology will be gradually improved as people learn more about the problems the technology creates. Technologies are generally not without problems, nor are they absolutely safe.

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