

Risks of Genetic Engineering

Many previous technologies have proved to have adverse effects unexpected by their developers. DDT, for example, turned out to accumulate in fish and thin the shells of fish-eating birds like eagles and ospreys. And chlorofluorocarbons turned out to float into the upper atmosphere and destroy ozone, a chemical that shields the earth from dangerous radiation. What harmful effects might turn out to be associated with the use or release of genetically engineered organisms?

This is not an easy question. Being able to answer it depends on understanding complex biological and ecological systems. So far, scientists know of no generic harms associated with genetically engineered organisms. For example, it is *not* true that *all* genetically engineered foods are toxic or that *all* released engineered organisms are likely to proliferate in the environment. But specific engineered organisms may be harmful by virtue of the novel gene combinations they possess. This means that the risks of genetically engineered organisms must be assessed case by case and that these risks can differ greatly from one gene-organism combination to another.

So far, scientists have identified a number of ways in which genetically engineered organisms could potentially adversely impact both human health and the environment. Once the potential harms are identified, the question becomes how likely are they to occur. The answer to this question falls into the arena of risk assessment.

In addition to posing risks of harm that we can envision and attempt to assess, genetic engineering may also pose risks that we simply do not know enough to identify. The recognition of this possibility does not by itself justify stopping the technology, but does put a substantial burden on those who wish to go forward to demonstrate benefits.

Potential Harms to Health

Here are some examples of the potential adverse effects of genetically engineered organisms may have on human health. Most of these examples are associated with the growth and consumption of genetically engineered crops. Different risks would be associated with genetically engineered animals and, like the risks associated with plants, would depend largely on the new traits introduced into the organism.

New Allergens in the Food Supply

Transgenic crops could bring new allergens into foods that sensitive individuals would not know to avoid. An example is transferring the gene for one of the many allergenic proteins found in milk into vegetables like carrots. Mothers who know to avoid giving their sensitive children milk would not know to avoid giving them transgenic carrots containing milk proteins. The problem is unique to genetic engineering because it alone can transfer proteins across species boundaries into completely unrelated organisms.

Genetic engineering routinely moves proteins into the food supply from organisms that have never been consumed as foods. Some of those proteins could be food allergens, since virtually all known food allergens are proteins. Recent research substantiates concerns about genetic engineering rendering previously safe foods allergenic. A study by scientists at the University of Nebraska shows that soybeans genetically engineered to contain Brazil-nut proteins cause reactions in individuals allergic to Brazil nuts.

Scientists have limited ability to predict whether a particular protein will be a food allergen, if consumed by humans. The only sure way to determine whether protein will be an allergen is through experience. Thus importing proteins, particularly from nonfood sources, is a gamble with respect to their allergenicity.

Antibiotic Resistance

Genetic engineering often uses genes for antibiotic resistance as "selectable markers." Early in the engineering process, these markers help select cells that have taken up foreign genes. Although they have no further use, the genes continue to be expressed in plant tissues. Most genetically engineered plant foods carry fully functioning antibiotic-resistance genes.

The presence of antibiotic-resistance genes in foods could have two harmful effects. First, eating these foods could reduce the effectiveness of antibiotics to fight disease when these antibiotics are taken with meals. Antibiotic-resistance genes produce enzymes that can degrade antibiotics. If a tomato with an antibiotic-resistance gene is eaten at the same time as an antibiotic, it could destroy the antibiotic in the stomach.

Second, the resistance genes could be transferred to human or animal pathogens, making them impervious to antibiotics. If transfer were to occur, it could aggravate the already serious health problem of antibiotic-resistant disease organisms. Although unmediated transfers of genetic material from plants to bacteria are highly unlikely, any possibility that they may occur requires careful scrutiny in light of the seriousness of antibiotic resistance.

In addition, the widespread presence of antibiotic-resistance genes in engineered food suggests that as the number of genetically engineered products grows, the effects of antibiotic resistance should be analyzed cumulatively across the food supply.

Production of New Toxins

Many organisms have the ability to produce toxic substances. For plants, such substances help to defend stationary organisms from the many predators in their environment. In some cases, plants contain inactive pathways leading to toxic substances. Addition of new genetic material through genetic engineering could reactivate these inactive pathways or otherwise increase the levels of toxic substances within the plants. This could happen, for example, if the on/off signals associated with

the introduced gene were located on the genome in places where they could turn on the previously inactive genes.

Concentration of Toxic Metals

Some of the new genes being added to crops can remove heavy metals like mercury from the soil and concentrate them in the plant tissue. The purpose of creating such crops is to make possible the use of municipal sludge as fertilizer. Sludge contains useful plant nutrients, but often cannot be used as fertilizer because it is contaminated with toxic heavy metals. The idea is to engineer plants to remove and sequester those metals in inedible parts of plants. In a tomato, for example, the metals would be sequestered in the roots; in potatoes in the leaves. Turning on the genes in only some parts of the plants requires the use of genetic on/off switches that turn on only in specific tissues, like leaves.

Such products pose risks of contaminating foods with high levels of toxic metals if the on/off switches are not completely turned off in edible tissues. There are also environmental risks associated with the handling and disposal of the metal-contaminated parts of plants after harvesting.

Enhancement of the Environment for Toxic Fungi

Although for the most part health risks are the result of the genetic material newly added to organisms, it is also possible for the removal of genes and gene products to cause problems. For example, genetic engineering might be used to produce decaffeinated coffee beans by deleting or turning off genes associated with caffeine production. But caffeine helps protect coffee beans against fungi. Beans that are unable to produce caffeine might be coated with fungi, which can produce toxins. Fungal toxins, such as aflatoxin, are potent human toxins that can remain active through processes of food preparation.

Unknown Harms

As with any new technology, the full set of risks associated with genetic engineering have almost certainly not been identified. The ability to imagine what might go wrong with a technology is limited by the currently incomplete understanding of physiology, genetics, and nutrition.

Potential Environmental Harms **Increased Weediness**

One way of thinking generally about the environmental harm that genetically engineered plants might do is to consider that they might become weeds. Here, weeds means all plants in places where humans do not want them. The term covers everything from Johnson grass choking crops in fields to kudzu blanketing trees to melaleuca trees

invading the Everglades. In each case, the plants are growing unaided by humans in places where they are having unwanted effects. In agriculture, weeds can severely inhibit crop yield. In unmanaged environments, like the Everglades, invading trees can displace natural flora and upset whole ecosystems.

Some weeds result from the accidental introduction of alien plants, but many were the result of purposeful introductions for agricultural and horticultural purposes. Some of the plants intentionally introduced into the United States that have become serious weeds are Johnson grass, multiflora rose, and kudzu. A new combination of traits produced as a result of genetic engineering might enable crops to thrive unaided in the environment in circumstances where they would then be considered new or worse weeds. One example would be a rice plant engineered to be salt-tolerant that escaped cultivation and invaded nearby marine estuaries.

Gene Transfer to Wild or Weedy Relatives

Novel genes placed in crops will not necessarily stay in agricultural fields. If relatives of the altered crops are growing near the field, the new gene can easily move via pollen into those plants. The new traits might confer on wild or weedy relatives of crop plants the ability to thrive in unwanted places, making them weeds as defined above. For example, a gene changing the oil composition of a crop might move into nearby weedy relatives in which the new oil composition would enable the seeds to survive the winter. Overwintering might allow the plant to become a weed or might intensify weedy properties it already possesses.

Change in Herbicide Use Patterns

Crops genetically engineered to be resistant to chemical herbicides are tightly linked to the use of particular chemical pesticides. Adoption of these crops could therefore lead to changes in the mix of chemical herbicides used across the country. To the extent that chemical herbicides differ in their environmental toxicity, these changing patterns could result in greater levels of environmental harm overall. In addition, widespread use of herbicide-tolerant crops could lead to the rapid evolution of resistance to herbicides in weeds, either as a result of increased exposure to the herbicide or as a result of the transfer of the herbicide trait to weedy relatives of crops. Again, since herbicides differ in their environmental harm, loss of some herbicides may be detrimental to the environment overall.

Squandering of Valuable Pest Susceptibility Genes

Many insects contain genes that render them susceptible to pesticides. Often these susceptibility genes predominate in natural populations of insects. These genes are a valuable natural resource because they allow pesticides to remain as effective pest-control tools. The more benign the pesticide, the more valuable the genes that make pests susceptible to it.

Certain genetically engineered crops threaten the continued susceptibility of pests to one of nature's most valuable pesticides: the *Bacillus thuringiensis* or Bt toxin. These "Bt crops" are genetically engineered to contain a gene for the Bt toxin. Because the crops produce the toxin in most plant tissues throughout the life cycle of the plant, pests are constantly exposed to it. This continuous exposure selects for the rare resistance genes in the pest population and in time will render the Bt pesticide useless, unless specific measures are instituted to avoid the development of such resistance.

Poisoned Wildlife

Addition of foreign genes to plants could also have serious consequences for wildlife in a number of circumstances. For example, engineering crop plants, such as tobacco or rice, to produce plastics or pharmaceuticals could endanger mice or deer who consume crop debris left in the fields after harvesting. Fish that have been engineered to contain metal-sequestering proteins (such fish have been suggested as living pollution clean-up devices) could be harmful if consumed by other fish or raccoons.

Creation of New or Worse Viruses

One of the most common applications of genetic engineering is the production of virus-tolerant crops. Such crops are produced by engineering components of viruses into the plant genomes. For reasons not well understood, plants producing viral components on their own are resistant to subsequent infection by those viruses. Such plants, however, pose other risks of creating new or worse viruses through two mechanisms: recombination and transcapsidation.

Recombination can occur between the plant-produced viral genes and closely related genes of incoming viruses. Such recombination may produce viruses that can infect a wider range of hosts or that may be more virulent than the parent viruses.

Transcapsidation involves the encapsulation of the genetic material of one virus by the plant-produced viral proteins. Such hybrid viruses could transfer viral genetic material to a new host plant that it could not otherwise infect. Except in rare circumstances, this would be a one-time-only effect, because the viral genetic material carries no genes for the foreign proteins within which it was encapsulated and would not be able to produce a second generation of hybrid viruses.

Unknown Harms

As with human health risks, it is unlikely that all potential harms to the environment have been identified. Each of the potential harms above is an answer to the question, "Well, what might go wrong?" The answer to that question depends on how well scientists understand the organism and the environment into which it is released. At this point, biology and ecology are too poorly understood to be certain that question has been answered comprehensively.

Risk Assessment

Having identified a list of possible harms that might occur as a result of using or releasing genetically engineered organisms, the next question is how likely are any of these to occur? Like the original "brainstorming" of potential harms, the answer to this question depends greatly on how well the organisms and their interaction in the environment are understood. Risks must be assessed case by case as new applications of genetic engineering are introduced. In some circumstances, it is possible to assess risks with great confidence. For example, it is vanishingly unlikely that genetically engineered palm trees will thrive in the Arctic regardless of what genes have been added. But for many potential harms, the answers are far less certain.

Risk assessments can be complicated. Because even rigorous assessments involve numerous assumptions and judgment calls, they are often controversial when they are used to support particular government decisions. For example, the approval of the first genetically engineered squash by the United States Department of Agriculture involved a controversial risk assessment.

Under the current US regulatory framework for biotechnology, some sort of risk assessment is routinely produced before decisions to allow commercialization of products under the Federal Plant Pest Act; the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA); and the Toxic Substances Control Act (TSCA). In the case of the Plant Pest Act, risk assessments are done according to the procedure specified by the National Environmental Policy Act (NEPA). Under NEPA, risk assessments could lead to full-blown environmental impact statements, but so far all evaluations of engineered agricultural organisms have led to the legal conclusion that no environmental impact statement is needed.

For the most part, risk assessments are done by scientists and policymakers in the relevant agencies (USDA or EPA) with information provided by the companies seeking the approvals. The public often has a brief opportunity to review and comment on the risk assessments.

There is no standard set of questions that risk assessments must answer because of the great range of potential impacts of biotechnology products. A risk assessment for a microbial pesticide, for example, would be substantially different from a risk assessment for genetically engineered salmon. Like all efforts at risk evaluation, risk assessments done for regulation depend on the base of scientific knowledge for generation of list of possible harms to be assessed.

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