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Frankenstein's Plants?

Are genetically engineered crops going to solve all our problems, or create new ones?

Many people are uneasy with the idea of tinkering with nature at its most basic level. Here in the United States, the Department of Agriculture (USDA) found itself overwhelmed by complaints when genetically engineered crops were included in its proposed definition of organic food. The USDA had been asked by the organic food community to define the terms for organic labeling for the sake of consumer confidence and consistency from state to state. The rules are now being rewritten to exclude genetically modified organisms from foods that are labeled organic.

In Europe, the public debate over genetically engineered crops has been fierce. Only a handful of genetically modified food crops have been allowed on the market in the European Union (as opposed to 36 in the United States), and none have yet been commercially planted in European fields, according to the *Economist* magazine. Prince Charles even joined the dispute, writing in a major newspaper that genetic engineering "takes mankind into realms that belong to God, and to God alone."

Proponents of the new technology argue that with world population growing rapidly, genetic engineering will be needed to boost world food production and help preserve the environment. They say opponents are ignorant of how the technology works and base their objections on religious or ideological reasons.

However, even within the scientific community, there are worries about the widespread use of genetically engineered crops. Those who argue that caution is in order say that no matter how much confidence proponents of this technology may have, there is inevitably some risk in planting millions of acres of novel crops and letting their products enter the food supply. It is very difficult to determine the subtle, long term effects these changes will have on human health and the environment.

"While you can recall a chemical that causes birth defects or pollutes ground water or soil," explains Brian Halweil of the Worldwatch Institute, "you can't recall an organism." In this light, it pays to look at this new technology very carefully.

What is Genetic Engineering?

To assess the risks of genetic engineering, it helps to remember what it is. Science fiction has taught us to fear walking killer plants and huge genetic disasters, but scientists still can't make even the simplest organism from scratch. What they can do is tweak an organism's genetic makeup by inserting a gene that makes it produce a foreign protein, or by turning off a gene to stop the production of an existing protein.

In a sense, humans have been "engineering" crops for 10,000 years by breeding plants to mix their genes and obtain just the right blend of traits. Most modern food crops are now a far cry from their ancestors. Some proponents of genetic engineering argue that genetic engineering simply speeds up this process, and is barely different from traditional breeding techniques. While this argument may be intended to calm what are seen as irrational fears, it overlooks some important distinctions.

Genetic engineering represents a major leap from previous plant breeding techniques (see primer on page 4). In the past, breeders could only mix genes in plants that could cross with each other to make fertile seeds. Now, "transgenic" or "recombinant" technology allows genes from any organism to be isolated in a laboratory and transferred to another organism.

"Recombinant technology permits the transfer of genes from any type of organism to another, no holds barred," says Liebe Cavalieri, a professor at SUNY's Purchase College. "There are no species barriers."

Currently technical problems prevent the absolute situation that Cavalieri describes, but minor differences between organisms can and are being overcome in the laboratory. Because the genetic code in DNA is universal across all species, with the insertion of a gene, bacteria can now successfully produce almost any protein from any organism. More and more proteins taken from creatures as diverse as soil bacteria and fish are now being produced in plants. The future will undoubtedly bring an exponential increase in the numbers of such transfers. This technology is a far cry from traditional plant breeding.

The Benefits It Might Bring

The argument for bioengineering is perhaps most persuasive when presented in light of the future world food situation. Even with the striking increases in agricultural yields during the past few decades, the battle to feed the world is not over yet (see Vol. 1, #1).

The growth rate of world agricultural production was 3 percent per year in the 1960s, according to the Food and Agricultural Organization of the United Nations (FAO), but has now dropped to 1.8 percent per year. Meanwhile, the United Nations warns that the Earth's population may nearly double by the year 2050. Many societies are becoming more affluent, further increasing the demand for agricultural production. With little arable land for agriculture to expand into, companies like Monsanto say that genetically engineered crops will be absolutely necessary in the future, providing one more tool to meet the drastic rise in demand we will be seeing in the coming decades.

Genetic engineering can be used to address the future production challenge in a variety of ways. Plants engineered with better frost resistance or drought resistance will be more tolerant of environmental stresses. Other research aims to boost the efficiency of photosynthesis. The engineering of herbicide-resistant plants and pesticide-producing plants are also touted to increase yields by letting crops grow without competition to their full potential.

Some argue that such genetically engineered plants can be used to make agriculture more environmentally friendly as well. Transgenic plants, for example, can displace industrially-produced chemicals like fertilizers and pesticides. Plants are also being designed to produce biodegradable substitutes for petroleum products like plastics and fuels. And the new technology might replace the industrial production of some pharmaceuticals, for example by making a cholera vaccine in an edible potato.

"I fear that continuing the status quo or returning to a low-tech style of agriculture will lead us to plow, drain or degrade much of the rest of the planet -- rain forest, wetlands, temperate forest, prairie, streams, lakes and seas," says Robert Horsch, a researcher at Monsanto. "I've come to the conclusion that we have a moral obligation to proceed."

Too Late To Stop?

The question of whether or not to proceed may be moot. The number of new genetically engineered crops in field tests has skyrocketed over the past decade (Figure 1). Genetically modified crops already comprise a large portion of the country's food supply. This year, according to *The Wall Street Journal*, 40 percent of soybean fields and 20 percent of corn fields in the United States are planted with genetically altered crops. The International Center for Technology Assessment (CTA) says that 36 transgenic plant varieties are on the market and have worked their way into a host of popular commercial products, including Similac Neocare, Doritos Nacho Cheesier, and Morningstar Farms Better 'n Burgers. Despite the possibility of higher seed costs for farmers, the fiscal advantages from greater yields will likely ensure that transgenic crops spread quickly around the globe.

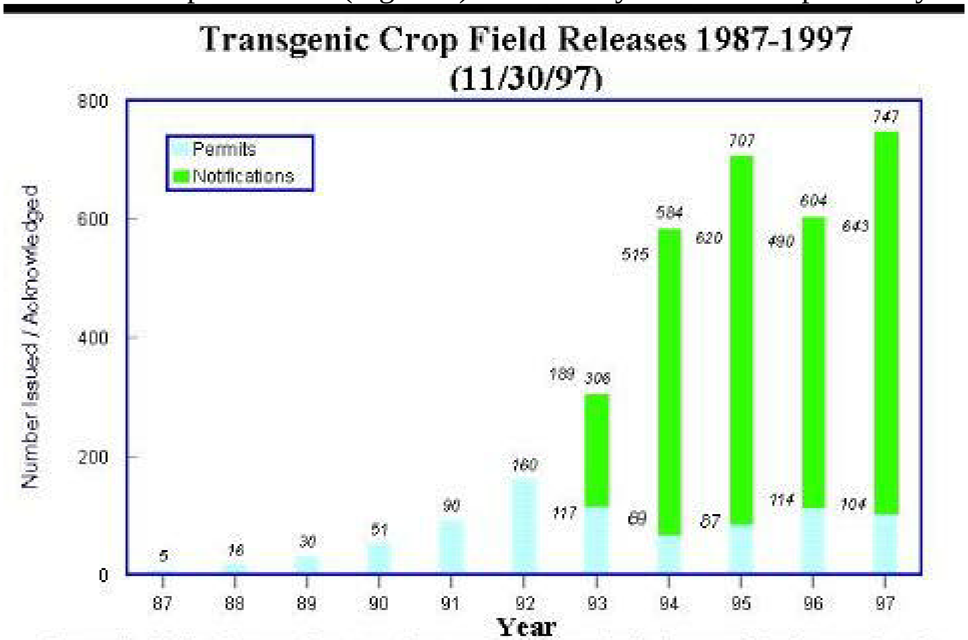

Figure 1. Field releases of transgenic crops have dramatically increased in the past decade. This graph shows trial applications approved by the USDA's Animal and Plant Health Inspection Service (APHIS). Graph: Courtesy of APHIS.

Some critics want the rate of progress to slow down. Agriculture, they say, may be moving too fast to assess the risks realistically. Small field trials, for example, say little about the long term effects of growing millions of acres of a crop.

"We are skeptical of the benefits of biotechnology in agriculture in general," says Jane Rissler, senior staff scientist at the Union of Concerned Scientists (UCS). "And we are concerned about the risks." Rissler says that while her organization does not believe that there are inherent risks in transgenic technology, it is worried about some of the current applications of the technology.

Human Health Issues: Marker Genes

In general, the concerns over transgenic crops fall into two general categories: human health and the environment.

Some opponents of genetic engineering worry that the widespread use of transgenic plants may bring new compounds into the food supply that are harmful to human health.

One broad concern has to do with marker genes (see primer on page 4). When scientists put transgenes into plants, they need some way of making sure the transformation is successful. To do this, they link their gene with a "marker" gene. Common marker genes are ones that confer antibiotic or herbicide resistance to plant cells. After the transformation, the scientists dose the cells with the antibiotic or herbicide. Thus, only those that have incorporated the transgene and its accompanying marker gene survive.

Peggy Lemaux in the Department of Plant and Microbial Biology at the University of California at Berkeley argues that this is not dangerous. If a person were to eat a plant containing a resistance protein to an antibiotic he or she was taking, the protein probably wouldn't inactivate the antibiotic in the gastric environment. Furthermore, she says, the situation would be highly unlikely to occur in the first place because the type of antibiotic used with plant cells is very rarely prescribed to humans.

Another concern is that bacteria in the gastrointestinal tract may be able to take up the transgenic plant DNA, spread the antibiotic resistance genes and thereby create widespread populations of bacteria resistant to an antibiotic. This type of gene transfer mechanism, however, has never been demonstrated. The possibility of it occurring is "vanishingly small", according to the FAO.

In any case, argues Thomas Okita, a plant biochemist at Washington State University, the technology to remove markers genes from the plant after transformation already exists. He expects that plant biotechnology companies will be developing it soon to address this criticism.

The Transgenes in Our Food

If the resistance markers are controversial, the genes that are intended to be transferred into the plant are even more so.

The US Food and Drug Administration (FDA) regulates foods derived from transgenic crops under the rules governing food additives. It requires premarket approval only for additives that are new to the food supply. If a transgenic crop does not contain any substances that are "significantly different" from those already in the diet, the FDA does not consider it a new food additive and therefore does not require any premarket approval. The FDA maintains that these guidelines are enough to ensure that new toxins will never reach the food supply, but some groups claim that the FDA rules are not thorough enough, arguing that recombinant additions may have unforeseeable effects on the biology of the plant.

Thomas Clemente, manager of the Plant Transformation Core Research Facility at the University of Nebraska-Lincoln, believes that opponents of genetically engineered food aren't putting the issue in perspective. "There's been zero safety assessment done to plants acquired through traditional breeding," he says. Plant breeders have been crossing in large pieces of DNA from wild plants for thousands of years, "and they have no clue as to what they're putting in there." In contrast, he argues, the genes that are being transferred through genetic engineering are very well studied.

The question of accidentally transferring food allergens, allergy-causing compounds, is also a serious concern in the world of transgenic crops. The FDA instructs companies to be cautious when transferring genes from certain foods. Pioneer Hi-Bred, for example, was developing a nutritionally enriched transgenic soybean using a gene from Brazil nuts when a study partly funded by the company found that the soybean caused allergic reactions in people allergic to Brazil nuts. Under current FDA rules, Pioneer Hi-Bred would have had to label its transgenic soybeans because of this allergen, but the company discontinued the research program as a result of the study, choosing not to pursue the product's development.

Some cite the Brazil nut incident as a success story: Pioneer Hi-Bred identified the allergen before their product was fully developed. But many scientists argue that human food allergies are poorly understood and that problems are difficult to foresee. "This study highlights gaps in our current knowledge of food allergies," wrote Marion Nestle of New York University in The New England Journal of Medicine, which published the Brazil nut study.

Lemaux of Berkeley counters, "We import more than 200 new fruits and vegetables into the United States every year, and nobody does a single test on any of those." She goes on to argue that genetic engineering may actually help people with allergies in the long run. "As we identify allergens in food, we can use genetic engineering to remove them."

"Ethically sensitive genes" pose yet another food problem. Can vegans eat a potato with a flounder gene? Could Jewish people eat, say, a cracker that had been made with wheat containing a pig gene? These questions illustrate some of the tough and complicated issues that a transgenic food supply will raise.

To Label or Not to Label?

The issue of labeling genetically engineered foods draws a wide variety of opinions. Some scientists support it, particularly when ethically sensitive genes or allergens may be present. Many citizen organizations would like to have genetically engineered foods labeled so that consumers could act on their preferences, but the FDA maintains that it is their role to protect the safety of the food supply, not to help people make such purchasing decisions.

Charles Margulis, the genetic engineering campaigner for Greenpeace, is very critical of this policy. "With a lack of labeling, we're going to see a really hard chance of tracing any health effects," he argues. "They'll say . . . 'it wasn't our crop. It could be anything else in the food stream.'"

This debate isn't likely to end soon, but with the USDA's organic rules being rewritten to exclude genetically engineered foods, people wary of the technology will be able to avoid it, at least in the United States.

Environmental Effects: Runaway Genes

The environmental risks of genetically engineered crops are also generating serious concern. The most debated environmental worry posed by them is the idea of gene escape, or gene flow. Environmental groups warn of uncontrollable superweeds and superviruses arising from the widespread use of transgenic crops.

Outcrossing, when a crop crosses with a weed to make a hybrid plant, is the most likely method of transgene escape. Virtually every species being genetically engineered has close relatives that are regarded as weeds somewhere in the world. Whether a crop poses a problem will depend on where it is grown.

Corn in the United States, for example, has no wild relatives for it to cross with, but weeds related to canola are "all over the place," according to Malcolm Devine, a plant scientist at the University of Saskatchewan. Speaking at a recent biotechnology roundtable organized by the American Bar Association (ABA), Devine said that "there is a very low but real possibility of hybrids occurring."

Allison Snow, a plant ecologist at Ohio State who specializes in pollen transfer and invasive plant species, is more pessimistic about the situation. "I think it's inevitable that there'll be gene flow to wild species from the crops." High winds, flooding, and insects can carry pollen as much as 800-1000 meters away from the original plant. "People agree that the genes are going to get out," Snow concludes.

But how dangerous would it be if a transgene escaped? Devine argues, "None of these hybrids we're talking about will be anything like a superweed. Being herbicide resistant is only going to make a small difference. If no herbicide is used, it won't make it a better weed." And even if herbicide-resistant weeds did thrive and invade a farm, the farmer could just use another herbicide to kill them.

Snow believes that such arguments are only considering the short-term view. "No one transgene is likely to have a huge impact," Snow explains, but "I think that the cumulative effect could cause weeds to become more abundant, more vigorous, and more competitive." A lot of weed populations are limited by the conditions they are growing under -- insects eat them, other plants compete with them, weather conditions weaken them. Crops are now being engineered with traits that release them from that regulation, with added genes for drought resistance and frost resistance, to name just two. "If these genes escape into wild plants," Snow says, "they are probably going to become more abundant."

"It's a slow, gradual change that most agronomists aren't that worried about," she says, "because they're always coming up with new ways to combat weeds. But ecologists worry about entire systems. We don't want to see new weeds evolving very quickly."

Techniques are now being developed to prevent the escape of transgenes into the environment (see The Front Lines of Research). The technology is still young, but some of this research may eventually put an end to worries about some kinds of transgene escape.

Crops as Weeds?

There also remains a danger that a transgenic crop could leave a farmer's field and become a weed itself. "It's silly to just focus on pollen because genes move around in seeds also," Snow says. "Seeds can be dispersed by wind and farm machinery."

There is a long history around the world of new plants introduced into ecosystems that later became unwelcome intruders. Kudzu, for example, was introduced to the United States in the late 1800s as an ornamental vine but has now spread out of control. Most scientists don't consider this type of gene escape as much of a threat as outcrossing because modern crops often need careful cultivation to thrive. However, it is possible. Oilseed rape, for example, is notorious in the United Kingdom for producing roadside populations because of seed spillage during transport. As more plants are improved through transgenic technology, such runaway plants could become more of a problem. And any seeds taking root away from farmers' fields would also increase the chances of outcrossing to related weeds.

Environment and Insects

Insects are vitally important for any ecosystem. They pollinate plants, degrade wastes, and comprise a crucial link in the food chain. But many are major crop pests.

Plants are now being engineered to produce insect toxins derived from the soil bacteria *Bacillus thuringiensis* (Bt). Bt toxins are natural pesticides that break down quickly in the environment and are safe for mammals. They have been used for decades in organic farming and are now very important to the industry due to their natural origin and their safety record. Conventional farms have not widely used Bt sprays because they demand more intensive management than most chemical pesticides. But now, the potential cost savings and environmental benefits of crops that constantly produce these toxins are driving their rapid spread.

Most of the current worries with pesticide-producing plants center around the fact that insect populations almost inevitably become resistant to any pesticide used on them. "Over 500 species of insects have evolved resistance to at least one insecticide," says Fred Gould, an entomologist at North Carolina State University.

In 1997, nearly 9 million acres of Bt crops were planted in the United States. Many warn that this widespread use of crops constantly producing Bt toxin will select Bt-resistant insects more quickly and enable them to spread rapidly, rendering the pesticide useless.

Strategies to manage pest resistance for Bt crops are difficult to design, particularly because there have been no transgenic pesticide-producing crops in the past to serve as a precedent. The US Environmental

Protection Agency (EPA) endorses the use of insect refuges, patches of plants that do not produce Bt. Refuges of non-BT plants are designed to keep a large number of Bt-susceptible insects alive and available to breed. When the relatively few insects that have survived exposure to the Bt crops look for a mate, they will almost certainly find a susceptible insect from the refuge, and will thereby dilute the resistance genes in the population. There is broad agreement that this strategy will stave off insect resistance to Bt, but the size of the required refuges is hotly debated. Effective refuge design for each crop requires a knowledge of local weather, insect movement, mating behavior, and the prevalence of Bt resistance in the local insect populations to begin with.

Arguments at the recent ABA biotechnology roundtable brought out the differences in approach. Eric Sachs of Monsanto said that his company wants to "avoid overly conservative strategies until the need for those strategies has been demonstrated." He added, "The goal is not to preserve this technology for 30 to 50 years." Monsanto has new pesticides in development, he said, that will be ready in 3 to 5 years.

Rissler of UCS argues that Bt sprays are the main biological control for organic farmers. Even Sachs acknowledges that if Bt were lost as an effective pesticide, "I have to admit there would be a greater challenge to organic agriculture to manage organic corn or cotton."

Worries about pesticide-producing plants go beyond these resistance management concerns. A recent scientific report to the EPA recommended a great deal more research on the ecological interactions these crops might spur. The long-term effects they will have on the environment are difficult to predict. For example, a recent report in *Environmental Entomology* documented how beneficial insects that prey on plant-eating pests were also killed by the Bt toxins, whether or not the pests themselves were affected by the Bt toxins. And there is always the danger that when one insect pest is targeted with Bt, other secondary insect pests that aren't affected by Bt can simply move in and become primary pests themselves.

John Obrycki, an entomologist at Iowa State University, says "there are numerous food webs and food chains that are affected. Trying to predict all the effects is impossible. I think there are definitely things to be looked at in the long term."

Super Viruses?

A unique variation of the gene flow problem is posed by the engineering of plants to be resistant to viruses. The genes being transferred into plants to give them virus resistance are originally derived from the target viruses themselves. Scientists are not quite sure why this strategy works, but it is now in widespread use. Papayas, for example, have been engineered for resistance to papaya ringspot virus with this method, and squashes have been engineered for resistance to three different viruses.

The viruses that attack plants are specialized to attack plant cells. They are already in the food supply, so transgenic virus proteins are not considered to pose any new health risk to humans. Some scientists worry, however, that when other unrelated viruses infect the plant in the field, they will take up the transgenic virus proteins to create recombinant viruses with new features.

These types of viral gene exchanges have already been shown to occur naturally in the wild. The widespread incorporation of transgenic viral proteins into plants may inadvertently speed up plant virus evolution beyond their natural levels. Just how much of a problem this will be is difficult to predict. Like many of these subtle issues, effective studies can really only be done after the fact. Only when we see new viruses in the field will we be certain we have a problem.

Who Benefits?

There are important safety issues to be considered when it comes to transgenic plants, both in human health and the environment. But beneath the arguments about safety lies a profound question: who does all this technology benefit?

Agricultural companies are rapidly consolidating into multinational conglomerates that control an ever growing portion of the international seed market. It remains unclear how the public sector will respond to these changes. Without intervention, higher costs along with intellectual property provisions may keep this new technology out of reach for poorer farmers and consumers.

The publicly stated motives for pushing ahead with transgenic technology may be feeding the world and saving the environment, but Rissler counters, "Feeding the world is not right now a technological problem. It's a political and economic problem. . . . This feeding the world is a ruse, if that's the right word, it's a way of making people feel good about biotechnology."

A look at the most frequent categories cited for transgenic crop field releases (Figure 2) gives a good snapshot of the general types of transgenic crops being tested, but it doesn't clearly answer the question of who these crops will benefit. For example, a crop designed to be resistant to a particular herbicide can be used in a system to more efficiently eradicate weeds and boost yields, lowering prices for consumers. But on the other hand, it can also help increase the global market for both the herbicide and its matching seeds. Jeremy Rifkin of The Foundation on Economic Trends argues that the new herbicide-resistant crops serve mostly to encourage the more frequent use of herbicides, as farmers won't have to worry about harming their crops with herbicides anymore.

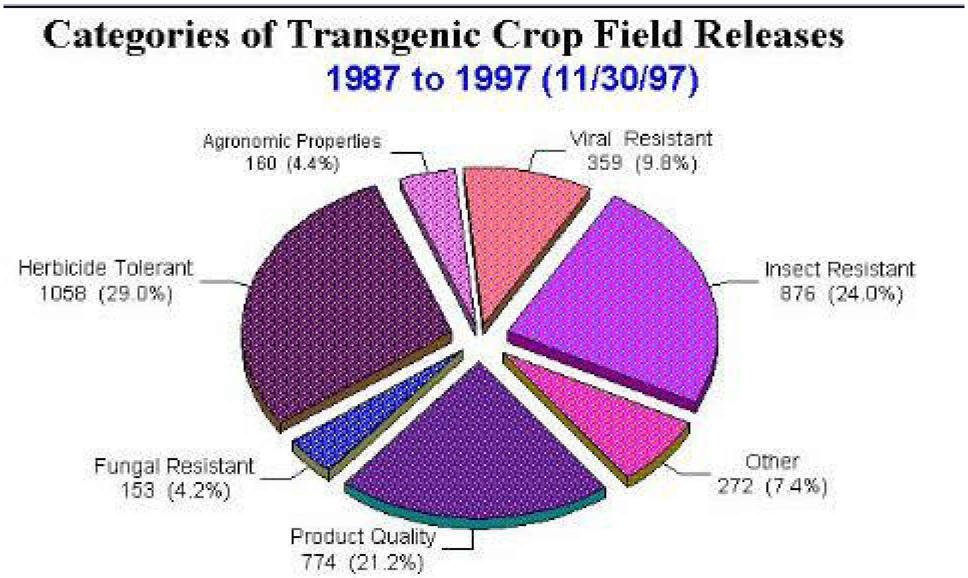

Figure 2. Permits issued and notifications acknowledged, Animal and Plant Health Inspection Service [APHIS]. Graph: Courtesy of APHIS.

If you look carefully at these crops, Rissler argues, "you would find that an awful lot of them are still producer oriented." The real goal of the genetic alterations, she believes, is to maximize profits.

Transgenic crops can be immensely beneficial to companies that can patent their technology. "I don't think they're really being honest about their strategy," says Margulis of Greenpeace. "They want to keep farmers on the same chemical treadmill they've always been on. Now they're doing it with Bt. . . . They're just moving them from chemicals to plants. I think that's been their strategy all along."

Meanwhile, worldwide public investment in agricultural research is not growing as many people think it needs to if the world's poorer farmers and consumers are to benefit from this new technology.

"Public sector investment is critical," says Gary Toenniessen, deputy director of agricultural sciences at the Rockefeller Foundation. "There has been a substantial increase in total plant genetic research due to company involvement and the potential for profits. How you transfer a portion of that to the public sector so they can meet [the] needs [of the poor] is still being sorted out," he says. "I worry about it."

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Genetically Engineering Plants: A Primer

Breeding

When plant breeders cross two plants using traditional breeding techniques, they are throwing together a massive mix of genes, and so the progeny of a cross between two plants contains a messy blend of characteristics from both parent plants. In traditional plant crosses, breeders relied on the phenotypes, the sets of physical characteristics, of the plants to decide which ones to cross. While effective, the process could be painstakingly slow.

Modern biotechnology allows scientists to pinpoint and track a specific region on a plant's chromosome that confers a desirable trait. Rather than rely on a plant's phenotype, which may be determined by a host of genes working either together or against each other, scientists can now breed according to genotype, its collection of genes. Scientists can analyze the set of genes that the plant contains and make sure that those they find most useful are successfully transferred. While it can be difficult to pinpoint a gene that confers a beneficial trait on a plant, once a region is identified, molecular tracking techniques can greatly speed up crop breeding. And since plants are crossed using traditional breeding techniques, there are no new dangers to this technology.

Transgenics

Transgenic technology lets scientists transfer a gene from any organism into a plant. Whether you look at a single-celled bacterium living in the bottom of a garbage pail or a plant cell on the underside of a rose leaf or a cell from your cheek, the information about what that cell looks like and what it will do with its life is carried in a molecule called DNA. Stretches of DNA form genes that tell the cell what proteins to make, and these proteins, in turn, determine most of the cell's characteristics. Since the genetic code is universal, genes can be transferred from one organism to another and direct the new cells to make the same protein as the old.

There are currently two strategies to transfer DNA into plants. One is to use a bacterium, *Agrobacterium tumefaciens*. These bacteria contain a large circular piece of DNA (called a plasmid) which can be injected into plant cells at the site of a wound. The Ti (for tumor inducing) plasmid normally contains a set of genes that cause plant cells to divide and grow, creating a tumor condition called crown gall disease. Scientist can use a Ti plasmid from which the tumor-causing genes have been removed, and insert a gene of their choice. The resulting "recombinant" plasmid (hence the commonly used term "recombinant technology") is transferred back into the *Agrobacterium*, and the bacteria then inject the plasmid with the desired genes into plant cells.

Another common technique for gene transfer into plants is through direct DNA delivery. This can be done with biolistics, in which beads coated with DNA are shot into cells using a particle gun, or by using a technique called electroporation, in which a short, high-voltage charge of electricity creates holes in the cell membranes, allowing DNA to enter.

With any of these techniques, only a few plant cells take up the desired new gene. To ensure that the inserted DNA has incorporated into the plant's own DNA structures (its chromosomes) scientists attach a "marker" gene to the one they are interested in inserting. The most common genes selected for this purpose give the plant cells antibiotic or herbicide resistance, enabling the scientists to simply kill all the cells that haven't incorporated the injected DNA with a dose of the antibiotic or herbicide.

Once it is confirmed that the gene insertion was successful, new plants can be regenerated from the transformed cells. The gene will then be passed throughout the plant as part of the plant's own chromosomes, and later passed on to the plant's progeny. The resultant plants will produce whatever protein the inserted DNA tells it to.

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The Front Lines of Research

Research Breakthroughs and Their Consequences

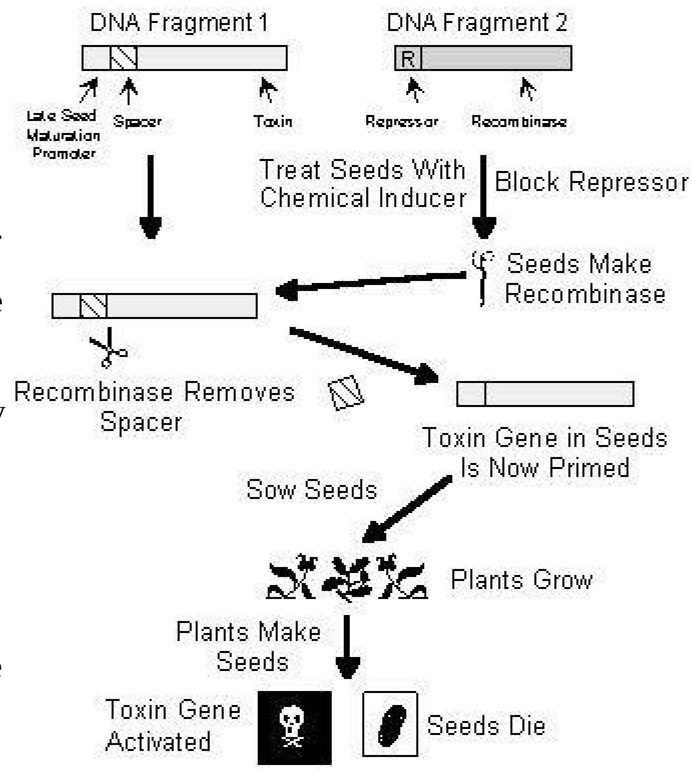
The Plant Terminator

The Technology Protection System, or "Terminator Technology", as it is dubbed by opponents, is one of the most controversial plant biology techniques to come along in some time. Proponents say that it will help prevent the spread of transgenes. Opponents argue that it will put poor farmers out of business. Herein, a look at the new technique and its consequences.

A controversial new patent was granted in March to the USDA and the Delta and Pine Land Company, now a subsidiary of Monsanto, for a technique that makes plants produce sterile seeds. As the use of transgenic crops spreads, advocates of the technology argue that it could be one way to prevent the escape of transgenes (see feature story). With this technique, even if pollen from a transgenic crop did fertilize a weed, its genes would never get any farther than a dead seed. The controversy arises from the fact that, contrary to traditional farming practices, farmers would have to buy new seeds for every planting.

Melvin Oliver, the scientist with the Agricultural Research Service (ARS) in Lubbock, Texas who developed the technique, says, "It's not a simple system." Three separate DNA fragments must be introduced into a plant for the system to work. The first fragment consists of a gene that encodes for something toxic to the plant and that is only produced late in seed development. The gene is initially made dormant by a "spacer" sequence of DNA (see diagram).

The second DNA fragment that is added to the plant encodes for a protein called a recombinase which removes the spacer and primes the toxin gene. The recombinase is blocked by a repressor protein encoded by a third DNA fragment. This repressor protein keeps the recombinase gene turned off until it is exposed to a chemical inducer.



This figure outlines how the "terminator technology" works. As long as no seeds are exposed to the chemical inducer, the the plants grown from them will produce healthy seeds. The chemical inducer sets this diagrammed chain of events in motion.

This tightly controlled system is needed because companies want to grow several generations of healthy, normal plants in order to make enough seeds for commercial distribution. Only when they sell the seeds do they want to activate the sterilizing mechanism to prevent farmers from collecting seeds for next season. Just before a batch of seeds is sold, a chemical is applied to them, activating the chain of events in the diagram above.

Key to the system, explains Oliver, is that "[t]he promoter that is driving that toxin only turns on very late in seed maturation." The chemically treated seeds can be sown normally and will germinate perfectly healthy plants until just before their own seeds start to dry in the farmer's field, according to Oliver, when the gene turns on and poisons the seeds.

Thus far, this technique has worked successfully in tobacco and cotton, but Oliver thinks it will be effective on a wide range of plants.

Advocates of the technique hope that, in addition to preventing transgene escape, it will help spur investment in the "marginal" crops that will be so important for feeding growing populations in the developing world. While much investment has been made historically in corn, wheat, and rice, companies currently have little incentive to invest in many other food crops that are important for the developing world.

Seeds for self-pollinated crops such as food legumes, for example, can simply be saved from year to year once the farmer buys an initial batch from the company. Some countries also have weak plant variety protection laws which can scare off investment. Giving companies the ability to make their plants produce sterile seeds, argues the USDA, will allow companies to protect their investments and will therefore lead to increased funding for research into improving these overlooked crops.

A very vocal constituency says that this technique will be very important in the battle between the corporate domination of agriculture and more traditional farming practices, where farmers save their own seeds from year to year.

The Rural Advancement Foundation International (RAFI) dubs the technique "terminator technology", arguing that taking away the ability of farmers to save seeds from year to year will imperil the 1.4 billion people around the world whose food is supplied by poor farmers.

"It's terribly dangerous," says Hope Shand, RAFI's research director. "Half the world's farmers are poor and can't afford to buy seed every growing season."

Proponents counter that poorer farmers can simply elect not to buy "technology protected" seeds. The continued availability of such unprotected seeds on world markets will doubtless be watched very carefully.

Containing Transgenes, Method II

A new technique called chloroplast transformation could help prevent the escape of transgenes into weeds. The technique has limited applications, but in certain situations it can provide a barrier to contain transgenes.

The escape of transgenes through pollen is, as described in the feature story of this newsletter, a serious environmental concern. A new way to prevent transgene escape via pollen was described in Nature Biotechnology.

The subject of study was glyphosate, the most widely-used herbicide in the world. Glyphosate is nontoxic to humans and animals, and its effects on the environment are short-lived as the compound is rapidly inactivated in the soil. At the same time, glyphosate is an extremely effective herbicide. Despite over 20 years of glyphosate use, weeds have developed little if any resistance to it. The problem with glyphosate is that it kills crops just as efficiently as it kills weeds, so it has historically been applied only between crop growing seasons.

Monsanto, which sells glyphosate, has found a way around this limitation by genetically engineering an ever-expanding range of crops resistant to the herbicide -- including corn, canola, cotton and soybean -- so that it may be sprayed to kill weeds at any time of the growing season. Worries about these added resistance genes escaping into weeds through pollen transfer and thereby creating "superweeds" have sparked furious debates over the past few years.

Henry Daniell and his colleagues at Auburn University have developed a new method for conferring glyphosate resistance on plants that at least partly circumvents the problem. The technique uses the same genes as before to make plant cells resistant to the herbicide, but it makes use of the small compartments within plant cells called chloroplasts. Chloroplasts are the power plants of the cell, converting the sun's light into energy for the plant. Although most of a plant cell's DNA is contained in chromosomes within its nucleus, chloroplasts also contain DNA.

The scientists used biolistics to bombard tobacco leaf cells with particles that were coated with a glyphosate-tolerant gene from petunia (see Primer for more on this technique). The DNA sequence that flanks the herbicide-resistance gene was specifically designed to direct it into chloroplast DNA. Once the new gene incorporates into the chloroplast DNA, the chloroplasts make the resistant protein and the cells become resistant to glyphosate. Glyphosate-resistant plants can then be grown from these transformed cells within 3-5 months. Because the targeted region of chloroplast DNA is common to many different plant species, the scientists claim that this technique should work for many crop plants.

One important advantage of chloroplast transformation, as this technique is called, is that there are many copies of the gene within each plant cell, so resistance levels are higher. The researchers already see high levels of resistance to glyphosate in their tobacco plants and, with some tweaking of the technique, hope to see "incredibly high levels of resistance to herbicides" in the future.

Attracting the most attention, however, is the potential environmental benefit of chloroplast transformation. Until now, transgenes were inserted into the plant's nuclear chromosomes and were therefore passed through pollen just like the plant's own genes. Chloroplasts can't be transferred through pollen in most plant species, so the transgene remains in the maternal line and can't escape from the field in pollen.

Gene "escape" from these plants can still occur through seed dispersal. The transformed crops can be fertilized by pollen from other crops or from weeds, and the resulting seeds can disperse outside the field. The herbicide-resistant crops can also become weeds in the fields themselves, by arising after harvest and competing with other rotated crops. Still, the new technique would eliminate one route of gene escape and simplify the risk assessment of transgenic crops.

Advocates of sustainable agriculture, however, argue that chloroplast transformation does not get around agriculture's increasing reliance on chemicals to solve its problems. Herbicide-resistant plants, says Jane Rissler of the Union of Concerned Scientists, just "increase the use of certain herbicides and maintain dependence on herbicides."

"The other problem, of course, with increasing the use of just one herbicide like gyphosate," she adds, "is that what's going to increase dramatically is the pressure for resistant weeds."

Creating resistant weeds through overuse of the chemical would defeat the whole purpose of chloroplast transformation in the first place.

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Readings

Vital Signs 1998: The environmental trends that are shaping our future by Lester R. Brown, Michael Renner, and Christopher Flavin. 1998. W.W. Norton & Company. 208 pages. $12.00.

In the seventh annual edition of Vital Signs, the Worldwatch Institute once again brings together, in their words, "an eclectic selection of disparate trends to offer a unique, multifaceted view of our rapidly changing world."

The book is filled with easily digestible short essays, tables and graphs on subjects affecting the environment from obvious candidates like coal use and paper recycling to more obscure trends like bicycle production and Internet use. The first two sections, "Food Trends" and "Agricultural Resource Trends", will be of particular interest to readers of this newsletter, with essays on trends in grain harvests, world grain stocks, fertilizer use, and irrigated areas. Most interesting, perhaps, is the essay by Brain Halweil entitled "Grain Yield Rises" in which Halweil argues that "[b]reeders have boosted the yield potential of cereals substantially in past decades, but are beginning to approach various biological limits to further growth."

Many plant scientists would disagree with Halweil and say that the organization tends to cry wolf. But the Worldwatch Institute, as always, documents its side of the debate with a wealth of tables, graphs and statistics so that readers can make their own judgments.

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