Weird Science

The Brave New World of Genetic Engineering

October 2003

U.S. PIRG Education Fund

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Executive Summary

If you listen to Monsanto, DuPont, and even the U.S. Food and Drug Administration (FDA), genetic engineering is merely an extension of traditional plant breeding. These companies and regulators say it is the same thing that farmers and plant breeders have been doing for generations, and thus FDA does not require any tests for these crops. But traditional plant breeders have never crossed wheat with chickens or rice with human genes.

Genetic engineering permits scientists to manipulate genetic materials in ways that were once inconceivable. But the technology relies on methods that result in haphazard insertion of genetic elements into a plant's genetic code. This in turn may lead to disruption of complex gene interactions and unintended, potentially catastrophic results. It is a technology that has the power to transform food and the food supply in ways not possible with traditional breeding. Genetic engineering is very different, very powerful, and worth a great deal of caution.

Currently, the process of introducing genes is done through a limited number of relatively crude methods resulting in haphazard placement that in no way can be described as precise. The imprecision of genetic engineering was dramatically revealed in May 2000, when Monsanto disclosed that its genetically engineered soybeans – the company's best selling genetically engineered crop – contained gene fragments that scientists had not intentionally inserted. Neither Monsanto nor government regulators had any idea the supposedly inactive pieces of genetic material were inserted during the process of engineering the crop. After that embarrassment, one year later Monsanto again had to admit it did not fully understand the genetic makeup of the product it brought to market, as further research uncovered additional unexpected DNA.

The science of genetic engineering as applied to agriculture has other fundamental differences with traditional plant breeding. One is that scientists insert marker genes, frequently one that codes for antibiotic resistance, in addition to the gene with the desired trait. This process raises serious questions since these genes may exacerbate the problem of antibiotic resistance in the general population. Another difference is the use of powerful "promoters," usually disabled plant viruses, to increase the expression of the gene in the new plant. These promoters may create problems of their own, such as turning on or off genes in the host plant, or they may become a major source of new viruses arising from recombination.

There also have been unexpected results in the field testing of genetically engineered plants. A field test of genetically engineered petunias designed to produce one color wound up having wildly fluctuating results in the field. An experiment on a plant in the mustard family found that a species that was normally self-pollinating and had very low rates of cross-pollination changed dramatically when it was genetically engineered. And after being commercialized, both genetically engineered cotton and soybeans have had unexpected problems, including massive crop failures.

Using genetic engineering, scientists can, for the first time, insert genes from different species, families, or even kingdoms, something inconceivable in traditional breeding. Despite all of the unknowns, proponents of genetic engineering continue to push forward with previously unheard of combinations.

Previous research found that between 1987 and October 2000, the U.S. Department of Agriculture (USDA) authorized 14 field tests of crops engineered with animal or human genes.[1] Between 2001 and mid-2003, USDA had authorized 29 additional field tests of crops engineered with animal or human genes, or more than double the total authorized during the first 13 years of USDA record-keeping.[2] Some of these combinations that have been field tested in the U.S. include:

- Chicken genes in corn, wheat, and creeping bentgrass;
- Human genes in barley, corn, tobacco, rice, and sugarcane;
- Mouse genes in corn, along with human genes;
- Cow genes in tobacco;
- Carp genes in safflower;
- Pig genes in corn;
- Simian immunodeficiency virus (SIV) and Hepatitis B genes in corn;
- Jellyfish genes in corn, rhododendrons, Bermuda grass, pink bollworms, and rice;
- Fruit fly genes in potatoes; and
- Rat genes in soybeans.

Genetic engineering is an imprecise and haphazard technology – something completely different from traditional plant breeding. Since the inception of the technology, biotechnology companies have clearly demonstrated that scientists cannot control where genes are inserted and cannot guarantee the resulting outcomes. Unexpected field results highlight the unpredictability of the science, yet combinations previously unimaginable are being field tested and used commercially.

To protect public health and the environment, genetically engineered food ingredients or crops should not be allowed on the market unless:

- Independent safety testing demonstrates they have no harmful effects on human health or the environment;
- They are labeled to ensure the consumer's right-to-know; and
- The biotechnology corporations that manufacture them are held responsible for any harm.

In addition, scientists should not engineer food crops to produce pharmaceuticals or industrial chemicals and should not conduct such experiments in the open environment.

Introduction

Genetic engineering proponents such as Monsanto and DuPont, and even the U.S. Food and Drug Administration (FDA), argue that genetic engineering is merely an extension of traditional plant breeding and therefore requires no additional regulation. Monsanto's website, for example, boasts that plant biotechnology is "an extension of this traditional plant breeding with one very important difference—plant biotechnology allows for the transfer of genetic information in a more precise, controlled manner."[3] But the veneer of precision and control breaks down under closer examination, as outlined in this report. In addition, genetic engineering violates barriers that exist in nature, making it possible for scientists to cross corn with chickens or tobacco with cows—things that are impossible to do using traditional plant breeding methods.

Genetic engineering permits scientists to manipulate genetic materials in ways that were once inconceivable. But the technology relies on methods that result in haphazard insertion of genetic elements into a plant's genetic code. This in turn may lead to disruption of complex gene interactions with unintended, potentially catastrophic results. It is a technology that has the power to transform food and the food supply in ways not possible with traditional breeding. Genetic engineering is very different, very powerful, and requires a great deal of caution.

Unpredictability of Genetically Engineered Crops

The genome of an organism can be aptly compared to an ecosystem. Full understanding of complex interplays is always a work in progress, and thus a minor perturbation can have minor consequences, or major ones. Proponents of genetic engineering maintain that scientists can locate genes and insert them into new plants with great precision. But currently, the process of introducing genes is done through a limited number of relatively crude methods resulting in haphazard placement that in no way can be described as "precise."

Of the two most common methods of insertion used, one uses bacteria that attach themselves to a plant and then transfer DNA into the host plant's genetic code. To use this bacterium in genetic engineering, scientists must delete the disease-inducing genes and insert genes that produce the desired traits. This engineered bacterium, sometimes called a bacterial "truck," is then mixed with the plant cells and allowed to infect them. In the other method, foreign genes are introduced directly into plant cells using a "gene gun" that shoots microscopic particles (such as gold) covered with the foreign DNA into the plant tissues. These techniques and others provide little control over the precise location of the inserted genetic material.[4]

Additional genetic material must accompany the foreign gene into the host plant. This often includes a marker gene that encodes for antibiotic resistance. Because of the inherent imprecision in the genetic engineering process, scientists use these genes to mark which plant cells incorporated the gene of interest and which did not. The antibiotic resistance genes serve no purpose outside of the laboratory, but remain in the plants regardless, posing human health and environmental risks.[5] Along with the gene of interest and often the antibiotic resistance marker gene, scientists also insert a promoter into the host plant. This promoter, functionally a genetic "on" switch that causes the gene of interest to be expressed at a high level, is usually a disabled virus. Many concerns have been raised about the safety of the most common promoter, the cauliflower mosaic viral promoter, including but not limited to "genome rearrangement, insertion mutagenesis, insertion carcinogenesis, the reactivation of dormant viruses and generation of new viruses."[6]

The imprecision of genetic engineering and the inability of developers of genetically engineered crops to fully understand what they are inserting into a plant cell have been revealed on many occasions. For example, in May 2000 Monsanto disclosed that its genetically engineered soybeans—the company's best selling genetically engineered crop—contained gene fragments that scientists had not intentionally inserted.[7] After four years of commercialization, researchers discovered two extra gene fragments in the soybeans. Neither Monsanto nor government regulators had any idea the supposedly inactive pieces of genetic material were inserted during the process of engineering the crop. After that embarrassment, one year later Monsanto again had to admit it did not fully understand the genetic makeup of the product it introduced to market, as new research discovered additional unexpected DNA.[8]

In 1997, the imprecision of genetic engineering was again revealed when Monsanto had to recall approximately 60,000 bags of canola—enough to seed between 600,000 to 750,000 acres of land—because the seed mistakenly contained an unapproved gene. According to some reports, quantities of seed had already been planted when Monsanto discovered the mistake.[9]

The Theory of Substantial Equivalence

The biotechnology industry and FDA claim that genetically engineered crops and traditionally bred crops are "substantially equivalent." The term appears to have been coined by the Organization for Economic Cooperation and Development in its 1993 publication "Safety Evaluation of Foods Derived by Modern Biotechnology: Concepts and Principles."[10] Because some crops that are genetically engineered can be characterized as similar in certain respects to crops that have not been genetically engineered, such as in overall levels of fat, protein, and starch, on the basis of essentially that alone the biotechnology industry and FDA assume they pose no new health or environmental risks. This concept, aggressively advocated by manufacturers of genetically engineered foods and crops, has been endorsed by the UN Food and Agriculture Organization and World Health Organization and forms the basis of regulation of these products by the United States government.

Although the idea of substantial equivalence is simple and may at first even seem plausible, other scientists critique it as insufficient and misguided.[11] The agencies regulating genetically engineered food have never properly defined the term. As a result, there are no guidelines to test foods to see if this assumption holds true. At the same time, this vagueness makes the concept particularly useful to industry. Monsanto's website, for example, quotes Henry Miller of the Hoover Institution saying that, "genetic engineering [is] essentially a refinement of the kinds of genetic modification that have long been used," and the company itself calls the technology an "extension" of traditional plant breeding, only "more precise."[12] However, a closer examination of the technology used to engineer plants and a look at some of the genes that scientists are inserting clearly demonstrates that traditional plant breeding and genetic engineering are radically different.[13] Some scientists have gone on not just to criticize the inadequate review process for genetically engineered crops, but the entire intellectual premise of genetic engineering, calling its foundation "spurious."[14]

Unusual and Unexpected Results in Field Tests

The unpredictability of genetic engineering was illustrated by an experiment performed on a plant in the mustard family frequently used for biological research.[15] Scientists compared three lines of the plant that all contained the same gene for herbicide tolerance—one developed by a modified form of conventional breeding and two by genetic engineering. Since the plant is normally a self-pollinating species with very low rates of cross-pollination, researchers thought that there would be virtually no gene flow to other individual plants and little risk of genes moving from engineered plants to non-engineered neighbors.

They designed an experiment to test these assumptions, planting engineered, semi-conventional, and wild varieties in close proximity, and later collected seeds from the wild variety to see how many carried genes for herbicide tolerance. The results, as the authors note elsewhere, have "great implications for biotechnology and the controversy surrounding the risk of releasing transgenic crops into the environment."[16] The two genetically engineered varieties were four and 36 times more likely to cross-pollinate than the semi-conventional variety.[17] With such a high rate of cross-pollination, the act of genetic engineering functionally turned a species that does not usually cross-pollinate into one capable of relatively higher rates of cross-pollination. This experiment demonstrates that genetic engineering can fundamentally change the basic character of a plant.

In another example, scientists attempted to suppress the color of petunia flowers by transferring a gene created to turn off a pigment gene in the host plants.[18] However, the inserted gene did not have the anticipated effect, and the color varied from plant to plant in both shade and pattern. The weather also affected the expression of the genes—some of the flowers changed colors or color patterns as the weather changed.

These problems were totally unexpected and unanticipated—and visible only because the scientists intended the results to be visible. In many cases, genetic engineering will bring about invisible alterations in the cell's metabolism, in some cases altering the nutritional status or toxin levels of genetically engineered crops. Researchers studying genetically engineered yeast found elevated levels of a toxic compound, causing them to caution that the results "give some credence to the many consumers who are not yet prepared to accept food produced using gene engineering techniques."[19]

Crop Failures: One More Problem

There have been a number of crop failures with genetically engineered cotton and genetically engineered soybeans. In the case of cotton, bolls were deformed and fell off the plant before harvest. Some attributed this problem to Monsanto hurrying Roundup Ready cotton to market without allowing state and federal cotton experts to test the seeds.[20,21] As a result of the losses suffered, the company had to compensate farmers in a number of states including Mississippi, Arkansas, Tennessee, Missouri, and Texas.[22] Farmers also discovered that Monsanto's genetically engineered soybeans grown in hot climates are more likely to grow shorter and have their stems split open. Genetically engineered soybeans grew an average of 15 centimeters in hot climates compared with a conventional height average of 20 centimeters, and 100% of the engineered plants had split stems compared with 50-70% for conventional varieties.[23]

Biopharmaceutical Crops

Since at least 1991, researchers have conducted field trials of plants genetically engineered to produce either pharmaceuticals or industrial chemicals in the open environment. Some of the plants have been engineered to produce contraceptives, potent growth hormones, blood clotters, blood thinners, industrial enzymes and vaccines. This application of genetic engineering introduces a new set of environmental and public health risks.[24] Although these plants are not intended to enter the food supply, there have been well-publicized episodes in which they have contaminated conventional crops.[25] How many times this has happened but not been detected is, of course, unknowable, but given the track record of the industry, entirely possible.

Confidential Business Information

Between 1987 and 1989, all field tests of genetically engineered organisms reported to the U.S. Department of Agriculture (USDA) disclosed the genes introduced into the host plant. But from 1989 through 2002, the percentage of crops containing genes declared Confidential Business Information increased dramatically, from 0 percent in 1989 to more than 69 percent in 2002.[26] One example of a commercial permit from DuPont, # 99-029-01, is for 18 release locations covering more than 5,000 acres, yet the identity of several genes transferred to the host plant is not publicly disclosed. But it is not only private corporations that are failing to disclose critical information regarding field experiments. Universities also are denying the public knowledge about what new creations are being introduced into the environment and potentially the food supply.

New Genetic Combinations, New Problems?

Conventional breeding allows only mixing and recombination of genetic material between species that share a recent evolutionary history, and primarily employs processes that occur in nature, such as sexual and asexual reproduction. These methods result in plants that accentuate certain desirable characteristics—characteristics that are not new, but rather are already present in the species' genome. Genetic engineering, however, makes it possible to combine genes from very different sources, with often unpredictable results.

Using genetic engineering, scientists can, for the first time, insert genes from different species, families, or even kingdoms, something inconceivable in traditional breeding. Under normal circumstances, for example, a strawberry can only acquire genetic material from other strawberries—that is, plants of the same or closely related species. However, using genetic engineering, scientists can develop strawberries containing genetic material from trees, bacteria, fish, pigs, or even humans if they choose.

Previous research found that between 1987 and October 2000, the U.S. Department of Agriculture (USDA) authorized 14 field tests of crops engineered with animal or human genes.[27] Between 2001 and mid-2003, USDA had authorized 29 additional field tests of crops engineered with animal or human genes, or more than double the total authorized during the first 13 years of USDA record-keeping.[28]

Owing to the tremendous secrecy surrounding the field testing of genetically engineered crops in the United States, the following is likely an abbreviated list of genetically engineered plants that have been authorized by USDA for open air experimentation in the United States between 2001 and the present.

- Barley and Humans -

Washington State University has developed a type of barley that contains a human gene to produce pharmaceutical proteins. In 2001, USDA allowed the university to field test this barley on three acres in Washington.[29]

- Corn and Hepatitis B and Simian Immunodeficiency Virus (SIV) -

ProdiGene genetically engineered a corn with genes from a number of viruses, including hepatitis B virus and the simian immunodeficiency virus. USDA issued a permit in 2001 for ProdiGene to field test this pharmaceutical corn on 53.5 acres in Nebraska.[30]

- Corn and Pigs and Hepatitis B -

ProdiGene also developed a genetically engineered corn that produces pharmaceutical proteins by engineering the corn with pig genes, hepatitis B virus and simian immunodeficiency virus. This corn was authorized to be grown in field trials in Hawaii on just under half of an acre of land.[31]

- Corn and Humans -

USDA gave Dow permission to grow more than seven acres of corn genetically engineered with human genes on Hawaiian soil; this corn was developed to produce pharmaceutical proteins. Meristem Therapeutics, a French-owned company with an office in Massachusetts, also grew corn that had been engineered with human genes on an acre of land in Kentucky.[32]

- Safflower and Carp -

Emlay and Associates created safflower that produces pharmaceutical proteins by genetically engineering the safflower with growth hormones from carp. USDA agreed in June 2003 for this crop to be grown on 11 acres in North Dakota and Nevada.[33]

- Glow-in-the-Dark Corn -

Iowa State University genetically engineered corn with jellyfish and mouse genes to create corn with proteins for green fluorescence. USDA authorized Iowa State to grow the corn in Iowa between June and November 2001.[34] Pioneer also received a permit to engineer jellyfish genes into corn and conduct field tests on 70 acres in Hawaii. According to the company, Pioneer's intent is to improve animal feed quality and create visual markers.[35] Rutgers University also used jellyfish genes with corn in a field test site located on one acre of land in Florida.[36] The University of California received permits for two test sites in California for a similar experiment.[37]

- Chicken and Corn -

The University of Florida engineered corn with chicken genes for release in Florida in 2003. USDA's database states that the test also included a cancer-related gene (e.g. B cell lymphoma).[38]

- Potatoes and Fruit Flies -

To make potatoes resistant to mold and fungus, Colorado State University has genetically engineered potatoes with a fruit fly gene. USDA authorized the university to test the crop in Colorado between April and November of 2001.[39]

- Tobacco and Cows -

The University of Kentucky inserted cow genes into tobacco plants to make the plants resistant to certain bacterial blight. This tobacco was authorized for testing in Kentucky between May 2001 and May 2002.[40]

- Tobacco and Humans -

CropTech engineered human genes into tobacco plants, receiving permission to release the plants in a half acre plot on sites in South Carolina and Virginia in 2001. The University of Kentucky was authorized to conduct a similar test on less than one acre of land in Kentucky in 2002. Tests conducted by both organizations were for pharmaceutical research.[41]

- Wheat and Chickens -

The University of Nebraska acquired three permits to grow field trials of wheat genetically engineered with chicken genes to produce fungal resistance. The field tests were authorized to occur between March 2002 and August 2003 in Nebraska.[42]

- Chicken and Grass -

The University of Nebraska inserted chicken genes into creeping bentgrass, receiving USDA authorization for a one acre field site in Nebraska for use from October of 2002 until October of 2003.[43]

- Nearly 500 Acres of Corn with Jellyfish and Undisclosed Genes -

Pioneer has genetically engineered corn with genes from jellyfish and more than 20 other organisms, many of which are not disclosed as part of the company's confidential business information. USDA issued a permit to Pioneer to grow this experimental corn on 490 acres in twenty states across the country, including California, Iowa, Illinois, Kansas, Michigan, Tennessee, Texas, and Wisconsin. The exact locations and purposes of these field trials are also undisclosed.[44]

- Jellyfish and Shrubs -

The University of Connecticut used jellyfish genes as a visual marker within rhododendrons in Connecticut. A researcher at the University stated that the field test was not intended for commercial application.[45] The University of Georgia obtained approval for a one acre field test of Bermuda grass engineered with jellyfish genes to produce tolerance to herbicides.[46]

- Humans and Rice -

Applied Phytologics, a biotechnology company, was given permission to implant several human genes into rice to produce pharmaceutical proteins. The field test was authorized to take place in Hawaii in 2001.[47]

- Jellyfish and Bollworms -

In the first known field release of a genetically engineered animal, the Animal and Plant Health Inspection Service (APHIS) used jellyfish genes as visual markers in pink bollworms. The bollworm is a moth caterpillar that eats and destroys corn and other agricultural crops. The three acre field test site is located in Arizona.[48]

- Jellyfish and Rice -

In May 2003, the University of California was granted permission to put jellyfish genes into rice, creating visual markers.[49] The test is authorized to take place in California.

- Humans and Sugarcane -

The Hawaii Agriculture Research Center engineered human genes into sugarcane to produce pharmaceutical proteins on half an acre in Hawaii.[50] The test was authorized in 2001.

- Rats and Soybeans -

The University of Kentucky used the genes of the Norwegian rat to alter the oil profile of soybeans. The test was authorized to begin in May 2003 on an acre in Kentucky and can continue until May 2004.[51]

- Man and Mouse and Corn -

Garst, Inc. combined human and mouse genes with corn to produce pharmaceutical proteins. Garst applied for a permit in 2003 to conduct field tests in Hawaii.[52]

Conclusion and Recommendations

Genetic engineering is an imprecise, haphazard technology — something completely different from traditional plant breeding. With alarming regularity, biotechnology companies have demonstrated that scientists cannot control where genes are inserted nor guarantee the resulting outcomes. Unexpected field results highlight the unpredictability of the science, yet combinations previously unimaginable are being field tested in the open environment and used commercially.

To protect public health and the environment, genetically engineered food ingredients or crops should not be allowed on the market unless:

- Independent safety testing demonstrates they have no harmful effects on human health or the environment;
- They are labeled to ensure the consumer's right-to-know; and
- The biotechnology corporations that manufacture them are held responsible for any harm.

In addition, scientists should not engineer food crops to produce pharmaceuticals or industrial chemicals and should not conduct such experiments in the open environment.

Appendix: Authorized Field Trials for Unusual Gene Combinations since 2001

Permit	Institution	Organism	Donor Gene	Release Location(s)	Acreage	Begin Date	Purpose
01-029-01r	APHIS	Pink bollworm	Jellyfish	AZ	3	10/01/01	Visual marker
01-206-01r	Applied Phytologics	Rice	Human	HI	n/a	n/a	Pharmaceutical protein
01-059-05n	Colorado State U	Potato	Fruitfly	CO	1	04/15/01	Fungal resistance
02-080-01r	CropTech	Tobacco	Human	SC, VA	0.5	05/07/02	Pharmaceutical protein
01-212-01r	Dow	Corn	Human	HI	7.9	10/23/01	Pharmaceutical protein
03-071-01r	Emlay and Associates	Safflower	Carp	ND, NV	11	06/03/03	Pharmaceutical protein
03-143-01r	Garst	Corn	Human/Mouse	HI	n/a	pending	Pharmaceutical protein
01-306-01r	Hawaii Agriculture Rsrch Ctr	Sugarcane	Human	HI	0.5	01/11/02	Pharmaceutical protein
01-135-01n	Iowa State U	Corn	Mouse/Jellyfish	IA	1	06/14/01	Visual marker
02-141-01r	Meristem Therapeutics	Corn	Human	KY	1	06/05/02	Pharmaceutical protein
03-022-01r	Pioneer	Corn	Jellyfish	CA, DE, GA, IA, IL, IN, KS, MD, MI, MN, MO, NC, ND, NE, OH, PA, PR, TN, TX, WI	490	04/22/03	Visual marker
03-022-02r	Pioneer	Corn	Jellyfish	HI	70	05/01/03	Visual marker
01-023-03r	ProdiGene	Corn	Hepatitis B/Simian Immunodeficiency Virus	NE	53.5	05/08/01	Pharmaceutical protein
01-187-01r	ProdiGene	Corn	Pig/Hepatitis B/Simian Immunodeficiency Virus	HI	0.4	11/13/01	Pharmaceutical protein
03-132-03n	Rutgers U	Corn	Jellyfish	FL	1	05/01/03	Visual marker
03-078-14n	U of California	Corn	Jellyfish	CA	0.2	05/15/03	Visual marker
03-078-13n	U of California	Corn	Jellyfish	CA	0.2	05/15/03	Visual marker
03-140-02n	U of California/Davis	Rice	Jellyfish	CA	0.5	05/28/03	Bacterial resistance
03-147-01n	U of Connecticut	Rhododendron	Jellyfish	CT	0.025	06/01/03	Visual marker
03-121-02n	U of Florida	Corn	Chicken	FL	0.1	08/15/03	Male sterile
03-160-01n	U of Georgia	Bermuda grass	Jellyfish	GA	1	05/15/03	Herbicide tolerance
01-081-02n	U of Kentucky	Tobacco	Cow	KY	1	05/15/01	Bacterial resistance
02-108-02r	U of Kentucky	Tobacco	Human/Mouse	KY	0.2	05/09/02	Pharmaceutical protein
03-091-18n	U of Kentucky	Soybean	Rat (Norwegian)	KY	1	05/01/03	Oil profile
02-039-01n	U of Nebraska/Lincoln	Wheat	Chicken	NE	1	03/10/02	Fungal resistance
02-088-06n	U of Nebraska/Lincoln	Wheat	Chicken	NE	1	03/10/02	Fungal resistance
02-263-22n	U of Nebraska/Lincoln	Creeping bentgrass	Chicken	NE	1	10/01/02	Fungal resistance
03-024-13n	U of Nebraska/Lincoln	Wheat	Chicken	NE	1	03/01/03	Fungal resistance
00-334-01r	Washington State U	Barley	Human	WA	3	03/22/01	Pharmaceutical protein

Source: Information Systems for Biotechnology, Virginia Tech, http://www.nbiap.vt.edu/cfdocs/fieldtests1.cfm.

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