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Biology Standard
B.5.c.

Student Edition

California Education and the Environment Initiative

High-Tech Harvest: Genetic Engineering and the Environment

California Education and the Environment Initiative
Approved by the California State Board of Education, 2010

The Education and the Environment Curriculum is a cooperative endeavor of the following entities:
California Environmental Protection Agency
California Natural Resources Agency
Office of the Secretary of Education
California State Board of Education
California Department of Education
California Integrated Waste Management Board

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Key Partners:
Special thanks to **Heal the Bay,** sponsor of the EEI law, for their partnership and participation in reviewing portions of the EEI curriculum.

Valuable assistance with maps, photos, videos and design was provided by the **National Geographic Society** under a contract with the State of California.

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http://www.calepa.ca.gov/Education/EEI/

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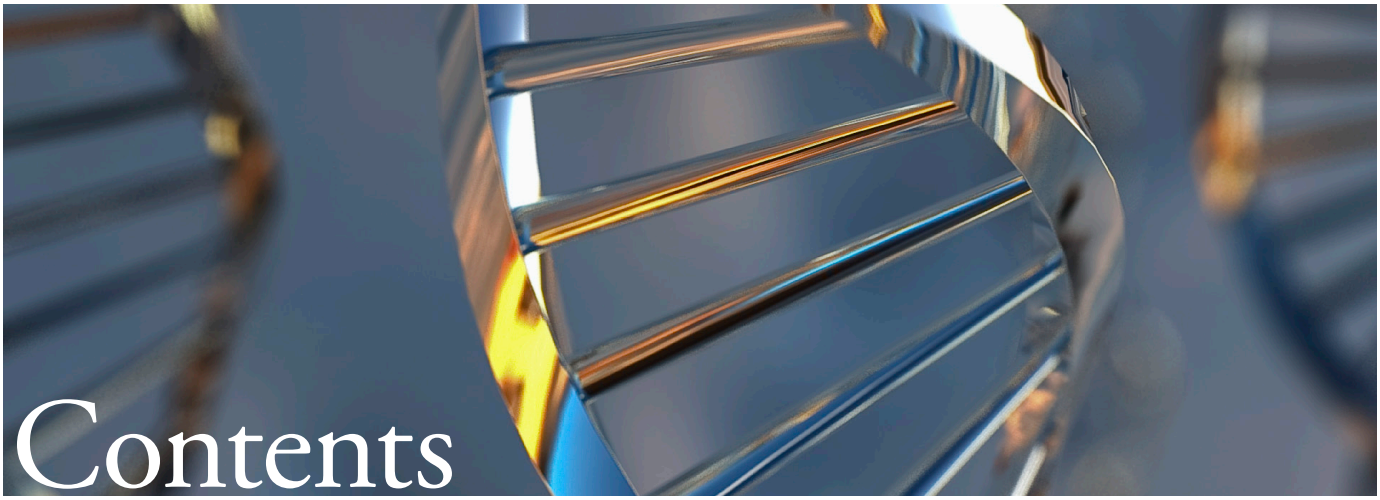

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None required for this lesson.

Rice Pharming in California

Part 1: Russ Greenwald and Ventria Bioscience

Russ Greenwald climbed out of his pickup as the big harvesters flushed blackbirds from the rice fields. Moving back and forth in the heat of midday, they carefully mowed between dark levees. Russ is a big man in his late 40s, a third generation California rice farmer.

Feeding the World

Lately he has seen many changes in the industry. "Rice is the engine that drives many rural economies in the Sacramento Valley," he said. "The small farmer used to know what to expect. Now, the future seems less certain."

California has been a major rice-producing state since 1920. Approximately 40,000 Chinese immigrants—all of whom depended on rice as their staple food—joined the thousands who flocked to northern California to find their fortunes during the Gold Rush of 1849. Farmers at that time found that the new rice crop they planted to feed this influx of Chinese immigrants grew easily in the heavy clay soil of the Sacramento Valley.

From a patchwork of 500,000 acres, California farmers now harvest approximately seven metric tons of rice per year, more rice

Aerial view of farming in Sacramento Valley

Rice ready to eat

per acre than any other region in the world. Japan buys nearly half of California's yearly rice crop; Taiwan, Turkey, and South Korea also buy large quantities of California rice. The rest of the state's rice crop finds its way to dinner tables and sushi restaurants and into rice beer and pet food in the United States. Today more people consume rice than any other grain on Earth; a third of the world's population eats rice every day.

Genetically Modified Rice

In 1998, the U.S. Department of Agriculture approved a Sacramento-based company's plan to carry out biogenetic experiments with rice. Using rice as a host, Sacramento-based Ventria Bioscience hoped to develop an oral rehydration solution, that would help cure infectious diarrhea. Doctors use rehydration solutions to help replace the body fluids lost in people suffering from diarrhea. Every year 2 million children around the world die of complications from this disease. It is the second largest killer of children under the age of five in developing countries. If not controlled, serious diarrhea can cause the human body to lose dangerous amounts of fluid, causing dehydration and potentially death.

Ventria Bioscience used a bioengineering technology to design a genetically modified rice grain that produces the natural proteins lactoferrin and lysozyme.

Rice in test tube

Rice ready for shipment

Lactoferrin and lysozyme are proteins found in mother's milk, tears, and saliva. Lactoferrin acts as an anti-bacterial agent and stimulates the immune system. Lysozyme can make dangerous bacteria less likely to be harmful. These proteins do not grow naturally in rice. Ventria tested inserting human genes for these proteins into the rice genome using bioengineering technology, creating a transgenic rice plant. Transgenic plants contain a gene or genes transferred from another species. When these rice-produced human proteins were extracted from the rice and added to an oral rehydration solution, they were intended to act together to reduce the risk of infectious diarrhea and inflammation of the intestinal tract.

Originally Ventria planted its test rice in separate plots away from commercial rice fields. The company aimed to reduce the risk of cross-pollinating the engineered rice with the traditional rice crops. Such cross-pollination could allow the medicinal proteins to make their way into regular rice. Ventria planned to grow more acres of its genetically modified rice in California after completing the experimentation phase of the project.

Biopharming

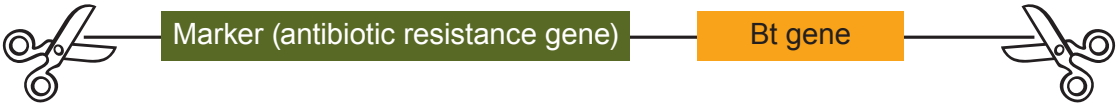
In 1999, Ventria asked Russ Greenwald to assist with its experi-ments. The company wanted to use part of his land for "biopharming," or growing genetically modified rice containing the diarrhea-preventing proteins. The word "biopharming" is a combination of "pharmaceutical" (meaning medical drugs) and "farming." Biotech and pharmaceutical companies see biopharming as a way to produce large quantities of useful drugs that can be delivered relatively cheaply and easily, especially to people in developing countries.

Self-pollinating Rice

Ventria offered to pay Greenwald by the acre to develop a rice pharm in northern California. The company said it would plant self-pollinating rice, which allows the rice plants to fertilize themselves with their own pollen. This appealed to Greenwald, who would not have to worry about keeping the genetically modified rice from mixing with his regular crop. It was at that time that he agreed to become a "pharmer."

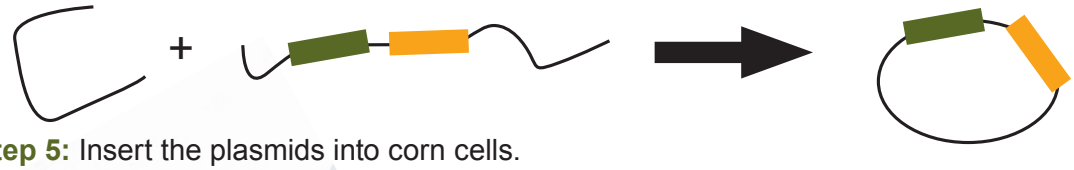
Step 1: Select the Bt gene from the bacterium *Bacillus thuringiensis* (Bt).

Step 2: Add a marker gene (such as a gene for resistance to antibiotics) to the Bt gene. Cut the ends with a restriction enzyme.



Step 3: Use a restriction enzyme to cut open a plasmid, creating a place to insert the marker/Bt genes.

Step 4: Mix the marker/Bt genes with the open plasmids. Use ligase to connect the DNA.



Step 5: Insert the plasmids into corn cells.

Step 6: Test the treated cells with an antibiotic. Only cells that have been transformed, or contain the marker gene and the Bt gene, will survive.

Step 7: Grow the surviving transgenic cells into plants. The plants produced from the seeds of these plants will produce the Bt toxin that kills insects.

Instructions: As a group, review **Taking Genes, Making Products: Resource Information,** which diagrams the method scientists use to genetically engineer corn. Use the materials provided to create your own visual model of this process. Attach the model to the large piece of paper, and include a key that identifies each component of the model.

Your model should represent all of the following components and show their roles in the genetic engineering process:

- Bt gene from the bacteria
- Marker gene (for antibiotic resistance)
- Plasmid
- Restriction enzyme (represented by the scissors)
- Ligase (represented by the tape)
- Corn cell
- New corn cell with Bt gene and marker gene inserted
- Pest-killing toxin produced by the genetically modified corn

Your group will present your model to the rest of the class. Plan a short (two- or three-minute) presentation that:

- includes the major steps in the genetic engineering process as described in the resource information.
- uses the materials provided to model and accurately describe the genetic engineering process.
- identifies the source of the genetic resources used to create this new product.
- identifies the naturally occurring substances used in the process of changing the corn DNA.

Bt Corn

For centuries, corn farmers have battled with the corn borer beetle as the pest destroyed huge amounts of their corn crops. For the last few decades, farmers have sprayed their corn with pesticides to kill the corn borer. These pesticides, however, carry some risks and have not always been as effective as farmers have hoped.

Recently scientists have genetically engineered Bt corn, a type of corn containing a gene that produces a toxin that kills common corn pests. This Bt corn is widely used by organic farmers who then do not have to spray with costly and harmful pesticides to eradicate corn borers.

The key questions are: "What else happens? What chain of events can this genetic modification set off? How might these genetically engineered products influence the composition, biological diversity, and viability of natural systems, as well as human health?"

First, genetically engineered corn may harm animal species other than the corn pests. Laboratory tests suggest that the pollen of such corn may kill monarch butterfly larvae, though field tests do not confirm this finding. On the other hand, the use of Bt corn should decrease the use of pesticides on crops. Some of these pesticides can harm beneficial insects or fish if they seep into the water. Populations of some pest species may increase if corn farmers reduce pesticide use. Scientists are concerned about how changes of this type could affect the delicate balance within surrounding ecosystems.

Human health may also improve if farmers grow this engineered corn in places where people cannot easily access pesticides or in places where pesticides cost too much. In this scenario, corn production could increase and result in better nutrition, as well as provide a new source of income in poor communities.

Farmers in other countries, such as Mexico, worry that genes from genetically engineered corn are contaminating their "heirloom" plants—rare varieties of crops that have remained unchanged for many years—often grown by families or on small farms. Heirloom varieties help preserve genetic diversity.

Corn pollen from Bt corn can move to neighboring fields via insects or the wind. As Bt corn pollen travels, it can land on other non-genetically engineered corn and cross-pollinate. Eventually, the old breeds of corn could be wiped out if they incorporate the genes from any commercial corn crop including the genetically manipulated varieties like Bt corn, a phenomenon called genetic contamination.

It is important to note that the consequences of the possible transfer genes from GMOs into natural systems or their effects on humans are not fully understood by scientists.

Larva of corn borer beetle

Malaria-Resistant Mosquitoes

Malaria is a painful and deadly disease that kills between 1 million and 3 million people each year. Most of the victims are children. The disease spreads primarily through mosquitoes in tropical and subtropical countries. Mosquitoes are the host to a protozoan that causes malaria. When they bite, infected mosquitoes transmit the disease into human blood.

Researchers have worked for decades on various ways to reduce the rates of malaria. Most of these measures focus on prevention (such as mosquito netting) and treatment. There are some effective, but expensive, antimalarial drugs that people can take after they contract the disease, but there is no malaria vaccine.

Recently genetic engineers have inserted genes into mosquitoes to make them resistant to malaria. Scientists believe that if a mosquito cannot carry malaria, it cannot spread the disease to people. They believe that such genetically engineered mosquitoes could greatly reduce malaria infections.

Mosquito feeding

Normally, genetically modified organisms are separated from nonengineered species. For example, researchers often grow genetically engineered crops far from traditional crops to prevent pollen from being carried by insects or the wind from moving it from one field to another. Such movement could lead to the transfer of genetically engineered genes to traditional crops and generate a host of problems for farmers and consumers.

In contrast, with malaria-resistant mosquitoes, scientists hope for interbreeding between genetically engineered and “wild” populations. The scientists are transferring malaria-resistant mosquito genes to future generations of wild mosquitoes, hoping to eventually replace wild populations of mosquitoes with a malaria-resistant ones. If these scientists succeed, it could lead to an international public health victory in the battle against malaria.

Opponents argue that scientists do not know how the genetically modified mosquitoes might affect species that they bite, species that feed on them, or other components of their natural system.

It is important to note that the consequences of the possible transfer genes from GMOs into natural systems or their effects on humans are not fully understood by scientists.

Microdiesel: Biofuels from Bacteria

Engineers and environmental advocates praise biofuel as the wave of the future. They consider it one of the best ways to reduce American dependence on oil. These same people argue that the use of biofuels should lead to a reduction in the use of nonrenewable fuels, such as oil, and decrease greenhouse gas emissions. In fact, the U.S. Department of Energy has set a goal of replacing 30% of gasoline used in the United States with fuels from renewable sources by 2030.

Biofuels are fuels produced from recently living organisms, most often plants. In the United States, corn and soybeans are two of the crops grown specifically for producing biofuels. As much promise as they have, the use of biofuels is not without problems, so some scientists are focusing instead on engineering bacteria to produce fuel, also known as microdiesel.

A team of German scientists led by Alexander Steinbüchel from the University of Munster has modified *Escherichia coli* bacteria to produce alcohol from sugar. The team combined this alcohol with oil to produce a fuel that can be burned in a diesel engine. The scientists dubbed this fuel "microdiesel." Similarly, California-based companies LS9 and Amyris Biotechnologies are using this new field of biology to engineer bacteria that can make hydrocarbons for fuel.

All of these companies hope to solve some of the problems that arise from biofuels made from soy, corn, or canola. Most biofuels are derived from plants that people also use as food. It takes large quantities of these crops to create biofuels, so if biofuels were to become widely used, they would compete with food for space on farms. Even if all of the fields of corn and soybeans in the United States were used just to make biofuels, Americans could make only 12% of the fuel consumers and businesses need. In addition, making room for the crops needed to create biofuels has already led to increased deforestation. For example, plantation owners have cleared parts of Borneo's rainforest to create palm oil plantations. The Global Forest Coalition reports that biofuels are becoming the main cause of deforestation in countries, such as Indonesia, Malaysia, and Brazil. Deforestation often leads to loss of biodiversity, erosion, and altered weather patterns. Eventually, some

Ethanol plant and corn field

Gas station

developing countries could have to choose between food and fuel. In contrast, scientists make fuels from genetically engineered bacteria in factories that require a fraction of the space as biofuels. With careful planning, microdiesel factories could be established on lands that are less ecologically sensitive.

Ethanol, made from corn, is a renewable biofuel but it contains 30 percent less energy than gasoline, so it must be mixed with gasoline before being burned in cars. For this reason, both LS9 and Amyris focus their efforts on creating fuel that contains more energy. Using fuel that contains more energy per molecule would allow cars to go farther on a gallon of gas and result in less pollution. Another challenge with ethanol is that it cannot be delivered in existing gasoline pipelines, but new microdiesel fuel can travel through existing pipelines and go into existing diesel engines.

Some scientists also assert that ethanol offers less energy than is used to make it. They assert that much of the energy used to make ethanol and other biofuels comes from nonrenewable sources, such as coal. In other words, a significant amount of pollution goes into the making of these fuels from corn. By contrast, microdiesel from genetically engineered bacteria is expected to require significantly less nonrenewable energy for production and so is expected to result in less pollution of natural systems than ethanol production.

Current research on production of microdiesel from genetically engineered bacteria could reduce the cost of making the fuel without using farmland that is now dedicated to growing food. Cost and space represent the two main obstacles preventing biodiesel from expanded use.

Coal

Toxic-Avenger Trees and More

Pollution-eating plants were once only the stuff of science fiction. Today they exist in the real world. Genetic engineers now modify plants and bacteria to transform pollutants and poisonous waste into nontoxic substances. For example, University of Georgia genetics professor Richard Meagher and his team have genetically altered trees and other plants to absorb toxic mercury from the soil and convert it into a less-harmful gas. The trees release this gas into the air through their leaves.

The U. S. Environmental Protection Agency recently identified mercury as the worst metal pollutant in the United States. Mercury is extremely toxic and pollutes tens of thousands of sites across the country. This metal leaches into soil and water from various types of waste, especially E-Waste (electronic waste, such as computers). Once in soil or water, mercury can enter the food chain and cause illnesses and birth defects in people and other animals.

For a long time, scientists have used mercury-eating bacteria to remove toxins from the soil. However, these bacteria are not effective enough to help clean up the estimated $200 billion worth of heavy metal pollution in the United States. For that reason, some scientists aim to transfer the bacteria's metal-eating traits into plants.

In one of his earliest experiments, Meagher inserted a modified bacteria gene into fast-growing poplar trees. The poplar has large leaves that provide plenty of surface area for releasing gases. Meagher's tests showed that the genetically engineered trees absorbed 10 times more mercury than traditional trees. He suggests planting these modified trees in a fringe around polluted areas to reduce the amount of contaminated runoff from reaching wetlands and the food chain. This technology could have a huge positive effect on any site contaminated with heavy metals, such as mercury.

But some people criticize Meagher's project. Mercury gas poses some health risks and some worry about large fields of plants releasing mercury vapor. Others also worry that, as with many genetically engineered plants and bacteria, the altered genes could migrate to other trees via

Mercury drops

insect- or wind-carried pollen. If mercury-eating genes start turning up in ordinary trees or plants, this feat of genetic engineering could endanger the genetic diversity of tree species and lead to increased environmental problems.

"It's not a perfect solution," Meagher admits. However, he argues that when less-toxic forms of mercury enter the air via the trees, the gases soon disperse. He says this release of mercury makes more sense than leaving the highly toxic metal in the soil where it threatens humans and wildlife. "It could prove to be a more viable, cost-effective alternative than current remedies like burying or burning contaminated soil," Meagher says. This research also suggests that plants could be engineered to remove other types of pollution in the soil, such as copper, lead, arsenic, and cadmium.

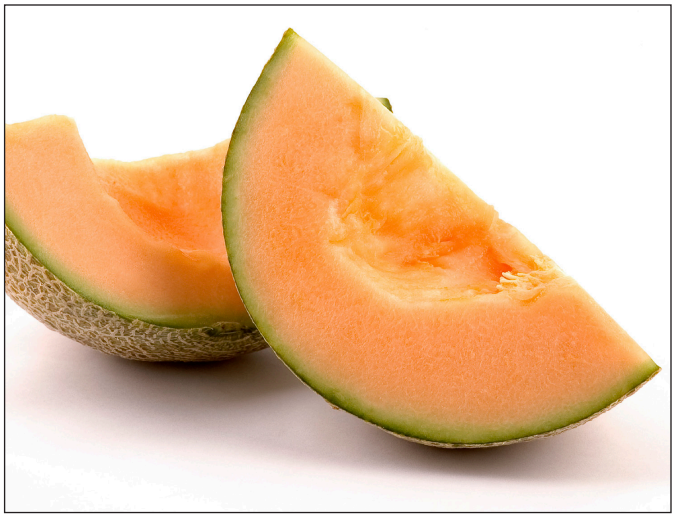
Poplar tree

Research scientist

Eat Your Vaccine

Could a banana a day keep the doctor away? Some scientists surely hope so. They are working on ways to engineer commonly eaten fruits to incorporate important vaccines for a variety of diseases. One group of scientists is engineering bananas to deliver an oral vaccine for hepatitis B, a virus that harms the liver. If the group succeeds, simply peeling and eating a banana could protect people from this disease.

Professor Gowda Ramanjini of the University of Agricultural Sciences in Bangalore, India, is working on genetically modifying a muskmelon (a cantaloupe is a type of muskmelon) to incorporate a rabies vaccine. Rabies kills thousands of people every year in India and infects countless dogs. The genetically engineered muskmelon could be a cheap and relatively easy way to immunize millions of people against the disease. Powder taken from the muskmelon could be added to dog food to immunize dogs as well. Tests show the fruit successfully prevents rabies in mice; new tests will soon take place with dogs. Similarly, Epicyte Pharmaceuticals in San Diego, California, has inserted a human gene into corn to make a vaccine for herpes.



Cantaloupe

Bananas

These genetically engineered vaccines offer a number of advantages. First, ordinary vaccines cost a lot of money to make and they must be refrigerated. In addition, they often require a medically trained person to administer them, making them difficult to deliver in areas of the world that lack electricity and access to good medical care. Second, ordinary vaccines consist

of killed or weakened microorganisms that could theoretically cause, rather than prevent, infection if not properly killed or treated. In contrast, the new genetically engineered vaccines could be administered via harmless organisms without the risk of causing an illness.

Genetically engineered vaccines, such as these also pose some problems and risks. Geneticists still need to find a way to control the amount of vaccine administered. The amount of vaccine in one banana or muskmelon could vary widely. Scientists may instead choose to give patients capsules of dried plant cells that contain the correct doses of a vaccine rather than administer an entire fruit.

As with all genetically engineered plants, vaccine plants could affect the environment and human health in unpredictable ways. Some scientists report cases in which the genes from genetically engineered plants have migrated to non-genetically engineered plants. For example, some researchers have found genes from engineered corn in a remote mountain region of Mexico and genes from genetically engineered cotton in traditional cotton fields in India. Such unintended gene exchange between plants can occur via pollen carried by insects or wind between fields. Some consumers and farmers are concerned that plant-grown drugs and vaccines could end up in food crops. No one wants to find out that the banana in his or her lunch box accidentally contains a vaccine for hepatitis. To prevent such a scenario, the Food and Drug Administration issued new regulations in 2003 to safeguard the food supply. These regulations are intended to prevent unintended gene exchange.

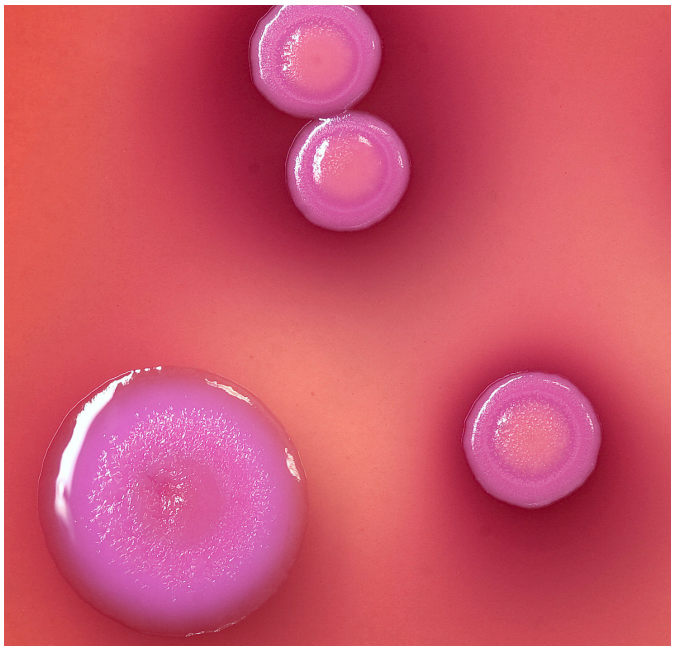
Heirloom apple orchard

Anthrax Vaccine from Tobacco

Since the terrorist attacks of September 11, 2001, the U.S. population has become more aware of the possibility of a domestic biological attack. Much of the media attention about biological attacks has focused on anthrax. In fact, shortly after 9/11, a number of politicians in the United States and Europe received anthrax-laced envelopes. Anthrax is a disease caused by the bacterium *Bacillus anthracis*. Once anthrax bacteria infect a human's respiratory system, they produce toxins that lead to illness and, possibly, death. Anthrax spores last a long time in the soil and can also affect wildlife.

A vaccine already exists for anthrax. If provided to everyone across the globe, the vaccine would protect people from an anthrax attack. Widespread vaccination could also deter terrorists from using anthrax as a weapon. However, the vaccine currently available costs a lot, takes time to produce, and carries some risk. For these reasons, some scientists are now focusing their efforts on creating a genetically engineered tobacco plant that could produce large amounts of an anthrax vaccine quickly and cheaply.

Scientist examining petri dish



Electron microscope view of bacteria

Scientists Henry Daniell and Stephen Leppla have inserted an anthrax bacteria-fighting gene into tobacco plant cells. Other scientists are conducting trials on mice to see if the vaccine made from this genetically engineered tobacco successfully inoculates an animal species. So far, mice immunized by the tobacco-produced anthrax vaccine have been able to survive what would have been lethal doses of anthrax. The next step for the anthrax vaccine to go forward would be for a company to work with the National Institutes of Health, the primary government agency for medical research, to conduct vaccine trials on people.

Such genetically engineered vaccines offer a number of advantages. First, this new method of producing the vaccine could help governments

Tobacco field

and health care providers worldwide overcome the problem of short supplies. Just one acre of plants can produce enough doses to vaccinate all Americans. Second, traditional vaccines contain a toxin that can cause harmful and painful side effects. Vaccines from plants do not contain this toxin. Third, unlike the traditional vaccine, the tobacco-produced vaccine does not get weaker over time, making storage and transportation easier.

Genetically engineered crops, however, can threaten the biodiversity of non-genetically engineered plants. Pollen from genetically engineered plants can move from one field to another. For example, pollen from genetically engineered herbicide-resistant corn can cross-pollinate with a weedy corn relative and make the relative herbicide-resistant. Daniell and Leppla have reduced this risk by harvesting tobacco leaves before they begin to flower. Since pollen is present only when flowers form, this early harvest prevents the flow of genes via pollen and, in turn, prevents contamination of non-genetically engineered crops. In addition, genetically engineered tobacco is unlikely to be mixed with foods because people do not grow tobacco as a food crop. The vaccine would not affect cigarette smokers, since smoking tobacco destroys the vaccine.

From Lab to Farm

Farmers and ranchers have long practiced selective breeding to get livestock with particular, desirable traits. Scientists are working toward similar results through genetic engineering. The first transgenic farm animal was a pig developed in 1988 by the research team at a United States Department of Agriculture lab in Maryland. The team aimed to create a pig that would produce leaner pork. The modified pig did, indeed, result in leaner meat but the animal also suffered from a variety of ailments including arthritis and kidney disease. Since then, scientists have learned more about how genetic engineering could work in pigs and other animals. They have developed a number of genetically modified animals for use as food, but for a number of reasons, no animals have yet made it to grocery store shelves.

Many companies and research groups around the world have focused on creating transgenic salmon, carp, and catfish that grow bigger and faster than their ordinary cousins. One company, Aqua Bounty Technologies, has created a breed of salmon that grows twice as fast as normal farmed salmon. Aqua Bounty's salmon contains a gene from a fish, the ocean pout, which grows throughout the year. Normal salmon typically grow only during the summer, so the addition of the ocean pout gene extends the genetically engineered salmon's growing season. They estimate the new salmon will enable the average salmon producer to cut costs by 35% per fish while doubling output. "It's like improving the mileage in your car," one scientist from the company explains.

Farmed salmon

But before the fish can be farmed for commercial sales, Aqua Bounty must get approval from the U.S. Food and Drug Administration. Aqua Bounty's toughest challenge has been to prove that if the engineered salmon escape from a fish farm into the open ocean, they would not mate with their wild counterparts. If this cross-breeding were to happen, the altered genes could spread to the offspring, which could then grow faster and out-compete other wild salmon. The gene would continue to spread, and the wild salmon population could be eliminated. Aqua Bounty could prevent this gene spread by focusing its efforts on sterile fish or fish grown indoors.

Other critics of genetically engineered fish are concerned that mixing genes from

different species could lead to unpredictable consequences. Some scientists suggest that the environmental implications of genetic engineering could be widespread and that many of the potential consequences are, as of yet, unknown. The consequences could include the loss of natural species that are "out-competed" by genetically engineered animals.

Traditional salmon farming poses environmental problems. Fish farmers grow these salmon in open cages with thousands of fish concentrated in a pen the size of a small house. The farmers often bind together a dozen or so of these pens. Fish feces pass into the waters around the pens and contaminate the water with as much raw sewage as a town of 65,000 people. Presumably, faster-growing fish would need more food and thus produce more feces and more contamination.

Still others are concerned about the potential health effects to those who eat modified fish. Developers say that the engineered fish will not look or taste any different to consumers, but critics point out that no one knows how proteins in genetically modified foods may differ from the proteins from which they originated. Farm raised salmon are known to contain higher levels of toxins, such as polychlorinated biphenyls (PCBs), than wild-caught salmon. If the cost of farmed fish declines and people's consumption of it increases, human health could be affected.

Salmon for sale

Experimental pigs

Golden Rice

According to the World Health Organization, many children around the world do not get enough vitamin A in their diets. This deficiency, also known as VAD (vitamin A deficiency), causes 250,000–500,000 children each year to go blind. VAD also weakens the immune system of approximately 40% of children under the age of five in developing countries. Damage to the immune system greatly increases the risk of serious complications from common childhood illnesses. Within a year after losing their sight due to VAD, more than half of the affected children die.

Researchers have been trying to combat VAD in developing countries, such as Asia and India, for years. Recently, genetic engineers have focused their efforts on inserting two genes into rice DNA to increase the amount of beta carotene present in the grains. When people eat beta carotene-rich rice—also called "golden" rice because the beta carotene makes it yellow—the body converts it to vitamin A.

The first generation of golden rice produced did not contain enough beta carotene to be effective. Newer versions of the rice contain more beta carotene. By eating 100–200 grams of golden rice a day, the amount most children in Asia and India already eat per day, children can obtain the amount of vitamin A their bodies need.

People without access to fresh fruits and vegetables are the people most likely to suffer from

Normal rice

Golden rice

vitamin A deficiency. Golden rice provides a cheaper and easier way to deliver vitamin A to the remotest of areas, since vitamins could essentially be grown on the spot and would not have to be transported. Golden rice is being donated to developing countries.

Researchers recognize that the best way to fight VAD would be with a healthy diet containing a variety of foods. But because of poor economies, agricultural variations, and traditional cultures, making changes in diets across the globe is not always achievable, especially in the short term. Golden rice offers a small step toward the goal of eliminating VAD in that it is a variation on a food that many communities already eat. Critics worry that if introduced on a large scale, golden rice could actually increase malnutrition by providing a single food that focuses on one nutrient.

As with many genetically engineered crops, golden rice poses an environmental risk since its pollen could contaminate nearby crops and cross-fertilize non-genetically engineered rice. The potential effects of such contamination on wild rice and native rice species are not known and may or may not be significant. Thai farmers, who produce 36% of global rice exports, do not want problems in exporting their rice to countries that ban all genetically modified food crops. Some scientists are also concerned about the possible ecological effects of a monoculture, the cultivation of the same crop in the same field each year without any crop rotation. A golden rice monoculture could potentially decrease the ability of the system to recycle nutrients, increase the need for pesticides or fertilizers, and cause environmental toxins to move through the food chain and end up in water and soil.

Terraced rice fields on Bali

Rice Pharming in California

Part 2: From the "Flavr Savr" to the 2007 Rice Crop

The sale of genetically engineered foods in the United States dates back to the 1990s. The first genetically engineered product—the Flavr Savr tomato—started selling in 1994, but was not a commercial success. Scientists engineered the Flavr Savr to stay fresh longer than conventional tomatoes. In 1996, the first genetically engineered soybeans became commercially available. By 2005, 60% of all soybeans grown in the world were genetically altered. As of 2007, more than 20% of all corn, cotton, and canola grown in the world were genetically altered varieties resistant to insects, disease, drought, and salts in the soil.

Super Rice

In 2000, scientists inserted genetic material from maize into the rice plant, creating "super rice" that could outproduce regular rice by 35%. Scientists have also genetically engineered rice to provide greater nutritional value. In 2000, they introduced "golden" rice, which offers 23 times the amount of beta carotene (vitamin A) found in regular rice. Like Ventria's pharm crop, Golden rice was developed to improve nutrition in developing countries. It is still being tested and is not yet available for human consumption.

Heirloom tomatoes

Resistance

Around the same time, a worldwide sentiment of public resistance began to grow against genetically engineered crops. Much of this resistance originated in Europe, where countries in the European Union have attempted to block engineered foods from the food supply. Japan has also refused genetically modified foods. Some opponents of bioengineering in the United States argue that eating genetically engineered food could carry health risks, such as allergic reactions and antibiotic resistance. They also caution that genetic engineering could reduce biodiversity by contaminating the gene pool of native species.

In 2000, an independent organization tested taco shells sold at a large supermarket chain and reported that it found evidence of genetically engineered corn approved only for livestock. The contamination led to an approximate 10% drop in the price of corn. California rice farmers began to worry that Japan might refuse their exports. In 2004, the California Department of Food and Agriculture (CDFA) blocked Ventria Bioscience from planting 120 acres of the nation's first commercial pharm crop. By taking this action, the CDFA hoped to send a message to Japan that the table rice crop would remain secure from genetic contamination. (Subsequent to these actions, concerns have been raised about the protocols that were followed in the research that was the basis for these decisions.)

Field Testing

The decision surprised Ventria Bioscience, which had already received approval for field-testing in California for many years. The company applied for permission to plant the modified rice in other states and settled in Kansas, where it plans to grow acres of the protein-producing rice. Unlike California, Kansas has no rice industry, so farmers can continue to grow their regular crops without fear of cross-pollination. Although normally self-pollinating, rare cross pollination can occur.

In 2007, the California rice crop was planted late. Gasoline prices were high, and the Department of Agriculture predicted a 13 percent drop in the rice harvest. To make things worse, in other parts of the U.S. small amounts of genetically modified rice appeared in stored rice destined for the food supply. The Department of Agriculture traced the modified rice to Bayer CropScience, a company that produced rice not meant for human consumption—it was resistant to a weed killer.

Overcoming Fears, Tightening Controls

When the news broke, rice futures (stocks) fell by $150,000,000 and European stores pulled all of the U.S. rice off the shelves. Japan announced that it would test every rice shipment entering the country and threatened to ban all U.S. rice imports if it found evidence of genetic modification. None of the questionable rice was found in California, but that did not seem to ease Japan's concerns.

Rice farmer Russ Greenwald said he worries that this event could be the end of California's rice exports to Japan. "We were hoping that fearful attitudes would change overtime," he said. "But now it looks like it might take longer." As a rice farmer, Greenwald knows how much California farmers depend on the sale of rice to Japan. He said he also believes that some types of genetically engineered food could potentially be unhealthy for human beings or bad for biodiversity. "But that's only part of it," he says, climbing back into his truck. "We also have an opportunity to improve the quality of life for people in developing countries. We should think about that as well."

Rice growing

In March 2007, the California Rice Commission called for an end to the production of all genetically engineered rice in California until tighter controls are placed on the growth and research of genetically engineered rice. California rice farmers continue to produce major crops of other rice varieties, such as basmati, arborio, and jasmine.

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