YOUR WORLD

Biotechnology & You

A magazine of biotechnology applications in healthcare, agriculture, the environment, and industry.

Biotechnology INSTITUTE

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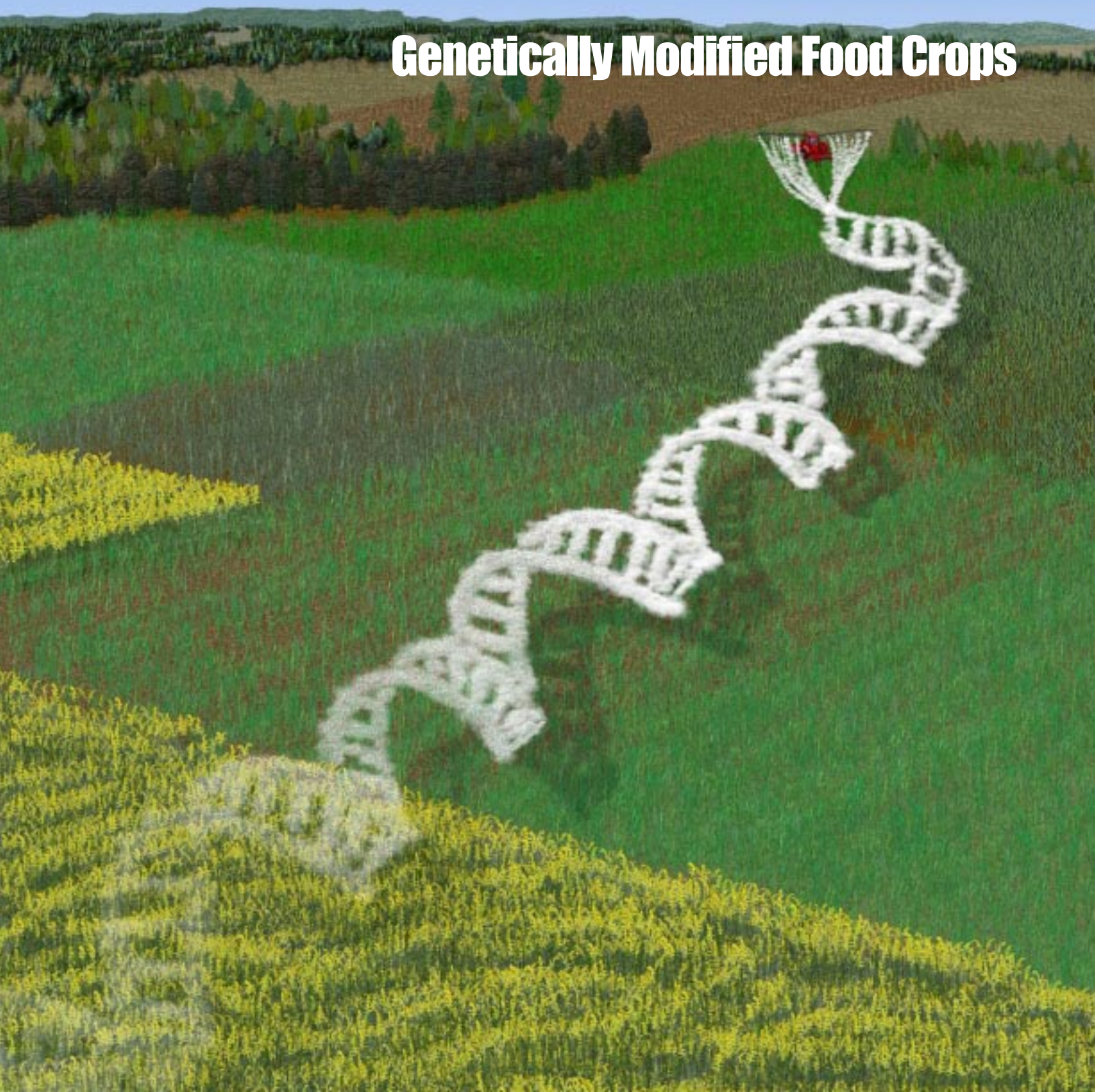


Genetically Modified Food Crops

About This Issue...

The Gene Revolution in Food

First Questions

- How is our food grown?
- Which food plants are wild?
- What do genes do?
- What plants are safe to eat?
- Can eating genes "infect" you?
- Are all bacteria bad for plants?
- Can carrots make you see better?

How many hours did you spend growing your food yesterday? You probably just walked to the fridge. But a hundred years ago you might have worked more hours in the fields than in school. In the developing world, that's still the case, and food is both scarce and expensive.

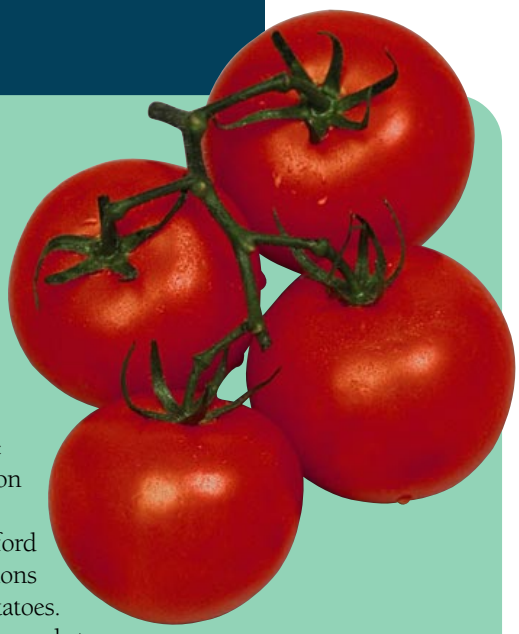
Throughout history, people's main concern was producing enough food. Civilization advanced as we developed agriculture. For 10,000 years we bred wild plants to produce more food with less work. Agriculture got a boost in the 1950s with new chemicals that control insects, weeds, and disease. At the same time, plant breeders developed more productive varieties of wheat, corn, and rice. Together, new farm chemicals and improved crops led to much higher ***yields*** (amounts produced). This increase in production was known as the "Green Revolution".

The Green Revolution happened at a time when the world's population was growing so fast that experts predicted massive famines. But the new, more productive crops came to the rescue. India more than tripled the wheat grown on the same amount of land. There have been localized famines caused by drought, war, and political corruption, but no worldwide starvation.

As we enter the 21st century, industrialized countries are struggling with side-effects of the Green Revolution. The overuse of agricultural chemicals is polluting our land, wildlife, and water. In addition, the world's population is

"Whoever could make two ears of corn, or two blades of grass grow upon a spot of ground where only one grew before would deserve better of Mankind, and do more essential service for his country, than the whole race of politicians put together."

-The King of Brobdingnag, Gulliver's Travels by Jonathan Swift, 1727



growing beyond the Green Revolution's capacity to feed it. People are destroying sensitive habitats to create more farmland, but even so, there will not be enough land to feed the 9 billion people predicted by 2050.

Worse, many of the world's poor have never benefited from the Green Revolution because it did not solve the underlying problem: poverty. Many farmers can't afford the chemicals and improved seeds. Millions still survive on a daily bowl of rice or potatoes. They have no roads to stores, no fresh produce, and no vitamin pills – and their health suffers terribly. What can help them?

Many scientists think a new "Gene Revolution" can help both hungry humanity and the sensitive environment. The Gene Revolution uses biotechnology to create new ***genetically modified*** or "GM" crops. These crops can potentially produce more food with fewer chemicals and higher nutritional value than traditional crops. Scientists think they can improve even more crops than the Green Revolution did: not only grains, but also the legumes, vegetables, roots, and fruits that people need for a balanced, nutritious diet.

But some people worry that these crops are not safe to eat and could threaten the environment with unforeseen problems. They question whether government agencies test the products enough and whether corporate profit motives outweigh safety concerns. Some protesters have destroyed research laboratories and burned fields of GM crops.

This issue of *Your World* will help you unravel conflicting reports about agricultural biotechnology. Is it safe and environmentally friendly or an out-of-control experiment? You will learn how plants with specific traits are created, how to weigh the pros and cons, and how you can investigate these problems.

Contents...

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The Biotechnology Institute is dedicated to enhancing the understanding of bioscience among lay audiences and in fostering public education collaborations among bioscience companies, universities, and non-profit organizations.

Your World describes the application of biotechnology to problems facing our world by bringing scientific discoveries to life. We publish issues on different topics each fall and spring. If you would like information on subscribing for individual, teacher, or library sets, or if you would like to sponsor distribution in your area, contact the Biotechnology Institute. Some of the fifteen back issues are available.

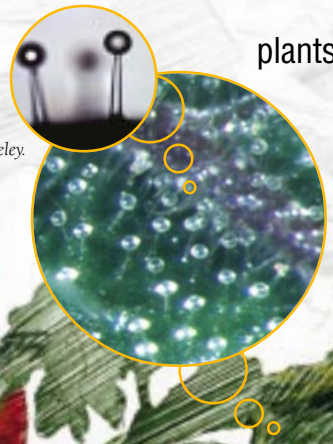
On the cover: For thousands of years, farmers have been crossbreeding plants to create better and healthier crops. Today, scientists are using their understanding of DNA to develop plants with specialized traits, ranging from disease and pest resistance to better taste and nutrition.

The Biotechnology Institute would like to thank the Pennsylvania Biotechnology Association, which originally developed *Your World.*

How do plants get different traits?

Creating Better Plants

Plants live in a hostile world. Animals chew them, insects chomp them, pushy plants surround them, and disease withers them. But plants are not helpless. They make oils, smells, and poisons to fight back.

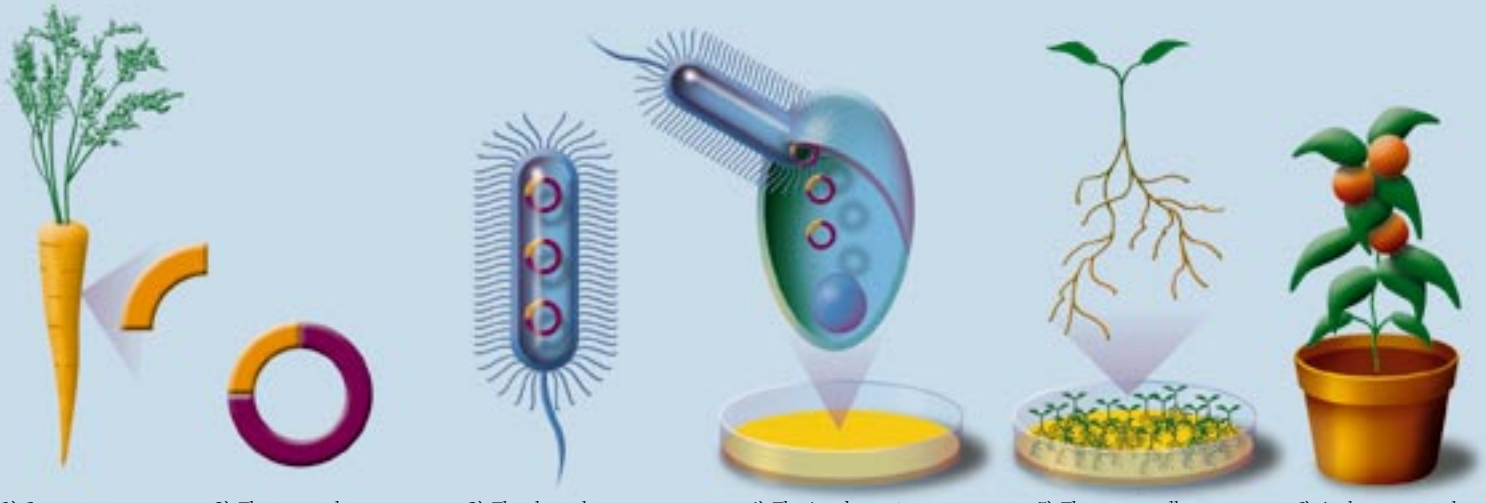


Photos courtesy of Shelia Colby, University of California, Berkeley.

If you look at a leaf of a tomato plant under a microscope, you'll see the leaf is covered with tiny hairs. These hairs emit chemicals that act like flypaper to trap little insects. How did this insect-fighting trait come about?

Creating a Vitamin-Rich Tomato with a Carrot Gene

The bacterium Agrobacterium *naturally infects plants. It carries some genes on a circular piece of DNA called a* ***plasmid*** *and inserts those genes into plant cells. Scientists are now able to remove the bacterium's genes that cause plant disease and add a gene for a desirable trait.*



1) Scientists copy a carrot gene that converts a pigment to beta-carotene.

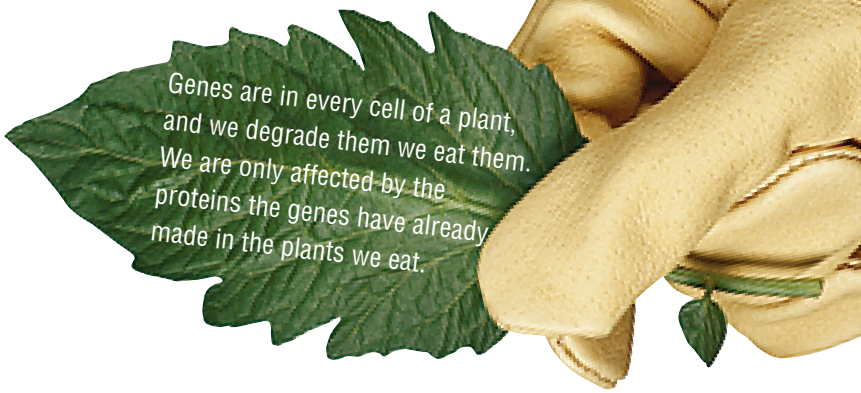
2) They insert the carrot gene into a plasmid.

3) The plasmid is reintroduced into the Agrobacterium.

4) The Agrobacterium *transfers the carrot gene to the cells of tomato leaves in a petri dish.*

5) The tomato cells grow and divide in a culture with hormones that encourage the cells to become new shoots and roots.

6) As the tiny new plants grow, the carrot gene converts the tomato's pigment into beta-carotene, creating an enhanced tomato.



Natural Selection

Wild tomatoes may have developed these tricky leaf hairs by chance. To reproduce, plants pollinate each other. In doing so, they exchange ***genes*** – the molecular instructions that produce different traits. The offspring have a different combination from either of their parents. Occasionally, genes undergo ***mutations*** (changes) during this mix. One such change made the leaf hair cells produce the sticky insect-fighting proteins. This mutation gave that plant an edge over others, so it passed its insect-resistance on to new generations.

Selective Breeding

Along came the age of farming, and people noticed the insect-resistant tomato. They selected it to pollinate other tomatoes, such as those with bigger fruits. To understand selective breeding, imagine that a gene is a book in a library. Different tomatoes have different versions of certain books. One plant may have a book for the insect-trapping flypaper. Another plant may have a book that makes big fruits. If a farmer cross-pollinates these two plants, eventually one offspring might combine both traits. But genes don't mix individually; they come "linked" with other books on their shelves. The big fruit book may come linked to a sour fruit book. Getting rid of that sour book might take generations of selective breeding, if it could be done at all.

Photo courtesy of Scott Camazine, Penn State University, Department of Entomology

Selective breeding has given us a huge variety of plants. Over time, cultivated varieties have little similarity to the original wild plant. For example, early Native Americans cultivated corn from a wild grass called teosinte. Carrots were yellow until a mutation created an orange one in the 1700s. Two thousand years ago a single gene mutation in a peach produced a nectarine. Observant farmers selected these pleasing surprises and bred them.

Discoveries Behind Genetic Engineering

The door to genetic engineering opened when scientists realized that all genes are written in the ***universal language of DNA***. Learning to use ***plasmids*** (see illustration) and special "cut and paste" proteins called ***restriction enzymes*** allowed them to "edit" DNA. Now, plant ***genomics*** is cataloging genes that could give plants beneficial traits, as well as genes we could eliminate to make food safer. (See box on page 7.)

Hybridizing Plants

Selective breeding has limitations. You can only breed tomatoes with closely related plants. What if you want a tomato with a trait found in a distant relative? Wild tomatoes, which are like little berries, can fight off a soil bug that attacks the roots, but many wild varieties can't pollinate modern tomatoes. Scientists broke the pollination barrier by combining their germ cells and nurturing them in a laboratory tissue culture. They produced a ***hybrid*** (mixed) tomato with the ability to repel soil bugs.

Inducing Mutations

Cross-pollinating and hybridizing depend on natural variations, and plant breeders search the world for useful traits. To entice more variations than nature provides, scientists zap seeds with radiation and chemicals. Occasionally this method produces a desirable variety, such as a bean that grows as a bush rather than a vine.

Think about it!

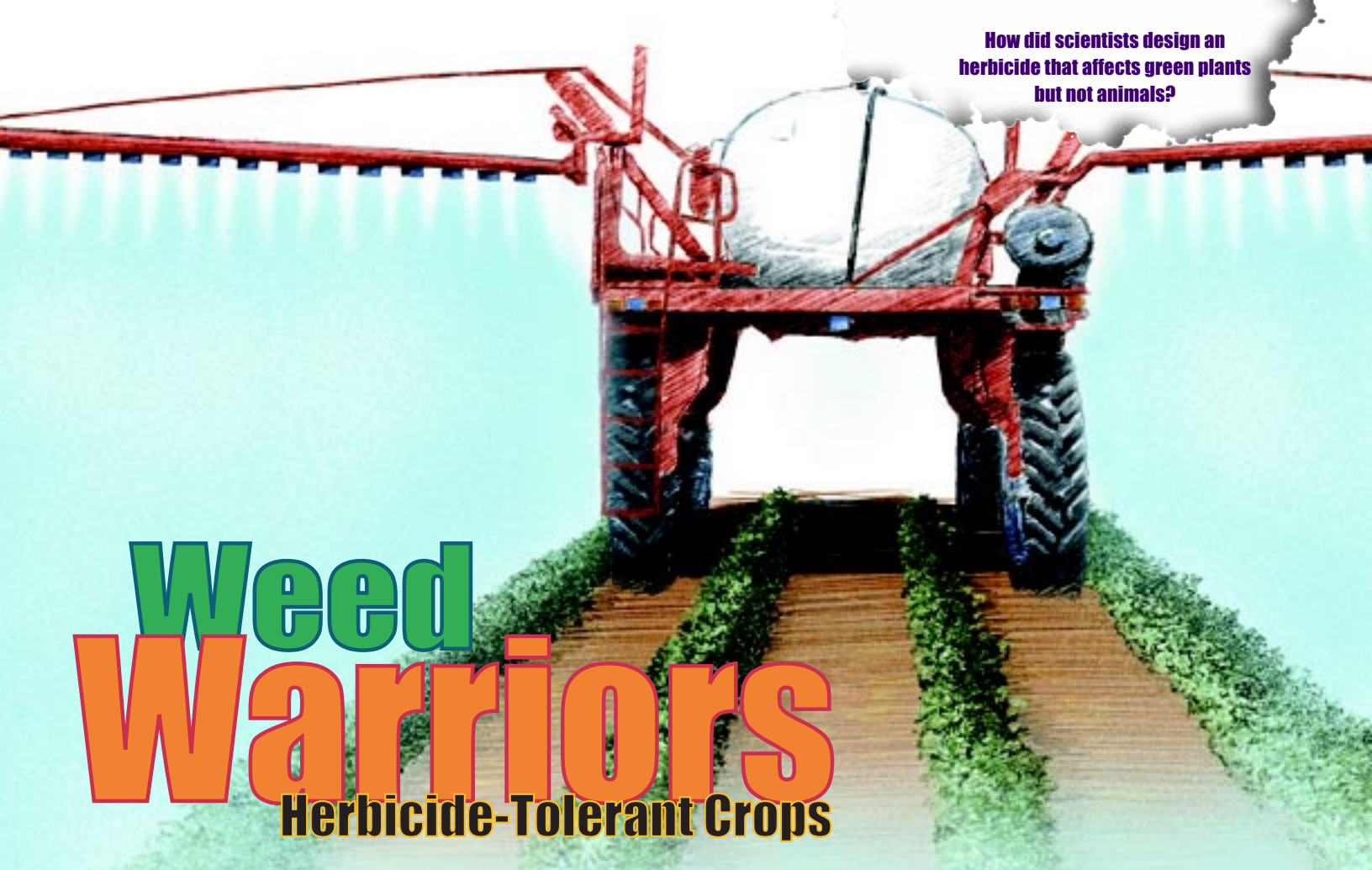
Is genetic engineering a logical continuation of the way farmers have been modifying food for centuries? Or is it an entirely new – and perhaps risky – process?

Genetic Engineering

All these methods give us some control over plant breeding, but they are time-consuming, trial-and-error processes. Since the 1980s, genetic sciences have made plant breeding more quick and precise – and expanded its reach. ***Genomics*** (the study of an organism's entire genetic instructions) is identifying genes that produce specific traits. Before, scientists didn't know which book gave the tomato leaf its sticky compound that traps insects. Now, they can pinpoint the exact book for the flypaper goo. They can pick that book off the shelf, copy it, and put it in other plants. In this way, they make a ***genetically modified*** plant. Scientists can borrow books from unrelated species to get traits like disease resistance, faster growth, better flavor or nutrition, or longer shelf life.

For example, tomatoes have a pigment that gives them their bright red color and special flavor. Carrots produce a protein that could turn that pigment into ***beta-carotene***, which our body turns into vitamin A. The illustration on page 4 shows how scientists used the "natural" genetic engineer, a bacterium called ***Agrobacterium***, to modify a plant. Another method coats a tiny gold pellet with genes and shoots it into plant cells that then grow into plants.

Career Connection: Plant Breeder: *Develop new plant varieties with needed traits.*



Weed Warriors

Herbicide-Tolerant Crops

Some of the first GM crops to hit the fields are popular with farmers but controversial with some people. These crops are engineered to withstand herbicides that are sprayed on fields to kill weeds.

Weeds can take over a field, and keeping them out takes backbreaking work. In Africa, most farmers are women, and they spend half their time weeding! Many farmers spray ***herbicide*** to kill specific weeds at different times. ("Herb" mean plant and "cide" means kill, as in homicide.) In Africa, some weeds are parasites that can't be sprayed without destroying the crop. Where herbicides can be used, weeds can become resistant to them, so farmers need ever-stronger and more diverse chemicals to kill them. But many herbicides harm animals and insects, and they last a long time in the environment.

Scientists developed less toxic herbicides to reduce these risks. One such chemical is ***glyphosate,*** which is marketed as Roundup®. Glyphosate kills green plants by shutting down the production of essential amino acids. Insects and animals get these compounds in their food, but plants have to make them. To do so, a molecular "key" fits into a protein "lock," turning on an essential amino acid "machine." Glyphosate mimics the key, slips into the lock, and jams it so the machine can't start. The plant starves to death! Animals don't have that molecular lock because we don't need the machine, so glyphosate doesn't affect us. It also breaks down quickly and doesn't stay in the environment.

If farmers sprayed glyphosate on their fields, it would kill both weeds and crops. Thus, scientists made crops that withstand this herbicide. They added a gene to produce a slightly different lock. The mimic key can't fit it, but the plant's own key can. The essential amino acid machine keeps working, so the crops survive while the weeds die. "Roundup Ready®" crops also allow farmers to kill parasitic weeds. The new gene doesn't change the crop plant in any other way.

Before, farmers only had the option of hoeing or plowing the fields to kill weeds before planting. This practice causes soil erosion and water pollution. With herbicide-resistant crops, farmers no longer have to till, saving them work and money. Zero tillage also helps preserve the soil and water.

Farmers in the United States adopted GM seeds for crops that traditionally need a lot of herbicides. In just four years since their introduction, more than half of the US soybean crops grew from GM seeds. Did you know you eat soybeans all the time? Look at the labels on your snack foods!

What could happen if no farmers used herbicides?

Are herbicide-resistant crops good or bad for the environment? Make a chart of the pros and cons! Should we use them?

Risks and Benefits

Soon, critics questioned the wisdom of GM crops. They might be convenient for farmers, but are they safe to eat? A GM plant has a tiny change in the protein lock that our bodies just digest like any other protein. Glyphosate itself is less toxic to us than table salt. However, the spray contains other ingredients that may pose risks to fish and wildlife if used irresponsibly – and to people who get the spray on them. Still, it is much less toxic than other herbicides. Also, farmers spray it before the edible parts of the plants form, so it isn't on the food we eat.

Superweeds?

Another concern is whether herbicide-resistant crops will lead to "superweeds." Could the crops pollinate weeds and give them herbicide resistance? Would these resistant weeds spread out of control like the invasive kudzu vine in the south? Scientists began studying this possibility when developing herbicide-tolerant crops through conventional crossbreeding.

A herbicide-resistant crop can only pollinate a closely related weed. The Western Hemisphere has no wild relatives for soybeans, so herbicide-resistant weeds seem unlikely in this case. In the Eastern Hemisphere, the soybean does have weedy relatives that could get the herbicide-resistant gene. But in the wild, no one sprays herbicides, so herbicide resistance wouldn't be an advantage and the weed might not take over in nature. In the soybean field, farmers could use other herbicides to kill the weed, since it would only resist glyphosate. U.S. regulatory agencies are closely monitoring fields to make sure herbicide-resistant weeds are destroyed if they appear.

Food Safety

Food safety is no laughing matter. Every year, hundreds of people die from food poisoning and many more are sickened by bacteria on food. Likewise, the green parts of potatoes contain a toxin (glycoalkaloid), which breeders monitor before they release the potato seed. U.S. regulatory agencies test produce for leftover chemicals (residues), and they also test GM crops. People are concerned that GM goods could create new, unknown food allergies. Companies test the introduced gene for allergic properties and they must label a food if the gene comes from a known allergen such as nuts or wheat. Fungus and molds on foods cause health risks, and they are more common on organic crops that don't use fungicides to kill them. A mold that grows on corn and peanuts produces the cancer-causing chemical aflatoxin and can cause a whole crop to be rejected.

Peanuts can cause deadly allergic reactions. Scientists have identified three genes that code for the allergic proteins. They are trying to deactivate these genes to make a non-allergenic peanut.

Herbicide-resistant crops have a gene that lets them bypass the glyphosate road block. They can still make the amino acids they need to live.

Career Connection: Field Researcher: *Expand upon laboratory research by testing in "real world conditions."*

Can insect-resistant corn harm butterflies?

The Monarch Butterfly Effect

Insect-Resistant Bt Corn

Bt crops carry a gene from a bacterium that kills insects. Already Bt crops have eliminated millions of gallons of pesticides, especially in cotton. Then reports that Bt corn kills monarch butterflies set off tornadoes of concern.

Decades ago, farmers discovered that a soil bacterium called *Bacillus thuringiensis* (Bt) infects and kills the caterpillars that eat their crops. The bacterium produces a protein that is harmless – until it turns toxic in the caterpillar's stomach. There, an enzyme cuts the Bt protein into pieces that lock into a special ***receptor*** (protein "lock)" in the caterpillar gut. This locking action destroys the gut and kills the caterpillar. Adult butterflies – and other insects and animals – don't have any "locks" for the Bt toxin. Bt doesn't harm wildlife the way traditional pesticide sprays do. In fact, organic farmers have relied on this natural biological pesticide for years.

Scientists inserted the gene for the Bt protein into crops that are frequently destroyed by caterpillars. The plants produce the Bt protein in their leaves. When the caterpillars eat the leaves, they die – without pesticide sprays.

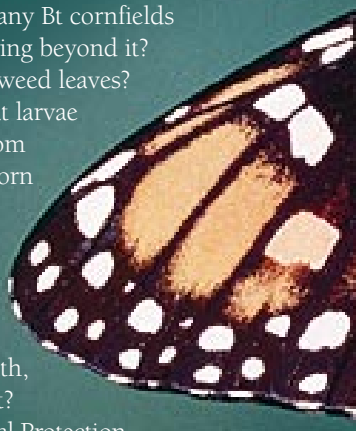
"Cheer as the mighty cornstalks battle wind, hail, and rainstorms."
CornCam — www.iowafarmer.com/corncam/corn.html

The Beautiful Monarch

Monarch butterflies begin their life cycle as caterpillars (larvae). The adults drink only the nectar of milkweeds, and they lay their eggs on the milkweed's leaves. Monarchs migrate far and wide throughout the United States, but all return to one small, unique area in Mexico for winter. Recently, part of that habitat has been destroyed, and pesticide sprays throughout the migration path have further reduced the monarch's numbers. Naturally, people are concerned about new threats to the butterfly's well being.

Several researchers planned a simple laboratory experiment to see what effect Bt corn had on monarchs. They grew two types of corn: a "control" corn and a Bt variety. Then they dusted the corn pollen on the leaves of milkweeds. Scientists put these leaves in petri dishes with monarch caterpillars, which ate the pollen. The larvae that ate Bt pollen died within days, while the other larvae lived. A press release of this study caused immediate concern. Bt corn was killing the beloved "Bambi" of the insect world!

Of course, life in the fields is not so simple. Other researchers are studying whether monarchs are actually harmed by the Bt corn grown in their migration path. Do the caterpillars eat significant amounts of corn pollen in the wild? Does Bt harm adult butterflies? Do milkweeds grow near cornfields? Does the corn pollen drift to the milkweeds in harmful amounts? Does the border of non-Bt corn that surrounds many Bt cornfields (see next page) keep Bt pollen from drifting beyond it? Does corn pollen stick to the waxy milkweed leaves? Does corn pollinate at the same time that larvae hatch, and how does this timing vary from region to region? Finally, how does Bt corn compare to the alternative – spraying non-selective pesticides over fields? Do pesticide sprays drift farther than corn pollen? How do these sprays affect wildlife, human health, and the environment?



The Environmental Protection Agency called for more studies to answer such questions. (For links on these studies – and to design one yourself – see page 15.)

"Farming looks mighty easy when your plow is a pencil, and you're a thousand miles from the corn field."

-Dwight D. Eisenhower

Photo provided by USDA

Corn Borer

Refuges from Superbugs

You may know that bacteria can become resistant to an antibiotic medicine. Bacteria mutate so rapidly that one offspring might survive an antibiotic attack. That offspring will thrive and produce a new strain of resistant bugs. The same thing happens with bugs in the field. Eventually, insects become resistant to pesticides – even to Bt crops. To delay that day, farmers must plant sections of non-Bt crops in their fields. These non-Bt sections are called ***refuges*** (safe places). Bt-resistance won't give insects in the refuge any advantage over non-resistant bugs. Thus, non-resistant bugs survive. When they mate with resistant insects, the offspring have less resistance. Researchers are testing what size and shape refuges should be. Farmers can also rotate crops to interrupt the multi-year life cycle of insects and they could use Bt crops only on a "prescription" when the bugs are thriving.

Think about it!

Should a GM food be treated differently because it was made using genetic engineering?

Regulation

"Natural medicines" such as Echinacea aren't tested unless it's proven that one causes serious harm. Likewise, traditional foods aren't government regulated, even though they can contain known toxins or allergens. GM crops were regulated from the beginning, and these regulations were strengthened in 2000. The Environmental Protection Agency (EPA) requires permits and testing for pest- and herbicide-resistant crops and is researching the potential problem of superweeds and superbugs. The Food and Drug Administration (FDA)'s position is "Product, not process." It judges a plant's nutrients, not the process used to make it (genetic engineering). Companies must submit detailed safety information to the FDA before introducing a new GM food. The Department of Agriculture (USDA) oversees field tests of GM crops.

Career Connection: Entomologist: *Study the insects that destroy crops and those that protect crops and delight our eyes.*

How are scientists modifying rice through genetic engineering?

Golden Rice

The bright orange of carrots comes from beta-carotene, which forms vitamin A in our bodies. Yet 250 million people suffer from vitamin A deficiency. Each year a half million children become blind from lack of vitamin A and over half of these die within months.

Ideally, everyone would have a varied diet with lots of produce that supplied ample vitamin A and other nutrients. Better nutrition could prevent up to two million deaths in children under the age of four each year. But that requires more prosperity for much of the world – something that's a long way off. Nearly half the world's population survives on a daily bowl of white rice, which contains no vitamin A. Making rice more nutritious could improve people's lives tremendously.

Nutritious Genes

A team of researchers decided to try creating a rice that contains beta-carotene (the compound we convert to vitamin A). They were inspired by the bright yellow daffodil. How did it produce beta-carotene? They found that several daffodil enzymes manufacture beta-carotene from other molecules. Rice has those other molecules, but it doesn't produce the enzymes to rearrange them into beta-carotene in its kernel. Could they give rice the genes for those enzymes and get them to work together? Previous researchers had inserted several genes that worked individually to make separate products. No one had successfully inserted a group of genes that had to work in sync to make one product.

They tried putting the genes in a gene gun and shooting them into rice cells. That didn't work, so they put two genes in one *Agrobacterium* and another gene in another *Agrobacterium*. Both bacteria "infected" the rice cells, inserted the new genes, and soon the lab grew rice plants carrying all three genes. It was easy to see that the genes worked because of the kernels' golden glow. A bowl of this "golden rice" provides enough vitamin A to keep a person healthy.

Photo courtesy of Peter Beyer, Institut Für Biologie II, Freiburg, Germany

Meanwhile, researchers are working on a related nutritional problem. White rice also contains very little useable iron, and without iron, children don't grow or learn well. Iron deficiency causes 40 million mothers to have premature and low weight babies. Many of these mothers and babies die of anemia. The solution also involves several genes from several sources: a fungus, another kind of rice, and a green bean. These genes produce proteins in the rice kernel that help the human body absorb and store iron. Again, they are using *Agrobacterium* to get the genes into rice.

Someday, researchers may crossbreed the rice plant that makes beta-carotene with one that makes iron to produce a hybrid that makes both essential nutrients.

The research team worked ten years on golden rice. They are working out legal issues so they can donate this rice to farmers in developing countries.

Photo provided by National Geographic Society

Terraced rice fields in Bali, Indonesia.

More Food Per Acre

We will need to double the food we grow to feed the world in 2050, but we can't double the amount of farmland. There just isn't that much arable land left, and we also want to preserve natural habitats and biodiversity. Over the past 50 years, more productive crops have spared millions of acres of wilderness around the world from becoming farms. GM plants may help increase food production so that we can produce the food we need without taking up more land. We may have plants that need less water for irrigation so we preserve our limited water supplies. Someday, crops may grow where it is too dry, too cold, or too salty for anything to grow now.

point counterpoint

Some people say GM crops can benefit poor, small farmers because they won't need chemicals or equipment to improve their farms. Others say farmers will become dependent on huge international seed companies. Follow this debate in the news!

More Rice in the Bowl

Golden rice may be more nutritious, but soon there simply may not be enough rice of any kind to feed the growing populations in Asia. These countries will need to grow 40% more rice by the year 2020. Earlier, scientists increased a rice crop's productivity through traditional crossbreeding. They bred a rice with a sturdier stalk that didn't flop down into the waters of the rice paddy and rot. This simple change increased yield by reducing waste. But for more dramatic improvements, scientists are turning to genetic engineering.

Some researchers seek to reduce waste even more by developing insect-resistant rice using variations of the Bt gene. Insects currently ruin about 25 million tons of rice each year, both as the plants are growing and after the rice is harvested. Reducing these yearly losses could feed 120 million people!

Another project boosts the productivity of rice by revving up its photosynthesis. Rice belongs to an old line of plants that developed when our atmosphere had more carbon dioxide (CO_2) than today. Newer plants, such as corn, evolved when the atmosphere had less CO_2. They use CO_2 more efficiently by using a kind of "CO_2 pump". Researchers put the genes for the "pump" proteins in rice. That rice grew faster and lusher, producing up to 35% more grain. Many other foods – potatoes, wheat, oats – also use CO_2 inefficiently. Tomorrow's scientists may be able to boost their yield to help feed the extra billions who will soon share the earth.

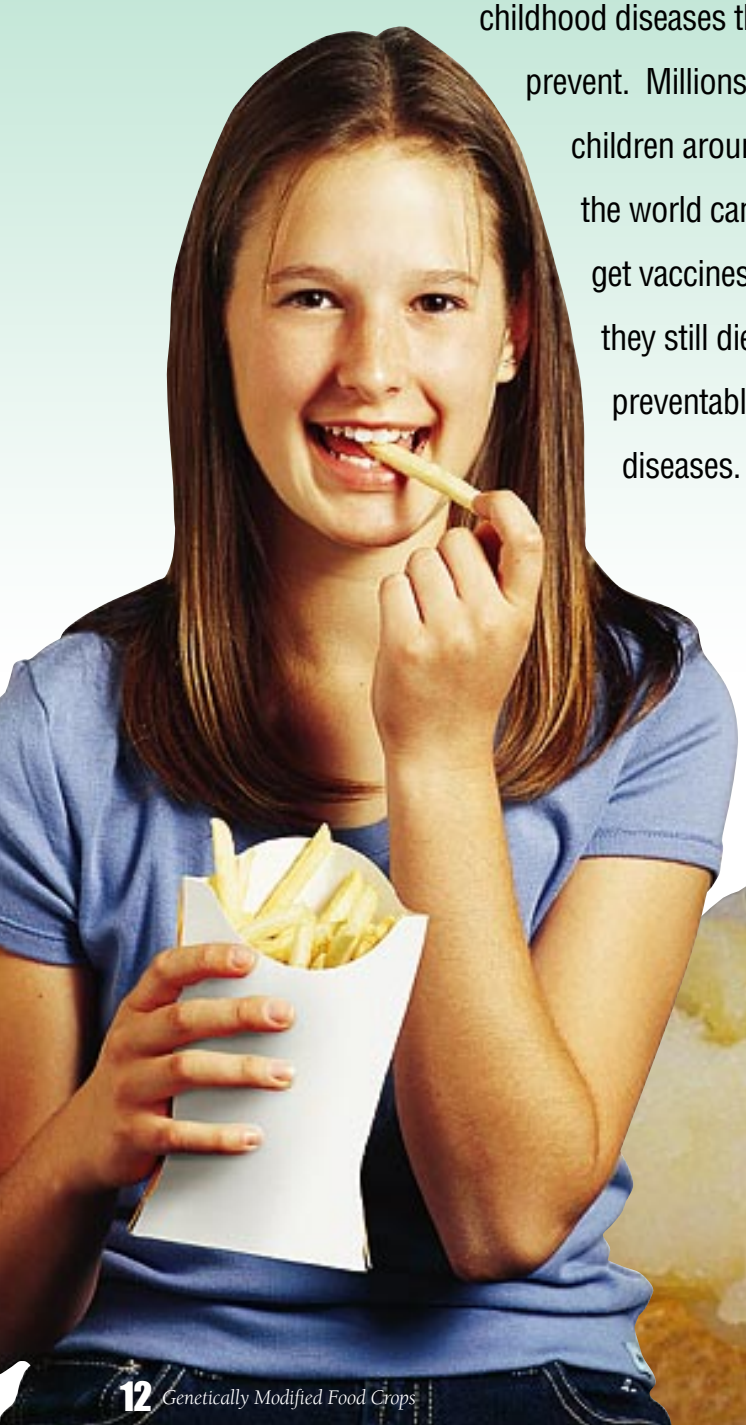
Career Connection: Greenhouse Technician: *Grow new varieties from tissue cultures and conduct experiments on plant growth and pest/disease resistance.*

How could plants improve medicine and health?

Potato Power

Edible Vaccines and Healthy Fries

You may have cried when you got your first vaccine shots, but at least you haven't died from the horrible childhood diseases they prevent. Millions of children around the world can't get vaccines, so they still die of preventable diseases.



Many poor countries can't afford vaccines or can't get them to remote villages. Clinics often can't refrigerate the vaccines or sterilize needles. These problems make safeguarding millions of children extremely difficult. In addition, most vaccines are made from the infectious organism that causes the disease. Every once in a while such vaccines can cause harmful side effects, even the disease they are supposed to prevent.

In 1991 the World Health Organization challenged scientists to create a simpler, safer, cheaper way to vaccinate children. Some scientists began to brainstorm about plants. Since plants naturally make a number of different compounds, could they be reprogrammed to make edible vaccines?

Potato Vaccines

Researchers tried making a cholera vaccine using plants. Cholera is a bacterial disease that causes deadly diarrhea. It spreads rapidly where people don't have clean water and it kills two to three million children each year. Researchers pinpointed part of the cholera bacterium that the human immune system can recognize, so it could be used as a vaccine. Scientists found the genes that make that bacterial part. After some trial and error, they put those genes into potatoes to

turn potatoes into a handy vaccine. Potatoes grow in many areas of great health need, and they can withstand long shipping and storage. But there is a snag. People don't eat raw potatoes. So scientists cooked them and found that some of the vaccine still survives. When people ate these cooked potatoes, their bodies made some of the antibodies that can protect them from cholera.

Imagine getting your vaccines and boosters from potatoes or some other food instead of painful shots! But that's still a ways off. With the cholera vaccine, researchers need to adjust the dose in each bite and find ways to package them. Of course, people will get their vaccine bits from nurses and clinics, not from the supermarket. Ideally, edible vaccines wouldn't spoil, which would cut the cost and difficulty of delivering them in the developing world. They'd be more pleasant, too.

Fries for the Overfed

In industrialized countries, most people don't suffer from too little food. They suffer from too much. Obesity is a major health problem even for children. We all know that we should avoid greasy french fries and sugary sodas, but it's hard! If we can't take the junk food away from people, maybe we can take the "junk" out of food – but keep the taste in.

Again, scientists are looking at the potato. When it's fried, oil replaces the water in the potato. But the starchier the potato, the less oil it soaks up. Restaurants pay a premium price for high starch potatoes because they make crisper, less greasy fries. Scientists are trying to develop potatoes with even more starch so they will soak up even less oil.

Another way to make a healthier fry is to make healthier oil. Scientists have already modified plants like soybean and canola to produce a less saturated, more healthy fat. Future plants may make even healthier oils that actually strip away fatty deposits from your arteries.

What about that soda with your fries? Scientists are working on that, too. They are modifying the sugar beet to produce an enzyme that changes sugar (sucrose) to fructan. Fructan tastes like sugar, but we don't digest fructan so it adds no calories. They have also cloned the gene for a protein in an African plant that tastes a thousand times sweeter than sugar! We could get the same sweetness with a thousand times less sweetener.

Other Branches

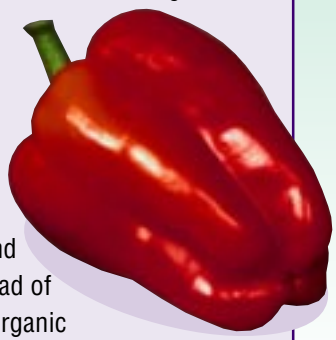
These are just a few examples of how plants can be engineered to make medicines and healthier foods. In addition to food crops, scientists are working on projects ranging from making more brilliant flowers that bloom longer to trees that can clean up mercury contamination in soil. Some of the methods used for genetic engineering can also be used to preserve endangered plant species that hold many valuable secrets.

Think about it!

- **Is any agriculture production system truly "natural"?**
- **Would third world farmers welcome GM crops that increase yield and nutritional value without chemicals?**
- **If it is immoral to make GM crops, what about not producing crops that could prevent starvation or disease?**

Organic Farming

Some people believe that GM crops are unnatural. Some believe we should expand sustainable organic farming instead of Green and Gene Revolution technologies. Organic farmers battle insects by rotating crops and using friendly ladybugs. They mulch and weed instead of spraying herbicides and they use manure instead of synthetic fertilizers. Organic farming is appealing, but can it feed the world? Most organic farms are small and can't mass produce food for huge populations. In general, organic farming doesn't produce comparable yields per acre, so it uses more land and costs more. Also, using uncomposted manure can increase the danger of bacterial contamination in food. Many farmers in the developing world are "organic", but not by choice. They are subsistence farmers with few resources, who can barely grow enough food for themselves. Often, they can't afford animals that produce manure for fertilizer. They have no means to fight the plant diseases and pests that destroy their crops. GM crops might be useful tools for them.



Career Connection: Food Scientist: *Study ways to turn plant products into safe, nutritious foods.*

PROFILE

Florence Muringi Wambugu grew up on a small subsistence farm in Africa. Now she directs the African Center of the International Service for the Acquisition of Agri-Biotech Applications.

Courtesy of ISAAA AfriCenter

Florence Muringi Wambugu

Florence Inspects banana plants in Kenya.

When Florence was a child, the farm provided her family's entire income and all their food. "My mother always tried to grow more food," Florence recalls. "She looked for better seeds. She couldn't afford chemicals, so she used ash to control insects. It was not easy, but she made enough money to send all of us to school. My mother was the inspiration for my career in agricultural research."

Florence wanted to use science to help communities like her own. She studied botany at the University of Nairobi in Kenya. She traveled to America for a Master's in plant pathology at North Dakota State University and then to England for a Ph.D. in virology from the University of Bath. Back in the U.S., she conducted post-doctoral research at Monsanto.

All the while, her heart never left her village. Her research focused on the sweet potato and the viral diseases that kill it. "When we were young, there was not always enough food. We grew many crops, but we depended on sweet potatoes. They were always there when there was nothing else to eat. But in the tropics, sweet potato crops produce only a third as many potatoes as they do in Asia. A virus kills up to 80% of the crops in Africa. A family's very survival is threatened when viruses strike their crops. I wanted to solve a national problem: creating a sweet potato with virus resistance."

Fighting viruses in crops is something only biotechnology can do. Pesticides, herbicides, and fungicides can't control plant viruses. Researchers have to find the genes that produce proteins that keep a virus from replicating. Florence devoted ten years to transferring such genes into sweet potatoes and preparing the plants for field trials in Kenya. During that time, she worked at the Kenya Agricultural Research Institute and at Monsanto in St. Louis with other Kenyan scientists.

Florence now directs the African Center of the International Service for the Acquisition of Agri-biotech Applications (ISAAA), introducing agricultural technology to benefit Africans. Virus-resistant sweet potatoes are just one of the genetically modified crops Florence thinks can help Africa. For example, GM seeds for a more productive banana cost more, but farmers are buying them. "One woman never sold more than five bunches of bananas in a day. She sold 48 bunches of the new banana. Now she has expanded her kitchen and banana orchard and increased her food and farming income."

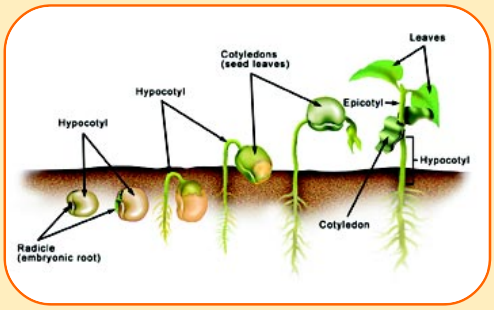
"People in wealthy countries criticize GM crops," Florence says. "They have no real need for them – nobody is hungry. But there is real need in Africa. A hungry person is not a myth. It's a person I know."

Growing Soybeans and Researching Monarchs

something You can Try

Growing Soybeans

Can you tell the difference between a genetically modified plant and a traditional one? Do the seeds look different? Do they germinate and develop differently? Do they respond differently to their environment? Find out by using an activity kit provided to your teacher. You will compare traditional soybeans and GM "Roundup Ready®" soybean seeds that have been genetically modified to withstand the glyphosate in the herbicide Roundup®. (See the "Weed Warriors" article on pages 6-7.) Here's what you will do:



Day 1: Plant four GM soybean seeds in one flowerpot and four traditional soybean seeds in a second flowerpot. Give them plenty of water and light, and record your observations daily.

Day 5: Sprinkle the pots with weed seeds and continue watering and observing the seedlings.

Day 15: Apply the herbicide Roundup® to all the soybeans and weeds in each pot.

Day 16: Observe and compare the results. Which plants are dying and which are still healthy? How can you explain the results?

Designing a Monarch/Bt Corn Study

You're concerned about monarch butterflies, so you want to design a field study to test whether Bt corn impacts monarchs in the wild. Your class will break up into groups and each group will select a question to study.

1) Do larvae eat corn pollen in the wild?
2) Does corn pollen drift from the field to milkweeds?
3) How much Bt corn pollen does it take to harm the larvae?
4) Does corn pollinate at the same time that larvae hatch throughout the monarch's migration path?
5) How do Bt corn pollen and pesticide sprays compare regarding the impact on monarchs and other insects and animals?

Before you design your study, you need to know more about monarchs. Gather information in the library; the Monarch Watch web site (www.monarchWatch.org); www.fooddialogue.com/monarch/index.html; www.sciencedaily.com; and Questionable Conclusions From Latest Monarch Study: http//agbioview.listbot.com

- **Research** What is the monarch life cycle, timing of reproduction, and migration path?
- **State the Inquiry** Which question/s will your group investigate?
- **Form a Hypothesis** What results do you expect to find?
- **Design a Procedure** How will you conduct your field study?
- **Conclusion** Describe what scientists could conclude from the results.
- **Extensions** Study butterflies yourself. Order a butterfly kit from Monarch Watch. Take a virtual tour of plant transformations: www-ceprap.ucdavis.edu/Transformation/transform1.htm

Career Connection: Biotechnology Education: *Help people understand new scientific discoveries.*

Biotechnology INSTITUTE

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Harvest Your Knowledge

The direction of plant science can profoundly change our approach to the world's food, medical, and environmental problems. Will we make of this science a "harvest of thorns or of flowers"? People have a responsibility to keep informed about these rapid advances so they can guide the outcome of scientific research. You probably now understand more about these complex issues than most adults. Go and educate your elders!

We must not hope to be mowers,
And to gather ripe, golden ears,
Unless we have first been sowers,
And watered the furrows with tears.
It is not just as we take it,
This mystical world of ours,
Life's field will yield as we make it,
A harvest of thorns or of flowers.

-Johann Wolfgang von Goethe

Sow Your Garden

www.BiotechInstitute.org

Ag Biotech Info-net: www.biotech-info.net

BIO: www.bio.org/food&ag/foodwelcome.html

Church of England Statement of Genetically Modified Foods, April 1999: www.agbioworld.org/articles/church_england.html

Food Safety: www.foodsafety.ufl.edu/index.html

Grocery Manufactures of America: www.gmabrands.com

Peggy G. Lemaux, "A Tomato is a Tomato, Or Is It? Consumer Acceptance of Genetically Engineered Food," plantbio.berkeley.edu/~outreach/FREIBURG.HTM

Links: www.hort.purdue.edu/hort/courses/HORT250/PBG's%20Bookmarks

New York Times Genetically Modified Foods: www.nytimes.com/library/national/science/health/gm-index.html

Time Magazine, July 31, 2000: Grains of Hope: www.time.com/time/magazine/articles/0,3266,50576,00.html

Union of Concerned Scientists: www.ucsusa.org

USDA: Science in your shopping cart: www.ars.usda.gov/is/np/siysc.htm and Sci4Kids: www.ars.usda.gov/is/kids/fair/story.htm

Winding Your Way Through DNA: Green Gene: www.accessexcellence.org/AB/WYW/fink/fink_1.html