Cooperative Extension
Colorado State University

AUTUMN 2001
VOLUME 21
ISSUE 5

FROM THE GROUND UP
Agronomy News

Genetically Modified Crops

Developments in transgenic technology require a continuing effort to inform the public.

Much has happened since the February 2000 issue of From The Ground Up provided an introduction to genetically modified organisms (GMOs) and transgenic technology. There are exciting breakthroughs in research and new genetically modified (GM) crops, but at the same time public debate about GM crops and foods has intensified. Clearly, the future of transgenic technology depends on consumer acceptance of its products. There is a need for public education about GM crops and foods: how the technology works, what it can do, what are the real benefits and potential risks.

A three-year grant awarded to Colorado State University and the University of Nebraska through the U.S.D.A. Initiative for Future Agriculture and Food Systems funds a project to provide information and public education about transgenic crops and foods. The project is described in more detail inside this issue, along with an update on GM crops: their current status, new products in development, and emerging issues of concern. For information on the nuts-and-bolts of transgenic technology, visit our web site at www.colostate.edu/programs/lifesciences/TransgenicCrops/

by Sarah Ward
Associate Professor
Plant Breeding and Genetics
Department of Soil and Crop Sciences

INSIDE THIS ISSUE

Colorado State University
Knowledge to Go Places

Transgenic Plants for the Future

Will the next generation of genetically modified crops improve public acceptance of biotechnology?

Critics of transgenic technology claim that genetically modified (GM) crops currently in commercial production only benefit producers and a few large agricultural corporations and offer nothing to the general public. While it can be argued that some changes in crop production associated with transgenics do benefit the consumer - reduced pesticide applications with Bt cotton, for example - it is true that the first GM crops to reach the market were not developed to provide direct benefits for consumers. New transgenics now in development, however, could change this dramatically, with crops being genetically modified for enhanced nutritional or other health benefits. Exciting current examples include golden rice, cavity-fighting apples, and antioxidant tomatoes, and edible vaccines in bananas.

Golden rice

Although rice is a staple in the diet of much of the world population, the grain is low in several key nutrients, including vitamin A. Golden rice has had two daffodil genes inserted coding for the enzymes which produce beta carotene. This is then converted to vitamin A in the human body. The presence of the beta carotene turns the rice grain yellow, hence the popular name for this GM crop. U.N.I.C.E.F. estimates that 124 million children around the world suffer from vitamin A deficiency, resulting in half a million cases of childhood blindness annually. Because the current version of golden rice does not deliver the full daily requirement of vitamin A, consuming golden rice will not solve this problem alone. However, it will make a contribution to a better diet for many people if supplies are made available at an affordable price. Golden rice arrived in the Philippines in January 2001, where plant breeders at the International Rice Research Center are now developing locally adapted strains for distribution to farmers.

Cavity-fighting apples

Medical researchers at Guy's Hospital in London and scientists at the Horticultural Research Institute in Kent, U.K., are developing apples with a bacterial gene coding for a protein which prevents decay-causing bacteria from attaching to teeth. Results to date suggest that eating the GM apples could significantly reduce cavity formation.

FROM THE GROUND UP

Agronomy News is a monthly publication of Cooperative Extension, Department of Soil & Crop Sciences, Colorado State University, Fort Collins, Colorado.

Web Site: http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/news.html

Jessica Davis
Technical Editor

Direct questions and comments to:
Deborah Fields
Phone: 970- 491-6201
Fax: 970-491-2758
E-mail: dfields@lamar.colostate.edu

Transgenic Plants for the Future

Antioxidant tomatoes

Flavonols are powerful antioxidants with the ability to neutralize harmful tissue-damaging molecules circulating in the body. Some foods, such as onions and tea, are naturally rich in flavonols, and several current research projects involving GM crops aim to increase beneficial antioxidant levels in other food plants. Scientists at Unilever have inserted a petunia gene into tomatoes which increases flavonol production up to 78 times over the relatively low levels normally found in the fruits. Taste is not affected, and 65% of the flavonols are retained when the tomatoes are processed into paste. Researchers have coined the term "functional foods" for items such as this, where conventional breeding or transgenic technology have enhanced levels of compounds in plant or animal products with health benefits beyond basic nutritional requirements.

Edible vaccines

Several crop species have been genetically modified to produce plant-based vaccines, which can be administered by consuming the plant product. One of most promising plant-based vaccines confers resistance to the liver disease hepatitis B through eating a dried GM banana chip. Researchers at the Boyce Thompson Institute at Cornell University have also modified tomatoes with a key gene from the hepatitis B virus, and found that small quantities of processed or dried tomatoes produced antibodies against hepatitis B when consumed. A dose of tomato- or banana-based hepatitis B vaccine costs around 2 cents per dose, less than 1% of the cost of a conventional hepatitis B vaccine.

Another frequent criticism of transgenic technology is that GM crops have not resulted in increased food production, especially in developing countries. New transgenics now in development could help solve the problem of feeding a world where the human population keeps expanding but usable agricultural land does not. Among examples recently in the news are salt-tolerant tomatoes and iron-pumping rice.

Salt-tolerant tomato

Researchers at the University of California at Davis have produced a GM tomato which can grow in soil irrigated by water containing up to 200 millimolar sodium chloride, 50 times the salt content normally tolerated by unmodifed tomatoes. The tomato contains a gene from thale cress (*Arabidopsis thaliana*) which segregates sodium ions from intracellular water for storage in vacuoles. Fruit from the salt-tolerant tomatoes tastes normal -- the salt is stored in vacuoles in the leaves.

Iron-pumping rice

Iron-deficient alkaline soils are common in many of the world's arid regions. Cereals such as corn and barley release an iron chelator known as deoxymugineic acid (DMA) when grown in such soils. DMA binds the iron and transports it across the root membrane, enhancing uptake by the plant. Rice normally produces very small quantities of DMA, making it an ineffective scavenger of iron in alkaline soils. Japanese researchers have transformed rice plants with two barley genes coding for enzymes which synthesize DMA. The GM rice plants have greatly enhanced DMA production and iron uptake, and yield up to four times more than non-GM rice when grown in iron-poor soils.

Public concern about transgenic technology in the U.S. and international opposition to it abroad, especially in Europe, have impacted markets for GM crops grown in the U.S. The future of GM technology depends on consumer acceptance of its products. Will the potential benefits offered by the next generation of GM crops be sufficient to persuade a skeptical international public?

by Sarah Ward
Associate Professor
Plant Breeding and Genetics
Department of Soil and Crop Sciences

Rootworm-Protected Hybrid Corn

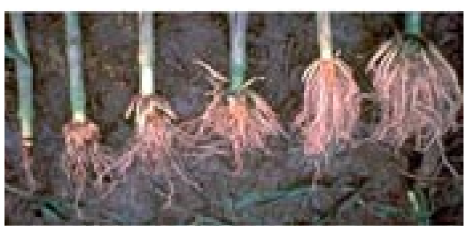
Genetically engineered hybrids on the horizon may reduce soil pesticide applications.

Corn growers may soon have another option for controlling rootworms: genetically engineered Bt corn targeted specifically to these pests. Like Bt corn for control of the European corn borer, which has been grown since the mid-1990s, the new hybrids incorporate genes from the soil bacterium *Bacillus thuringiensis* that produce insecticidal proteins. Rootworms are killed after munching on roots of engineered plants, but before they cause significant damage.

Corn rootworm feeding on young maize roots.

Corn rootworms (a complex of four species in the genus *Diabrotica*) are among the most serious pests of corn in the U.S. In Colorado, the western corn rootworm is an important pest on medium to heavy textured soils throughout the state, whereas the northern corn rootworm occurs much less commonly. Root feeding by these insects weakens root systems, thereby reducing yield and making plants more likely to fall over. The national economic impact of corn rootworm is estimated at $1 billion annually, which includes yield losses and the cost of control measures (Ostlie, 2001. Nature Biotechnology 19:624-625).

Corn growers currently use three strategies for limiting rootworm damage: crop rotation, application of soil insecticides at planting, and spraying insecticides mid-season to control adult rootworm beetles and thus reduce rootworm damage the following season. However, each approach is problematic. In some growing areas, northern and western rootworms have adapted to rotational practices, rendering that strategy less effective. Large-scale use of soil insecticides, estimated to be applied on 25% of the U.S. and the Colorado corn crop, has raised a number of environmental and health concerns, including contamination of ground and surface water, toxicity to birds and other non-target organisms, and health effects on farm workers. Insecticidal sprays are limited by timing and application difficulties, and by development of resistance to the sprays.



Damage from corn rootworm feeding from severe (left) to no damage (right).

Both Monsanto and Pioneer Hi-bred International have developed rootworm-resistant corn plants, which are currently undergoing the evaluation and regulatory process. The companies have used different genes in their products. Monsanto has inserted a gene for the Cry3B(b) toxin, chemically related to the protein incorporated into European corn borer-resistant hybrids. Pioneer's version produces two novel proteins, both of which need to be present for optimal rootworm control. Although the proteins in Pioneer's corn are from *B. thuringiensis*, they reportedly are not similar to previously identified Bt insecticidal proteins (Moellenbeck et al., 2001. Nature Biotechnology 19: 668-672).

Adult stage of western corn rootworm searching for pollen on corn silk

Although rootworm-resistant hybrids apparently offer pest management and environmental benefits, there are several concerns that must be addressed before they are approved for use. These include the following issues:

- What are appropriate resistance management strategies to prevent the adaptable rootworm from quickly developing resistance to the Bt hybrids? Because of differences in physiology and behavior, the high dose/refuge strategy used for management of resistance to European corn borer may not be effective for corn rootworm.

Rootworm-Protected Hybrid Corn

- What is the effect of these new plants on other elements of the ecosystem, especially non-target soil organisms?

- Will the grain produced by the new hybrids be accepted in export markets? Monsanto says it will not sell rootworm-resistant hybrids in the U.S. without regulatory approval in Japan. The company will also attempt to keep the grain from European markets through channeling efforts.

Seed of the new hybrids may be marketed as early as 2002.

by Patrick Byrne
Assistant Professor
Department of Soil and Crop Sciences

Acceptance of genetically engineered crops varies; some gain popularity, some withdrawn.

Planting of genetically engineered crop varieties in the U.S. increased for soybeans and cotton and remained about the same for corn in 2001. U.S.D.A. estimates that 68% of soybean acreage, 69% of cotton acreage, and 26% of corn acreage were planted to transgenics.

The U.S. Environmental Protection Agency is reviewing Bt insect resistance traits in corn and cotton as part of the re-registration process for that technology. The public comment period ended September 21. E.P.A. will decide whether to extend the registrations, as well as whether to impose conditions such as monitoring insect resistance and the impact of Bt pollen on non-target organisms.

Monsanto has discontinued marketing of its "NewLeaf" potato varieties, genetically engineered with the Bt gene to provide resistance to the Colorado potato beetle. NewLeaf potatoes never commanded a large share of the market, partly because several fast-food chains and chip makers declined to accept them.

For past issues of the Agronomy News on agricultural topics such as:

- Carbon Sequestration
- Research and Outreach Summaries
- Metals and Micronutrients
- Biotechnology
- Dry Bean Production
- Dryland Corn
- Precision Agriculture
- Salinity
- Nitrogen Fertilizer
- Phosphorus and Runoff

Visit our web site:

http://www.colostate.edu/Depts/SoilCrop/extension/Newsletters/news.html

Research on Transgenic Plants

CSU researchers use transgenic technology in a variety of ways.

Transgenic technology can be used as a tool for both basic research and practical applications. Colorado State University researchers use it both ways. June Medford, Patricia Bedinger, and Cecil Stushnoff are investigating plant processes with the help of transgenic plants, while Anireddy Reddy, Chris Lawrence, and Elizabeth Pilon-Smits are pursuing practical applications in disease resistance and phytoremediation.

meet...

Dr. Anireddy S.N. Reddy
Department of Biology

Dr. Reddy's laboratory is developing a potato variety that is resistant to late blight, the fungal disease that caused the Irish potato famine in the 1860s. Dr. Reddy and his co-workers have found two genes in *Arabidopsis thaliana* that inhibit the growth of fungi. They have inserted these genes into the DNA of potato plants using Agrobacterium as the vehicle for transformation. In greenhouse trials, the transformed plants were exposed to late blight (*Phytophthora infestans*) and to early blight (*Alternaria solani*). Disease symptoms from exposure to late blight were reduced by up to 70% and disease symptoms from exposure to early blight were reduced by up to 82%. Field trials are now underway to confirm that results from tests in the laboratory and greenhouse predict disease resistance under field conditions.

Potatoes are an important food crop, following wheat, rice, and maize in worldwide production. The San Luis Valley of Colorado is one of the centers for production of "seed" potatoes, that is, potatoes that will be planted to produce the crop for market. Because both early blight and late blight occur in Colorado, a blight-resistant potato cultivar could benefit farmers in this area.

Dr. Reddy's web page is available at http://www.colostate.edu/Depts/Biology/Faculty/reddy.htm.

meet...

Dr. Chris Lawrence
Department of Bioagricultural Sciences and Pest Management

The main project is centered upon the interaction between the model plant *Arabidopsis thaliana* and the necrotrophic fungus *Alternaria brassicicola*. Dr. Lawrence's laboratory is using several approaches to study the molecular basis of resistance to this pathogen. Once disease resistance genes are isolated from *Arabidopsis*, they can be transferred to other crops such as cabbage, canola, and other crucifers that are susceptible to this pathogen.

Another project, funded by the University of Kentucky Research Foundation, is centered upon increasing resistance to tobacco blue mold, a downy mildew type of disease caused by the fungus *Peronospora tabacina*. This disease costs Kentucky farmers over 100 million dollars per year and threatens to interfere with "molecular farming" of tobacco for the production of vaccines and pharmaceuticals. Dr. Lawrence's lab is employing several strategies for developing transgenic plants with increased blue mold resistance, including expressing genes that encode antifungal enzymes as well as modifying the plant's inherent defense system. The final anticipated stage of the project is to tailor or adapt these strategies to control pathogens of economic importance in Colorado.

Dr. Lawrence maintains a web site at http://lamar.colostate.edu/~clawrenc/.

Research on Transgenic Plants

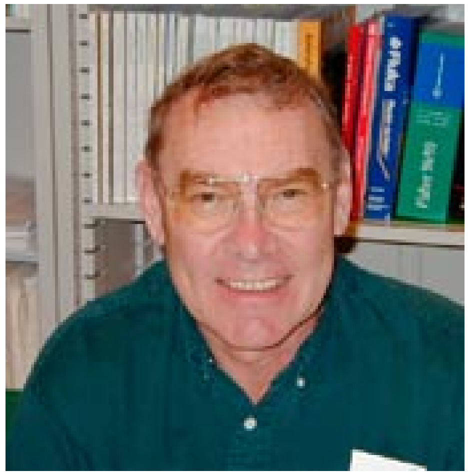
meet...

Dr. June Medford
Department of Biology

Dr. Medford's laboratory uses transgenic *Arabidopsis* plants to study the influence of naturally produced plant hormones on the development of plant shoots. The isolation of hormone suppressing genes and the characterization of the regulation of gene expression should help to elucidate the biological mechanisms by which plants control their growth.

Dr. Medford maintains a web site at http://www.biology.colostate.edu/Faculty/medford.htm.

meet...



Dr. Cecil Stushnoff
Department of Horticulture and Landscape Architecture

Dr. Stushnoff's laboratory is working on the processes by which plants stabilize their tissues when they are exposed to environmental stresses including low temperature, high temperature, and excessive salt. Petunia plants transformed via Agrobacterium to produce the sugar mannitol are used as a model plant system to explore physiological responses to salinity and low temperature stresses.

Dr. Stushnoff maintains a web page at http://www.colostate.edu/programs/pbp/.

meet...

Dr. Patricia Bedinger
Department of Biology

Dr. Bedinger's laboratory uses transgenic *Arabidopsis* and transgenic tomato plants to study the role of pollen proteins in pollination. Pollination is a complex process involving the exchange of molecular signals between the pollen grains and the stigma on which they fall. Transgenic plants may help to elucidate the methods that the pollen grains and the stigma use to recognize each other.

Dr. Bedinger maintains a web page at http://www.colostate.edu/Depts/Biology/Faculty/bedinger.htm

Research on Transgenic Plants

meet...

Dr. Elizabeth Pilon-Smits
Department of Biology

Dr. Pilon-Smits and her research team are using genetic engineering to improve the natural phytoremediation properties of plants. Phytoremediation, or using plants to remedy undesirable conditions, is emerging as an important approach to environmental pollution. While many plants are killed or severely stunted by the presence of selenium and heavy metals in the soil and water, some plants are able to tolerate these chemicals and can even change the chemicals into less toxic forms. These traits may be valuable in the effort to clean up pollutants such as the chemicals left in the soil around an abandoned mine. Dr. Pilon-Smits uses Indian mustard (*Brassica juncea*) as a model system. This plant is a good remediator of most trace elements, and it can be genetically engineered. Eight enzymes involved in selenium or heavy metal accumulation have already been produced in larger-than-normal quantities in Indian mustard. Increased production of two enzymes responsible for the uptake and reduction of selenate resulted in increased selenium accumulation and tolerance. Other transgenic plants, overproducing the heavy metal binding peptides called phytochelatins, showed increased cadmium accumulation and tolerance. Dr. Pilon-Smits is testing some of her plants at Leadville, Colorado, where water around an old mine is polluted with heavy metals.

Dr. Pilon-Smits maintains a web site at http://lamar.ColoState.EDU/~epsmits/.

On-line articles explore the impact of Bt corn pollen on butterflies.

Six articles on the impact of Bt corn pollen on butterflies have been published on-line in the Proceedings of the National Academy of Sciences and will be published in the print version of the journal later this fall.

The on-line citations are:
Hellmich et al., 2001, Monarch larvae sensitivity to Bacillus thuringiensis-purified proteins and pollen www.pnas.org/cgi/doi/10.1073/pnas.211297698

Oberhauser et al., 2001, Temporal and spatial overlap between monarch larvae and corn pollen www.pnas.org/cgi/doi/10.1073/pnas.211234298

Pleasants et al., 2001, Corn pollen deposition on milkweeds in and near cornfields www.pnas.org/cgi/doi/10.1073/pnas.211287498

Sears et al., 2001, Impact of Bt corn pollen on monarch butterfly populations: A risk assessment www.pnas.org/cgi/doi/10.1073/pnas.211329998

Stanley-Horn et al., 2001, Assessing the impact of Cry1Ab-expressing corn pollen on monarch butterfly larvae in field studies www.pnas.org/cgi/doi/10.1073/pnas.211277798

Zangerl et al., 2001, Effects of exposure to event 176 Bacillus thuringiensis corn pollen on monarch and black swallowtail caterpillars under field conditions www.pnas.org/cgi/doi/10.1073/pnas.171315698

Risks and Concerns

StarLink corn, the Monarch butterfly, and "superweeds" made the news this year.

The introduction of transgenic crops and foods into the existing food production system has generated a number of questions about possible negative consequences. Three recent developments in this area involve the possible allergenicity of StarLink corn, the effects of Bt corn pollen on butterflies, and the potential for gene flow to nearby crops and weeds.

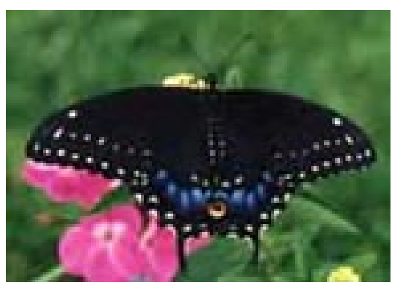
StarLink corn

StarLink corn, a Bt variety that was not approved for human consumption because of concern that it might cause allergic reactions, has been in the news for the past year after foods showing traces of the StarLink protein were found on supermarket shelves.

The possibility that we might see an increase in the number of allergic reactions to food as a result of genetic engineering has a powerful emotional appeal because many of us suffered from food allergies before the advent of transgenic crops or know of someone who did. However, there is no evidence so far that genetically engineered foods are more likely to cause allergic reactions than are conventional foods.

Of several dozen transgenic products that have been approved for commercial use, only StarLink corn carried indications of possible allergenicity. The preliminary finding is that StarLink corn is probably not allergenic, although the scientific debate continues. The government's scientific advisory panel in July recommended further laboratory tests and an aggressive effort to gather input from practicing physicians to resolve the remaining uncertainties about allergenicity.

Despite requests from Aventis, the maker of StarLink, the U.S. government has declined to approve the corn for human consumption, even at low levels. In an effort to prevent unintentional spread of the transgene, the government has bought up and destroyed seed corn that tested positive for StarLink. Aventis no longer sells StarLink corn, and the level of accidental presence of the gene in the corn supply, estimated at 0.125 percent, should continue to decline as contaminated stocks are tested and removed.



Black swallowtail butterfly
Photo: Jacalyn Loyd Goetz

Bt and butterflies

The 1999 report in the scientific journal Nature (Losey et al., 1999. Nature 399:214) that the Bt protein in transgenic corn pollen could kill Monarch butterfly larvae raised public awareness of the potential for damage to non-target species. The toxic protein in Bt corn was designed to kill insects in the Order *Lepidoptera*, which contains thousands of butterfly and moth species as well as the well known Monarch butterfly, native to North America, and the European corn borer, which is the primary target pest.

Monarch butterfly

After several years of improving the research methods and collecting data on different Bt corn varieties, U.S. and Canadian scientists have expanded on Losey's original findings. Two varieties of Bt corn, called MON 810 and Bt 11, contain very little toxic protein in their pollen and do not kill Monarch larvae even during the period of maximum pollen shed when the larvae are exposed to high levels of pollen. A third variety, Bt 176, contains high levels of the Bt protein in its pollen. This pollen is toxic to Monarch larvae at levels typically found in and near a corn field.

Laboratory tests show that black swallowtail butterfly larvae also are killed by high concentrations of Bt 176 pollen but are unaffected by pollen from MON 810. Bt 176 appeared to stunt the growth of black swallowtails in field tests. Caterpillars living on parsnip plants next to a Bt 176 corn field were only one-third as large as caterpillars 7 meters from the field, according to studies done at the University of Illinois.

Risks and Concerns

Two black swallowtail butterfly larvae.
Photo by Jacalyn Loyd Goetz

Bt 176 is not commonly grown in the U.S., accounting for less than 2% of the corn acreage, so experts suggest that insect populations in the U.S. are unlikely to suffer harm. Registration of Bt 176 will expire this fall, unless a request for renewal is filed, and no such request is expected.

Gene flow
The potential for the spread of genes from transgenic crops to nearby plants raises concerns on several fronts. Movement of pollen from a transgenic field to an organic field involves farmers in discussions about the distance required between fields to ensure purity of a crop and about who must pay if unwanted genes move into a neighbor's crop. Hybridization of crops with weedy wild relatives may cause weeds to acquire traits we wish they didn't have, such as resistance to herbicides. Research results (Science 293: 1425-1426) presented at an ecology convention this past summer suggest that the effects of crop-to-weed gene flow merit consideration.

While studies show that transgenic crop plants themselves are unlikely to persist in the wild without cultivation by humans, crop genes that escape to wild plants may persist for years in wild populations. A six-year study by Ohio State University professor Allison Snow found that crop genes from cultivated radishes escaped to wild, weedy radishes and persisted for generations. Genes that provide a competitive edge, such as resistance to viral disease, could benefit weed populations around a crop field. Wild oats are often handicapped by infection with barley yellow dwarf virus, but in greenhouse tests the weedy wild oats grew better than crop oats when both were disease-free, according to Cornell University professor Alison Power.

The movement of genes depends on several factors, including the pollination strategy of the crop, the presence of compatible crop plants or wild relatives in the area, and the overlap of flowering times. The likelihood that transgenes will spread can be different for each crop in each area of the world. Self-pollinating plants, such as soybeans and wheat, are less likely to spread their transgenes than cross-pollinating plants such as corn and beets. Transgenic soybeans grown in the U.S. and transgenic maize grown in Europe have no relatives nearby, while transgenic soybeans in Asia and transgenic maize in Mexico are likely to be able to hybridize with local plants that flower at the same time as the crop.

The chart on the page 11, developed from several published sources, provides a review of cultivated crops that are known to hybridize with wild relatives in various areas of the world is available at

New transgenic crops will need to be evaluated on a case-by-case basis with respect to the potential for crop-to-weed gene flow for each species in each geographic location.

A discussion of gene flow from transgenic plants is available on pages 80-93 of Genetically Modified Pest-protected Plants, published in 2001 by the National Academy Press.

by Judy Harrington
Research Associate
Department of Soil and Crop Sciences

Table 1. Some cultivated species and their sexually compatible wild relatives.

Crop species	Pollination	Area where grown	Compatible relatives
alfalfa *Medicago sativa*	mostly cross-pollinated	USA	wild alfalfa *Medicago sativa*
asparagus *Asparagus officinalis*	mostly cross-pollinated	USA	wild asparagus *Asparagus officinalis*
blueberry *Vaccinium angustifolium*	mostly cross-pollinated	USA	wild blueberry *Vaccinium angustifolium*
burmuda grass *Cynodon dactylon*	mostly cross-pollinated	USA	wild burmuda grass *Cynodon dactylon*
carrot *Daucus carota*	mostly cross-pollinated	USA	wild carrot *Daucus carota*
celery *Apium graveolens*	self- and cross-pollinated	USA	wild celery *Apium graveolens*
chicory *Chicorium intybus*	mostly cross-pollinated	USA	wild chicory *Chicorium intybus*
clover *Trifolium* spp.	some cross-, some self-pollinated	USA	wild clover *Trifolium* spp.
corn *Zea mays* ssp. *mays*	mostly cross-pollinated	Mexico and Central America	wild relatives of corn *Zea mays* ssp. *mexicana* *Zea mays* ssp. *parviglumis* *Zea mays* ssp. *huehuetenangensis* *Zea diploperennis* *Zea perennis* *Zea luxurians*
cranberry *Vaccinium macrocarpon*	mostly cross-pollinated	USA	wild cranberry *Vaccinium macrocarpon*
foxtail millet *Setaria italica*	mostly self-pollinated	France	green foxtail *Setaria viridis*
lettuce *Lactuca sativa*	mostly self-pollinated	USA	wild lettuce *Lactuca serriola*
oats *Avena sativa*	mostly self-pollinated	USA	wild oats *Avena fatua*

Table 1. some cultivated species and their sexually compatible wild relatives. ***(continued).***

Crop species	Pollination	Area where grown	Compatible relatives
oilseed rape, canola *Brassica napus*	mostly self-pollinated	France USA	wild radish *Raphanus raphanistrum* wild brassicas *Brassica napus* *Brassica campestris* *Brassica juncea*
quinoa *Chenopodium quinoa*	mostly self-pollinated	USA	wild quinoa *Chenopodium berlandieri*
radish *Raphanus sativus*	mostly cross-pollinated	USA	wild radish *Rapahnus raphanistrum*
rice *Oryza sativa*	mostly self-pollinated	USA	red rice *Oryza sativa*
tobacco *Nicotiana tabacum*	mostly self-pollinated	USA	tobacco escaped from cultivation *Nicotiana tabacum*
sorghum *Sorghum bicolor*	mostly self-pollinated	USA	Johnsongrass *Sorghum halapense*
squash *Cucurbita pepo*	mostly cross-pollinated	USA	wild squash *Cucurbita texana*
strawberry *Fragaria X ananassa*	self- and cross-pollinated	USA	wild strawberry *Fragaria virginiana*
sugar beets *Beta vulgaris*	mostly cross-pollinated	France	wild beets *Beta vulgaris*
sunflower *Helianthus annuus*	mostly cross-pollinated	USA	wild sunflower *Helianthus annuus*
walnut *Juglans regia*	self- and cross-pollinated	USA	California walnut *Juglans hindsii*
wheat *Triticum aestivum*	mostly self-pollinated	USA	jointed goatgrass *Aegilops cylindrica*

Sources for table:

Arriola and Elstrand, 1996. American Journal of Botany 83(9):1153-1160.
Baranger et al., 1995. Theoretical and Applied Genetics 91:956-963.
Desplanque et al., 1999. Theoretical and Applied Genetics 98:1194-1201.
Doebley, 1990. BioScience 40(6):443-448.
Klinger et al., 1992. American Journal of Botany 79(12):1431-1435.
Saeglitz et al., 2000. Molecular Ecology 9:2035-2040.
Snow and Palma, 1997. BioScience 47(2):86-96. BioScience 47(2):86-96.
Till-Bottraud et al., 1992. Theoretical and Applied Genetics 83:940-946.
Zemetra et al., 1998. Weed Science 46:313-317.

Labeling Genetically Engineered Foods

The challenge is to satisfy consumers' desire for information at a reasonable cost.

Whether or not to require labeling of genetically engineered (GE) foods is likely to be the hot topic in food biotechnology over the next year. The issue has already surfaced several times in Colorado. A bill requiring mandatory labeling was introduced in the Colorado legislature in 2001, but died in committee. There have also been unsuccessful attempts to place citizen initiatives on the ballot, both statewide and in the city of Denver. Similar efforts are expected in 2002.

Current policy

The Food and Drug Administration currently requires labeling of GE foods only if the food has a significantly different nutritional property, or if a new food includes an allergen that consumers would not expect to be present. Early in 2001, the FDA proposed voluntary guidelines for labeling food that does or does not contain GE ingredients (see Table 2. on page 15). FDA is still accepting public comment on these guidelines at http://www.cfsan.fda.gov/~dms/biolabgu.html .

Issues in mandatory labeling

Although mandatory labeling of GE ingredients may appear to be a straightforward measure, there are several complex issues that would have to be resolved prior to implementation.

What specific technologies for crop variety development would require a label?

The target of most labeling efforts is food products that have been genetically engineered, that is, they contain genes artificially inserted from another organism. However, some legislative efforts have defined the term "genetically modified" more broadly to include an array of techniques that were in use by plant breeders well before the GE era.

What percentage of a GE ingredient must be present in a food before a label is required?

One percent is a figure that is commonly proposed, but figures ranging from 0.1 to 5% have also been suggested.

Would meat and dairy products derived from livestock fed transgenic crops require a label?

Some labeling proposals include these products among those that would require labels, yet the biological rationale for doing so has not been demonstrated, that is, DNA or protein from inserted genes have not been found in livestock products.

What is the economic impact of labeling?

The cost of labeling involves far more than the paper and ink to print the label. Accurate labeling would require an extensive identity preservation system from farmer to elevator to grain processor to food manufacturer to retailer (Maltsbarger and Kalaitzandonakes, 2000. AgBio Forum, www.agbioforum.org/ in Vol. 3, no. 4). Testing would have to be done at various steps along the food supply chain. A recent study commissioned by the Canadian government estimated mandatory labeling would require a 10% increase in food prices. This would mean, for example, that a package of tortillas costing $1.50 would increase to $1.65.

Pro-labeling arguments

- Consumers have a right to know what's in their food, especially concerning products for which health and environmental concerns have been raised.

- Surveys have indicated that a majority of Americans support mandatory labeling (although the surveys generally do not specify the effect on food prices).

- To date, 22 countries have announced plans to institute some form of mandatory labeling (Phillips and McNeill, 2000. AgBio Forum, http://www.agbioforum.org/, Vol. 3, no.4). The U.S. could follow their lead in handling the logistics of product separation.

- For religious or ethical reasons many Americans want to avoid eating animal products, including animal DNA.

Anti-labeling arguments

- Labels on GE food imply a warning about health effects, whereas no significant differences between GE and conventional foods have been detected. If a nutritional or allergenic difference were found in a GE food, current FDA regulations require a label to that effect.

Labeling Genetically Engineered Foods (cont.)

- Labeling of GE foods to fulfill the desires of some consumers would impose a cost on all consumers. Persons at lower income levels would be the most affected by an increase in the cost of food.
- Consumers who want to buy non-GE food already have an option: to purchase certified organic foods, which by definition cannot include GE ingredients above defined threshold levels.
- The food system infrastructure (storage, processing, and transportation facilities) in this country could not currently accommodate the need for segregation of GE and non-GE products.
- Consumers wanting to avoid animal products need not worry about GE food. No GE products currently on the market or under review contain animal genes.

Additional information resources

Food and Drug Administration. Report on consumer focus groups on biotechnology. http://www.cfsan.fda.gov/~comm/biorpt.html.

AgBio Forum, http://www.agbioforum.org/, Vol. 3, No. 4 is devoted to labeling of GE foods.

The Center for Food Safety, www.centerforfoodsafety.org/facts&issues/VoluntaryLabelingMemo.html, argues against voluntary labeling and in favor of mandatory labeling.

by Patrick Byrne
Assistant Professor
Department of Soil and Crop Sciences

Table 2. Examples of voluntary labeling under proposed FDA guidelines

Wording on label	FDA comment
GMO free; Not genetically modified	Not recommended. "Free" implies zero content, which is nearly impossible to verify. "Genetically modified" is an inappropriate term, in that all crop varieties have been modified by plant breeders.
We do not use ingredients produced using biotechnology.	OK
This oil is made from soybeans that were not genetically engineered.	OK
This cantaloupe was not genetically engineered.	May be misleading, because it implies that other cantaloupes may be genetically engineered. Currently, there are no such varieties on the market.
Genetically engineered	OK
This product contains cornmeal that was produced using biotechnology.	OK
This product contains <u>high oleic acid soybean oil</u> from soybeans developed using biotechnology to decrease the amount of saturated fat.	OK. The underlined part is mandatory because it indicates a nutritional change. The rest is voluntary under the proposed guidelines.

Clearfield® Wheat Variety Released

New, non-transgenic herbicide-tolerant variety developed by Colorado State University will facilitate weed management.

A new hard red winter wheat variety, named Above, which incorporates the Clearfield® herbicide resistance technology, was released to seed producers by Colorado State University Agricultural Experiment Station researchers in August 2001. Above is the first wheat variety developed in the Great Plains that, when used in conjunction with imidazolinone herbicide, will allow selective control of several key grass (e.g., jointed goatgrass, brome, cheat, and feral rye) and broadleaf weeds in wheat. Prior to the development of

few if any viable options for control of some of these economically devastating weeds. Certified seed of Above should be available for planting in fall 2002.

Scientists at BASF (then American Cyanamid) discovered the gene that confers tolerance to imidazolinone herbicide in wheat in the early 1990s. Clearfield® wheat was developed through a commonly used breeding technique known as seed mutagenesis, a process by which the function of a key enzyme in the plant (acetohydroxyacid synthase, or AHAS) was altered to allow continued wheat plant growth and development following herbicide treatment. While the Clearfield® technology is relatively new to wheat, it has already been commercialized in both corn and canola and is currently under development in rice, sugarbeets, and sunflower.

The availability of Clearfield® wheat represents a unique partnership between public-sector wheat breeding (CSU) and a private interest (BASF) that holds a U.S. patent on a commercially viable biotechnological product. As with other recent CSU wheat variety releases, ownership of Above was transferred to the Colorado Wheat Research Foundation, which has agreements in place with BASF to foster the promotion and intellectual property protection of Clearfield® wheat. Other important aspects of Clearfield® Wheat include the following:

- Because no foreign DNA was transferred, Clearfield® wheat is non-transgenic (i.e., not genetically engineered and not considered "genetically modified"). Producers will experience no barriers in either domestic or overseas markets.

- Potential exists for herbicide resistance to develop in weed populations either by artificial selection or by transfer of the tolerance gene by outcrossing to jointed goatgrass.

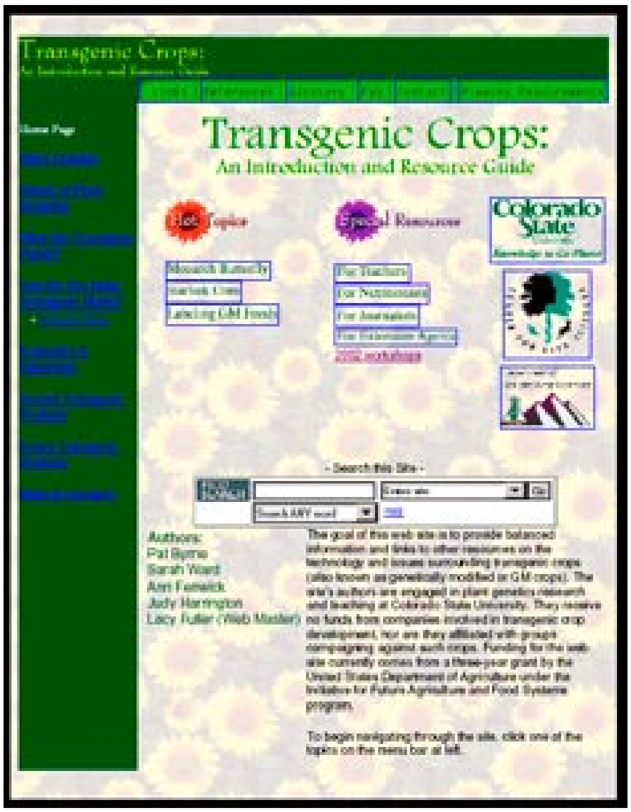
- Stewardship programs, designed to forestall herbicide resistance development in weed populations, will focus on promotion of crop and herbicide rotations and requirements for purchase of certified Clearfield® wheat seed for production of each commercial crop. The use of "farmer-saved" or "bin-run" seed will be prohibited.

Society and consumers have expressed various concerns over the development and use of transgenic crop plants. Although Clearfield® Wheat is non-transgenic, herbicide resistance that is transgenic (e.g., Roundup Ready® wheat) is currently under development by Monsanto in partnership with various university and private wheat breeding programs. If domestic and foreign marketing concerns are resolved, Roundup Ready® spring wheat could be available in the U.S. and Canada by 2003. Most university and private winter wheat breeding programs in the Great Plains region are also working with Monsanto on Roundup Ready® wheat, but this effort lags far behind the efforts already expended in the spring wheat producing areas.

by Scott Haley
Associate Professor
Department of Soil and Crop Sciences

Biotechnology Education Grant

In a joint project, Colorado State University and the University of Nebraska-Lincoln work on "Meeting Diverse Educational Needs in Agricultural Biotechnology."



Transgenic crops are the subject of a spirited public controversy about the potential benefits and the potential risks of this new technology. We are pursuing a transgenic crops public information project on three fronts: maintaining a web site for the general public, offering workshops to information disseminators, and evaluating the results of our efforts with survey instruments that provide data for statistical analysis. The participants are Dr. Sarah Ward and Dr. Pat Byrne at Colorado State University, Dr. Deana Namath, Dr. Susan Fritz, Dr. Nancy Lewis, and Dr. Julie Albrecht at University of Nebraska-Lincoln, supported by a cast of staff members, graduate students, and undergraduate employees at both locations.

Public information

Our web site, "Transgenic Crops: An Introduction and Resource Guide," provides balanced and accessible information on the scientific aspects of the technology along with links to many other resources. The web site at http://www.colostate.edu/programs/lifesciences/TransgenicCrops/ includes the following features. An animation sequence illustrates genetic engineering methods. News briefs cover events such as the latest move to label transgenic foods. Discussions of the risks and concerns associated with transgenic crops are presented. Information is provided about transgenic varieties now on the market and those being developed. The U.S. government system for regulating transgenic crops is explained. References to books and scientific journals containing further information are provided. An extensive list of links to other web sites lets the viewer access additional information. A Spanish-language version is now under construction.

Public education

Along with colleagues at the University of Nebraska-Lincoln, we are

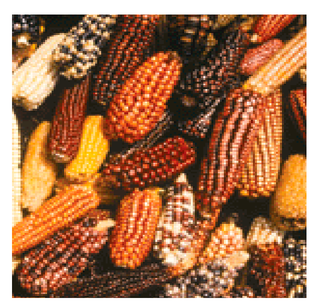
- developing lesson modules for on-line distance education courses,
- offering free workshops on transgenic crops to science teachers, extension agents, and nutritionists,
- making printable/downloadable materials available on the web site.

Evaluation

We are surveying participants before and after the workshops. Data will be compiled and reported to the scientific community.

This collaborative effort between CSU and the University of Nebraska-Lincoln may result in a more informed public debate on the subject of transgenic crops.

by Judy Harrington
Research Associate
Department of Soil and Crop Sciences



Some of the genetic diversity for ear and kernel traits found in Mexican maize.
Photo: CIMMYT

Biotechnology Information on the Web

General

http://www.ca.uky.edu/brei
Biotechnology Research and Education Initiative: Well-maintained, attractive and accessible site providing educational resources and updates on new discoveries in agricultural biotechnology. Authored by a multi-disciplinary research, teaching and extension team at the University of Kentucky.

http://www.agbios.com
AGBIOS: Extensive site with excellent articles and briefings from different sources on a variety of GM-related topics, together with one of the best searchable databases available. If you have a specific technical question about a transgene, GM crop, transformation event, regulation issue - or whatever - this is a good place to start. AGBIOS is a Canadian consulting company but the site provides good U.S. and international coverage as well.

http://www.colostate.edu/programs/lifesciences/TransgenicCrops/
The Transgenic Crops web site provides balanced and accessible information on the scientific aspects of the biotechnology along with links to many other resources, including: an animation sequence illustrating genetic engineering methods, news briefs on events such as the latest move to label transgenic foods, discussion of risks and concerns associated wit transgenic crops, information about transgenic varieties now on the market and those being developed, information about the U.S. government's system for regulating transgenic crops, references to books and scientific journals containing further information, an extensive list of links to other web sites, and a Spanish-language version, now under construction.

http://special.northernlight.com/gmfoods/
Northern Light Special Edition: Genetically Modified Food: News, views, and links to other web sites provided by this well respected academic search engine.

http://www.nbiap.vt.edu/
Information Systems for Biotechnology: The monthly news reports are an excellent source of reporting on agricultural biotechnology research. Of special note is an extensive annotated list of web sites in the January 200 issue. The site also includes sections on regulatory issues and risk assessment.

http://www.ncbe.reading.ac.uk/NCBE/GMFOOD/menu.html
National Centre for Biotechnology Education, University of Reading, U.K.: News and policy reports on GM foods from a European perspective.

http://www.americanradioworks.org/features/gmos_india/index.html
Minnesota Public Radio story on transgenic crops: This presentation, Engineering Crops in a Needy World, explores many aspects of the controversy in India over transgenic crops.

http://www.checkbiotech.org
Check Biotech: Lots of news items and special reports on such topics as the pros and cons of GM food and Bt and the Monarch butterfly. Good, even-handed treatment of many issues despite its industry funding.

http://croptechnology.unl.edu/
Crop Genetic Engineering, University of Nebraska-Lincoln: A set of lessons accompanied by animations on cloning, manipulating, and exploiting genes in agricultural crops.

Biotechnology Information on the Web

Labeling

http://www.cfsan.fda.gov/!dms/biolabgu.html
FDA proposed voluntary guidelines for labeling food that does or does not contain GE ingredients. FDA is still accepting public comment on these guidelines.

http://www.agbioforum.org
Accurate labeling would require an extensive identity preservatin system from farmer to elevator to grain processor to food manufacturer to retailer (Maltsbarger and Kalaitzandonakes, 2000. AgBio Forum) To date, 22 countires have announced plans to institute some form of mandatory labeling (Phillips and McNeill, 2000.).

Butterflies

http://www.pnas.org/cgi/doi/10.1073/pnas.211297698
Bellmich et al., 2001, Monarch larvae sensitivity to *Bacillus thuringiensis*-purified proteins and pollen.

http://www.pnas.org.cgi/doi/10.1073/pnas.211234298
Oberhauser et al., 2001, Temporal and spatial overlap between monarch larvae and corn pollen.

http://www.pnas.org.cgi/doi/10.1073/pnas.211287498
Pleasants et al., 2001, Corn pollen deposition on milkweeds in and near cornfields

http://www.pnas.org/cgi/content/abstract/98/21/11937
Sears et al., 2001, Impact of Bt corn pollen on monarch butterfly populations: A risk assessment.

http://www.pnas.org/cgi/content/abstract/98/21/11931
Stanley-Horn et al., 2001, Assessing the impact of Cry 1Ab-expressing corn pollen on monarch butterfly larvae in field studies.

http://www.pnas.org/cgi/doi/10.1073/pnas.171315698
Zangerl et al., 2001, Effects of exposure to event 176 *Bacillus thuringiensis* corn pollen on monarch and black swallowtail caterpillars under field conditions.

Other Resources

Test strips

Buy test strips for the various Bt varieties on-line from these sites:
http://www.identitypreserved.com/
http://www.agdia.com

PCR analysis

For information on polymerase chain reaction tests to detect transgenic varieties, you can visit:
http://www.stalabs.com
http://www.genetic-id.com

Books

"Pandora's Picnic Basket" by Alan McHughen (Oxford University Press, 2000. $17.50). Good, clear analysis of different facets of the GM crops debate, including issues such as labeling, intellectual property rights, environmental impacts and consumer choice.

"The Green Phoenix" by Paul Lurquin (Columbia University Press, 2001. $25). Recounts the history and development of GM crop technology. An interesting and sometimes surprising story, lucidly told by a professor of genetics at Washington State University.

Video

"Harvest of Fear" (PBS 2001). A 2-hour Frontline/Nova special which aired earlier this year. Excellent in-depth look at GM crop technology and associated issues, including thought-provoking interviews with folk on different sides of the controversy. Highly recommended. The video costs $19.98 and can be ordered online at www.shop.pbs.org.