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Genetically Modified Food Crops: Frankenfoods or a boon to third world countries?

The debate over genetically modified foods has exploded over the last couple of year becoming a world-wide public relations disaster for the biotech industry and casting science in the role of villain.
Web Sites with balanced views of these issues:

http://www.geo-pie.cornell.edu/

http://www.colostate.edu/programs/lifesciences/TransgenicCrops/
golden rice

http://www.nbiap.vt.edu/

See this link for a summary of Risks and Benefits of Genetically Engineered Organisms:
http://www.geo-pie.cornell.edu/issues/issues.html
How old is agriculture (plant domestication)?
• Genetically manipulated plants are as old as agriculture itself.
• All domesticated plants and animals are genetically modified
• We were genetically manipulating plants and animals long before we every had a clue about genes

So, what is the big deal about genetically modified plants?
There is an important difference between traditional breeding and genetic engineering

In the past we modified organisms:
• but the range of genetic variants we could choose from was limited to what already existed with the species (or within a closely related species)
• in traditional breeding experiments, hybridization transfers genes between closely related species

Biotechnology allows the transfer of genes between organisms from different kingdoms-- we can take a gene from a bacteria or a mammal and put into a plant

GM (genetically modified) plants = transgenic crop

Transgenics: transfer of specific genes from one species to another

Transgenic plants: plants containing foreign genes
Biotechnology allows the transfer of genes between organisms from different kingdoms

Classes of genetic modification:
1. **Wide transfer**: movement of genes from organisms of other kingdoms into plants
2. **Close transfer**: move of genes between species of plants
3. **Tweaking**: manipulation of levels or patterns of expression of genes already present in a plant’s genome

**Tweaking**: manipulation of levels or patterns of expression of genes already present in a plant’s genome:
- Grains from cereal grasses are deficient in the amino acid lysine.
- Induced mutations in cultured rice cells have increased their production of lysine and protein.
- Plants from these cells have increased production of lysine and protein.
What traits have been genetically engineered in plants?

http://www.geo-pie.cornell.edu//traits/traits.html

http://www.colostate.edu/programs/lifesciences/TransgenicCrops/

"A Growing Focus on Consumer Benefits"
New York Times 2/14/06
HEALTHIER SOYBEAN OILS -- Soy oil is being modified to increase its stability and eliminate the need for hydrogenation -- the process that produces unhealthy trans fats. Foods made with the modified oils would have reduced trans fats or none. Both Monsanto and DuPont recently introduced soybeans with healthier oils made by conventional breeding, which Kellogg plans to use for several products. In three to six years, similar products created by genetic engineering may be on the market.

IMPROVED SOY PROTEIN -- DuPont is working on improving the taste of soy protein used in protein bars and other products.

INCREASED OMEGA-3 FATTY ACIDS -- These chemicals, healthy for the heart and brain, come from fish, who get theirs from eating algae. Both Monsanto and DuPont are developing soybeans with the omega-3 fatty acid gene from algae.

MORE DIGESTIBLE AND NUTRITIOUS SORGHUM -- This product is being developed by DuPont with nonprofit groups. Sorghum is a staple food for many people in Africa, but it is hard to digest and not very nutritious.

NONALLERGENIC CROPS -- Genetic engineering might be used to make soy, wheat, peanuts and other crops that do not cause allergic reactions. Still in the early research phase.

ENHANCED RICE -- Vitamin A-enhanced rice, also known as golden rice, may prevent blindness caused by vitamin A deficiency, found in developing countries.

CANCER-FIGHTING TOMATO -- Research on tomatoes with higher levels of lycopene, an antioxidant, has slowed.

BETTER-TASTING PRODUCE -- Hardier tomatoes can ripen on the vine longer, producing superior taste.
Natural mechanisms for horizontal transfer:

- endosymbiosis
- bacteria-bacteria exchange (three mechanisms)
- plant-bacterial exchange
- viruses

Genetic manipulation often takes advantage of naturally occurring systems for introducing DNA into cells:

- viruses (gene therapy using retroviruses and adenovirus)
- Agrobacterium -- plants: a naturally occurring “genetic engineering” system

Great agrobacterium web site
http://www.ppws.vt.edu/~sforza/agro/agro.html
In the process of causing crown gall disease, the bacterium *Agrobacteria tumefaciens* inserts a part of its Ti plasmid (a region called the T DNA) into a chromosome of the host plant.

The genes on the T DNA direct the synthesis of cytokinins which stimulate plant cell division.

crown gall on a rose plant
http://helios.bto.ed.ac.uk/bto/microbes/crown.htm
http://www.ppws.vt.edu/~sforza/agro/agro.html
Ti (tumor inducing) plasmid

- The Ti plasmid is routinely used to produce transgenic plants
- Naturally occurring plasmid found in the soil bacterium *Agrobacterium fumeaciens*
- This bacterium causes crown gall disease in which the infected plant produces tumors or galls at the base of the plant
- When the bacterium infects the plant cell, part of the Ti plasmid (the T-DNA) is transferred and inserted, more or less at random into the genome of the host cell
- The gene functions required for this transfer are encoded by the Ti plasmid outside of the T-DNA
- The T-DNA codes for proteins involved in the synthesis of plant hormones that cause tumorous growth of the plant cell
- The T-DNA genes have eukaryotic gene structure
- T-DNA also codes for proteins that direct the plant cell to produce some unusual amino acid derivatives that the bacteria uses as sources of carbon and nitrogen
Agrobacterium hosts a natural genetic engineering system

Figure 8-33
The generation of a transgenic plant through the growth of a cell transformed by T-DNA. Cultured cell are grown up on kanamycin

Transfer of recombinant T-DNA to a plant cell
• Bacteria containing the recombinant Ti plasmid are used to infect segments of plant tissue -- such as pieces of leaf tissue
• Bacterial cells attach to a wounded site on the tissue
• If the leaf tissue are placed in a medium with kanamycin, only plant cells that have acquired the recombinant T-DNA will grow
**Wide transfer:** movement of genes from organisms of other kingdoms into plants

**Example of Wide transfer:**

**Bt gene from Bacillus transferred into corn**
- Bacteria of the genus *Bacillus* are common soil microorganisms
- Some *Bacillus* species (such as *B. thuringiensis* -- commonly known as BT) are insect pathogens because they produce toxic crystalline proteins
- These proteins interfere with insect development and can therefore be used as an insecticide
- [these toxins may allow the growth of bacteria in dead or weakened insect larvae -- natural history of Bt not fully understood]
- a large variety of crop pests are sensitive to the Bt proteins
- Many pesticides have been developed using Bt
A strain of corn has been engineered so that the corn plant itself is capable of synthesizing the Bt toxins

• These GM plants making Bt toxins are highly resistant to rootworms -- larvae of three related beetle species
• Corn rootworms are traditionally controlled either by rotating crops or with chemical pesticides
• Such chemical insecticides cost farmers about $200 million each year -- about 20% of the total spent on insecticides for all crops in the US
• The new GM corn could dramatically reduce the use of this chemical insecticide
• Bt proteins are harmless to humans and to beneficial insects such as ladybugs and honeybees
• In 1998, 20% of the total corn acreage was planted with Bt corn -- 15 million acres
An estimated 40% of the US corn crop in 2003 was grown to genetically engineered corn hybrids *(see map that follows).

Genetically Engineered Corn Production in 2003

Statewise percentage of total corn acres planted with genetically engineered corn hybrids in major corn producing states. Corn produced in these states represents 81% of US corn production.

**Bt corns (majority) and Roundup Resistant Corn (or combo)
Round up is a broad-spectrum herbicide
So What’s the problem (with Bt corn)?

See also:
*The Ecological Risks and Benefits of Genetically Engineered Plants*
*Science 290: 2088  Dec. 15, 2000*

Specific Potential Problems relating to Bt corn:

- **potential collateral** damage to other insect species -- pollen from corn that lands on milkweed may be consumed by monarch butterfly caterpillars -- it will kill or stunt the growth of caterpillars that eat it in the lab -- not clear what will happen in the environment.

Two studies in 1999 suggested that pollen from genetically engineered corn may affect the growth and survival of monarch butterfly larvae. **BUT Several studies later published in the Proceedings of the National Academy of Science (PNAS) suggest that this affect in nature is negligible.**

- the **power of selection** against insect predators -- exposure of a homogeneous subecosystem continuously to the toxin is bound to create Bt-resistant pests (among insects in continuous contact with the monoculture) because of the heavy selection pressure.

How to address the selection problem?

[http://www.epa.gov/pesticides/ppdc/resistbt.htm](http://www.epa.gov/pesticides/ppdc/resistbt.htm)
The US EPA has released new rules for the planting of Bt corn:
*Farmers who plant Bt corn must plant at least 20% non-Bt corn in their fields*

Logic of this requirement:
- traditional corn will provide a refuge for insect pests that are susceptible to the Bt toxin
- by maintaining a large population of susceptible pests, farmers increase the chances that pests resistant to the insecticide will mate with a susceptible offspring
- their offspring are likely to be susceptible
  --assuming that resistance is ………………?

- But in one study involving Bt cotton the insects feeding on the Bt plants developed more slowly than those in the non-transgenic buffer and therefore were predominantly mating with each other

*Other considerations:*
- if the traditional corn is planted around the edges of Bt corn fields, it would create a buffer to prevent toxic pollen from blowing into butterfly habitat
Ecological/Environmental/Population Genetical Problems:

**Impact on non-target species:** such as the unintentional poisoning of beneficial insects

**Evolution of pests that are resistant to new strategies for their control**

*Risk of invasiveness:* crop-to-wild hybridization resulting in the evolution of increased weediness in wild relatives
HOW CONCERNED SHOULD WE BE?

Key experiments on both the environmental risks or benefits are lacking.

The complexity of ecological systems presents considerable challenges for experiments to assess the risks, benefits and inevitable uncertainties of genetically engineered plants.

To explore this topic in more depth:
*The Ecological Risks and Benefits of Genetically Engineered Plants*
*Science 290: 2088     Dec. 15, 2000*
Potential invasiveness of transgenic plants: generally difficult to predict the occurrence and extent of long-term environmental effects when non-native organisms are introduced into ecosystems

Science 290: 2089  Dec. 15, 2000

**Figure 1:** The flow chart illustrates two main pathways (self-sustaining populations or introgression of genes) for how an introduced organism could have negative impacts on natural ecosystems. These stepwise factors are necessary for an invasion but not sufficient to cause one

introgression: introduction of genes through hybridization with a distinct race or species
**Health issues relating to GM food consumption**

- allergic or toxic reactions to the product of the transgene
- consumers might be exposed to higher levels of herbicides if crop species are made herbicide resistant (ie. farmers could apply herbicides to their fields with impunity)

**Social/Moral/Ethical issues**

- Big companies control too much about our world already
- This sort of technology is too expensive for developing countries
- Philosophical/moral issues related to patenting life-forms
- Morally or ethically wrong to “play God”:
To produce transgenic plants, an intermediate vector of manageable size is used to clone the gene/DNA sequence of interest. In the strategy shown here, the intermediate vector is then recombined with a “disarmed” (attenuated) Ti plasmid to generate a recombinant plasmid carrying the DNA of interest and Kan^R genes beween the T-DNA boundary sequences.
The natural capabilities of the Ti plasmid can be used by the plant geneticist to generate transgenic plants, where specific genes are introduced on the T-DNA

Engineered Ti vector has the tumor genes removed—considered a nuisance

- intermediate vector has contains selectable markers; bacterial spec\(^R\) for spectinomycin resistance and bacterial kan\(^R\) [kanamycin resistance] engineered for expression in plants
- spectinomycin used to select for Agrobacterium cells with the intermediate vector stably integrated into a modified Ti plasmid

The intermediate vector cannot replicate in agrobacterium cells, so it is lost if it doesn’t recombine with the modified Ti plasmid already present in the cell
How is the DNA transferred? A familiar “conjugation” theme

Mechanism of transfer of T-DNA to the plant cell

The Ti plasmid codes for the vir A-E genes. Levels of vir A protein increase dramatically upon stimulation with plant phenolic inducer molecules (produced when the plant is traumatized). Vir A activates Vir G and Vir G activates transcription of other vir genes. Vir D is an endonuclease and Vir B forms the conjugation bridge between the bacterial cell and the plant cell.
Future transgenic crops?

• Crop resistance to drought (genes from desert petunias inserted into cultivated petunias -- these transgenic plants require much less water)
• Atmospheric nitrogen fixation by crop plants (obviate the need for crop rotation and/or application of nitrogen-containing fertilizer)
• Tolerance to high-salt soils and to flooding
• Increased nutritional value of plant storage proteins
• Longer storage life of fruits and vegetables
• Enhanced productivity in ornamental and food plants
• Polymers: lipids for nutrition and industrial use; cotton-polyester fibers; biodegradable plastics
• Health-care products such as pharmaceuticals and vaccines. Plants containing vaccines are important for developing countries because the vaccines are inexpensive, orally administered (eating a seed?) and easy to deliver to remote areas.
• Production of the nonfood commercial product lauric acid -- a 12-carbon fatty acid used to make soaps and detergents

last 3 = molecular “farming”