GMO Crops: Basic Concepts, Risks and Benefits

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Part I. GMO Crops: Basic Concepts

- Word processing: a metaphor for how genetic engineering works
- Nature, the “Mother of all Frankenfoods”
- Compare/contrast to other crop improvement techniques
- Discussion: Future programming needs

http://www2.ca.uky.edu/anr/WMV/GMODiscussion1Jan132015.wmv
Part II. GMO Crops: Risks and Benefits

- Examples of present-day GMO crops, and impacts
- Potential risks of GMO crops
- Potential benefits of GMO crops
- Discussion: Future programming needs
Examples of present-day GMO crops, and impacts
Adoption of genetically engineered crops in the United States, 1996-2014

Percent of planted acres

- HT soybeans
- HT cotton
- Bt cotton
- Bt corn
- HT corn

Data for each crop category include varieties with both HT and Bt (stacked) traits.

http://www.ers.usda.gov/media/1141089/biotechcrops.png
Glyphosate usage, 2011

Corn herbicide use and environmental impact

**Herbicide use (kg/ha)**

**Cornell EIQ Index**

Soybean herbicide use and environmental impact

Herbicide use (kg/ha)  Cornell EIQ Index

Cotton herbicide use and environmental impact

Herbicide use (kg/ha) vs Cornell EI Q Index

Adopters of HT soybeans had higher rates of adoption of conservation tillage relative to users of conventional varieties, 2006

Conservation tillage includes no-till, ridge-till and mulch-till.
Adopters of herbicide-tolerant crops used conservation tillage more than did growers of conventional varieties: corn, 2005

Conservation tillage includes no-till, ridge-till and mulch-till.


Adopters of herbicide-tolerant crops used conservation tillage more than did growers of conventional varieties: cotton, 2007

Conservation tillage includes no-till, ridge-till and mulch-till.

Effect of reduced tillage on soil health

Figure 3. The effect of organic matter on the same soil type managed using conventional plow tillage (left) or zone tillage for 10 years (right).

From http://soilhealth.cals.cornell.edu/extension/manual.htm
Insecticide use in corn and cotton declined in most years following GE crop adoption


Papaya ring spot virus damage in Hawaii in 1994

http://www.agbioforum.org/v7n12/v7n12a07-gonsalves.htm
Transgenic papaya resistant to papaya ringspot virus
‘Rainbow’ papaya (transgenic) surrounded by ‘Sunrise’ papaya

http://www.agbioforum.org/v7n12/v7n12a07-gonsalves.htm
Squash with virus resistance

Some perceived risks
Corporate control of food supply
Risks of consuming GMOs
Support or Oppose of Government Policies

![Chart showing support and oppose percentages for various policies](http://agecon.okstate.edu/faculty/publications/4975.pdf, Jan 2015)
No unique/increased risk from GE crops

What matters is not how a genetic change was made, rather what that change does in the plant.
Scientific societies and organizations

SOCIETY OF TOXICOLOGY POSITION PAPER
The Safety of Genetically Modified Foods Produced through Biotechnology

Executive Summary

The Society of Toxicology (SOT) is committed to protecting and enhancing human, animal, and environmental health through the sound application of the fundamental principles of the science of toxicology. It is with this goal in mind that the SOT defines here its current consensus position on the safety of foods produced through biotechnology (genetic engineering). These products are commonly termed genetically modified foods, but this is misleading, since conventional methods of microbial, crop, and animal improvement also produce genetic modifications and these are not addressed here.

Studies of this type have established that the level of safety to consumers of current genetically engineered foods is likely to be equivalent to that of traditional foods. At present, no verifiable evidence of adverse health effects of GM foods has been reported, although the current passive reporting system probably would not detect minor or rare adverse effects or a moderate increase in effects with a high background incidence such as diarrhea.

The changes in the composition of existing foods produced through biotechnologies are subtle, limited...
Europe, the continent of “No to GMOs”

Consumption of GMO Crops:
Examples of Quotes from Position Papers of Scientific Organizations

Paul Vincelli
University of Kentucky
Dated 26 Jan 2015


“The main conclusion to be drawn from the efforts of more than 130 research projects, covering a period of more than 25 years of research, and involving more than 500 independent research groups, is that biotechnology, and in particular GMOs, are not per se more risky than e.g. conventional plant breeding technologies.” A Decade of EU-funded GMO Research (2001-2010) (2013). European
Pesticidal gene silencing
(=pesticidal RNA)
Plant Pathology Seminar

Dr. Vicki Vance
Professor of Botany
Department of Biology
University of South Carolina

Evidence for Uptake and Function of Plant-Produced MicroRNAs in Mammals

Monday, March 9 at 3:00 PM
Cameron Williams Auditorium
Plant Science Building
Radiofrequency electromagnetic fields (including wireless phones) are a Class 2B carcinogen.
Transgene flow

Transgenic crop

Pollen flow

Nontransgenic wild or weedy relatives and hemizygous transgenic F1 hybrids

Hybridization, growth.
(Repeat…)
Risk of gene flow from outcrossing

<table>
<thead>
<tr>
<th>Crop</th>
<th>Frequency of gene flow from outcrossing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Crop to crop</td>
</tr>
<tr>
<td>Oilseed rape</td>
<td>High</td>
</tr>
<tr>
<td>Sugar beet</td>
<td>Medium to high</td>
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<tr>
<td>Maize</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Potatoes</td>
<td>Low</td>
</tr>
<tr>
<td>Wheat</td>
<td>Low</td>
</tr>
<tr>
<td>Barley</td>
<td>Low</td>
</tr>
<tr>
<td>Fruits - strawberry, apples, grapevines and plums</td>
<td>Medium to high</td>
</tr>
<tr>
<td>Raspberries, blackberries, blackcurrant</td>
<td>Medium to high</td>
</tr>
</tbody>
</table>

Genetically modified organisms (GMOs), The significance of gene flow through pollen transfer, European Environment Agency, 2002
GMOs favor genetic uniformity
Herbicide tolerance trait promotes pesticide-dependent agriculture
Corn herbicide use and environmental impact

Glyphosate-resistant palmer amaranth

Image by Stephanie Porter, Burrus Seed
https://twitter.com/skporter/status/550295212514631680/photo/1
THE RISE OF SUPERWEEDS

Weed species often become resistant to herbicides. Glyphosate resistance, once deemed unlikely, rose after genetically engineered crops were introduced in the mid-1990s.
Field-evolved resistance by western corn rootworm to multiple *Bacillus thuringiensis* toxins in transgenic maize

Aaron J. Gassmann¹, Jennifer L. Petzold-Maxwell, Eric H. Clifton, Mike W. Dunbar, Amanda M. Hoffmann, David A. Ingber, and Ryan S. Keweshan

Department of Entomology, Iowa State University, Ames, IA 50011

Edited by Charles J. Arntzen, Arizona State University, Tempe, AZ, and approved January 27, 2014 (received for review September 12, 2013)

The widespread planting of crops genetically engineered to produce insecticidal toxins derived from the bacterium *Bacillus thuringiensis* (Bt) places intense selective pressure on pest populations to evolve resistance. Western corn rootworm is a key pest of maize, and in continuous maize fields it is often managed through planting of Bt maize. During 2009 and 2010, fields were identified in Iowa in which western corn rootworm imposed severe injury to maize producing Bt toxin Cry3Bb1. Subsequent bioassays revealed Cry3Bb1 resistance in these populations. Here, we report that, during 2011, injury to Bt maize in the field expanded to include mCry3A maize in addition to Cry3Bb1 maize and that laboratory analysis of western corn rootworm from these fields found resistance to Cry3Bb1 and mCry3A and cross-resistance between these toxins. Resistance to Bt maize toxins in this population includes the Cry3Bb1 and mCry3A toxins and indicates that this population of western corn rootworm is evolving resistance. In 2003, Cry3Bb1 maize was registered by the United States Environmental Protection Agency (US EPA) for management of western corn rootworm larvae (7). In 2009, farmers in Iowa observed severe injury to Cry3Bb1 maize by larval western corn rootworm in the field, and subsequent laboratory assays revealed that this injury was associated with Cry3Bb1 resistance (13). More fields with Cry3Bb1 resistance were identified in 2010 (14), and research in fields identified in 2009 as harboring Cry3Bb1-resistant western corn rootworm found no difference in survival for this pest between non-Bt maize and Cry3Bb1 maize (11).
Insect resistance to Bt crops: lessons from the first billion acres

Bruce E Tabashnik¹, Thierry Brévaught² & Yves Carrière¹

Evolution of resistance in pests can reduce the effectiveness of insecticidal proteins from Bacillus thuringiensis (Bt) produced by transgenic crops. We analyzed results of 77 studies from five continents reporting field monitoring data for resistance to Bt crops, empirical evaluation of factors affecting resistance or both. Although most pest populations remained susceptible, reduced efficacy of Bt crops caused by field-evolved resistance has been reported now for some populations of 5 of 13 major pest species examined, compared with resistant populations of only one pest species in 2005. Field outcomes support theoretical predictions that factors delaying resistance include recessive inheritance of resistance, low initial frequency of resistance alleles, abundant refuges of non-Bt host plants and two-toxin Bt crops deployed separately from one-toxin Bt crops. The results imply that proactive evaluation of the inheritance and initial frequency of resistance are useful for predicting the risk of resistance and improving strategies to sustain the effectiveness of Bt crops.

Studies show importance of high-dose refuge strategy.


Figure 5: Resistance to Bt crops and dose criterion. Resistance evolved more slowly when the high-dose criterion was met (left, n = 6 cases) than when it was not met (right, n = 13 cases). Red, >50% resistance and reduced efficacy reported; orange, >50% resistance and reduced efficacy expected; yellow, 1–6% resistant individuals; blue, <1% resistant individuals; green, no decrease in susceptibility (see Table 1 and text for details).
“We are eating insecticide.”

The acute oral toxicity data submitted support the prediction that the Cry1F protein would be non-toxic to humans. Male and female mice (5 of each) were dosed with 15% (w/v) of the test substance, which consisted of Bacillus thuringiensis var. aizawai Cry1F protein at a net concentration of 11.4%. Two doses were administered approximately an hour apart to achieve the dose totaling 33.7 mL/kg body weight. Outward clinical signs and body weights were observed and recorded throughout the 14 day study. Gross necropsies performed at the end of the study indicated no findings of toxicity. No mortality or clinical signs were noted during the study. An LD$_{50}$ was estimated at $>5050$ mg/kg body weight of this microbially produced test.

LD$_{50}$ of table salt (rat) = 3000 mg/kg

“Lock and key” metaphor

http://www.epa.gov/oppbppd1/biopesticides/pips/bt_brad2/2-id_health.pdf
Loss of cultural identity
Some perceived benefits
Adopters of HT soybeans had higher rates of adoption of conservation tillage relative to users of conventional varieties, 2006

Conservation tillage includes no-till, ridge-till and mulch-till.
Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services

Yanhui Lu¹, Kongming Wu¹, Yuying Jiang², Yuyuan Guo¹ & Nicolas Desneux³

Over the past 16 years, vast plantings of transgenic crops producing insecticidal proteins from the bacterium *Bacillus thuringiensis* (Bt) have helped to control several major insect pests¹,³ and reduce the need for insecticide sprays¹,⁶,⁶. Because broad-spectrum insecticides kill arthropod natural enemies that provide biological control of pests, the decrease in use of insecticide sprays associated with Bt crops could enhance biocontrol services⁷-¹². However, this hypothesis has not been tested in terms of long-term landscape-level impacts⁹. On the basis of data from 1990 to 2010 at 36 sites in six provinces of northern China, we show here a marked increase in abundance of three types of generalist arthropod predators (ladybirds, lacewings and spiders) and a decreased abundance of aphid pests associated with widespread adoption of Bt cotton and reduced insecticide sprays in this crop. We also found evidence that the predators might provide additional biocontrol services spilling over from Bt cotton fields onto neighbouring crops (maize, peanut and soybean). Our work extends results from general studies evaluating ecological effects of Bt crops¹-⁴,⁶,¹²,¹³ by demonstrating that such crops can promote biocontrol services in agricultural landscapes.

rapidly planted on a large scale, rising to $2.4 \times 10^6$ ha by 2011 (more than 95% of the cotton crop in northern China). It managed CBW effectively, which led to decreased insecticide use on this pest³,²¹.

The widespread adoption of Bt cotton may have favoured an increase in generalist natural enemy populations and promoted their associated biocontrol services. We therefore performed two assessments: first, whether implementing Bt cotton on a large scale induced an increase in populations of three groups of key generalist predators in China (ladybirds, lacewings and spiders) in both Bt cotton and three common neighbouring crops, namely maize, peanut and soybean; and second, whether this trend resulted in increased biocontrol services in agricultural landscapes in China. Aphids were selected as a pest model because they are common prey for generalist predators. During 1990–2011, research was conducted in six major cotton-growing provinces (Henan, Hebei, Shandong, Shanxi, Anhui and Jiangsu) in northern China, where about $2.6 \times 10^6$ ha of cotton and $3.3 \times 10^7$ ha of other crops (notably maize, peanut and soybean) are cultivated annually by more than ten million small-scale farmers.
A photo taken in the early 1900s in what is now Great Smoky Mountains National Park shows the massive size some American chestnut trees reached. (Great Smoky Mountains National Park/Via Associated Press)

A nut rests inside the spiny bur of a rare surviving American chestnut tree. A fungus wiped out almost all of the trees, which once numbered in the billions. (The American Chestnut Foundation/Via Associated Press)

Citrus greening

http://en.wikipedia.org/wiki/Orange_juice
Bacterial spot resistance from a pepper gene in tomato

http://www.growingmagazine.com/article-10066.aspx
African family suffering epidemic of begomoviruses in cassava

Fuente de foto: Mark Lynas, https://twitter.com/Pvincell/status/363999930349654016
Cassava with resistance to begomoviruses

Source: Mark Lynas at https://twitter.com/mark_lynas/status/362877275470962688/photo/1
Bacterial wilt of banana

Staple food for 100,000,000 people in Eastern Africa

http://www.promusa.org/Xanthomonas+wilt
http://r4dreview.org/2008/09/the-future-of-african-bananas/
http://www.asareca.org/content/regional-efforts-control-banana-wilt-disease
Control of bacterial wilt with transgene

Research in Uganda

**GM Projects**: bananas resistant to bacterial wilt, black sigatoka, and nematodes; banana with iron and Vitamin A; cassava resistant to cassava mosaic virus and cassava brown streak; drought-tolerant maize, rice tolerant to low N; sweet potato resistant to potato feathery mottle virus; resistant to bollworm.

Micronutrient deficiencies

Vitamin A deficiency

The challenge

Vitamin A deficiency (VAD) is the leading cause of preventable blindness in children and increases the risk of disease and death from severe infections. In pregnant women, VAD causes night blindness and may increase the risk of maternal mortality.

Vitamin A deficiency is a public health problem in more than half of all countries, especially in Africa and South-East Asia, hitting hardest young children and pregnant women in low-income countries.

A few salient facts

- An estimated 250 million preschool children are vitamin A deficient and it is likely that in vitamin A deficient areas a substantial proportion of pregnant women is vitamin A deficient.
- An estimated 250 000 to 500 000 vitamin A-deficient children become blind every year, half of them dying within 12 months of losing their sight.
Reduced pesticide poisonings in China

Improved food security from Bt technology in peasant families in India

Genetically Modified Crops and Food Security

Matin Qaim¹, Shahzad Kouser¹,²

¹ Department of Agricultural Economics and Rural Development, Georg-August-University of Goettingen, Goettingen, Germany, ²Institute of Agricultural and Resource Economics, University of Agriculture, Faisalabad, Pakistan

Abstract

The role of genetically modified (GM) crops for food security is the subject of public controversy. GM crops could contribute to food production increases and higher food availability. There may also be impacts on food quality and nutrient composition. Finally, growing GM crops may influence farmers’ income and thus their economic access to food. Smallholder farmers make up a large proportion of the undernourished people worldwide. Our study focuses on this latter aspect and provides the first ex post analysis of food security impacts of GM crops at the micro level. We use comprehensive panel data collected over several years from farm households in India, where insect-resistant GM cotton has been widely adopted. Controlling for other factors, the adoption of GM cotton has significantly improved calorie consumption and dietary quality, resulting from increased family incomes. This technology has reduced food insecurity by 15–20% among cotton-producing households. GM crops alone will not solve the hunger problem, but they can be an important component in a broader food security strategy.


Editor: M. Lucrecia Alvarez, TGen, United States of America
Eggplant with Bt used by peasant farmers in Bangladesh

https://t.co/0zcYKDkUSX
Mycotoxins

**Fusarium**
Fumonisins

**Aspergillus**
Aflatoxins

Birth defects associated with fumonisins

Potato with 50% less acrylamide, less bruising
Arctic® Apple

Sliced/bruised yesterday - our #ArcticApples are holding up well on day 2 of the @GLEXPO (booth 548) pic.twitter.com/Rh1S9Op9EY
High concentration of anthocyanin in tomato

Bumper harvest for GM purple tomatoes

https://www.youtube.com/watch?v=ifDr6ueBUPA
Project to produce N-fixing cereals

http://dx.doi.org/10.1016/j.tibtech.2014.11.008
C4 rice project

Roadmap

- Gene discovery and molecular toolbox development
- Characterize regulatory controls
- Transform rice to express Kranz anatomy and the C4 metabolic enzymes
- Optimize C4 function in transgenic rice
- Breed C4 from transgenics into local varieties

Research Grant from the Bill & Melinda Gates Foundation (BMGF)

http://c4rice.irri.org/index.php/component/content/article/19-about/56-what-is-c4-rice
Discussion

- Questions/concerns
- Future programming needs