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# Genetically Engineered Crops: Emerging Opportunities

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# Genetically Engineered Crops

## Emerging Opportunities

Paul Vincelli, Plant Pathology

### Background Information

Biotechnology is “any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use.”<sup>1</sup> This definition encompasses many, many applications, including traditional ones such as fermentation of alcoholic beverages.

In certain biotech crops, their genetic material (DNA) has been purposefully manipulated in the laboratory. These genetically engineered crops are often called “GMOs,” an acronym for “genetically modified organisms.” These GMOs are the focus of this publication.

DNA is merely chemical information, like words in a book. Just as we can use a word processor to edit sentences or to transfer them from one book into another, laboratory techniques allow us to edit DNA or transfer it from one organism into another. In and of themselves, words are not poisonous. Similarly, in and of itself, DNA is not poisonous. Changing the words in a book changes how it reads. Similarly, changing the DNA of an organism can change its appearance or function.

All foods contain DNA. We eat DNA with every meal. Eating DNA is not dangerous. Consuming DNA of any crop or animal—whether they are traditional varieties or biotech ones—does not cause that DNA to be inserted into our own DNA. If DNA in our food somehow inserted itself into human DNA, our bodies would contain genes from the foods people have eaten for thousands of years. But we don’t find wheat genes or rice genes in humans because the DNA naturally present in our foods does not insert itself into human DNA.

The genetic modification of plants is nothing new. Nature genetically modifies organisms in bizarre and remarkable ways (see 1: *Sweet Potato, Genetically Engineered by Nature* and 2: *Is This Genetically Engineered Corn?*). Humans have guided genetic changes in crops for thousands of years through simple selection. More recently, plant breeders have employed a variety of more advanced breeding techniques. In all instances, the breeder is seeking crops with improved plant performance.

Improved performance may include improved nutritional qualities, increased yield, more efficient use of fertilizer or water, tolerance to stresses like drought and heat, disease resistance, etc. Breeders seek improved crop performance in order to provide benefits to farmers, consumers, and the environment.

Some breeding techniques cause substantial genetic changes, including some very well accepted, conventional breeding techniques. Commercial genetically engineered crops are designed so that they generally have very limited and precise genetic changes. In fact, the genetic changes in genetically engineered varieties typically have less impact on the crop’s metabolism than all other crop-improvement techniques.

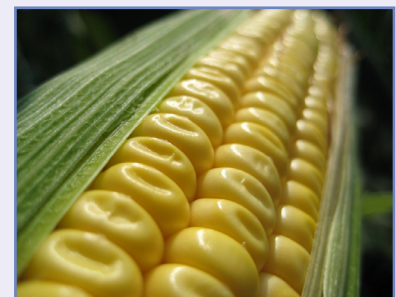
Many will be surprised to learn that much of what they know about genetic engineering is becoming obsolete. The most up-to-date methods of genetic engineering can produce remarkably modest and precise genetic changes in plants. And they can do so in a way that leaves no trace of “foreign DNA.” This new technique is called *genome editing*, and it can produce genetic changes in specifically targeted genes, and



Sweet potato, an example of a natural GMO

Photo courtesy of Steve Patton

**1 Sweet Potato, Genetically Modified by Nature.** Transfer of genes from one organism to another seems bizarre until one realizes that this process happens regularly in natural ecosystems. Gene transfer is one of the ways that Nature creates biodiversity. For example, scientists recently reported that sweet potato, a crop many of us enjoy every Thanksgiving, naturally contains at least four genes from a soil-dwelling bacterium. Examples of natural gene transfer are common in the scientific literature, and more are being discovered regularly as science advances.



Genetically engineered corn is still just corn.

Photo courtesy of Chad Lee

**2 Is This Genetically Engineered Corn?** You can’t tell by looking at it. Genetically engineered corn is corn, pure and simple. There are no “Frankenfoods,” except those that Nature has created on her own.

<sup>1</sup> From the UN Food and Agriculture Organization, <http://www.fao.org/docrep/014/i1905e/i1905e00.pdf>.

those changes may be as minimal as a one-nucleotide change. This process is like changing one letter in an entire book. A change of one nucleotide is the most precise and minimal change that is physically possible in a plant's DNA. Such a change is so minimal that scientists cannot distinguish such a change from a mutation that occurred naturally. Thus, genome editing allows one to engineer plants in a minimally invasive way, leaving no trace of laboratory manipulation. For this reason, genome editing complicates the regulatory picture. For example, if a crop variety engineered by genome editing cannot be distinguished from one that was not engineered, can it be regulated? Should it be regulated?

Wise breeders use the best method available to solve particular problems. In cases where traditional breeding techniques provide an adequate level of crop improvement, these are preferred to techniques that are more technically demanding or expensive. For example, conventional breeding has made more progress in creating drought-tolerant corn than genetic engineering, at least for now. However, if a breeding objective cannot be met using conventional methods, a genetically engineered approach makes sense to most scientists. (See *Benefits of Genetic Engineering* on page 8 for examples.) Most crop scientists think that the wise use of genetic engineering will help reduce food insecurity and make food production more sustainable.

**Genetic engineering has been part of American life for decades.** Genetically engineered corn has been grown in the USA since 1996. Most cheeses in the US are made using genetically engineered enzymes approved in 1990 by the U.S. Food and Drug Administration (FDA). High-quality enzymes for making cheese are produced by genetically engineered bacteria in fermentation tanks instead of obtaining enzymes from the stomachs of dead calves. Insulin for diabetics produced by genetically

engineered bacteria was approved by FDA for human use as long ago as 1982. Numerous medications are based on genetic engineering, and more such medications are coming. For example, a promising, potentially life-saving experimental vaccine for Ebola is genetically engineered.

**Which genetically engineered crops are grown in the USA?** Most genetically engineered crops are not consumed directly by humans. In the USA, most are grown for animal feed, for processing, or for fuel production. Certain varieties—though not all—of the following crops grown in the USA are derived from genetic engineering:

- Alfalfa
- Canola
- Corn (both field corn and sweet corn)
- Cotton
- Papaya
- Soybean
- Squash
- Sugar beet

In addition, certain genetically engineered apple and potato varieties are in the process of commercialization, and other genetically engineered crops are likely to be commercialized in the near future. If you wish to avoid all foods derived from genetic engineering, you can buy certified organic foods or those specifically labelled to be GMO free.

## Concerns about Genetic Engineering

### ▶ Is genetic engineering natural?

Nature commonly and naturally produces dramatic changes in the genetics of plants.<sup>2</sup> An example is described in 1: *Sweet Potato: Genetically Engineered by Nature*. Many more examples are described in the scientific literature. This natural "genetic turbulence" often seems bizarre. However, these are merely some of the ways that Nature creates biodiversity. In fact, our laboratory techniques of genetic engineering were developed by studying the creative things Nature does with DNA.

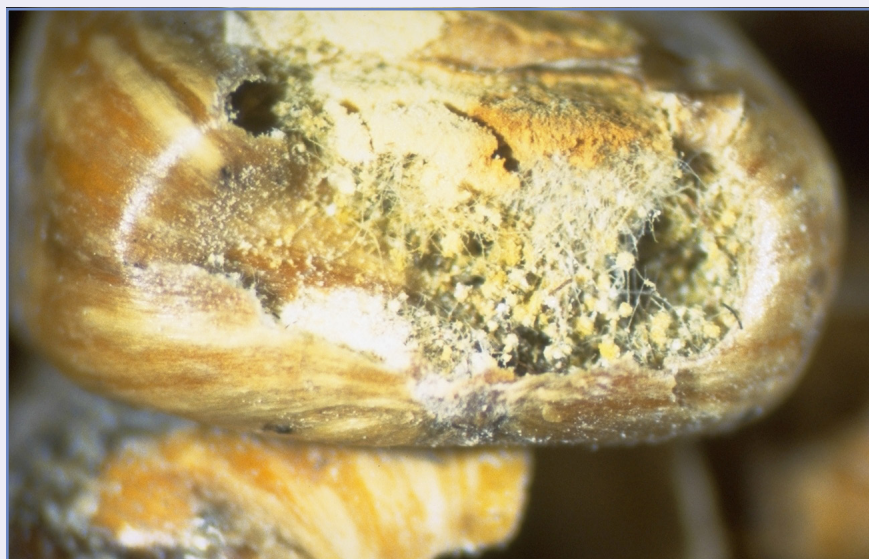
### ▶ Are genetically engineered crops safe to eat?

- Genetically engineered crops grown in the USA are subjected to scrutiny for safety to humans and to the environment. Three federal agencies are involved in evaluating the safety of genetically engineered crops: the US Department of Agriculture, the US Food and Drug Administration, and the US Environmental Protection Agency. In contrast to genetically engineered crops, non-engineered (non-GMO) crop varieties typically receive very little to no formal evaluation by government agencies. Genetic engineering technologies are advancing very rapidly. Consequently, in July 2015, the federal government began a process to review and update the oversight of genetically engineered crops.
- Many scientific experts worldwide agree that genetically engineering a crop generally presents no new health risks that cannot also arise from conventional plant breeding. As explained in footnote 2, recombinant DNA is quite natural and common in our foods, and has been so for thousands of years. What matters is not the presence of recombinant DNA, but what the DNA does in the plant. You can read in-depth about what scientific organizations say on the topic of genetic engineering and food safety in the file named *Quotes from Science Academies on Consuming GMO Crops*, online at <https://kentuckypestnews.wordpress.com/2015/03/31/consumption-of-genetically-engineered-gmo-crops-examples-of-quotes-from-position-papers-of-scientific-organizations/>.
- Certain genetically engineered traits can actually *improve* the safety of food. See 3: *Improving Food Safety through Genetic Engineering*.

<sup>2</sup>These natural changes include diverse mutation; insertion, deletion, and duplications of jumping genes or other genetic sequences; gene duplication; "cutting and pasting" that results in inversion, translocations, and novel gene assemblies; shuffling of gene fragments; chromosomal duplication; transfer of genes and gene fragments between unrelated organisms; and incorporation of virus genes into the plant's own genetics. All of these are instances of Nature itself creating recombinant DNA. Although recombinant DNA is often thought of as a human invention in the laboratory, our crops contain a surprisingly large amount of "all natural" recombinant DNA.

### 3 Improving Food Safety through Genetic Engineering.

It surprises some to learn that engineered crops can actually be safer than conventional foods. For example, corn grain can be naturally contaminated by mycotoxins, which are natural toxins produced by fungi. Fumonisin is the most common mycotoxin found in corn in Kentucky and many other regions throughout the world. Aflatoxins are less common, but when they occur, they can cause serious disruption to grain marketing, because of their high toxicity. Both mycotoxin families pose health risks to livestock. Pigs and horses are highly sensitive to poisoning by fumonisin. Aflatoxins in the feed can be very hazardous to chickens. In addition, both mycotoxin families pose risks to human health. In certain countries where corn meal is a significant part of the daily diet, maternal exposure to natural fumonisin in contaminated corn during pregnancy has been associated with increased frequency of



Close-up of *Aspergillus* ear and kernel rot of corn. The fungus that causes this disease can produce aflatoxin contamination.

Photo by Paul Vincelli



*Fusarium* ear and kernel rot of corn. Fungal growth in the kernels can result in contamination by fumonisin.

Photo by Paul Vincelli

birth defects called neural tube defects. Long-term consumption of fumonisin-contaminated corn is also considered a risk factor for esophageal cancer. Aflatoxins are very potent toxins, causing a wide variety of effects. They are also very potent, natural carcinogens of the liver.

One of the ways corn growers can reduce the level of mycotoxin contamination is through the use of varieties with a Bt trait (See Text Box #10: Plants that Fight Back Against Insects). Bt traits often reduce feeding on the grain by cer-

tain insects. This, in turn, means that there are fewer wounds on the kernels. Fewer wounds often means less invasion of the grain by mycotoxin-producing fungi. You can learn more about Bt and corn mycotoxins at <http://grain-crops.blogspot.com/2013/08/gmos-and-corn-mycotoxins.html>. Other genetic-engineering traits near commercialization will help improve food safety in other ways.

- There is ongoing scientific discussion over a particular application of genetic engineering: the engineering of crops to be tolerant to the weed-killer called *glyphosate*. Numerous studies show no significant health risk to humans from government-approved uses of glyphosate. However, some experts do raise questions about the safety of long-term exposure to glyphosate in the diet. This is one reason some people want products derived from genetically engineered crops to be labeled. For more on this, see 4: *Crops Tolerant to a Weed-Killer*.

- University of Kentucky scientists always remain open-minded to new discoveries. If credible, validated research raises food-safety concerns, these will quickly become part of our Extension programming. This is true whether the crop of concern is conventional or biotech.
- ▶ **Can genetic material from genetically engineered crops spread in pollen?** Yes, potentially so. This is a legitimate concern, although there are ways to reduce this risk. Concerns are:
  - Genetically engineered genes may move into wild relatives of crop plants when pollen from the genetically engineered crop lands

on the flowers of a wild relative. This concern applies even to genes spreading from conventional, non-genetically engineered varieties. However, there is greater concern over pollen from genetically engineered crops. This is because genes that are foreign to native plant species may be introduced through the pollen. Such gene spread could negatively impact biodiversity in some instances. No such cases have been documented to date, though it is a legitimate concern, and one that we should minimize whenever developing or using genetically engineered crops.

- Genetically engineered genes may move into fields of producers growing crops intended to be free of genetically engineered genes. There is some evidence that this has happened in traditional varieties of corn grown by smallholders in Mexico, the historic origin of corn. Although there is still some scientific uncertainty that this has happened, many scientists are concerned about the possibility. Smallholder farmers in Mexico are also extremely concerned about this risk. See [5: Protecting Cultural Heritage](#). There is evidence of trans-gene spread into a canola field in Australia intended for organic certification. This resulted in very unpleasant litigation between formerly friendly neighbors. Instances

like these highlight a significant challenge for the use of those genetically engineered traits that may spread in pollen. These instances stress the importance of minimizing these risks.

- ▶ **Do patents on seeds or genetic traits cause concern?** There are several concerns.
  - The majority of acreage planted to genetically engineered crops in the USA is—or was, at one time—patented by multinational corporations. Federal laws allow for such patents, as patents help protect the investment of those that develop new genetic technologies. Farmers may not save seed from a patented genetically engineered crop unless they pay a fee. Patent-holders some-

times aggressively protect their investment through litigation against farmers. A few such instances have resulted in negative publicity for the patent-holder.

- From a producer’s perspective, paying the cost of legally using a patented genetically engineered trait can increase cost of crop production. More importantly, patents can restrict seed-saving and seed-sharing.
- In developing countries, resource-poor farmers and indigenous peoples often prefer seed that is not genetically engineered, particularly if such seed prohibits seed saving and sharing. See [6: Patents Can Inhibit Seed Saving and Sharing](#).
- In developed nations, many farmers choose to pay for the genetically

**4 Crops Tolerant to a Weed Killer.** The genetically engineered crops that have received the most negative attention are those engineered to be tolerant of the weed-killer glyphosate (found in products like Roundup® herbicide). Spraying glyphosate on plants normally kills almost all plants—crops as well as weeds. However, a single gene from a bacterium can be inserted into crops to make them tolerant to this herbicide.

Glyphosate-tolerant crops are perceived differently by different people. Many farmers appreciate glyphosate-tolerant crops because weed control is easy, effective, and inexpensive. Many people also appreciate the expansion of no-tillage agriculture which, in some crops, has been facilitated by using crop varieties genetically engineered to tolerate applications of glyphosate. No-tillage means that crops are produced without physically disturbing the soil. This has benefits for the environment, including protecting the soil from erosion and reducing fuel usage. Also, many experts say that glyphosate has less environmental impact than some of the herbicides it has replaced in field crops.

While recognizing the above benefits, there are also concerns with glyphosate-tolerant crops. Over the years, repeated use of glyphosate has caused the buildup of weeds resistant to this herbicide. Some herbicide manufacturers are now engineering plants to be tolerant to more than one herbicide. Glyphosate still controls many weeds, but

engineering additional resistance to the herbicides 2,4-D or dicamba allows for control of glyphosate-resistant weeds. Farmers currently need these herbicides, but it means that some producers must now use more herbicides than before to control weeds. This is sometimes referred to as a “pesticide treadmill.”

Weeds resistant to herbicides are not unique to glyphosate. Herbicide-resistant weeds occur even in crops that are not genetically engineered. Furthermore, herbicide tolerance in crops is not just due to genetic engineering. There are commercial, herbicide-tolerant crops created by conventional breeding techniques, as well. Thus, herbicide-resistant weeds are not a problem with genetic engineering per se but with this particular application of genetic engineering. In any case, many (including the author) believe that engineered tolerance to glyphosate is not a sus-

tainable, long-term approach to weed control.

Numerous studies show no significant health risk to humans from government-approved uses of glyphosate. However, some experts raise questions about possible long-term health impacts of trace amounts of glyphosate in the diet. The World Health Organization recently categorized glyphosate as a “probable human carcinogen.” If ongoing research validates long-term health concerns regarding glyphosate use, this would be a very important issue, given the widespread and varied use of this herbicide throughout the world. This is one reason some people want products derived from genetically engineered crops to be labeled. Again, any concerns over glyphosate are not a problem with genetic engineering per se but with this particular application of genetic engineering. Applications of genetic engineering must be evaluated on a case-by-case basis.



**Only Roundup Ready corn survived the application of Roundup® herbicide in the field shown in this picture.**

Photo by Paul Vincelli



Farmers in Nicaragua who prefer traditional “landrace” varieties of corn to genetically engineered varieties

Photo by Paul Vincelli

**5 Protecting Cultural Heritage.** In Mexico and Central America, resource-poor farmers often grow landraces of corn, which are corn varieties that may be centuries old. These traditional varieties may not produce top yields but they often perform adequately under a wide range of environmental conditions. This helps assure food security for their families. Landraces are also considered a cultural inheritance. Therefore, resource-poor farmers are often worried about genetically engineered crops pollinating with local landraces.

In order to protect cultural heritage, it is very important that biotechnological innovations designed for developing countries be the product of teams that include local biotechnologists as well as others that can express local concerns (including local farmers and social scientists).

engineered seed because they value its agronomic performance. However, even in the USA, some dislike seed patents if they infringe on the free and open saving and sharing of seed. (But as noted above, our federal laws do permit patents on seed and on genetic traits).

- Some are concerned about corporate control of the food supply. Patents on genetically engineered crops have played a part in the consolidation of the global seed industry in recent decades. Three



Central American farmer with saved corn seed

Photo by Paul Vincelli

**6 Patents Can Prohibit Seed Saving and Sharing.** Resource-poor farmers may always save and share non-patented seed. Some farmers appreciate the agronomic benefits offered by genetically engineered traits. Genetically engineered traits often are patented. Resource-poor farmers and indigenous peoples are not required to buy patented seed. However, if they do buy patented seed, patent laws may prohibit them from saving or sharing it, unless they pay a fee. Since many resource-poor farmers and indigenous peoples like to save and share seed, many prefer non-patented seed, whether it is genetically engineered or non-genetically engineered.

transnational corporations (Monsanto, DuPont, and Syngenta) dominate the global seed market. The consolidation of an important sector of our food system in the hands of a few transnational corporations creates concern for some. This is an issue worthy of public discussion. However, this consolidation was not caused only by the sale of genetically engineered seed. Other factors were also

involved. In fact, the beginnings of the consolidation of the seed industry occurred decades before the first genetically engineered crops. Furthermore, large corporations do not own all genetically engineered traits. Some are developed by public research institutes and humanitarian foundations. These organizations may choose to distribute their genetically engineered traits freely. Finally, patents on genetically

engineered traits do not last forever. In the USA, they expire 20 years after they are issued. Once a patent expires, the genetically engineered trait is in the public domain. See 7: [Genetically Engineered Crops For All Farms and All Farm Sizes](#).

- ▶ **Are food cultures affected by genetically engineered crops?** Some people believe that the use of genetically engineered crops conflicts with their regional food culture, which may have a foundation of centuries of history. Strong—and legitimate—objections to genetically engineered crops may be based on such a cultural belief. See 5: [Protecting Cultural Heritage](#).
- ▶ **Does genetic engineering foster monoculture farming?** Large-scale monoculture offers important advantages to farmers (and thus, to consumers), which is why it is so common in diverse farming systems throughout the world. However, an important down-side of monoculture is that it is potentially subject to destructive outbreaks of diseases and insect pests. To some extent, genetic engineering can foster monoculture. Genetically engineered crops are often well-suited to farming systems of large-scale plantings of a single, genetically uniform crop species. However, monoculture is not caused by genetically engineered crops. Indeed, monoculture farming existed long before genetically engineered crops were first created, and monoculture is commonly practiced today on non-genetically engineered crops throughout the world. Wheat in the USA is a good example. It is rarely grown in any way other than in large-scale monoculture and yet it is completely free of engineered genes. Furthermore, genetic engineering is not just being used for crops grown by large-scale producers. Genetically engineered traits in locally adapted varieties are also being used by smallholder farmers in developing countries. See 7: [Genetic Engineering Crops For All Farms and Farm Sizes](#).
- ▶ **Do genetically engineered crops cause loss of biodiversity?** There are two aspects to this issue: biodiversity in non-agricultural ecosystems (some-

times called “wild diversity”) and biodiversity in agroecosystems (sometimes called “domesticated diversity”).

- **Biodiversity in non-agricultural ecosystems** (wild diversity).
- The destruction of tropical forests, such as the Amazon region, results in substantial loss of biodiversity. These deforested lands are sometimes planted to monocultures of corn and soybeans, and these may be planted to genetically engineered varieties. While it would probably be impossible to find a scientist in favor of tropical deforestation, deforestation is not caused by genetically engineered crops but by other socioeconomic forces.
- Thus far, there are no reports of direct negative impact on biodiversity from genetically engineered crops in ecosystems surrounding farmlands. In fact, the National Academy of Sciences concluded, “Generally, GE [genetically engineered] crops have had fewer adverse effects on the environment than non-GE crops produced conventionally.” This is in part because certain



Farmer in Bangladesh with eggplant genetically engineered to resist insects

Photo courtesy of Mark Lynas

**7 Genetically Engineered Crops for All Farmers and All Farm Sizes.** In the developed world, genetically engineered crops are commonly used on large-scale farms. However, in developing countries, genetically engineered crops are often used by smallholder farmers. Smallholders who use genetically engineered traits often report higher crop productivity and reduced pesticide use. In Colombia, female farmers who grew genetically engineered cotton appreciated not having to pay the cost of insecticide application on their crop.

genetically engineered crops can reduce pesticide use, which helps protect the ecosystems surrounding farms. However, one can never rule out the possibility of negative ecological effects from genetically engineered crops, especially through movement of engineered genes in pollen. It is important to minimize such risks. For this and other reasons, genetically engineered crops are studied more than any other food in history. See 8: [The Monarch Butterfly and Genetic Engineering](#).

- **Biodiversity in agroecosystems** (domesticated diversity). Smallholder farmers often grow traditional crop varieties that harbor substantial genetic diversity. The concern with genetically engineered crops is that they will displace traditional varieties, resulting in erosion of crop genetic diversity. This is a valid concern, as this erosion of diversity has certainly happened. However, it is worth remembering that useful engineered genes can commonly be moved (by conventional breeding) into locally adapted varieties. This provides the farmer with the advantages of the genetically engineered trait while still growing their locally adapted varieties. Thus, genetically engineered crops do not necessarily cause a loss in local diversity of crop genetics. For each genetically engineered trait, it depends on how it is used and on who owns the patent. This is one reason why genetically engineered crops should always be evaluated on a case-by-case basis.
- ▶ **Do genetically engineered crops promote pesticide use?**
- Many emerging genetically engineered traits have no impact on pesticide use. Certain genetically engineered traits can actually reduce pesticide use. See 9: [Genetically Engineered Crops that Reduce Pesticide Use](#) and 10: [Plants that Fight Back against Insects](#). More such pesticide-reducing genetically engineered traits are expected in the future, especially for control of diseases and insects.



Monarch butterfly

Photo courtesy of State Archives of Florida, Florida Memory, <http://floridamemory.com/items/show/92059>

## 8 The Monarch Butterfly and Genetic Engineering.

The Monarch butterfly overwinters in Mexico. Populations of this butterfly in known overwintering sites have fallen dramatically in recent years. Some scientists are concerned that the decline is due to the widespread use of genetically engineered crops with tolerance to the weed-killer called **glyphosate**. The caterpillars of the Monarch butterfly depend on milkweed plants, where they feed. By sowing glyphosate-tolerant crops, producers can achieve excellent weed control by spraying glyphosate on the field. This results in very low levels of weeds in cropland, including milkweed.

It makes sense that excellent control of milkweed might be one of the reasons Monarch populations have suffered. Unfortunately, there is still some scientific uncertainty about the reasons for the Monarch declines in known overwintering sites. Furthermore, even if glyphosate plays a central role, this is not a problem with genetic engineering *per se*. It is simply the outcome of excellent weed control, something farmers like.

If you care about Monarch butterflies, consider planting a Monarch Waystation, a garden to help them feed and reproduce (<http://monarchwatch.org/>).



Some crop production systems are dependent on pesticide applications. Genetic engineering is expected to continue to help reduce pesticide use.

Photo by Paul Vincelli

9 **Genetically Engineered Crops that Reduce Pesticide Use.** Some crops receive moderate to heavy pesticide use. Many research programs are developing genetically engineered traits that make plants resistant to important diseases and insect pests. Such traits are being developed in public laboratories as well as in commercial laboratories. In the author's own scientific discipline—plant pathology—there are numerous, exciting genetic strategies which show great promise for safe, sustainable control of crop diseases with less dependence on pesticides. Many of these genetic traits actually come from crops already in the food supply. In other words, a potato variety can be made more disease-resistant by transferring one or more genes from another potato variety (or from a close relative).

If we are transferring genes within a crop species, why not just use traditional breeding instead of genetic engineering? Indeed, sometimes traditional breeding are the best approaches to addressing particular challenges in crop improvement. However, sometimes genetic engineering offers the best approach. For example, moving desirable genes through genetic engineering can sometimes be faster than using traditional breeding techniques. Another advantage is that genetically genetic engineering causes less genetic disruption to the original variety than traditional breeding. A further advantage of genetic engineering is that resistance genes can be “stacked.” This means that several resistance genes can be placed end-to-end in a genetic sequence and inserted simultaneously, making it easier for the breeder to insert all of the beneficial genes. A breeder might do this to speed the breeding process. In addition, another reason for “stacking” genes is to create crop varieties with durable resistance that could prove to be effective for many years.

In addition to transferring genes within a crop species or its close relatives, a crop variety may be made more disease-resistant by transferring a disease-resistance gene from another crop species. For example, a tomato variety can be made more disease-resistant by transferring a gene from pepper. In most instances, such gene transfers between crop species might not be possible without some form of genetic engineering. For some consumers, transferring genes into crops from plants already in the food chain may be more acceptable than transferring genes from evolutionarily distant organisms (like bacteria, for example). Some of these new traits are in the final stages of federal review and will likely be commercialized soon. A research “pipeline” of other traits will undoubtedly lead to important new disease-resistance traits.





Corn at left with Bt trait which protects against fall armyworm damage; conventional corn at right showing significant damage from fall armyworm

Photo courtesy of Ricardo Bessin

**10 Plants that Fight Back against Insects.** Bt insecticidal proteins are natural products used for insect control. (“Bt” stands for *Bacillus thuringiensis*, the bacterium that is the source of these insecticidal proteins.) Bt proteins bind to the gut of insects, eventually killing them. These natural insecticides have a history of safe use by both conventional and organic farmers. Certain genetically engineered crops have been engineered to produce one or more Bt proteins in the plant itself. Crops that produce Bt proteins need less insecticide than their conventional counterparts. This has many benefits, including less pesticide in the environment, greater survival of beneficial insects in farmlands, and less pesticide in our diets.

Bt proteins are powerful for controlling certain insects, but the good news is that they have extremely low toxicity to humans. In fact, they are actually less toxic to humans than common table salt. To pose a risk, a person would have to eat tens of thousands of pounds of Bt corn in one day, which is physically impossible. Bt corn can actually be safer for people and livestock than conventional corn because it sometimes has lower levels of natural toxins called mycotoxins. See 9: *Improving Food Safety through Genetic Engineering*.

One concern about crops engineered to produce Bt proteins is that they will foster the development of insect resistance to pesticides that use live *Bacillus thuringiensis* or Bt-derived proteins. For example, in many locations, the western corn rootworm is resistant to certain Bt-derived proteins. This reduces the effectiveness of Bt-based pesticides available to organic growers, as well as conventional growers. Farmers often use practices to reduce the risk of insect resistance to Bt toxins, but the widespread use of engineered crops expressing Bt proteins does present risks for the development of insect resistance.

- There are concerns that the use of crops engineered to be tolerant to herbicides can lead to increased herbicide use over the long term. There is concern that this creates a “pesticide treadmill.” See 4: *Crops Tolerant to a Weed-Killer*. There also is concern that overuse of a single genetically engineered trait for pest control may erode its effectiveness over the long term, through the buildup of resistant pests.
- These examples illustrate that each genetically engineered trait should be evaluated on a case-by-case basis. Also, it is important to distinguish genetic engineering (which is a form of crop breeding) from risks due to the pesticides that may be applied to engineered crops.

## Benefits of Genetic Engineering

### ► Human health and nutrition.

Genetically engineered crops can improve human health and nutrition. Some examples:

- Genetically engineered crops are being developed to alleviate food allergies. For example, people who suffer from celiac disease cannot tolerate gluten, which are certain proteins found in wheat. Celiac sufferers must follow a strict diet free of wheat flour. However, promising research is creating genetically engineered wheat with greatly reduced gluten content. If successful, genetically engineered wheat may allow those suffering celiac disease to enjoy bread, pasta, pizza, and other products normally made with wheat flour. Other researchers are working to develop hypoallergenic peanuts.
- Some genetically engineered crops under development are designed to alleviate serious nutrient deficiencies in humans, especially in the developing world. There are several genetically engineered crops under development which are expected to improve the nutrition of children, women, and men in many parts

of the world. These includes crops designed to alleviate deficiencies of Vitamin A, folate (a B vitamin especially important for women of child-bearing age), Vitamin C, iron, and other micronutrients and minerals. See 11: *Golden Rice for the Health of Children in Developing Countries*.

- Strange as it may seem, toxic substances occur naturally in our foods. This includes conventional foods, organic foods, and any others.<sup>3</sup> Many of these substances are produced naturally by plants as they grow. Others are formed during food preparation. Naturally occurring toxins usually occur at low concentrations in modern foods, but they still cause some concern to nutritionists and other scientists. Certain genetically engineered crops can have considerably lower concentrations of naturally occurring toxins, such as mycotoxins, which can have serious health impacts. Other genetically engineered crops will reduce our consumption of acrylamide, classified as a probable human carcinogen.<sup>4</sup> Thus, genetically engineered crops can help us reduce our dietary exposure to natural toxins. See 3: *Improving Food Safety through Genetic Engineering*.
- Genetically engineered crops are being developed to provide sustainable sources rich in certain health-promoting omega-3 fatty acids for use as fish feed in aquaculture. Presently, fish and seafood from the oceans are the predominant source of these fatty acids for human diets, but the oceans are being overfished. See 12: *Creating Sustainable Sources of Health-Promoting Fish Oils*.
- Genetically engineered crops can be developed to have high amounts of healthy oils. For example, a variety of soybean has been engineered to produce high amounts of a healthy oil called oleic acid. Other crops with greater amounts of healthy oils are expected.

<sup>3</sup> See, for example, the well-known paper by Dr. Bruce N. Ames et al. (1990) at <http://www.pnas.org/content/87/19/7777.abstract>.

<sup>4</sup> See <http://www.cancer.gov/about-cancer/causes-prevention/risk/diet/acrylamide-fact-sheet>.



Normal rice at left, Golden Rice at right

Photo from the Golden Rice Humanitarian Board, [http://www.golden-rice.org/Content4-Info/info1\\_photos.php](http://www.golden-rice.org/Content4-Info/info1_photos.php)

**11 Golden Rice for the Health of Children in Developing Countries.** Crops enriched with important vitamins, micronutrients and minerals may help reduce malnutrition in the developing world. Millions of pre-school children are affected by Vitamin A deficiency. Ideally, all children would obtain sufficient Vitamin A through a diversified diet, and nutrition programs are making headway against Vitamin A deficiency. Unfortunately, in some regions of the world, many impoverished or even landless families are presently unable to provide adequate dietary Vitamin A to their children.

Part of the solution to this problem may be Golden Rice. Golden Rice is rice with two genes added: one from a plant and another from a bacterium. These two genes allow rice to make beta-carotene (also called provitamin A), giving the grains a golden color. Beta-carotene is the same natural substance that makes carrots orange. When people consume Golden Rice, the beta-carotene is naturally converted to Vitamin A. Presently, one challenge is to create Golden Rice varieties that produce rice yields at least as good as prevailing rice varieties. Scientists are working to address this challenge.

Golden Rice is not the only genetically engineered approach to alleviating nutrient deficiencies. Corn enriched for multiple important nutrients has also been developed by genetic engineering. Sometimes conventional breeding is successful in increasing nutrition content of certain crops. Nutrition-enhanced crop varieties are badly needed, whether they are developed through conventional breeding or genetic engineering. Nutrition-enhanced crops varieties will not address issues of poverty or social justice. However, if developed with respect for local populations, local cultures, and sustainable economies, they could contribute to improved quality of life for some of the poorest among us.



Seedheads and seeds of genetically engineered *Camelina* sp., a source of important omega-3 fatty acids

Photo courtesy of Rothamsted Research

**12 Creating Sustainable Sources of Health-Promoting Fish Oils.** Omega-3 fatty acids are important

in the human diet, because our body cannot make them; we must obtain them from food. They also help to promote health. We humans obtain some of the most important omega-3 fatty acids<sup>1</sup> from fish caught in the oceans. Unfortunately, the oceans are being overfished, so this is an unsustainable source of these health-promoting fatty acids. Even aquaculture (fish-farming) is unable to provide what we need, since fish in aquaculture systems also get their health-promoting fatty acids from fish obtained from the oceans. Genetically engineered plants are being developed to provide a novel source of omega-3 long-chain polyunsaturated fatty acids for use in fish feeds, potentially helping to make aquaculture more sustainable.

<sup>1</sup> The omega-3 (n-3) long-chain polyunsaturated fatty acids, particularly those abbreviated EPA and DHA. These are not found in plant-based sources of omega-3 fatty acids.

- Genetically engineered tomatoes with deep purple color may have significant health benefit. See 13: [Purple Tomatoes That May Help Fight Cancer](#).
- **Less pesticide.** Studies commonly have shown reductions in pesticide use through the use of certain genetically engineered crops, such as those engineered to produce Bt protein. (See 10: [Plants that Fight Back Against Insects](#) and 9: [Genetically Engineered Crops that Reduce Pesticide Use](#)). This is true in both developed countries and developing countries, including on smallholder farms. This has important benefits



Genetically engineered purple tomatoes with potential cancer-protective health benefits

Photo courtesy of Cathie Martin, John Innes Centre

**13 Purple Tomatoes May Help Fight Cancer.** Both red and purple tomatoes have natural plant pigments called **anthocyanins**, but the purple ones shown here have substantially more. The high-anthocyanin tomatoes in this photo are due to the insertion of two genes from snapdragon. Using laboratory mice with a strong tendency to develop cancer, the researchers found that consuming these purple tomatoes extended the lives of the mice by 30%. Juice from these purple tomatoes may help reduce cancer risk, once it is commercialized. Certain heirloom varieties of tomatoes are also deep purple color and may offer the same health benefits, although they have not been similarly tested for such benefits. Furthermore, the genetically engineered genes potentially may be more easily moved into other tomato varieties adapted to other regions than the genes in the heirloom varieties.

to consumers (less pesticide residues on foods) and the environment (less contamination of ecosystems). Furthermore, significant benefits for farmers and farm workers include less exposure to pesticides and fewer pesticide poisonings. This is true even on smallholder farms. More such pesticide-reducing genetically engineered crops are expected in the future. Numerous public and private research projects throughout the world are working to use genetics (including genetic engineering) instead of pesticides in order to control crop diseases and insect pests.

- **Environmentally friendly pest control.** Certain genetically engineered crops are designed to be resistant to damaging insects and diseases. This can help increase yield as well as reduce pesticide use, as mentioned above. Some genetically engineered crops promote the buildup of natural enemies of destructive insect pests. This is because these crops need less insecticide use. Less insecticide use protects the natural enemies. See 10: [Plants that Fight Back against Insects](#), 14: [Restoring the Once-Mighty American Chestnut](#), 15: [Virus-Resistant Papaya Saves an Industry](#), and 16: [Saving Florida Oranges](#).
- **Lower environmental footprint.** Most scientists believe that present and future genetically engineered crops can help reduce the environmental footprint of our food system. Examples include: 12: [Creating Sustainable Sources of Health-Promoting Fish Oils](#), 10: [Plants that Fight Back against Insects](#), and 17: [Fertilizer from Thin Air](#). In addition to these examples, genetically engineered crops currently under development are expected to use fertilizer and irrigation more efficiently, reducing the impact of farming on water quality and water supply. Others are expected to reduce emissions of greenhouse gases. Still others are expected to reduce food waste, which will have important environmental benefits.
- **Soil conservation.** In some crops, use of certain genetically engineered varieties can facilitate the expansion of no-tillage agriculture. This protects the land from erosion and helps promote healthy soils. No-tillage farming may also increase natural carbon storage in soils. This helps to mitigate climate change. Finally, no-till farming helps protect rivers, lakes, and streams, by reducing runoff of nutrients and soil that pollute surface waters. See 4: [Crops Tolerant to a Weed Killer](#).
- **Increased yield.** Numerous studies have found yield increases associated with the use of genetically engineered crops. Yield increases from the current generation of genetically engineered crops have usually been due to improved insect and weed control. Future genetically engineered crops may produce higher yields via other mechanisms, possibly including more efficient photosynthesis. Conventional breeding also produces yield increases, so you can expect crop improvement to benefit from conventional techniques and from genetic engineering. Producing high yields of food and fiber on cropped land is beneficial because it preserves other land for wildlife habitat and watershed protection.
- **Reduced labor costs.** Genetically engineered crops that allow for pesticide reductions often mean that labor costs are reduced. As an example, women who farm genetically engineered cotton in Colombia appreciate how they no longer have to pay someone to spray their crop with insecticides. Reduced labor costs are beneficial for the farmer and ultimately for the consumer (because of lower food prices). However, it is important to note that reduced labor needs may affect local employment, which can be a negative consequence of improved farming efficiency.



**Fallen chestnut tree**

Photo by Andrej Kunca, National Forest Centre—Slovakia, Bugwood.org

## 14 Restoring the Once-Mighty American Chestnut.

The American chestnut was one of the most common and valued trees in North American forests. It has been nearly wiped out by a non-native, invasive fungal disease, called chestnut blight. For over a century, conventional disease-control approaches have failed to undo the ecological damage caused by chestnut blight. However, researchers have made a significant advance that may help in the restoration of this classic American tree. A single gene from wheat, transferred into American chestnut, makes it resistant to the damage caused by the chestnut blight fungus. Presently, this genetically engineered American chestnut is undergoing federal review.

## 15 Virus-Resistant Papaya Saves an Industry.

In the 1990s, a naturally occurring virus called papaya ringspot virus was destroying the papaya industry in Hawaii. Researchers at Cornell University developed two genetically engineered papaya varieties which contain a small fragment of the genetic sequence of the virus. This fragment triggers natural disease resistance in the papaya. Eating this genetic fragment poses no known health risks. In fact, when consumers eat non-engineered papaya, they often are eating the entire virus, not simply a small fragment of its genetics. Virus-resistant papaya was commercialized in 1998, and it has helped to save the papaya industry in Hawaii. Many more examples of disease-resistant genetically engineered crops are under development. These are expected to reduce loss from diseases, as well as reduce the use of disease-control chemicals.



Non-engineered papaya (at left) and papaya engineered to resist the virus.



Papaya fields in 1994, severely affected by papaya ring spot virus. These fields were abandoned because of the disease damage.



Aerial view of field trial begun in 1995, showing a solid block of virus-resistant papaya growing well while the surrounding susceptible papaya is severely damaged by the virus. Photo taken 19 months after start of the field trial.

Photos reproduced, with permission, from:

- Gonsalves, D., Gonsalves, C., Ferreira, S., Pitz, K., Fitch, M., Manshardt, R., and Slightom, J. 2004. Transgenic virus-resistant papaya: From hope to reality in controlling Papaya ringspot virus in Hawaii. APsnet Features. Online. DOI: 10.1094/APsnetFeature-2004-0704.
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**Citrus tree exhibiting citrus greening**

Photo by H.D. Catling, Bugwood.org

**16 Saving Florida Oranges.** Citrus greening is a highly destructive disease that invaded Florida in 2005. Since its detection, 135,000 acres of Florida citrus production have been abandoned due to citrus greening, and there is concern that the state eventually will lose most of its citrus production. So far, conventional disease-control techniques, including breeding, have performed poorly. Orange producers are applying substantial amounts of insecticide in a desperate attempt to slow disease development, but this has provided poor results. Recently, through genetic engineering, a single gene from spinach was inserted into an orange plant. This orange variety has exhibited a high level of resistance to citrus greening. It is currently undergoing federal review. Citrus greening has also been detected in other citrus-producing states in the USA.

- **Higher profits.** Many times, farmers' profits are higher with genetically engineered crops. This has been documented in developing countries as well as developed countries. In developed countries, this helps support farmers, the people that grow our food. In developing countries, higher profits mean greater food security and a better quality of life for farm families.
- **Stress-tolerant crops.** In order to feed us, farmers must produce crops under the environmental stresses of a changing climate. Genetically engineered traits are being developed to protect against those stresses, including crop tolerance to flooding, drought, and temperature extremes. Genetic engineering is most successful when a trait depends on one or a few genes. Sometimes, crop tolerance to stresses is due to complex genetics. In such cases, conventional breeding is sometimes more effective than genetically engineered technologies. However, there are cases where genetically engineered can be highly effective in increasing stress tolerance. See [18: Rice Tolerant to Drowning](#), for an example.

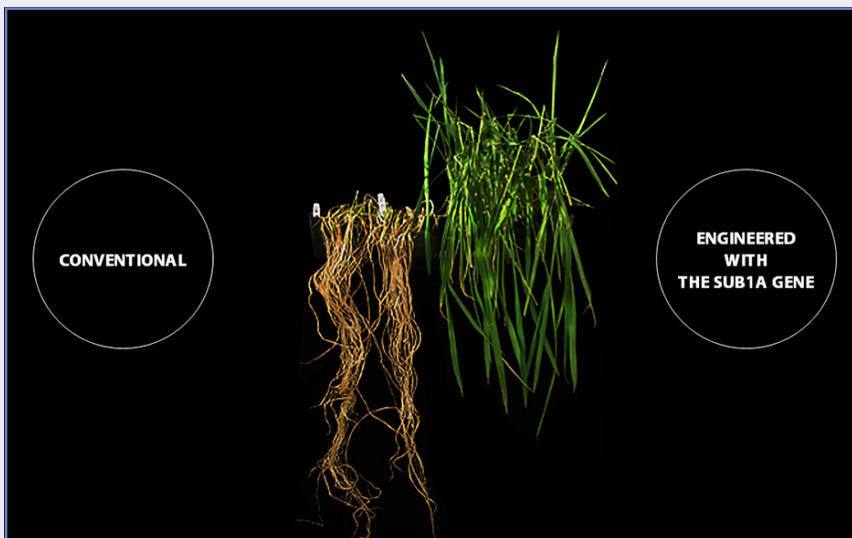


**Corn at right shows symptoms of nitrogen deficiency.**

Photo courtesy of Dr. Andrew Leakey, University of Illinois

**17 Fertilizer from Thin Air.** Deficiencies of nitrogen can affect crop growth, as is evident in this photo. In cereals like corn, rice, and wheat, nitrogen is typically supplied by applying fertilizer to the soil. This practice helps farmers attain high yields. Unfortunately, fertilizer applications to the soil can result in contamination of rivers, lakes, and groundwater with nitrogen. Furthermore, the manufacture and use of nitrogen fertilizers can contribute to global warming.

One of the most exciting areas of genetic engineering research are studies working on transferring genes into cereal crops so they can capture nitrogen out of the air. If this research is successful, this will be an advance of incalculable value to humanity. Cereal farmers throughout the world will no longer need to purchase nitrogen fertilizer, and pollution caused by the manufacture and use of nitrogen fertilizer will be greatly reduced.



Conventional rice at left, which was killed by submersion for several weeks; engineered rice at right, tolerant of the “drowning” conditions that killed the conventional plant

Photo courtesy of Pamela Ronald

**18 Rice Tolerant to Drowning.** Insertion of a single gene from an ancient rice variety into a modern rice variety allows this genetically engineered rice to tolerate as much as nearly three weeks of submersion under water. This new genetically engineered trait is now being used on millions of farms. This is important because each year, submergence causes the loss of enough rice to feed over 30 million people. Sometimes crop tolerance to environmental stress is due to complex genetics, which would make genetic engineering less effective than other breeding techniques. However, this is a case where a single gene, transferred by genetic engineering, was very effective.

## Reviewers

Reviewers of previous drafts of this publication include Jannine Baker, Ricardo Bessin, Lynn Blankenship, Dennis Duross, Michael Goodin, Krista Jacobsen, Lee Meyer, Janet Mullins, Robert Perry, Keiko Tanaka, and Mark Williams, of the University of Kentucky; Rebecca Harrison, of the Cornell Alliance for Science; Maria Mercedes Roca, of Tecnológico de Monterrey; and David Tribe, of the University of Melbourne.

## Disclosure

The author declares no conflicts of interest (past or present) with respect to genetic engineering. Interested readers can find a completed conflict-of-interest form in the file named *coi\_disclosure\_GE\_crops\_Paul\_Vincelli*, at [https://www.dropbox.com/sh/ys0gsvqrn03cvld/AAADepHoD0TvKxqcJ\\_118vO\\_ka?dl=0](https://www.dropbox.com/sh/ys0gsvqrn03cvld/AAADepHoD0TvKxqcJ_118vO_ka?dl=0).

In addition, please see the disclosure statement at <http://out-of-the-box-vincelli.blogspot.com/2015/11/disclosure-statement-on-industry.html>

## Selected References

Below are a few examples of the very extensive collection of peer-reviewed scientific articles that are the foundation of this University of Kentucky Extension fact sheet, **Genetically Engineered Crops: Emerging Opportunities**. Italicized comments are provided for each citation. Most of these articles are freely available to the general public. A few require payment for access, although a summary is publically available. Although we regret the cost for those that require payment, they are included because they form an important part of the scientific literature and may be of interest to readers.

- ▶ Carrière and others, 2015. **Optimizing pyramided transgenic Bt crops for sustainable pest management.** Nature Biotechnology doi:10.1038/nbt.3099. <http://www.nature.com/nbt/journal/v33/n2/full/nbt.3099.html>. *An example of the ways scientists work to reduce the buildup of resistant pests when using biotech traits on large acreages.*

**19 Engineering with Genes from Close Relatives.** Genetic engineering sometimes involves the transfer of genes among organisms which are completely unrelated to one another. For example, a gene from a bacterium can be inserted into a plant's genetics. This process is called **transgenesis**, and a transferred gene is called a **transgene**. It is interesting to contemplate the fact that bacterial genes can function when inserted into our crop plants. They work because the genetic code of life on Earth is essentially *universal*. Thus, genes from one organism will often function quite well when transferred in another organism.

While transgenes commonly do function in the plant that receives them, some consumers are uncomfortable with crossing species boundaries through laboratory manipulation. They are more comfortable with **cisgenesis**.

Cisgenesis is the engineering of crops using only genetics from the crop's breeding pool. For example, a cisgenic potato may have a gene inserted by genetic engineering, but that gene (and all others) must come from either cultivated potato or from wild potato. These are both within the breeding pool of potato. Cisgenic crops can thus take advantage of genetically engineered laboratory techniques. However, because the genetic engineer is only using genes from the natural **breeding pool** of potato, cisgenic changes could, in principle, arise through traditional breeding techniques. This makes them more acceptable to some consumers who may oppose transgenesis.

You might wonder, if cisgenic varieties could be produced by traditional breeding, why even bother with genetic engineering? One answer is because, for some crops, using conventional breeding techniques may take years to decades to achieve what might be possible in the laboratory in as little as one year or less. Using genetic engineering would be a way to “fast-track” important genes, while still staying within the crop's natural breeding pool. Furthermore, sometimes traditional breeding is limited because of **linkage drag**. This is a technical term that basically means that some of the best qualities of an elite crop variety may be lost as a result of the breeding process. Genetic engineering is a way to introduce important genetic traits quickly and without linkage drag.

- ▶ Davis and Dyer, 2015. **Long-Term Trends in Eastern North American Monarch Butterflies: Collection of Studies Focusing on Spring, Summer, and Fall Dynamics.** *Annals of the Entomological Society of America*, pages 1–3; DOI: 10.1093/aesa/sav070. <http://aesa.oxfordjournals.org/content/early/2015/08/03/aesa.sav070>. *An introduction to the latest science revealing the complexity involved in the efforts to determine why Monarch populations have fallen drastically in Mexico.*
- ▶ Duke, 2015. **Perspectives on transgenic, herbicide-resistant crops in the United States almost 20 years after introduction.** *Pest Management Science* Vol. 71, pages 652–657. <http://onlinelibrary.wiley.com/doi/10.1002/ps.3863/abstract>, accessed 3 Jul 2015. *A scientific review of GE-based crop tolerance to herbicides, including the challenges of resistance in weeds to herbicides.*
- ▶ Fernandez-Cornejo and others, 2014. **Genetically Engineered Crops in the United States.** USDA Economic Research Report No. ERR-162. <http://www.ers.usda.gov/publications/err-economic-research-report/err162.aspx>, accessed 3 Jul 2015. *This report from the US Department of Agriculture presents information on GE crops used in the USA and their impacts.*
- ▶ Gressel, 2014. **Dealing with transgene flow of crop protection traits from crops to their relatives.** *Pest Management Science* DOI 10.1002/ps.3850. <http://onlinelibrary.wiley.com/doi/10.1002/ps.3850/abstract>, accessed 3 Jul 2015. *A scientific review of the concern that genetic material from GE crops may transfer to wild relatives. The review also discusses ways such risk might be reduced.*
- ▶ Klumper and Qaim, 2014. **A meta-analysis of the impacts of genetically modified crops.** *PLoS ONE* 9(11): e111629. doi:10.1371/journal.pone.0111629. <http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0111629>, accessed 3 Jul 2015. *A scientific review reporting on the impacts of GE crops in both developed and developing countries.*
- ▶ Kouser and Qaim, 2011. **Impact of Bt cotton on pesticide poisoning in smallholder agriculture: A panel data analysis.** *Ecological Economics* Vol. 70, pages 2105–2113. <http://www.sciencedirect.com/science/article/pii/S0921800911002400>, accessed 3 Jul 2015. *This research reports reduced pesticide poisonings where a GE crop was used, one that was designed to reduce pesticide use.*
- ▶ Kyndt and others, 2015. **The genome of cultivated sweet potato contains *Agrobacterium* T-DNAs with expressed genes: An example of a naturally transgenic food crop.** *Proceedings of the National Academy of Sciences* /doi/10.1073/pnas.1419685112. <http://www.pnas.org/content/112/18/5844>, accessed 3 Jul 2015. *A recent example of the discovery of genetic material that appears to have moved across species and genus boundaries. Many other such studies are available. These studies suggest that similar laboratory manipulations by human are not at all unnatural.*
- ▶ Ladics and others, 2015. **Genetic basis and detection of unintended effects in genetically modified crop plants.** *Transgenic Research* DOI 10.1007/s11248-015-9867-7. <http://link.springer.com/article/10.1007%2Fs11248-015-9867-7>, accessed 3 Jul 2015. *Presents current scientific findings on many aspects of GE crops, especially in relation to other techniques of crop improvement.*
- ▶ Nicolia and others, 2013. **An overview of the last 10 years of genetically engineered crop safety research.** *Critical Reviews in Biotechnology*. DOI: 10.3109/07388551.2013.823595. <http://informahealthcare.com/doi/abs/10.3109/07388551.2013.823595>, accessed 3 Jul 2015. *A scientific review of recent research on the question of whether GE crops are safe to consume.*
- ▶ Snell and others, 2012. **Assessment of the health impact of GM plant diets in long-term and multigenerational animal feeding trials: A literature review.** *Food and Chemical Toxicology* Vol. 50, pages 1134–1148. <http://www.sciencedirect.com/science/article/pii/S0278691511006399>, accessed 3 Jul 2015. *A scientific review of long-term feeding studies for GE crops.*
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- ▶ US-Food and Drug Administration. 2015. **Questions & answers on food from genetically engineered plants.** <http://www.fda.gov/Food/Food-ScienceResearch/Biotechnology/ucm346030.htm>, accessed 3 Jul 2015. *An overview by the US-FDA on genetically engineered crops. FDA evaluates GE crops for food safety.*
- ▶ Vincelli, 2013. **GMOs and corn mycotoxins.** *Kentucky Pest News* <http://graincrops.blogspot.com/2013/08/gmos-and-corn-mycotoxins.html>, accessed 3 Jul 2015. *A short overview of how certain GE traits have improved food safety for corn.*
- ▶ Vincelli, P. 2015. **Consumption of Genetically Engineered (=GMO) Crops: Examples of Quotes from Position Papers of Scientific Organizations.** *Kentucky Pest News*, <https://kentuckypestnews.wordpress.com/2015/03/31/consumption-of-genetically-engineered-gmo-crops-examples-of-quotes-from-position-papers-of-scientific-organizations/>, accessed 3 Jul 2015. *This article provides a list of quotes from many prestigious scientific organizations about the safety of consuming GE crops.*
- ▶ Yang and others, 2014. **Engineering anthocyanin biosynthesis in plants.** *Current Opinion in Plant Biology*. Vol. 19, pages 81–90. <http://dx.doi.org/10.1016/j.pbi.2014.05.011>, accessed 18 Jul 2015. *Provides some of the scientific basis for the purple tomatoes that may help reduce cancer risks.*





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