Do we really need GMOs, gene editing and other new technologies?

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Why I am interested in GMOs and agricultural biotechnology

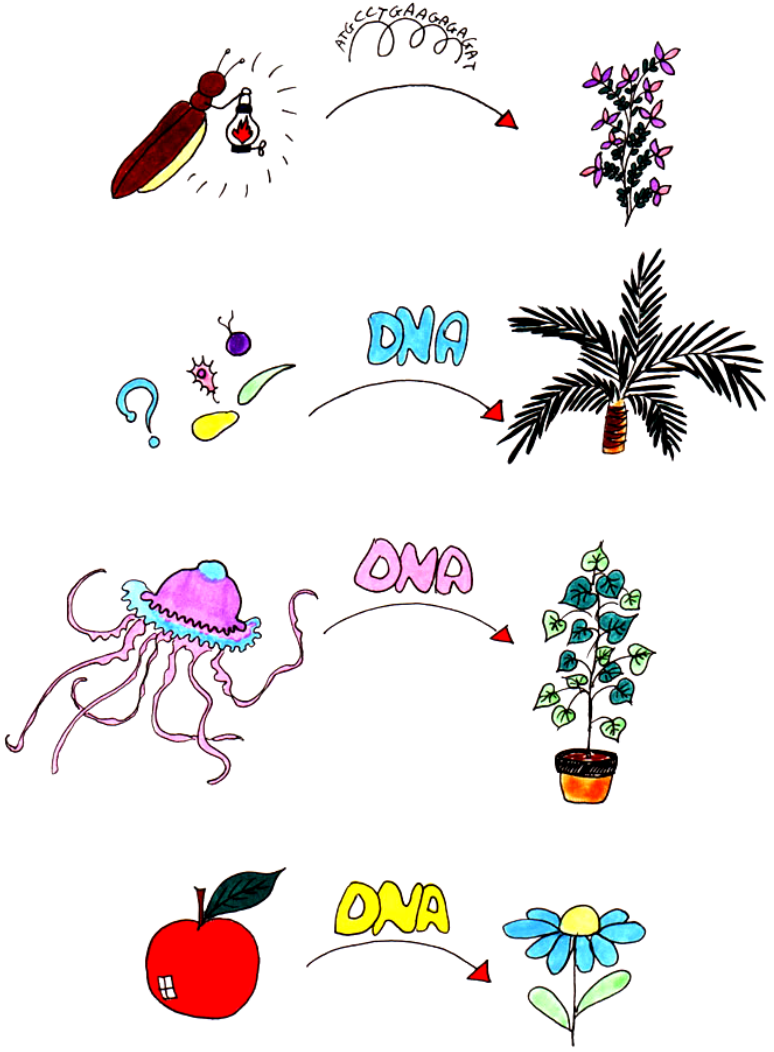
- A fascinating topic (at least for me!) that involves interesting science, new agricultural technologies and a little bit of controversy
- My background and training is in plant molecular biology
- The first transgenic plants were produced in 1983, one year after I came to Purdue
- I teach an undergraduate class on agricultural biotechnology

What am I going to talk about?

- The science that underlies GMOs, how they are made, what they are used for, issues and concerns
- New biotechnology – gene editing
- Can we change public attitudes about GMOs?
- I am **not** going to tell you where to buy your food or what to eat!
- I like Michael Pollan's guidelines on this topic:
  - Eat food. Not too much. Mostly plants.
  - No more than 5 ingredients
  - Food should come from a plant, not be made in a plant

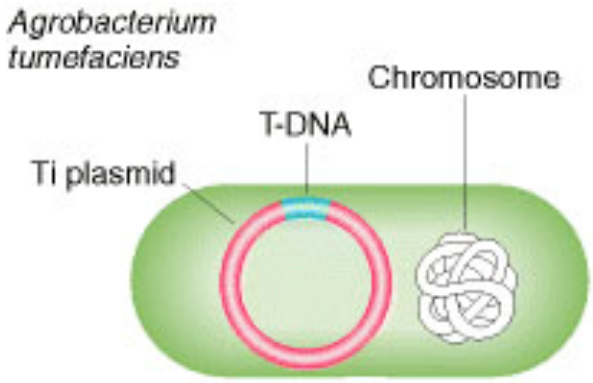
Agricultural Biotechnology new genes for old crops

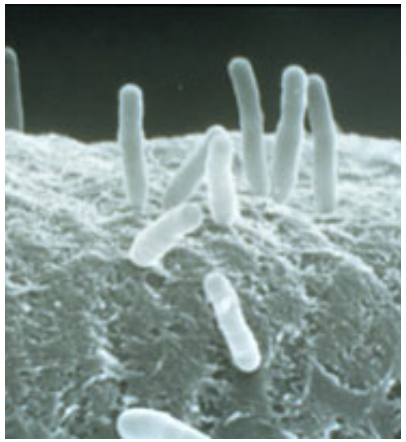
- 1983 – new methods are developed to transfer genes into plants
  - based on our knowledge of DNA and how it functions as an information system
- Now we can use genes from any source to modify and improve crop plants
- Genetically modified organisms, an inaccurate term at best

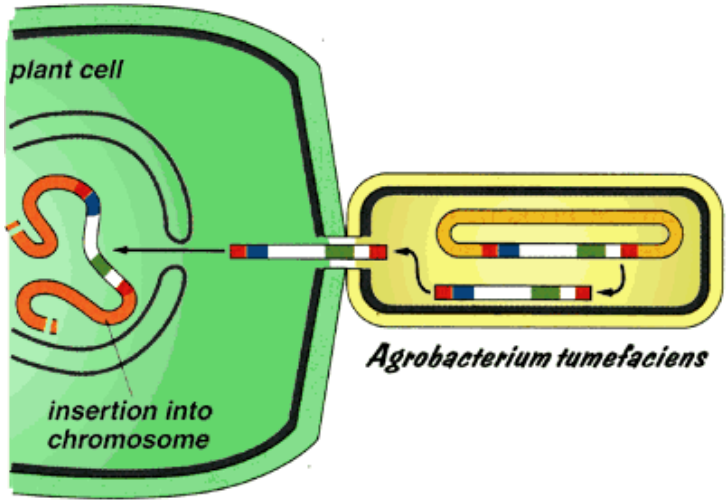


Agrobacterium – Nature's own genetic engineer

- *Agrobacterium tumefaciens* transfers DNA into plant cells to cause crown gall disease
- This DNA transfer system can be modified to transfer any DNA into plant cells







Biotechnology traits and genes

One or two genes can be added to a crop plant to change specific characteristics such as

- herbicide tolerance
- insect resistance
- other traits including disease resistance, shelf life, ornamental properties, stress tolerance

Where do these genes come from?

- any other organism

For herbicide tolerance and insect resistance traits, these genes usually come from bacteria

Herbicide resistant crop plants

Two approaches to make crop plants resistant to herbicides such as Roundup or Liberty

- bypass the metabolic blockage (Roundup Ready)
- metabolize the herbicide (Liberty Link)

No weed control

Weed control with Roundup

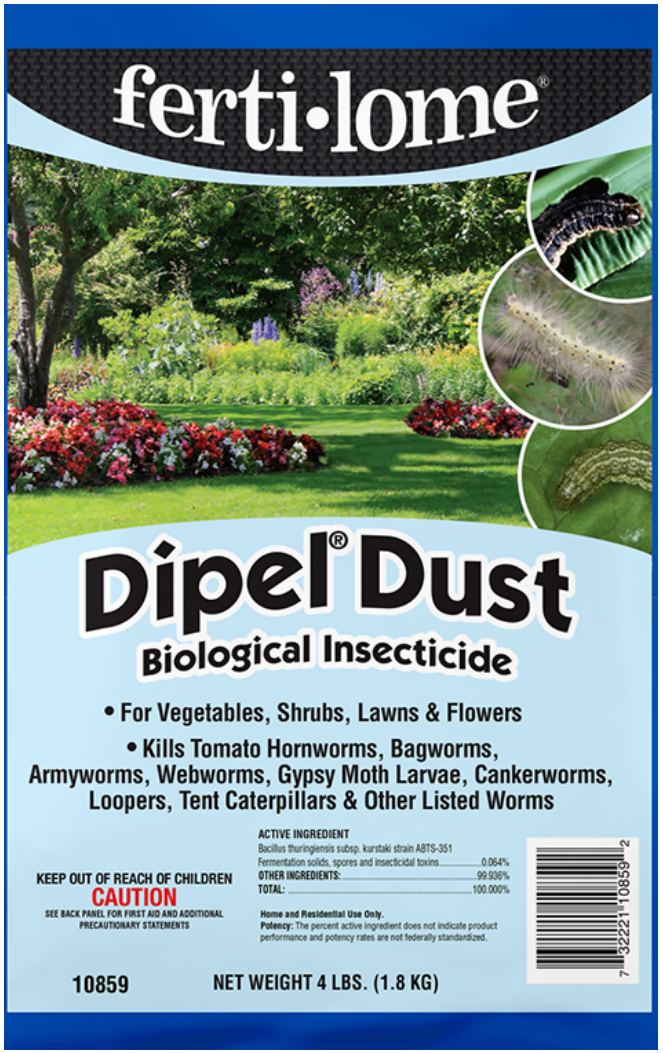
Before herbicide

After herbicide

Genes for resistance to insects

Bacillus thuringiensis

- a soil bacterium
- Spores of this bacterium are widely used as organic insecticides, e.g. Dipel, Thuricide
- *Bacillus thuringiensis* produces proteins called Bt toxins that kill various insects



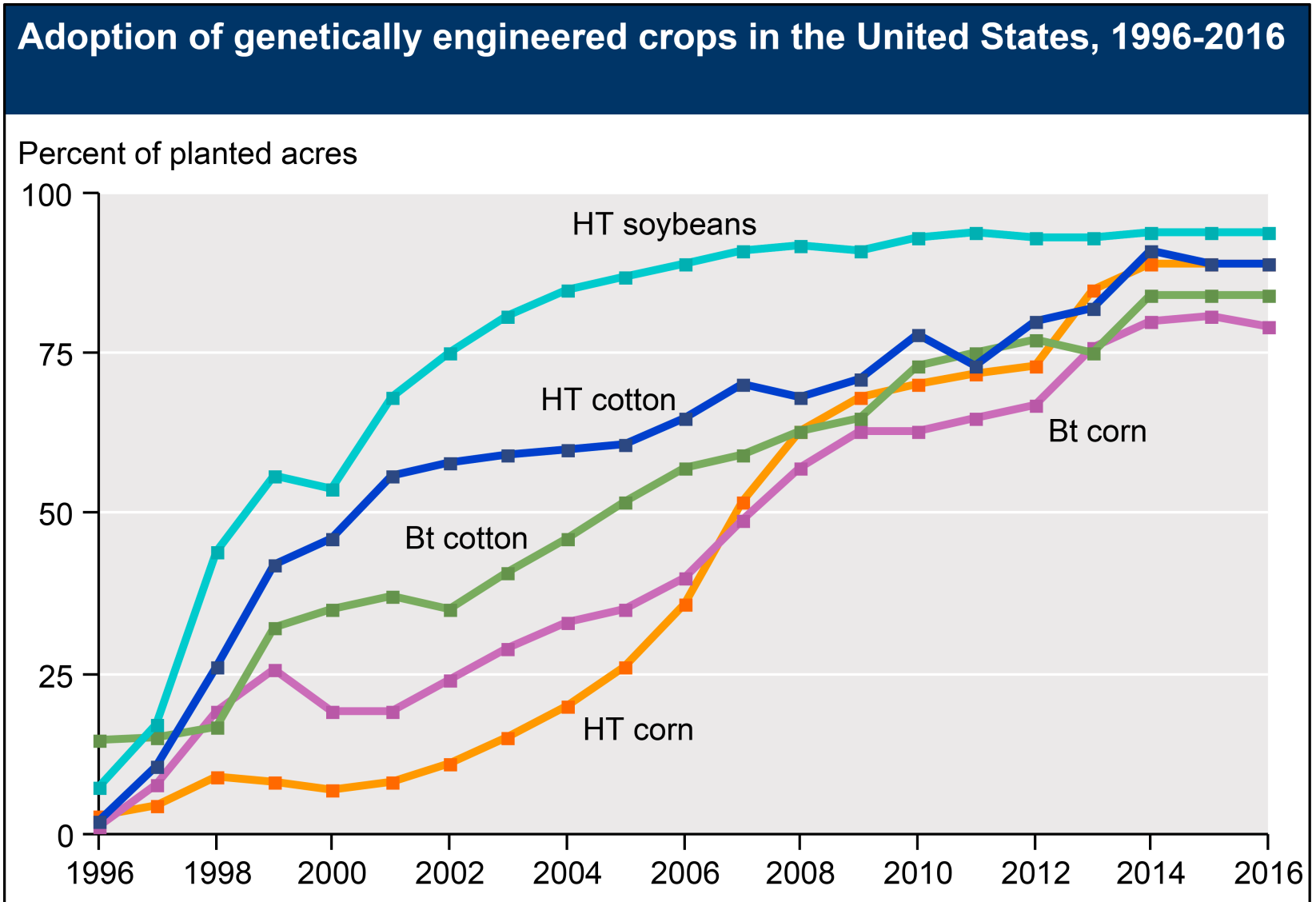
Bt genes and Bt crops

- Genes encoding Bt toxin proteins have been isolated from *Bacillus thuringiensis* and transferred into various crop plants
- These genetically modified plants produce their own Bt toxins that make them resistant to some insect pests
  - Bt corn - European corn borer, rootworm
  - Bt cotton – bollworm, budworm
  - Bt potato - Colorado potato beetle

Bt cotton

Conventional non-GM cotton

Transgenic crops have been very widely adopted in the United States



Marvel or malady?

In spite of their widespread adoption in the US, concerns and fears about GMOs are widespread. People are concerned that

- GMOs are unnatural
- GMOs are not safe to eat
- GMOs are damaging to the environment
- GMOs have consolidated control of agriculture in the hands of a few corporations
- GMOs provide no benefit to consumers
- GMOs have not delivered on their promise

Our crop plants are not natural

- All crop plants and livestock have been genetically modified during the process of domestication

Wild cabbage (above) and these cole crops (right) are all the same species, *Brassica oleracea*

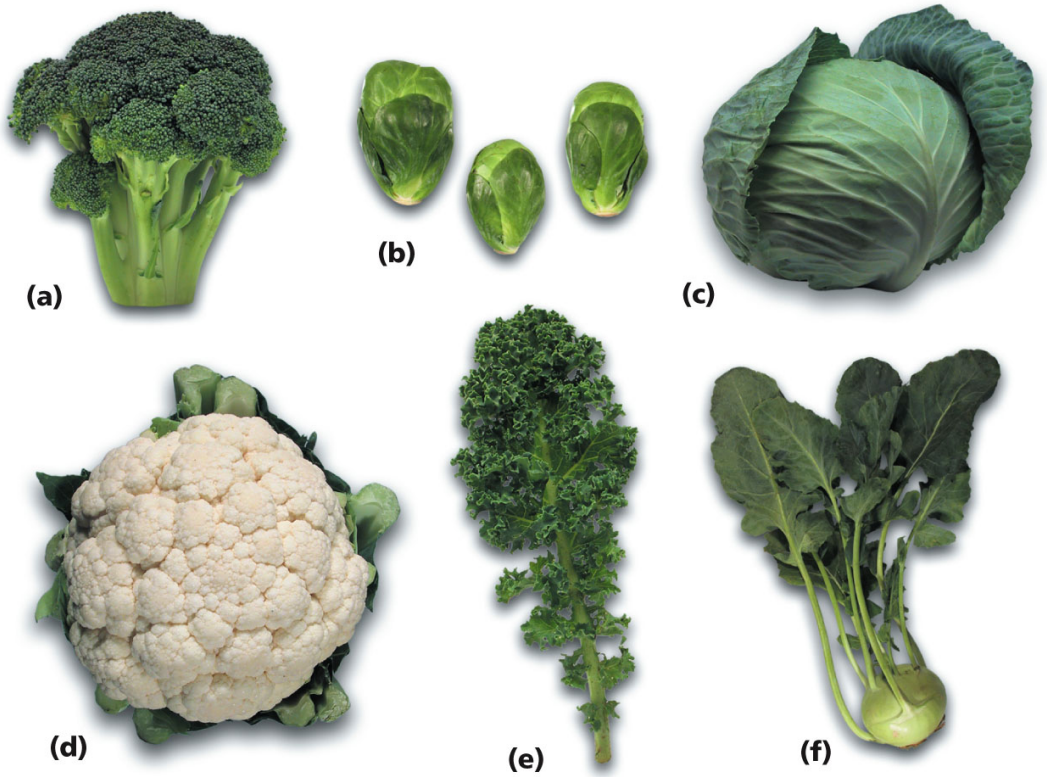


Figure 16.5 Plant Biology, 2/e

Domestication of crop plants

- All of the crops we grow (grains, fruits, vegetables) have been "domesticated" (selected and modified) to produce the foods we eat today
- These are all examples of genetic modification!

Many unnatural methods are used to develop improved crop varieties

- Mutation breeding using radiation or chemicals
- Wide crosses between different species (e.g. triticale, VFNT genes in tomato varieties)
- Tissue culture methods for embryo rescue, protoplast fusion
- F1 hybrids
- Manipulating chromosome number (e.g. seedless watermelons)
- Grafting

Are GMOs equivalent to other methods used to improve crops?

In some regards, the methods are equivalent

- GMOs are simply another way to access and use novel sources of genetic variation for crop improvement

But this technology is different

- In most cases the transferred genes could not have been incorporated into a plant by any of the "conventional" crop improvement methods
- GMOs contain novel combinations of genes that would not occur in nature
- GMOs are NOT natural

What has been the impact of herbicide tolerant crops?

- You can argue that not much has changed; herbicides are still used for weed management
- Dramatic changes in which herbicides are used
  - increased use of Roundup, decrease in other herbicides
- Increased cost for seeds, reduced cost of weed management, simpler weed management
- Evolution of weeds with resistance to herbicides
  - started long before the first GMO was planted
- Now have to use more herbicides to manage these herbicide-resistant weeds

Herbicide resistance and GMOs

- This could have been delayed with better stewardship and management of Roundup Ready technology
- There is no silver bullet solution to this problem
- Adding more genes for herbicide resistance and using more herbicides – the herbicide treadmill
- Better management of weeds and the weed seedbank

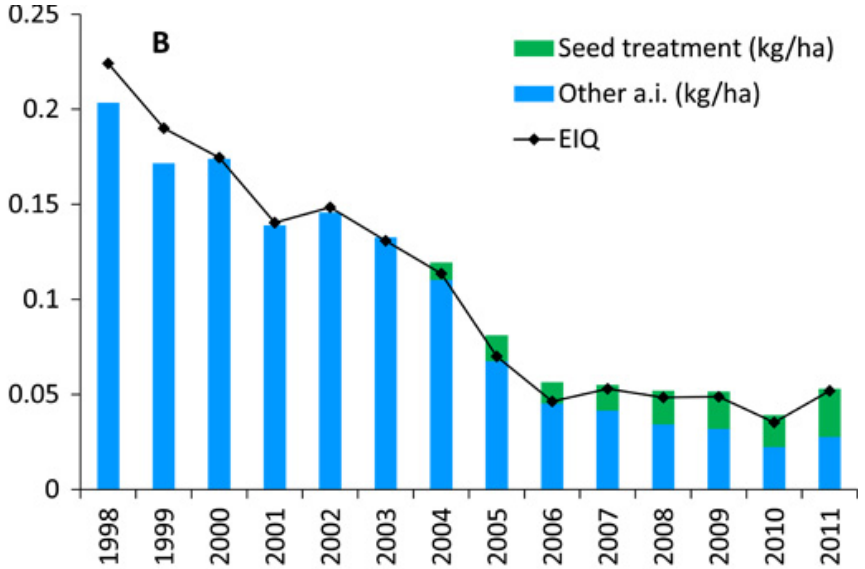

Glyphosate Resistant Giant Ragweed (*Ambrosia trifida*) infesting Roundup Ready Corn. Photo: D

What has been the impact of insect tolerant crops?

- Widespread adoption in the US and other countries, especially for Bt cotton
- Substitution of genes for insecticides
- Significant reduction in the use of insecticides on cotton and corn
- Regulations introduced to delay the development of insects with resistance to Bt toxins (planting refuges, using multiple toxins) have been quite effective

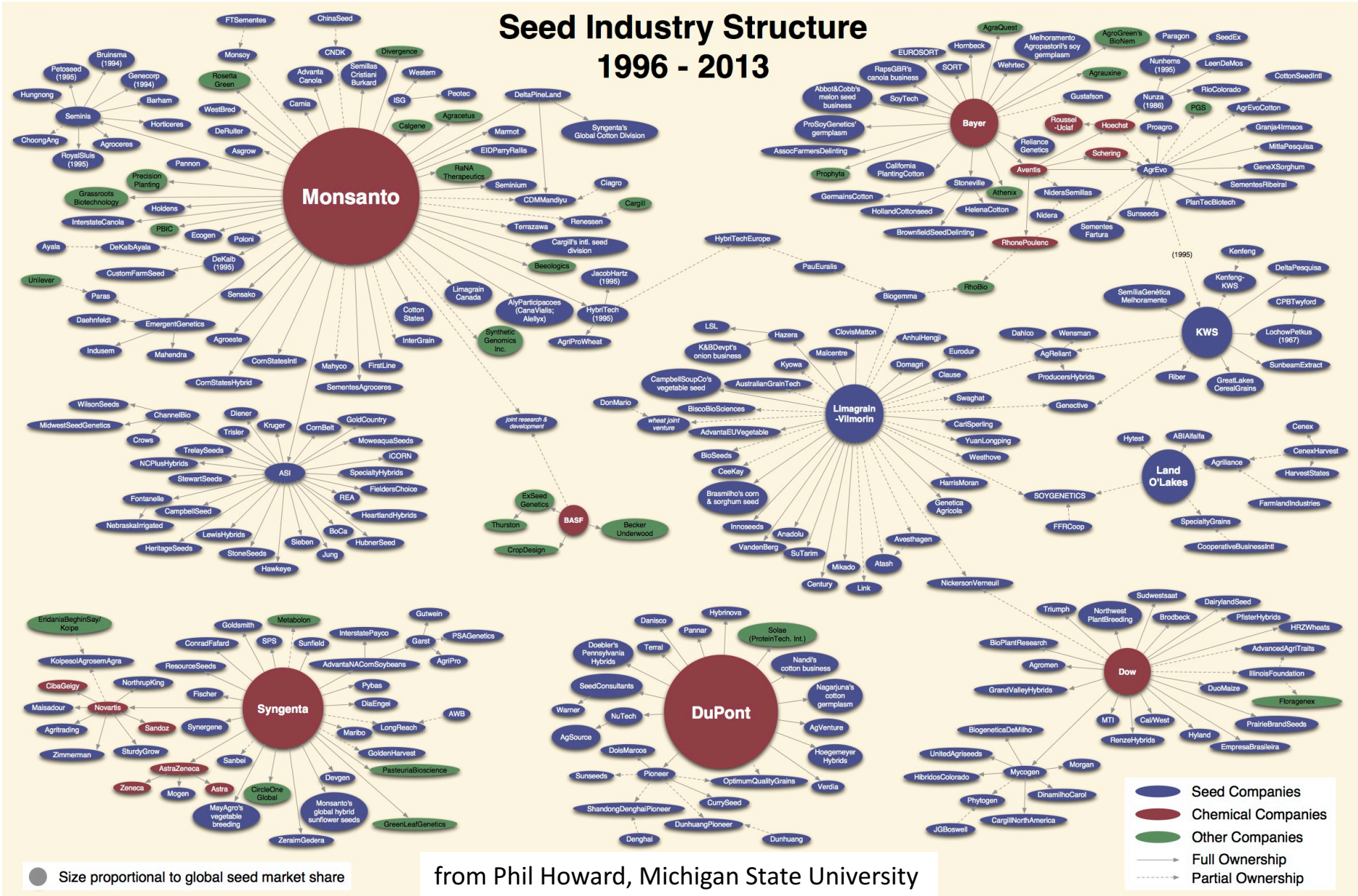
Reduced insecticide use in Bt crops

- Bt corn has reduced populations of the European corn borer and the amount of insecticides used to manage corn borers and corn rootworm
- Bt cotton has increased yield and reduced insecticide use in China and India. This has increased farmers' income and improved their health because of reduced exposure to insecticides



Reduced use of insecticides on corn from 1998 to 2011 because of Bt corn adoption (Perry et al. Sci Adv 2016)

Consolidation of the seed industry



from Phil Howard, Michigan State University

Are GMOs safe to eat?

Scientific and medical organizations have concluded there is no specific health risk from current GMOs

- American Association for the Advancement of Science: The science is quite clear: crop improvement by the modern molecular techniques is safe
- National Academy of Sciences: No evidence of human health problems associated with the ingestion of these crops or resulting food products have been identified
- American Medical Association: No overt consequences on human health have been reported and/or substantiated

Gene editing

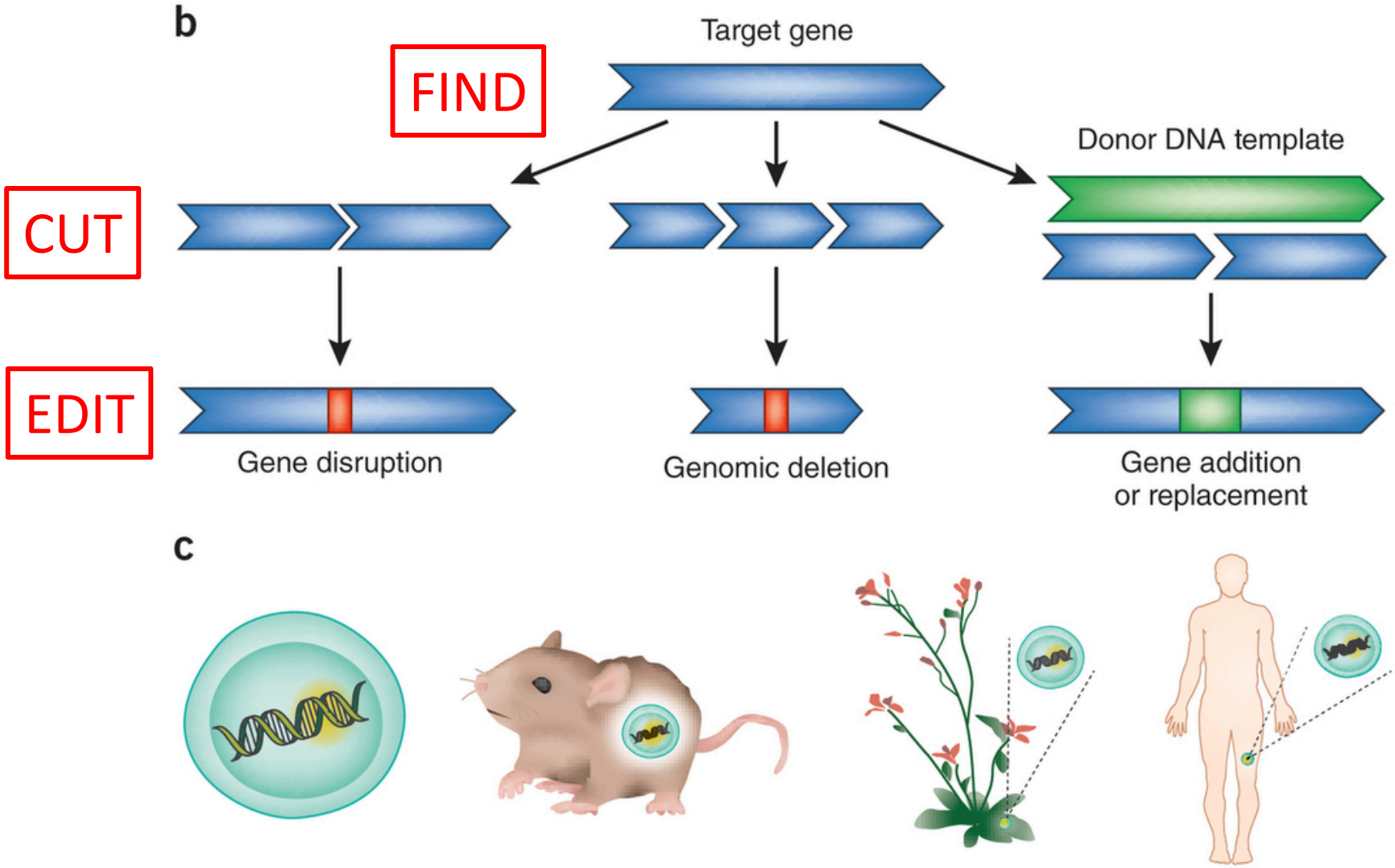
Transgenic methods cannot produce all of the desired types of genetic modification

- Cannot make precise changes to an existing gene or insert genes at specific locations in the genome

A number of tools have been developed to overcome these limitations including

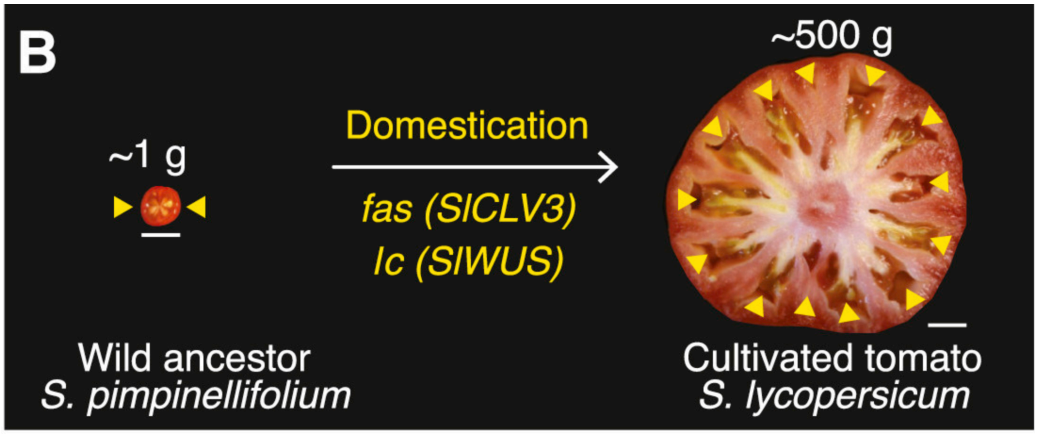
- ZFNs – zinc finger nucleases
- TALENs – transcription activator-like effector nucleases
- And then along came CRISPR (clustered regularly interspersed short palindromic repeat) and Cas9

How to edit a gene in 3 easy steps



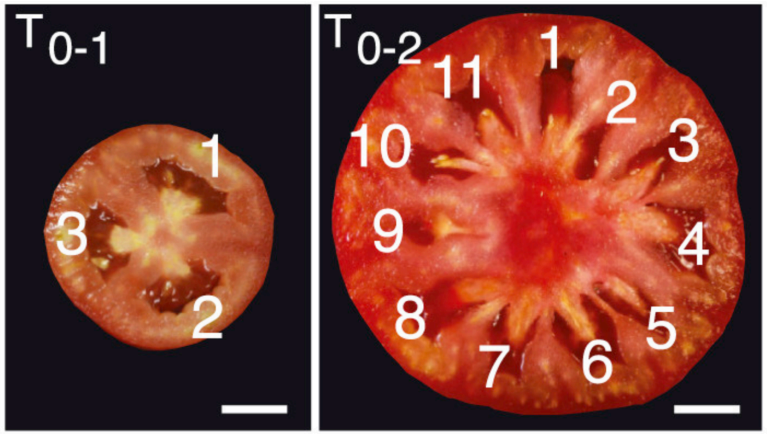
Gene edited tomatoes – 2017 edition

- Domestication resulted in a large increase in the size of the tomato fruit
- The genes and alleles responsible for large fruit size have been identified
- Gene editing with CRISPR can reproduce these alleles in a single generation to produce tomatoes with large fruits



Domestication over hundreds or thousands of years

Wild ancestor



Gene editing reproduces large fruit size in one generation

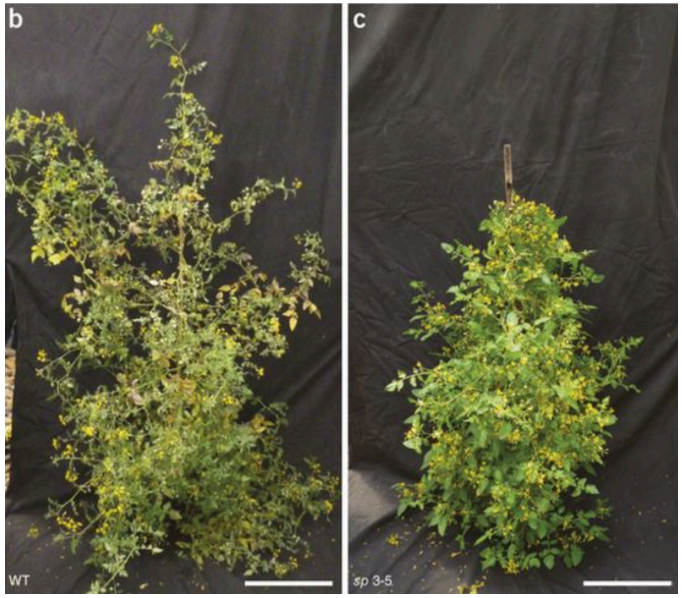
Gene edited tomatoes – 2018 edition

- A study published in October 2018 describes the editing of 6 genes in *Solanum pimpinellifolium* (the wild ancestor of cultivated tomato)

The following traits were modified by gene editing:

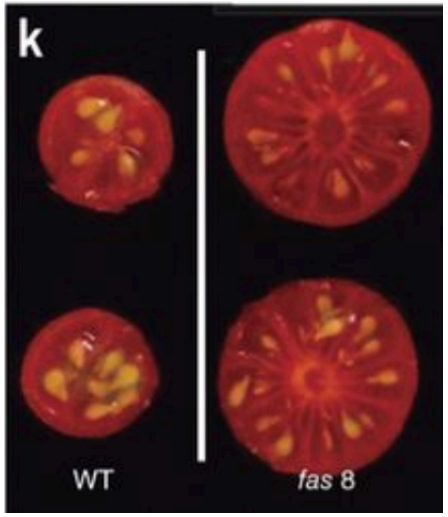
- fruit size – from pea size to cherry tomato
- plant height – from 5 feet to 3 feet tall
- fruit shape – from round to oval
- flower and fruit number – from 20 to 100 flowers per inflorescence to increase yield
- lycopene content –five fold higher than typical tomato varieties

Gene edited tomatoes – 2018 edition



shorter plants

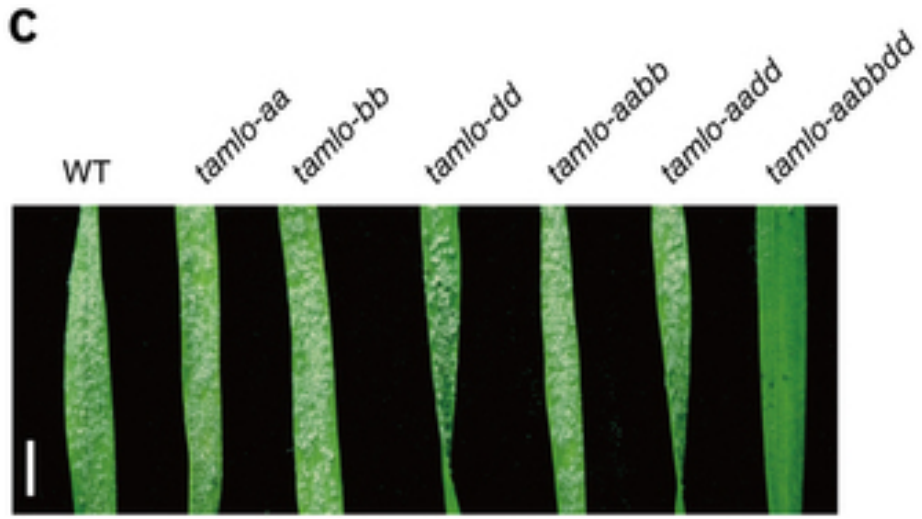
more flowers and fruits



larger fruits

oval tomato fruits

more lycopene



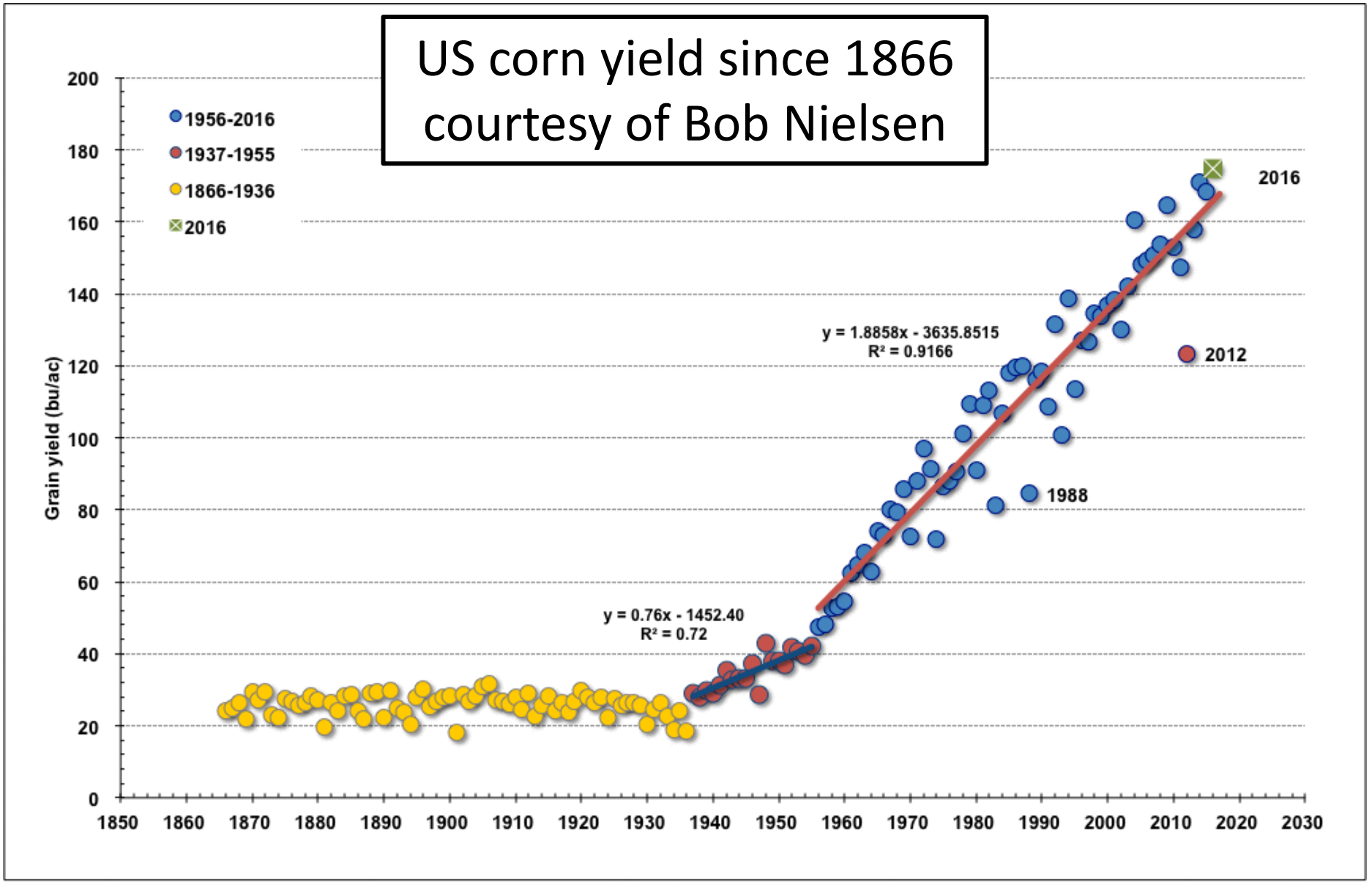
Disease resistant wheat

Hornless dairy cattle

CRISPR pigs

Gene-edited human embryos

Do we really need biotechnology?



Potatoes with resistance to late blight disease

- Late blight is one of the most important diseases of potato, managed primarily with fungicides
- Biotechnology (GMOs and gene editing) provides new methods to manage this devastating disease

Conventional Transgenic

Making photosynthesis more efficient

WT Sox

WT Sox

WT Sox

By increasing the expression of one enzyme (SBPase) in the Calvin-Benson cycle, GM wheat plants (Sox) have enhanced photosynthesis, increased biomass and higher seed yield than normal, non-GM plants (WT)

Driever et al (2017) Phil Trans Royal Society B 372, 20160384

Why is the public fearful and concerned about GMOs?

- 88% of scientists believe GMOs are safe
- Only 37% of the general public thinks GMOs are safe
- This is the widest discrepancy between these two groups on controversial science issues including climate change and vaccines
- If the public learns more about the science, they should understand and accept these new technologies
- Referred to as the “cognitive deficit model”
- If only it was that simple!

This debate is NOT about science

Opinions and positions about GMOs are more about emotion, not the science

- What benefit does the consumer gain from GMOs?
  - Hard for the consumer to identify benefit in terms of price, quality, availability
- Lack of transparency about GMOs
  - Opposition to labeling, until recently
- Unfulfilled claims for GMOs
  - Feed the world, reduced use of pesticides, etc.

Different values about food systems

GMO supporters

- Food is a commodity
- Food production is a business, valued in economic terms
- How much food is produced?
- How much does it cost?
- Most of this audience probably shares these values about food

GMO opponents

- Food is a necessity, a human right
- Who grows their food?
- How is the food produced?
- Where does their food come from?
- Farmers markets, organic foods, customers of Whole Foods

The GMO controversy is a proxy for something else

Opposition to GMOs reflects other concerns

- Corporate control of agricultural inputs
  - seeds, chemicals, information
  - underlying patents and limits on seed saving
- Loss of personal control over food
- Consumer demand for “clean-label” foods
  - Chipotle – GMO-free but with a side of *E. coli*
- Opposition to GMOs has become a source of identity, a rallying cry, for these communities

Closing remarks

- We need all of these technologies if we are going to meet the challenges of food production in the future
- This controversy is fueled by emotion
  - food, genes and fear
- Do I expect many people will change their opinions about GMOs after hearing me talk?
  - probably not!
  - there are lots of obstacles to overcome
- Still important to provide information, explain the science, engage in a discussion