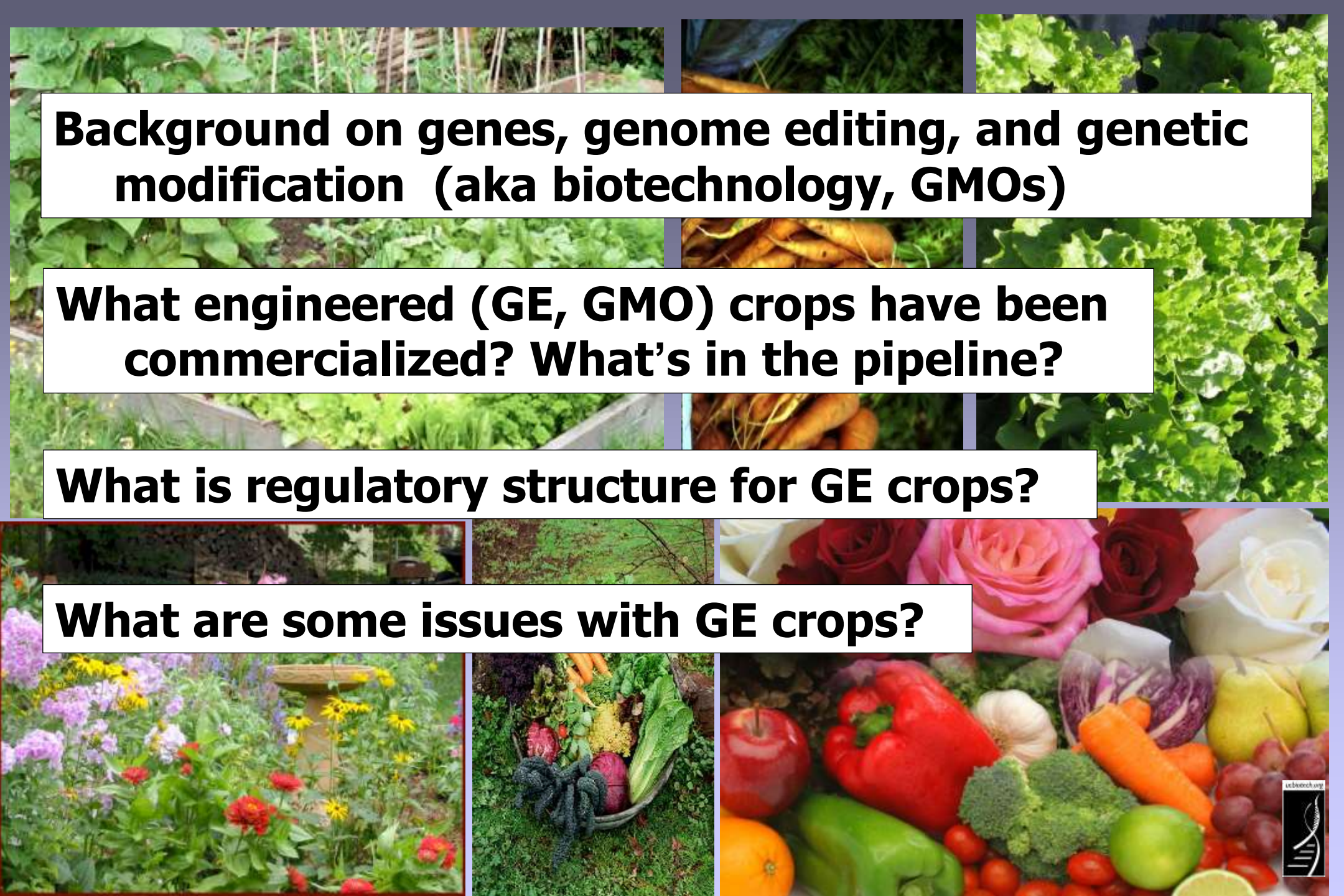

Engineered & Edited Crops –
Where are we?
Peggy G. Lemaux
University of California, Berkeley
http:/ucbiotech.org
http://nature.berkeley.edu/lemauxlab



Background on genes, genome editing, and genetic modification (aka biotechnology, GMOs)

What engineered (GE, GMO) crops have been commercialized? What's in the pipeline?

What is regulatory structure for GE crops?

What are some issues with GE crops?

Genes and chromosomes are modified to create new plant varieties by classical breeding?

Triticum monococcum

Ancient variety

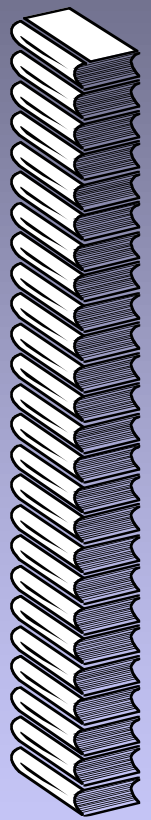
Triticum aestivum

Modern bread variety

Information in the wheat genome

Chemical units represented by alphabetic letters

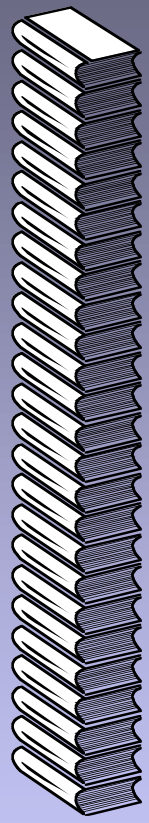
...CTGACCTAATGCCGTA...



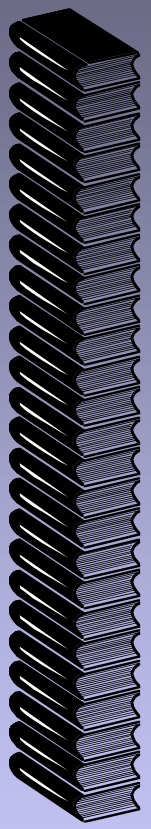
1700 books
1000 pages each

1700 books
(or 1.7 million pages)

Hybridization or cross-breeding of wheat



X



What is the outcome of the cross?

Random retention of

n

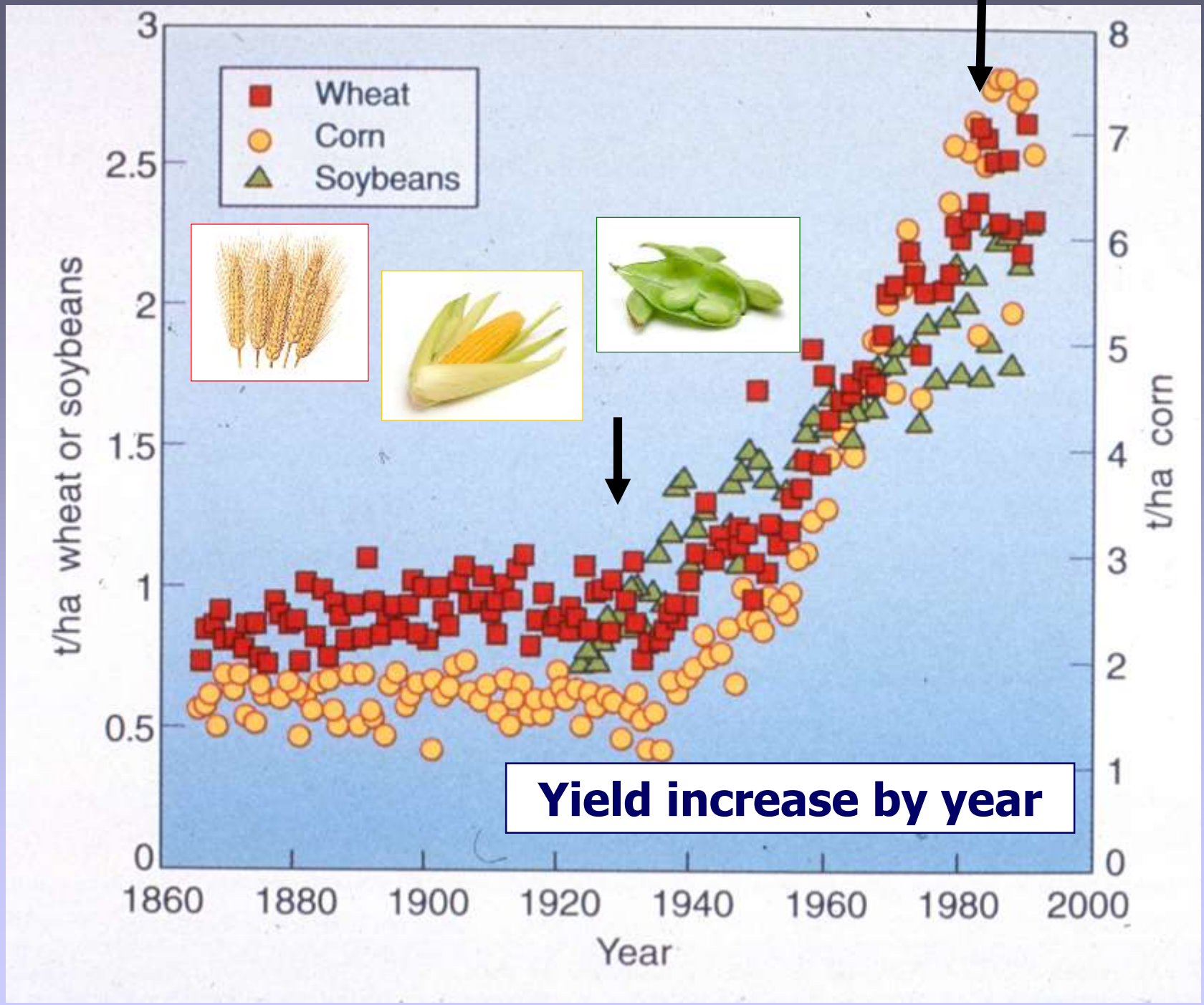
parent

1700 books
(or 1.7 million pages)

1700 books
(or 1.7 million pages)

1700 books
(or 1.7 million pages)

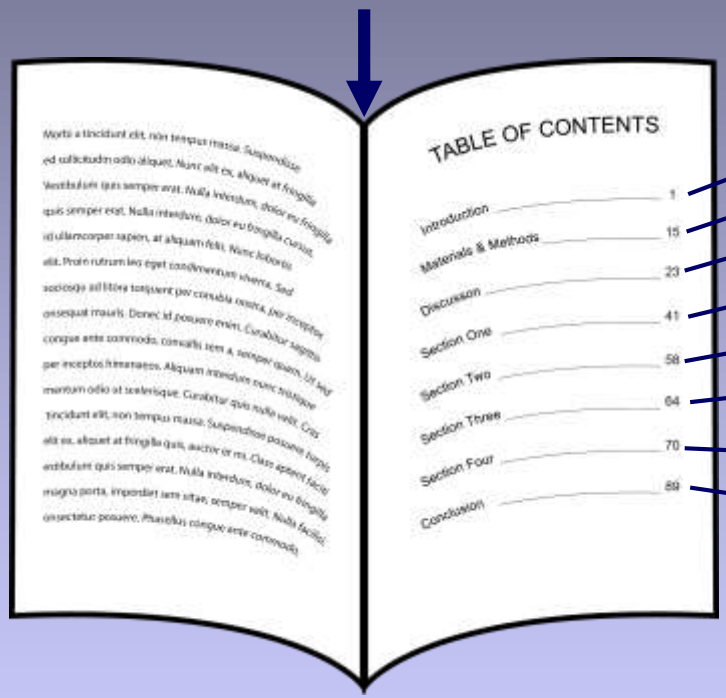
Genetic modification that <u>is not</u> GE or GMO


Wheat
Corn
Soybeans
t/ha wheat or soybeans
t/ha corn
Year
0
0.5
1
1.5
2
2.5
3
1
2
3
4
5
6
7
8
1860
1880
1900
1920
1940
1960
1980
2000
Yield increase by year

New breeding methods

Uses table of contents of genes for marker assisted selection

...CTGACCTAATGCCGTA...



Increases speed of breeding process

1700 books
(or 1.7 million pages)

Genetic modification that is not GE or GMO

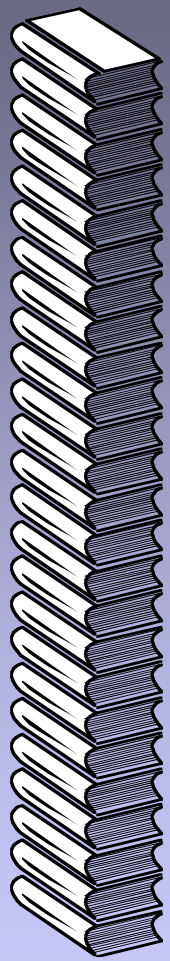
Can’t We Just Do All Modification This Way?

Marker-assisted selection used to protect rice against bacterial blight and blast disease

Limited to diversity in crop and compatible relatives


But there are other ways to create new varieties using the modern tools of genetics

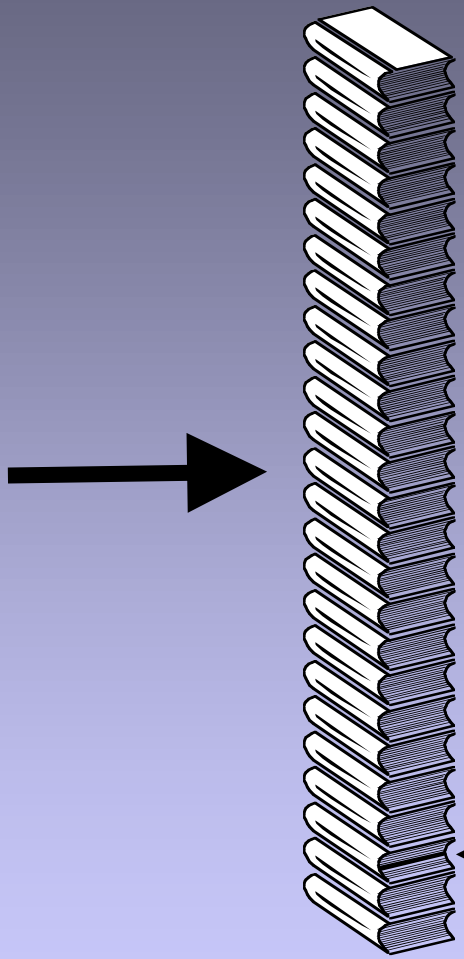
Genetic Engineering Methods



1700 books
(or 1.7 million pages)

+

One-half page
equivalent to a gene



Inserts
randomly
in genome

Inserted
gene(s)

1700 books
(or 1.7 million pages)

Genetic modification
<u>that is</u> GE and GMO

How Do You Prepare Genes to Introduce into Plants?

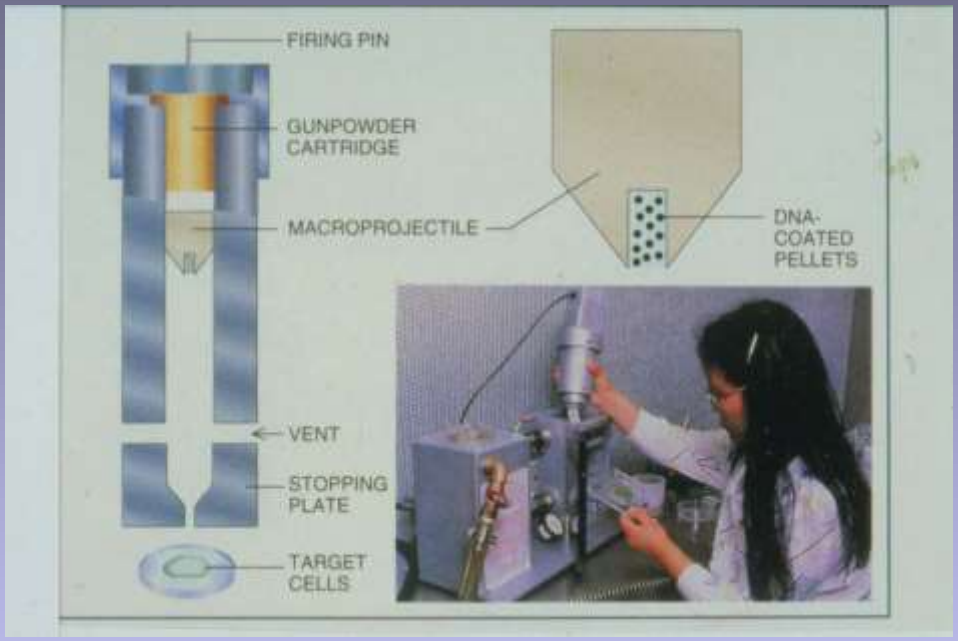
On switch: controls when and where gene product is made

Off switch: turns off production of gene product

Gene of interest: gene of interest you want to put into the plant

Marker: Indicates which plants have the gene of interest; antibiotic resistance, sugar usage

How Do You Introduce the Genes into Plants?

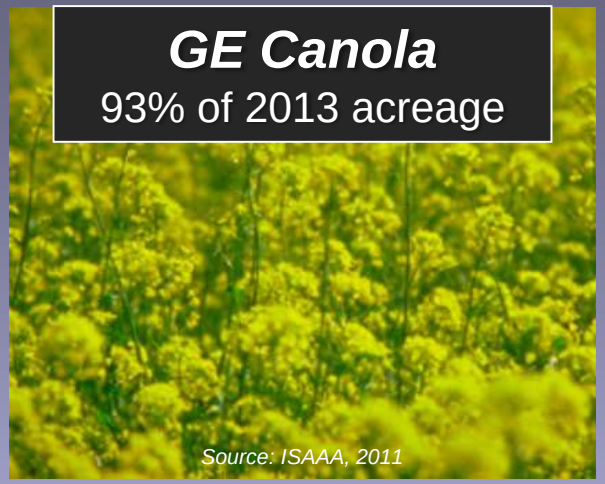


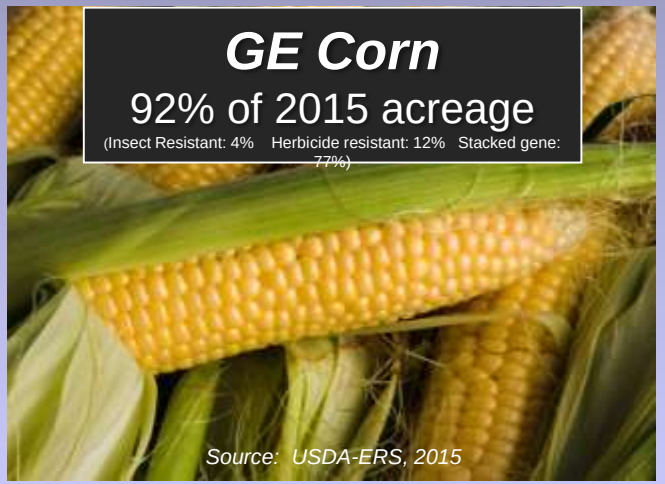
Gene gun

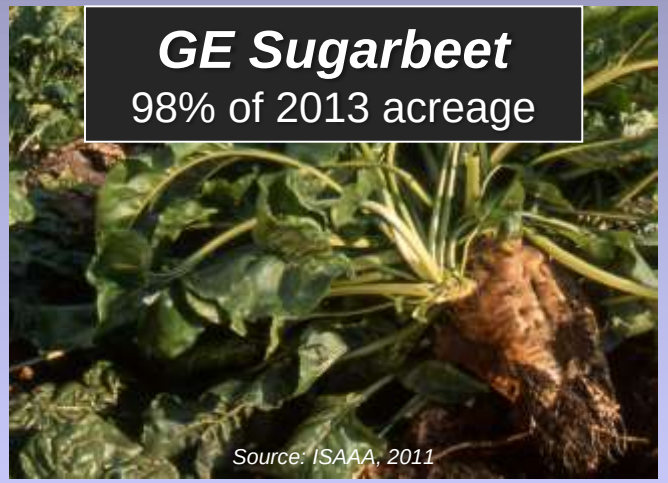
Agrobacterium

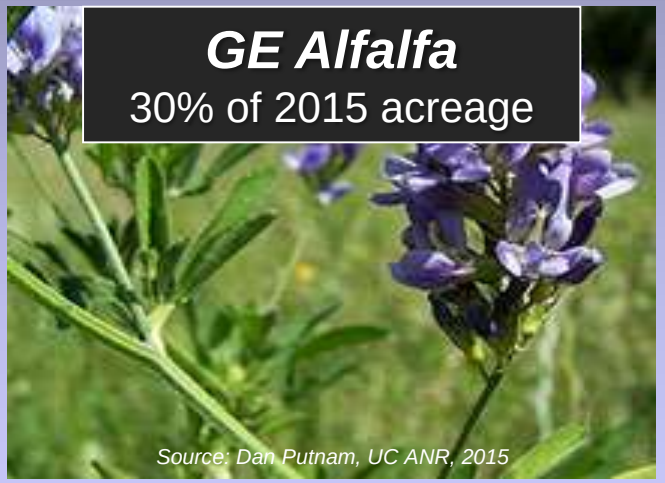
Both methods introduce DNA into genomes of plant cells

Number of commercially available GE crops is limited









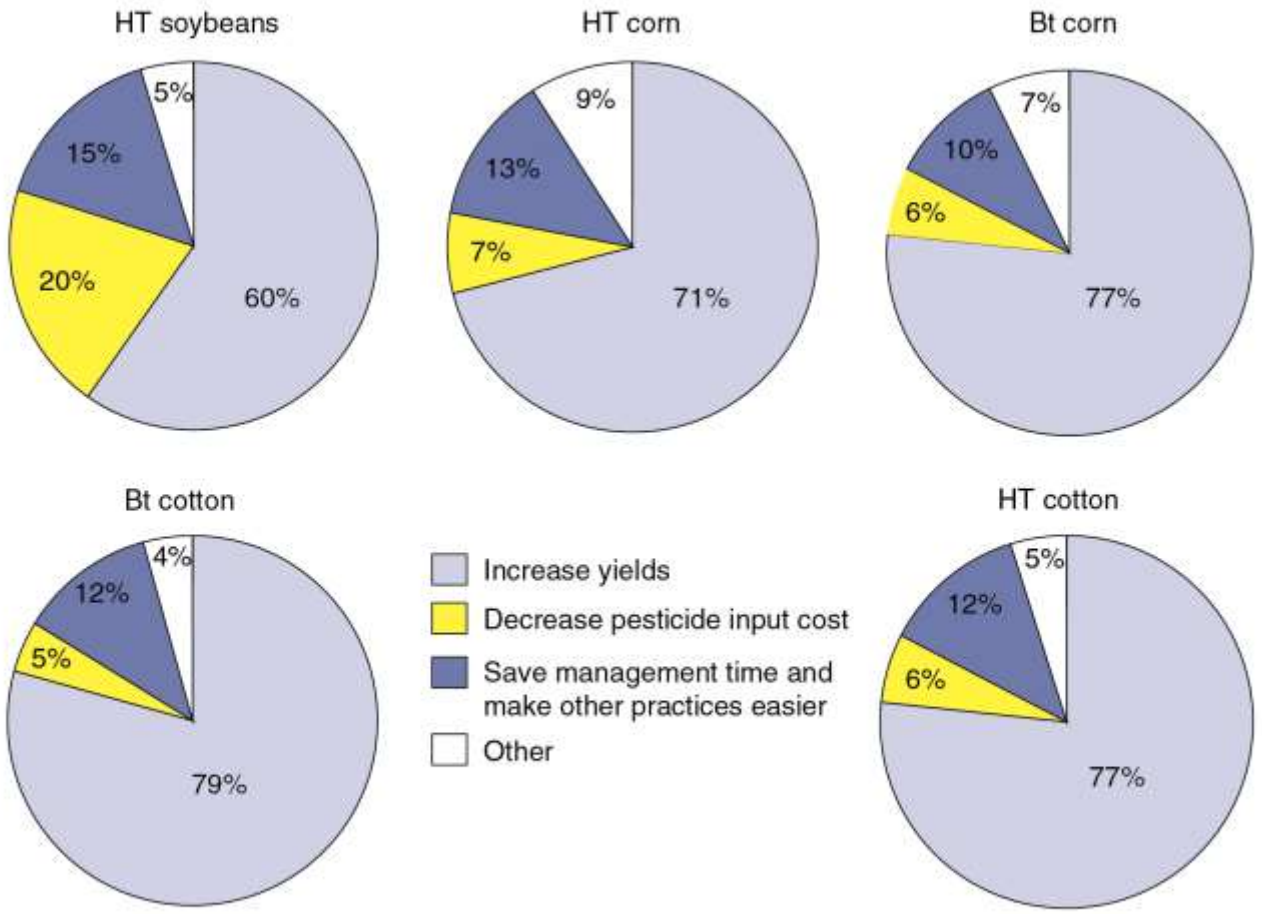
Number of different traits available in large acreage GE crops is also limited

Insect-tolerant Bt crops - engineered for resistance using gene from naturally occurring bacterium

Herbicide-tolerant - engineered with gene to tolerate herbicide application

Crops with stacked traits - both Bt and HT - are available

Why do growers adopt the GE crops?



Reasons vary from crop-to-crop but the predominant reason is to improve yield

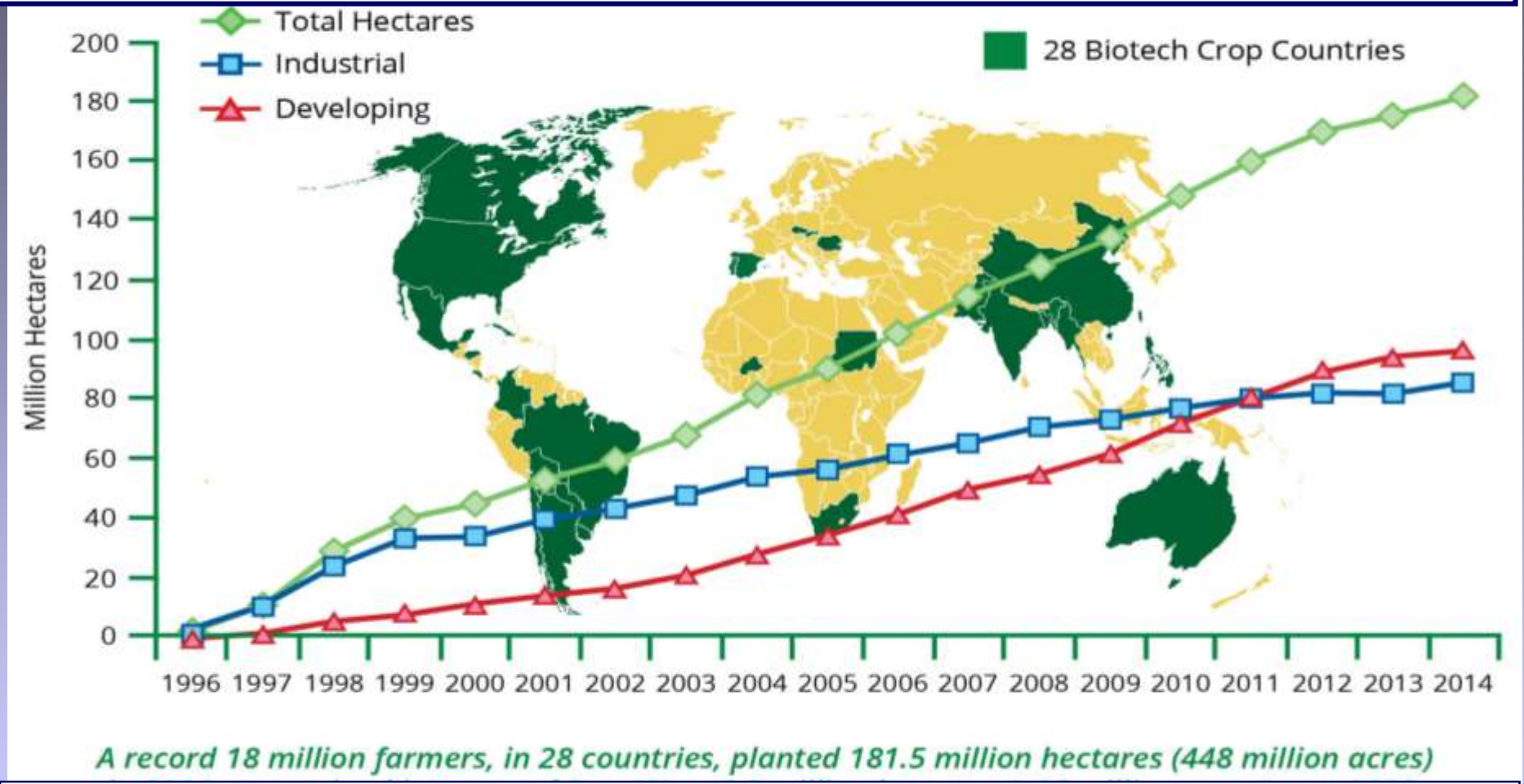
SOURCE: Fernandez-Cornejo, J., Wechsler, S., Livingston, M. and Mitchell, L. 2014. Genetically Engineered Crops in the United States. USDA Economic Research Service Report No. 162, February 2014.

These types of large-acreage GE crops lead to estimates that 60-80% of processed foods in U.S. have GE ingredients

There are only a few whole, GE foods that have been commercialized

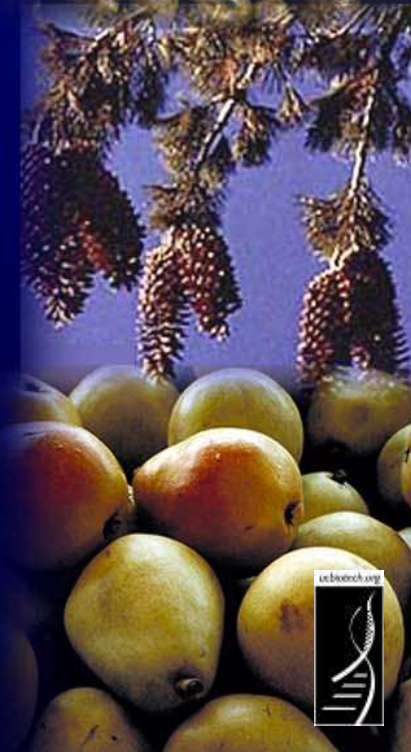
Two more are just being introduced

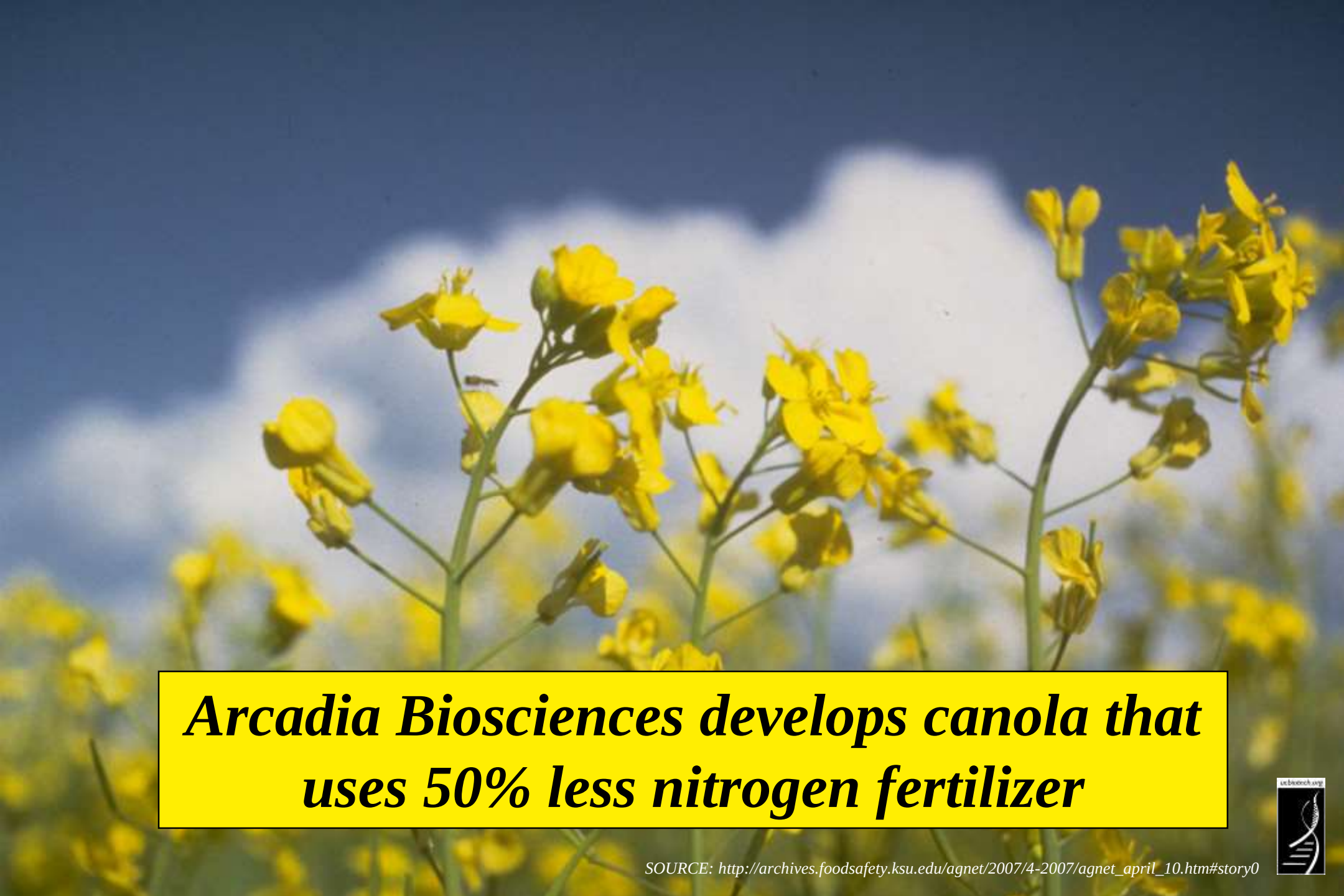
Despite limited crop and trait types, worldwide acreage is increasing in 20 developing, 8 developed countries



2014: 18 million farmers in 28 countries
448 M acres planted: >3X size of California
>90% were small acreage farmers

WHAT'S IN THE PIPELINE?





Arcadia Biosciences develops canola that uses 50% less nitrogen fertilizer

SOURCE: http://archives.foodsafety.ksu.edu/agnet/2007/4-2007/agnet_april_10.htm#story0

UCD researcher engineers drought tolerance: results in vigorous growth after prolonged drought

Tobacco after 2 weeks without water then 1 week watered

Control, non-GE

GE tobacco

SOURCE: Rivero, R.M., Kojima, M., Gepstein, A., Sakakibara, H., Mittler, R., Gepstein, S. and Blumwald, E. 2007. Delayed leaf senescence induces extreme drought tolerance in a flowering plant. Proceedings of the National Academy of Sciences USA 104: 19631-19636.

Australian researchers identify grape genes that provide resistance to powdery mildew

SOURCE: Western Farm Press, volume 26, number 16

Potato with gene from wild relative protects against late blight disease, cause of Irish potato famine

amiga
Assessing and Monitoring
www.amigaproject

eagasc
Agriculture and Food Development Authority

WAGENINGEN UR
For quality of life

GM material developed in The DuRPh programme of Wageningen University

Chestnuts engineered with a wheat gene prevents cankers from forming; replanted with $104K raised through crowd funding campaign

http://www.newscientist.com/article/dn25644-american-chestnut

High anthocyanin purple GE tomatoes. Diets with 10% purple tomatoes increased lifespan of cancer-prone mice

Butelli et al. 2008. https://www.jic.ac.uk/staff/cathie-martin/purple-tomatoes.html

MIT Technology Review

Chinese Researchers Stop Wheat Disease with Gene Editing

Researchers have created wheat that is resistant to a common disease, using advanced gene editing methods.

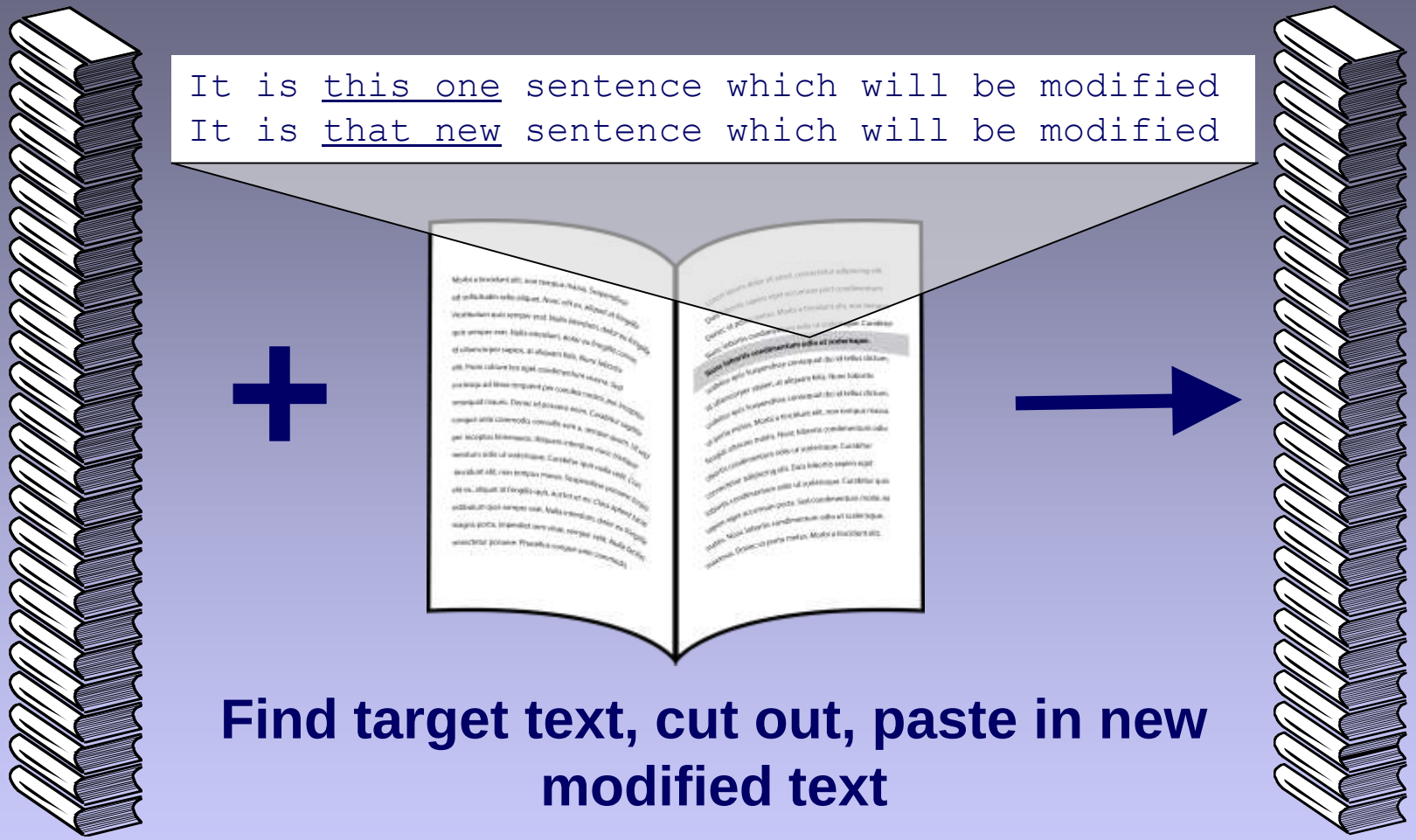
By David Talbot on July 21, 2014

Advanced genome-editing techniques have been used to create a strain of wheat resistant to a destructive fungal pathogen – called powdery mildew – that is a major bane to the world's top food source, according to scientists at one of China's leading centers for agricultural research.

Wheat resistant to powdery mildew created using new genome-editing techniques

SOURCE: "Chinese Researchers Stop Wheat Disease with Gene Editing", MIT Technology Review, July 21, 2014
http://www.technologyreview.com/news/529181/chinese-researchers-stop-wheat-disease-with-gene-editing/

What is Genome Editing?



Find target text, cut out, paste in new modified text

Inserts specifically in genome

1700 books (or 1.7 million pages)

Genome editing is not GE or GMO

1700 books (or 1.7 million pages)

What is the regulatory structure for GE crops?

U.S. Regulatory Agencies

USDA

- Field testing
  -Permits
  -Notifications
- Determination of non-regulated status

Plant pest?

FDA

- Food safety
- Feed safety

Danger to people?

EPA

- Pesticidal plants
  -tolerance exemption
  -registrations
- Herbicide registration

Risk to environment?

Regulation is based on an outdated system, created in 1986, which is now causing problems:

- **New products emerge with no rules to govern them**
- **Old products are not on the market because there are no clear pathways for commercialization**
- **New products created to step around regulatory system**

EXAMPLES:

In April 2016: USDA APHIS decided not to regulate a mushroom and corn genetically modified with CRISPR–Cas9 genome editing. Reason: no DNA from other species introduced.

These types of examples have resulted in loud calls for revamping U.S. regulatory oversight

Genetically engineered crops that fly under the US regulatory radar

To the Editor:

Recently, the US Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) has categorized as outside the scope of its regulations several genetically

cisgenesis/intragenesis and site-directed nucleases, may be a deliberate strategy for smaller entities to navigate the US GE crop regulatory framework. The fact that the US Coordinated Framework is on the one hand

A first step taken on July 2, 2015 by a White House Initiative to clarify roles of agencies: what products fall under which authority? How will products created with genome editing be regulated?

Many of these inquiries originate from public institutions or small biotech companies, suggesting that the use of technologies, such as null segregants, novel delivery systems,

enough flexibility to evolve with accumulating scientific knowledge and technologies and, importantly, that allows the participation of small companies and public sector institutions.

Camacho et al. 2014. Nature Biotech. 32:1087-1091

Are There Food Safety Issues with GE Crops?

Occasionally there are widely publicized studies that cast doubt on safety of GE foods - one published by French researcher in Sept. 2012

Later reviewed by European Food Safety Authority and found to have no merit

But did you ever hear that on Dr. Oz?

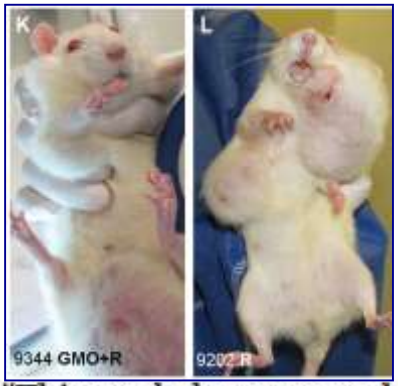
French academies trash GM corn cancer study

By **RFI**

A controversial study that linked genetically modified maize to cancer in la[illegible] six in a[illegible]

Featured on Dr. Oz Show

The report's author, Gilles-Eric Séralini, with his book All Guineapigs
AFP /Jacques Demarthon



Claim that Monsanto's RR corn causes tumors in rats

"This work does not enable any reliable conclusion to be drawn," they say, adding that the publicity surrounding the publication has "spread fear among the public."

The joint statement - an extremely rare event in French science - is unsigned and issued in th[illegible] names of the national academies of agriculture, medicine, pharmacy, science, technology and veterinary studies.

What have other published studies shown?

Are There Food Safety Issues with GE Foods?

Meta-analysis review from France published in 2012 showed GE foods are nutritionally equivalent to non GE foods and can be safely consumed in food and feed.

Based on 12 long-term (>90d to 2yr) and 12 multigenerational (2 to 5 generation) feeding trials of GE feed in animals

maize

potato

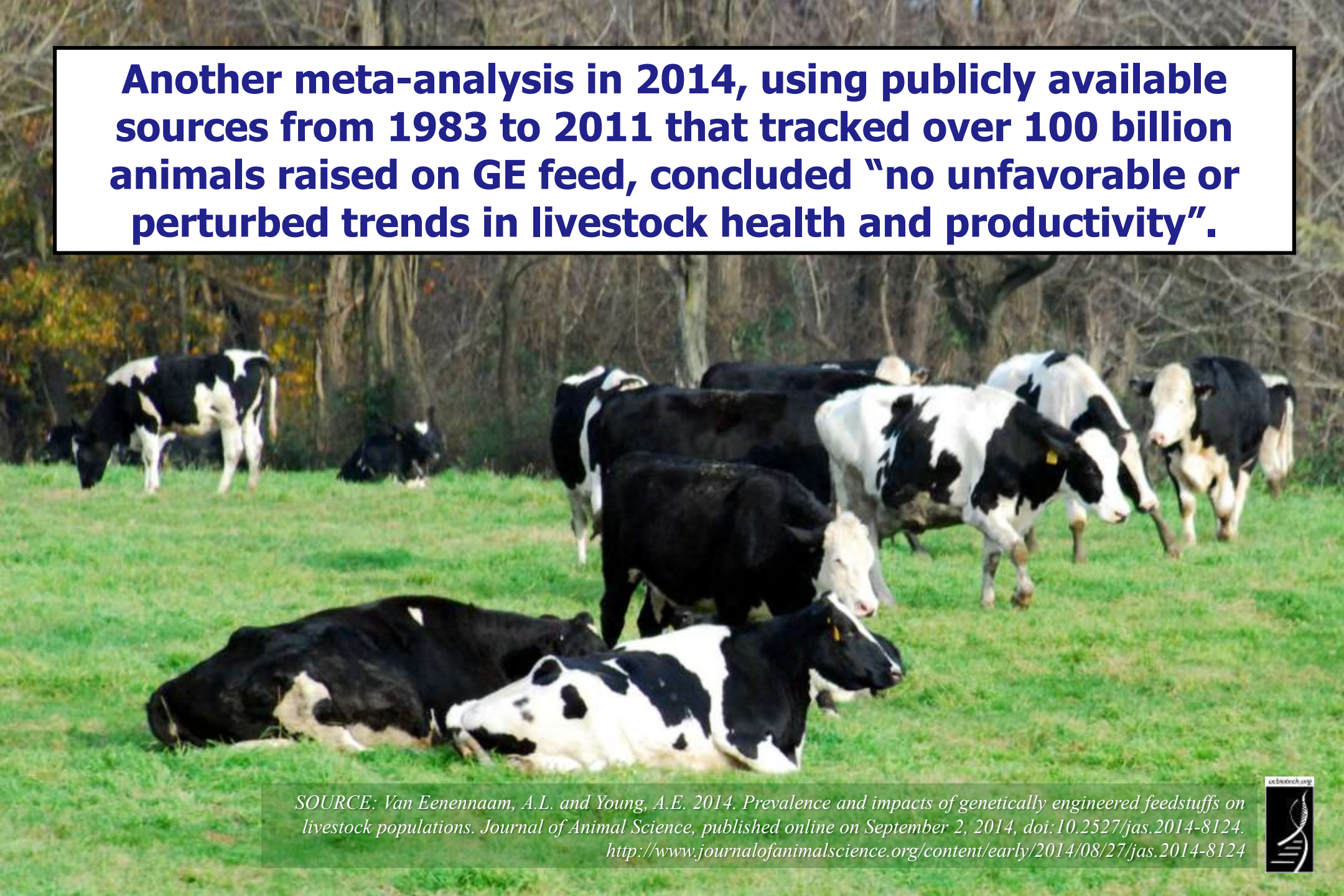
soy

rice

triticale

SOURCE: Snell C, Bernheim A, Berge J-P, Kuntz M, Pascal G, Paris A, Ricroch AE. 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 50: 1134-1148.

Another meta-analysis in 2014, using publicly available sources from 1983 to 2011 that tracked over 100 billion animals raised on GE feed, concluded "no unfavorable or perturbed trends in livestock health and productivity".



SOURCE: Van Eenennaam, A.L. and Young, A.E. 2014. Prevalence and impacts of genetically engineered feedstuffs on livestock populations. Journal of Animal Science, published online on September 2, 2014, doi:10.2527/jas.2014-8124. http://www.journalofanimalscience.org/content/early/2014/08/27/jas.2014-8124

Are there environmental issues with GE crops?

Loss of efficacy of engineered trait?

Insect Resistance

B.t. cotton and corn engineered for insect resistance with gene(s) from naturally occurring bacterium.

To date minimal insect resistance has occurred

Loss of efficacy of engineered trait?

Herbicide Tolerance

Environmental impact associated with herbicide and insecticide use, measured by the EIQ indicator, fell by 17.1%

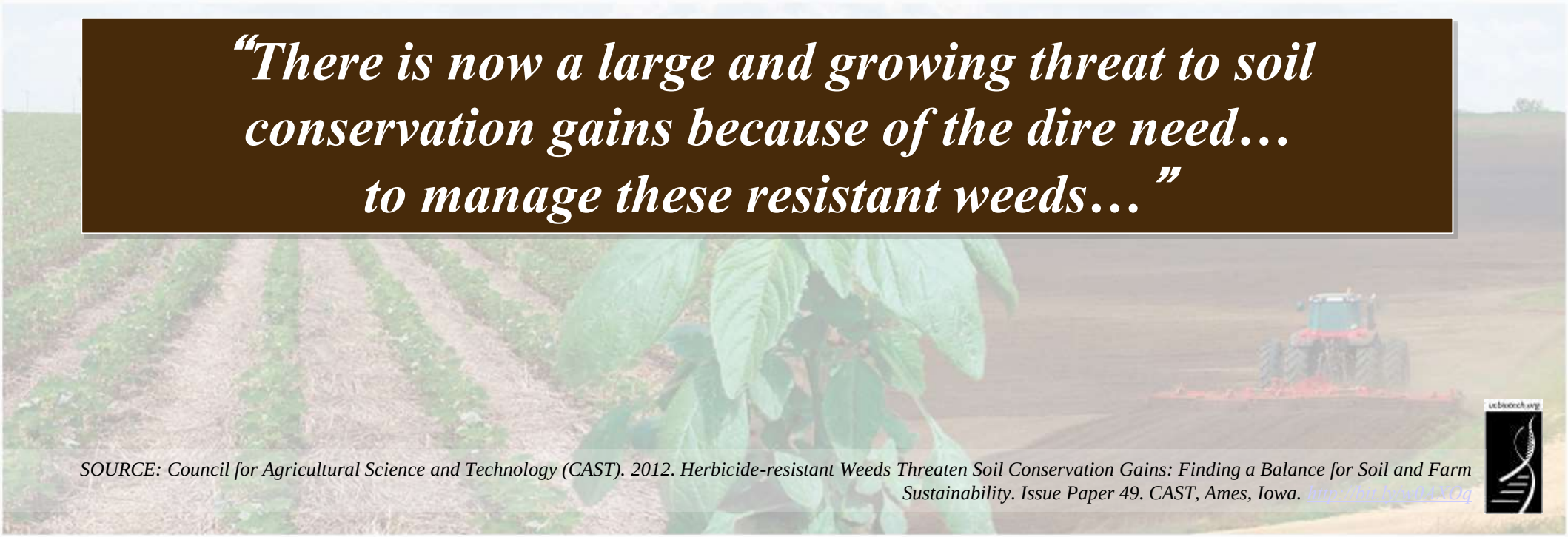
But was there a consequence?

SOURCE: Brookes, G. 2012. Genetically Engineered Crops: Environmental Impacts 1996-2009. ISB Report, January 2012, pp. 1-5
Brookes, G. and Barfoot, P. 2011. Global impact of biotech crops: Environmental effects 1996-2009. GM Crops 2: 34-49

CAST® Issue Paper
Number 49
February 2012

"When any single herbicide mechanism of action is used repeatedly without alternative management tactics, selection pressure becomes intense for plants that are tolerant or resistant to that herbicide."

"There is now a large and growing threat to soil conservation gains because of the dire need… to manage these resistant weeds…"

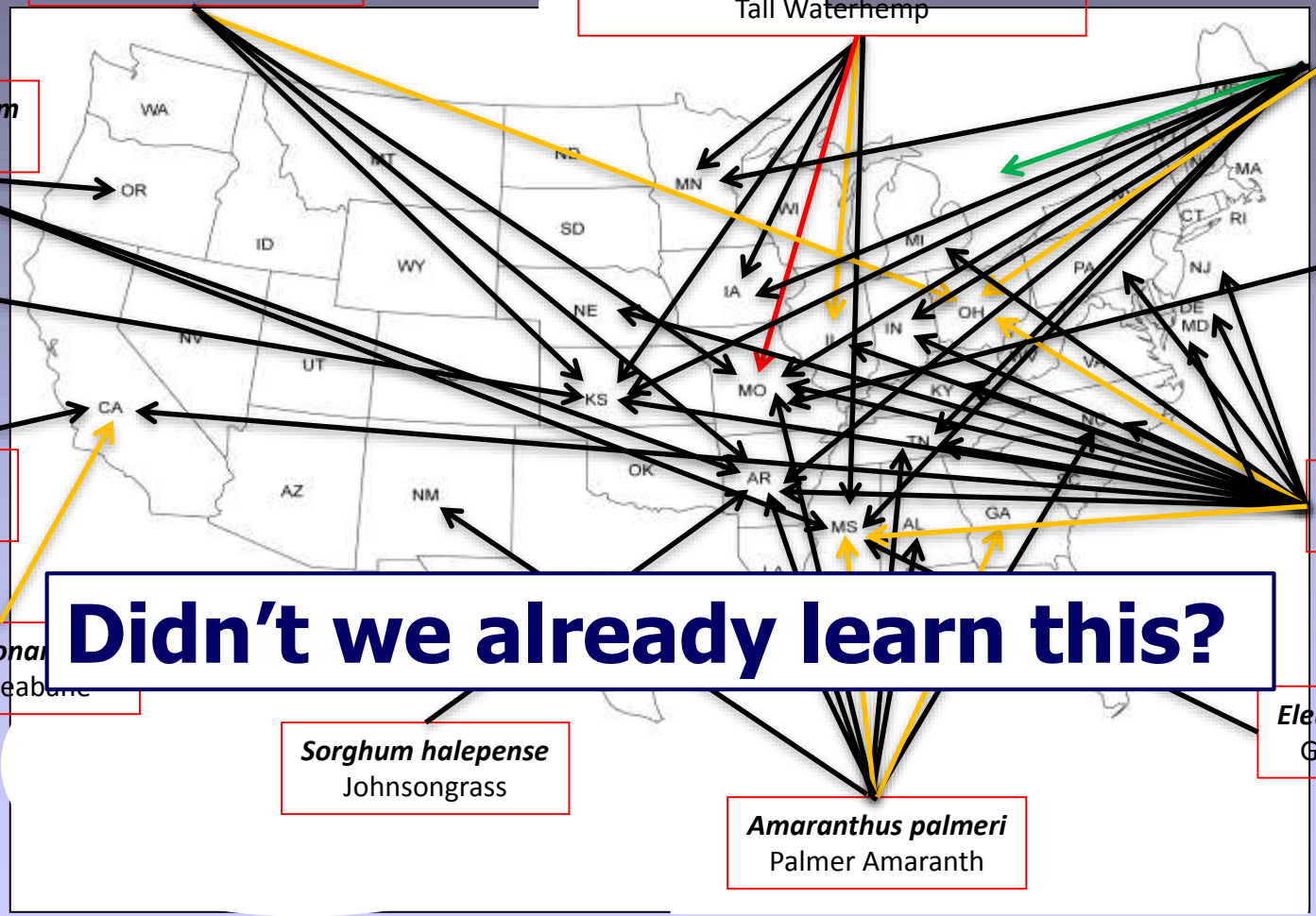


SOURCE: Council for Agricultural Science and Technology (CAST). 2012. Herbicide-resistant Weeds Threaten Soil Conservation Gains: Finding a Balance for Soil and Farm Sustainability. Issue Paper 49. CAST, Ames, Iowa. http://bit.ly/xQAXOq

Glyphosate-resistant weeds due to mutation, gene flow, weed shift – exacerbated when same herbicide is used repeatedly

Glyphosate- Resistant Weeds – USA

December 13, 2010 – adapted from: www.weedscience.org



Ambrosia artemisiifolia
Common Ragweed

Amaranthus tuberculatus (syn. rudis)
Tall Waterhemp

Ambrosia trifida
Giant Ragweed

Lolium multiflorum
Italian Ryegrass

Poa annua
Annual Bluegrass

Kochia scoparia
Kochia

Lolium rigidum
Rigid Ryegrass

Conyza canadensis
Horseweed

Didn't we already learn this?

Conyza bonar
Hairy Fleabane

Sorghum halepense
Johnsongrass

Eleusine indica
Goosegrass

Amaranthus palmeri
Palmer Amaranth

K. Neil Harker
AAFC - Lacombe,

More questions? Check out the Biotech Information section of ucbiotech.org