

# Food Safety and Nutrition of Genetically Engineered Foods

*Peggy G. Lemaux  
University of California, Berkeley  
<http://ucbiotech.org>*



*As dietitians, what role do you play in informing consumers about genetics, diet and nutrition*

In 2009 33% of consumers say that medical sources, including physicians, nutritionists, dietitians, and other medical professionals, are the most believable information resource on genetics as it relates to diet and nutrition.



*Intl Food Information Council,  
2009 Functional Foods/Foods For Health Consumer Trending Survey*





## An Eye toward Personalized Nutrition and the Future of Food Fortification

This article is the third and final article in a series on food fortification. The first article, "Is Food Fortification Necessary? A Historical Perspective," and the second article, "Food Fortification in Today's World," can be accessed on our Web site [www.foodinsight.org](http://www.foodinsight.org).

What will food fortification look like in

study the body's response to food and to determine whether dietary interventions can increase or decrease the risk of diet-related chronic diseases. Disease risk is complicated by the fact that it is not just diet or heredity that plays a role but several environmental factors (e.g., physical activity, smoking) add to the complexity of disease development. Also, nutrients don't act in isolation

aware of personalized nutrition with 20 percent saying they know a "fair amount." Additionally, 32 percent of consumers were "very interested" and 47 percent were "somewhat interested" in learning more about personalized nutrition. Compared to 2005 survey results, the percentage of consumers who are "somewhat favorable" towards the idea has significantly risen over the past four

*Major milestone in personalized nutrition came with the sequencing of the human genome.*

completed the goal of sequencing the entire human genome. This had led to a number of 'omic (from the Greek

determines the way the body responds to stress, such as how the body breaks down, uses, and stores nutrients. A person

Nanotechnology refers to the science of working with objects 1-100 nanometers (1 nm is equivalent to

*Now scientists can better understand complex interactions between genes, nutrients and diet-related diseases – diabetes, cardiovascular disease and obesity.*

Personally Yours

Nutrigenomics and nutrigenetics are

Scientists may understand these


great deal of scientific work still remains to be done and, moving

*Nutrigenomics and nutrigenetics: two emerging fields that study relationship between genes and diet.*

advanced genomic tools are used to

the majority of those surveyed were

# HOW MUCH HOW MUCH D MUCH DNA



All living things contain DNA – including the foods we eat

So let's start with some basics of genetics...

ing thi  
nation  
That chemi  
The isolated

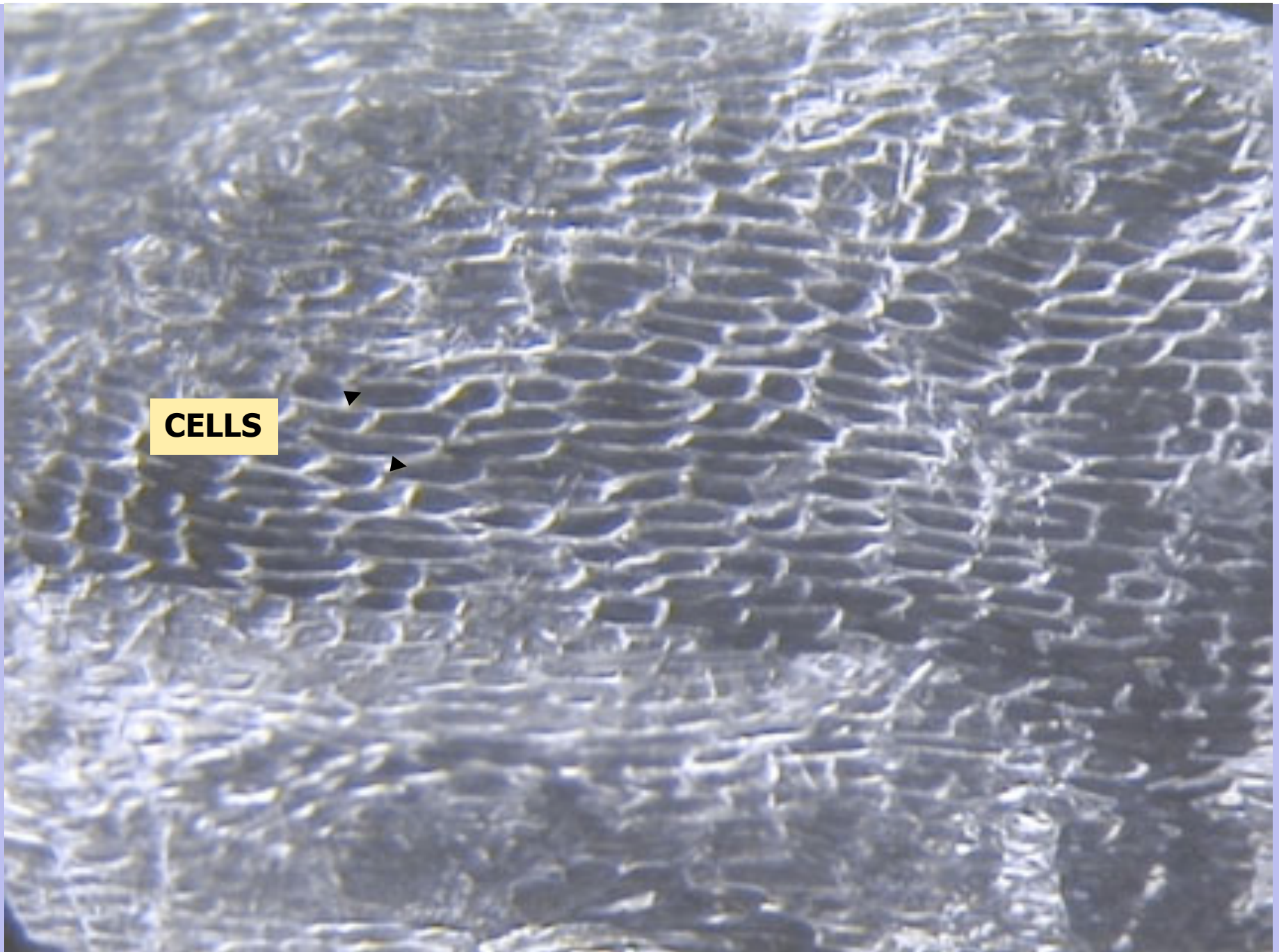
# *Tour d'Onion*









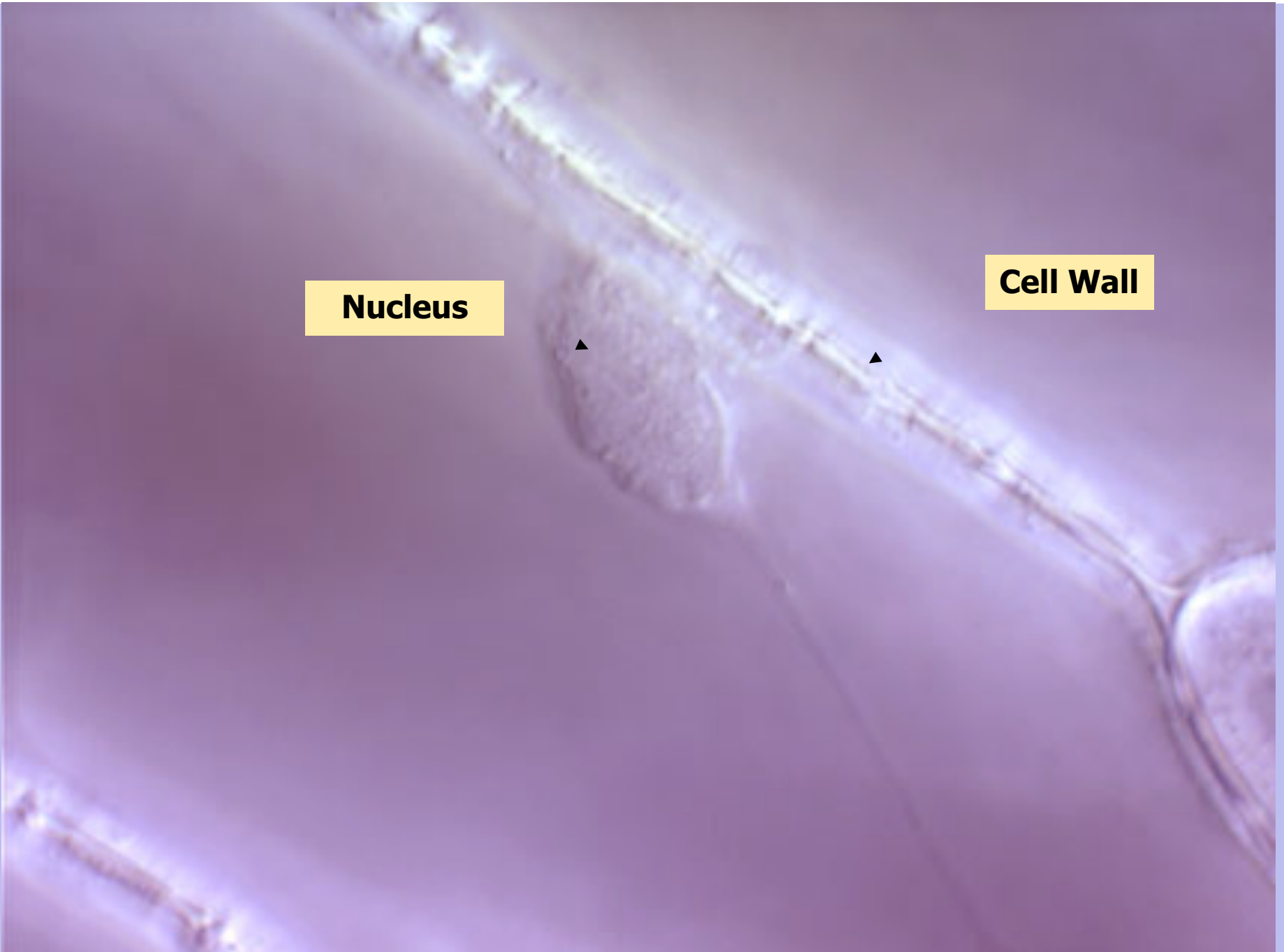


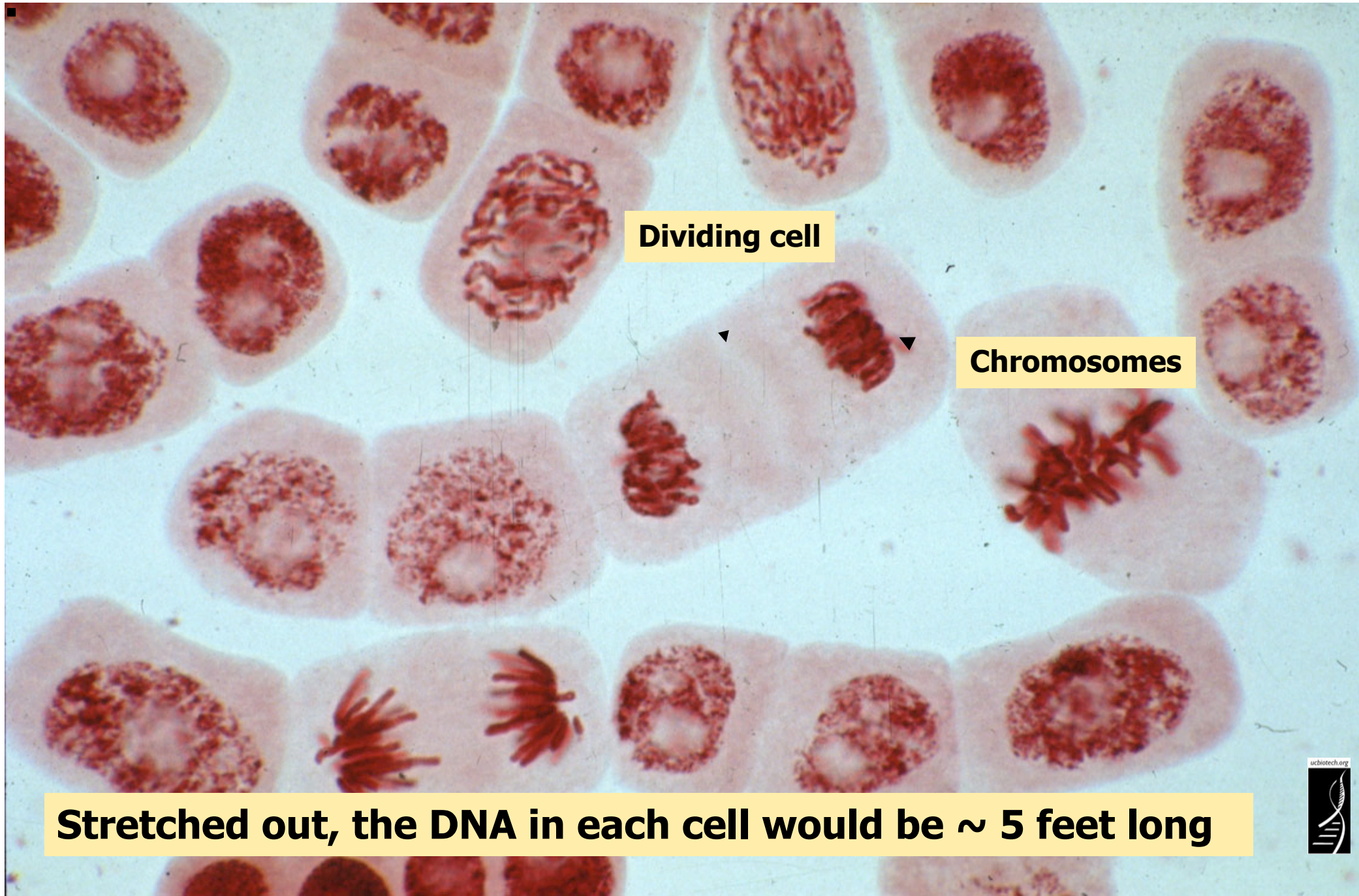
**CELLS**



**Nucleus**

**Cell Wall**





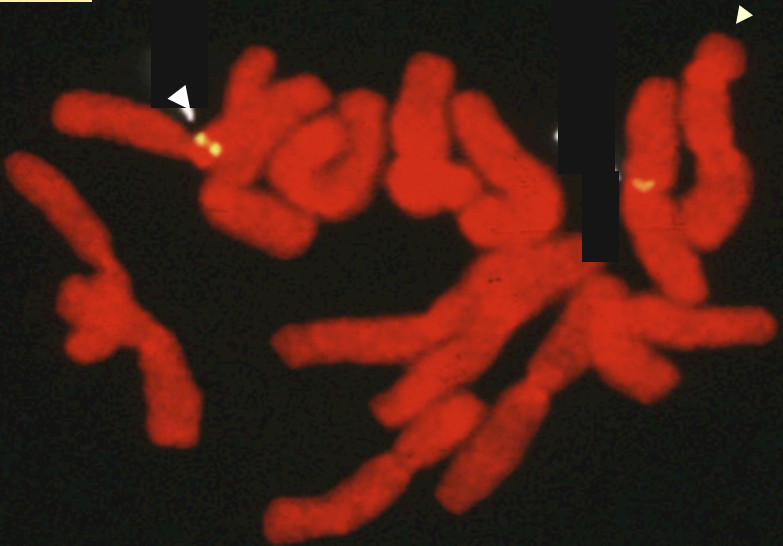
**Dividing cell**

**Chromosomes**

**Stretched out, the DNA in each cell would be ~ 5 feet long**

**Genes**

**Chromosome**



**How can you use this knowledge of genetics to create a new wheat variety – one with better nutritional qualities – using an ancient wheat variety?**

**What happens to all of the genetic information in sperm and egg of the two parents?**

**Modern bread variety**

**Ancient 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



1700 books  
(or 1.7 million pages)

**X**



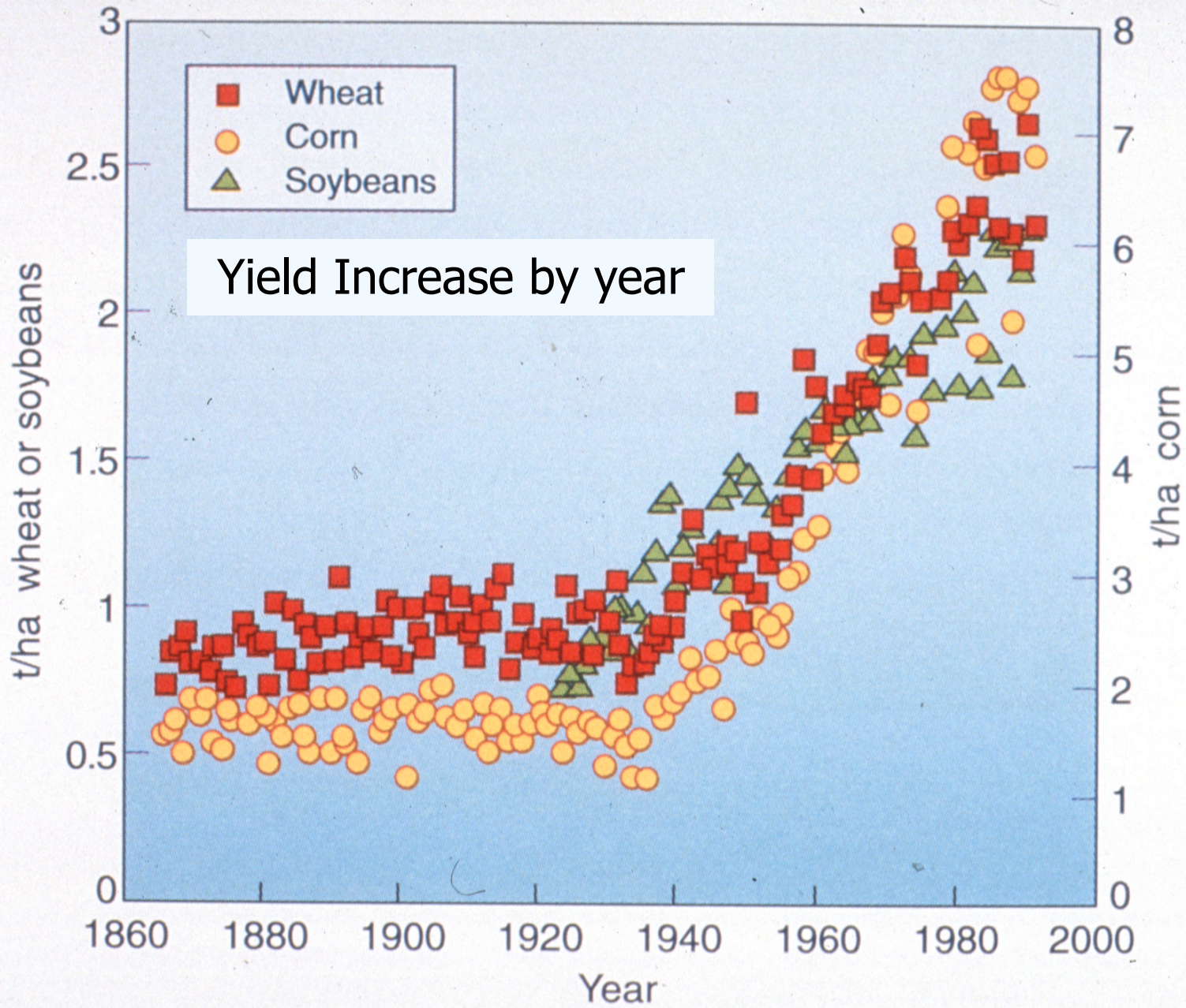
1700 books  
(or 1.7 million pages)



1700 books  
(or 1.7 million pages)

Random  
retention of  
information  
from each  
parent

This is what is termed “classical breeding”





# Table of contents for genes in wheat

...CTGACCTAATGCCGTA...



By “reading”  
entire  
genome,  
information  
can be used  
for what is  
termed,  
“Marker-  
Assisted  
Breeding”

**Genomics**

**1700 books  
(or 1.7 million pages)**

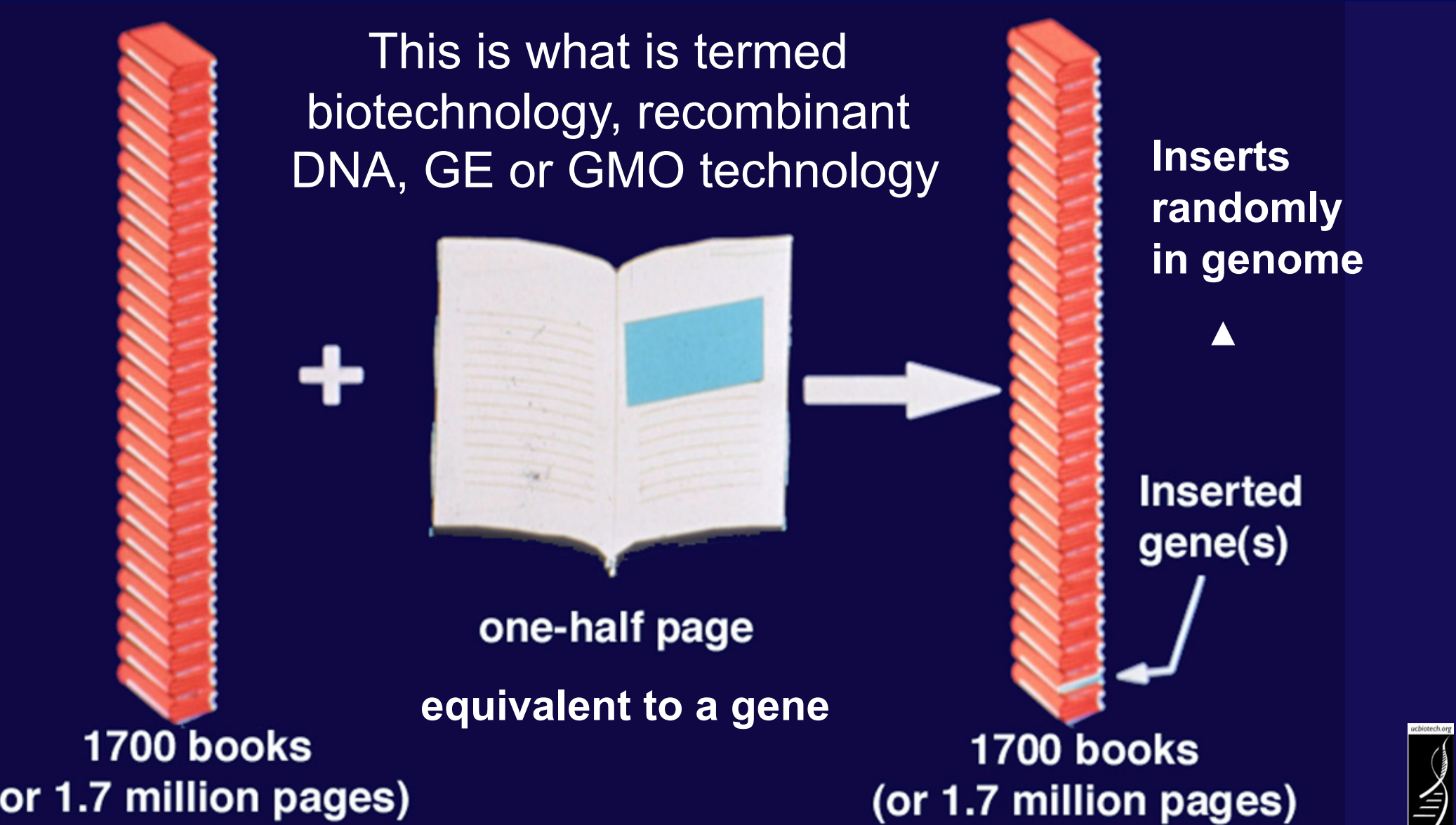




Marker-assisted breeding used to protect rice against two devastating bacterial diseases



# Genetic Engineering Technology



# ***Classical Breeding***

compared to

# ***Genetic Engineering***

Uses plant machinery in plant

Uses plant machinery in laboratory

Gene exchange is random  
involving entire genome

Gene exchange is specific,  
single or a few genes

When/where genes expressed  
not controlled by breeder

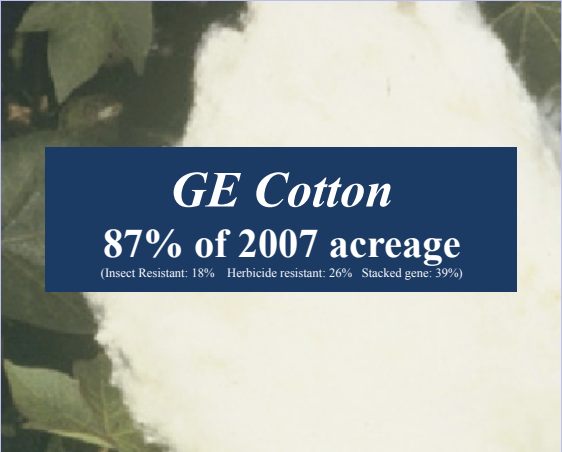
When/where gene expressed  
can be controlled precisely

Only between closely related or  
within species

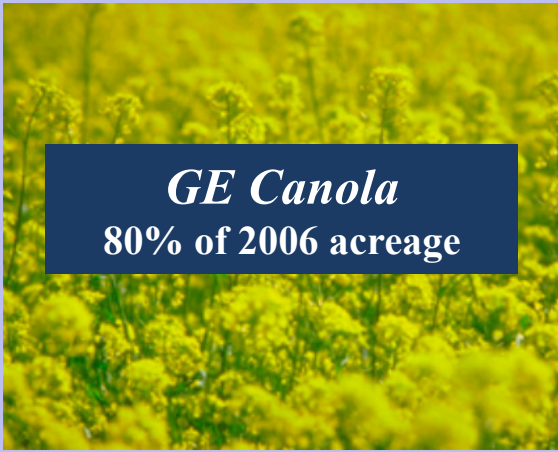
Source of gene from any  
organism



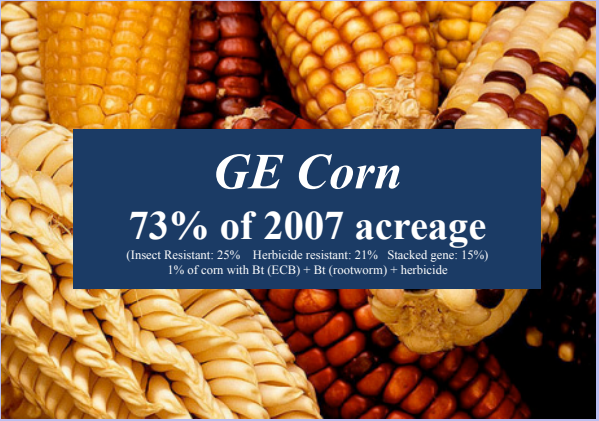
***GE Soybean***  
**91% of 2007 acreage**  
(Herbicide resistant: 89%)



***GE Cotton***  
**87% of 2007 acreage**  
(Insect Resistant: 18% Herbicide resistant: 26% Stacked gene: 39%)



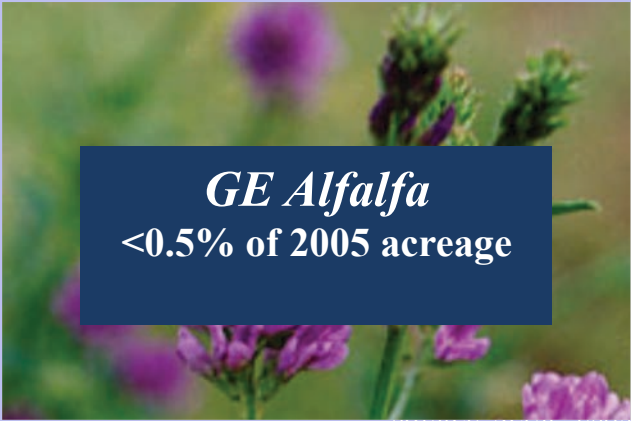
***GE Canola***  
**80% of 2006 acreage**



***GE Corn***  
**73% of 2007 acreage**  
(Insect Resistant: 25% Herbicide resistant: 21% Stacked gene: 15%)  
1% of corn with Bt (ECB) + Bt (rootworm) + herbicide



***GE Sugar beet***  
**95% of 2009 acreage**  
(Source: Capital Press, 2/8/10)



***GE Alfalfa***  
**<0.5% of 2005 acreage**





*Bollgard Cotton<sup>TM</sup>*

**Engineered for insect resistance using  
gene from naturally occurring bacterium**

# *Roundup Ready Soybean™*



**Engineered with bacterial gene to tolerate herbicide application**

# Global Area of Biotech Crops, 1996 to 2008: Industrial and Developing Countries (M Has, M Acres)



M Acres

346 140

296 120

247 100

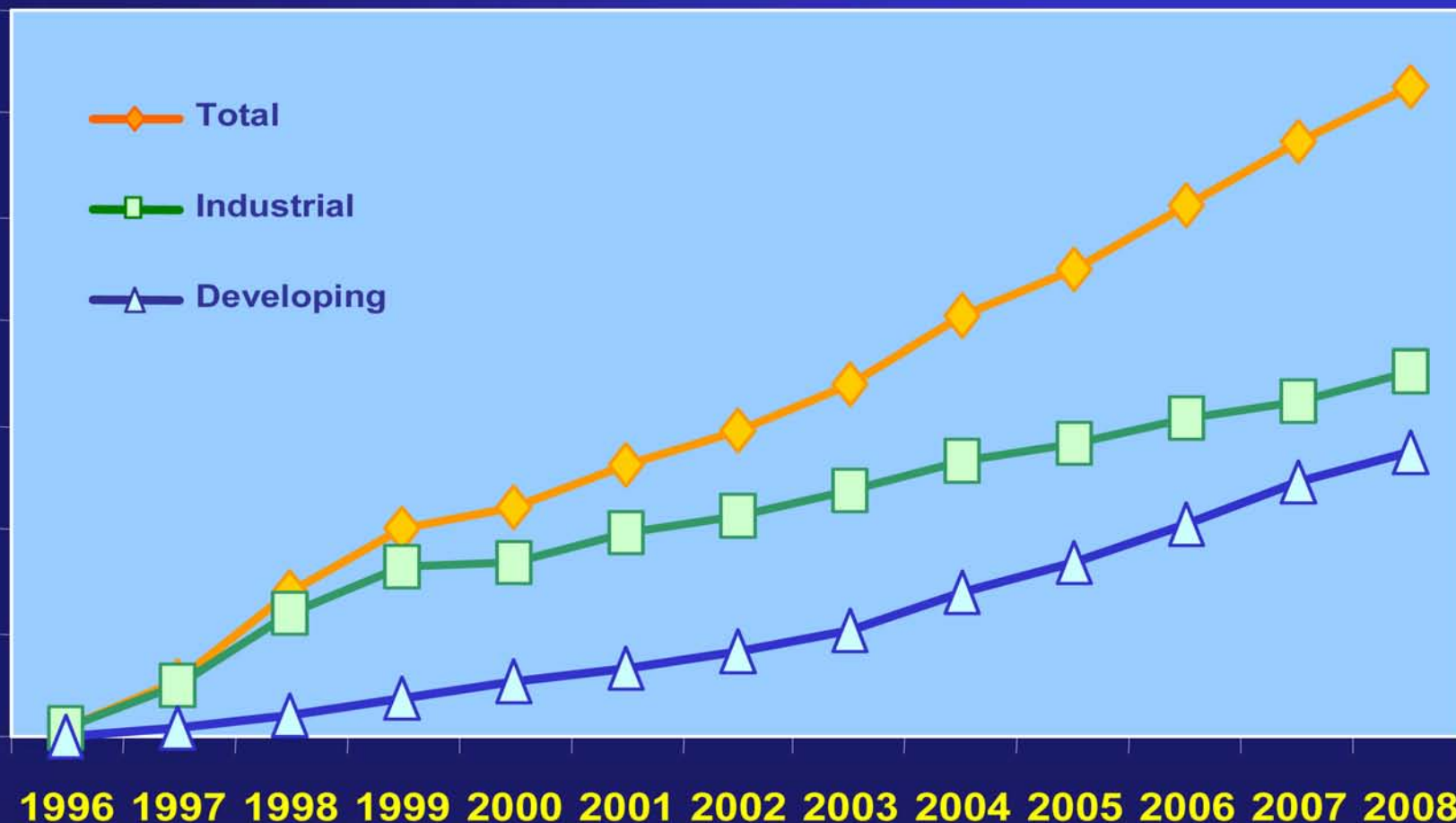
198 80

148 60

99 40

49 20

0



Source: Clive James, 2009





Estimated over 75% of Processed Foods Have GE Ingredients



**Only a few whole foods on  
the market are genetically  
engineered**



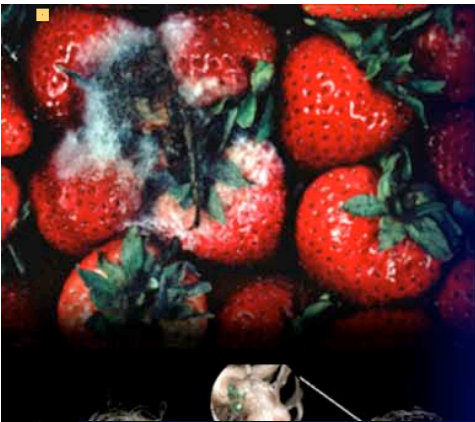
*GE Sweet Corn*



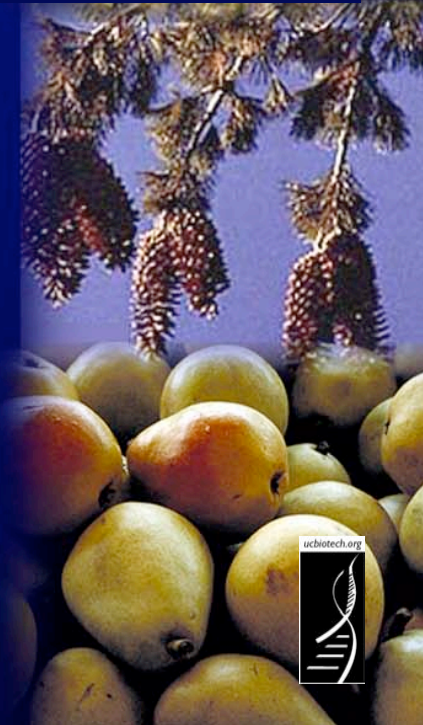
*GE Squash*



*GE Papaya*



# BRIEF GLANCE AT WHAT'S IN THE FOOD QUALITY PIPELINE?



**Mitigating food allergies,  
like peanut, soy and  
wheat, through  
engineering of plants**



## Safflower Oil Enhanced with Omega-3 and Omega-6 Fatty Acids

SOURCE: Arcadia Biosciences





**Flavonoid-enriched GE tomato has lower levels of protein associated with high risk of cardiovascular disease**

*SOURCE: Rein, D. et al., 2006. J. Nutr. 136: 2331-2337.*



## Using Foods as Medicines

*Rice-based edible vaccine  
for allergic diseases like  
asthma, seasonal allergies  
and atopic dermatitis*



SOURCE: March 2006, ISB News Report  
<http://www.isb.vt.edu/news/2006/news06.mar.htm#mar0601>





*Expression of human  
immune protein, CD14, in  
plants could prevent ocular  
infections in infants*

SOURCE: Information Systems for Biotechnology News Report, July 2006, p. 2  
<http://www.isb.vt.edu/news/2006/news06.jul.htm#jul0601>





**What is the U.S. regulatory process that governs these engineered plants?**

# **U.S. Regulatory Agencies (based oversight on existing regulations)**

## **USDA**

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

## **FDA**

- **Food safety**
- **Feed safety**

## **EPA**

- **Pesticidal plants**
  - tolerance exemption
  - registrations
- **Herbicide registration**

# **Safety of engineered food: Is it as safe as a conventional food?**

Concept of substantial equivalence:

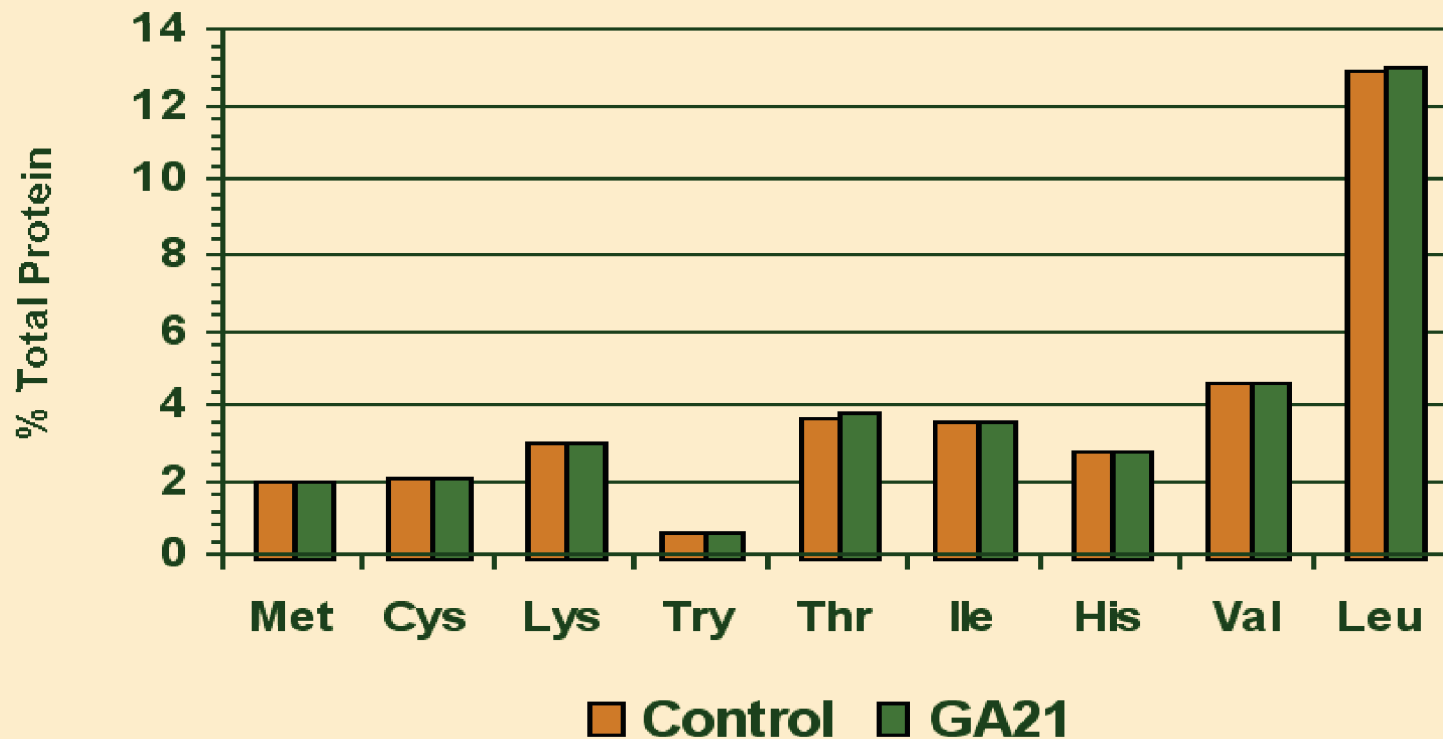
Modified food has essentially all characteristics of nonmodified food with respect to food and feed value except

**for introduced genetic material and products made from it. These are tested and analyzed separately - looking at, for example, specificity and mode of action of protein, source of protein, stability during digestion and processing**

SOURCE: Safety of Genetically Engineered Foods: Approaches to Assessing Unintended Health Effects 2004. Natl Acad Press

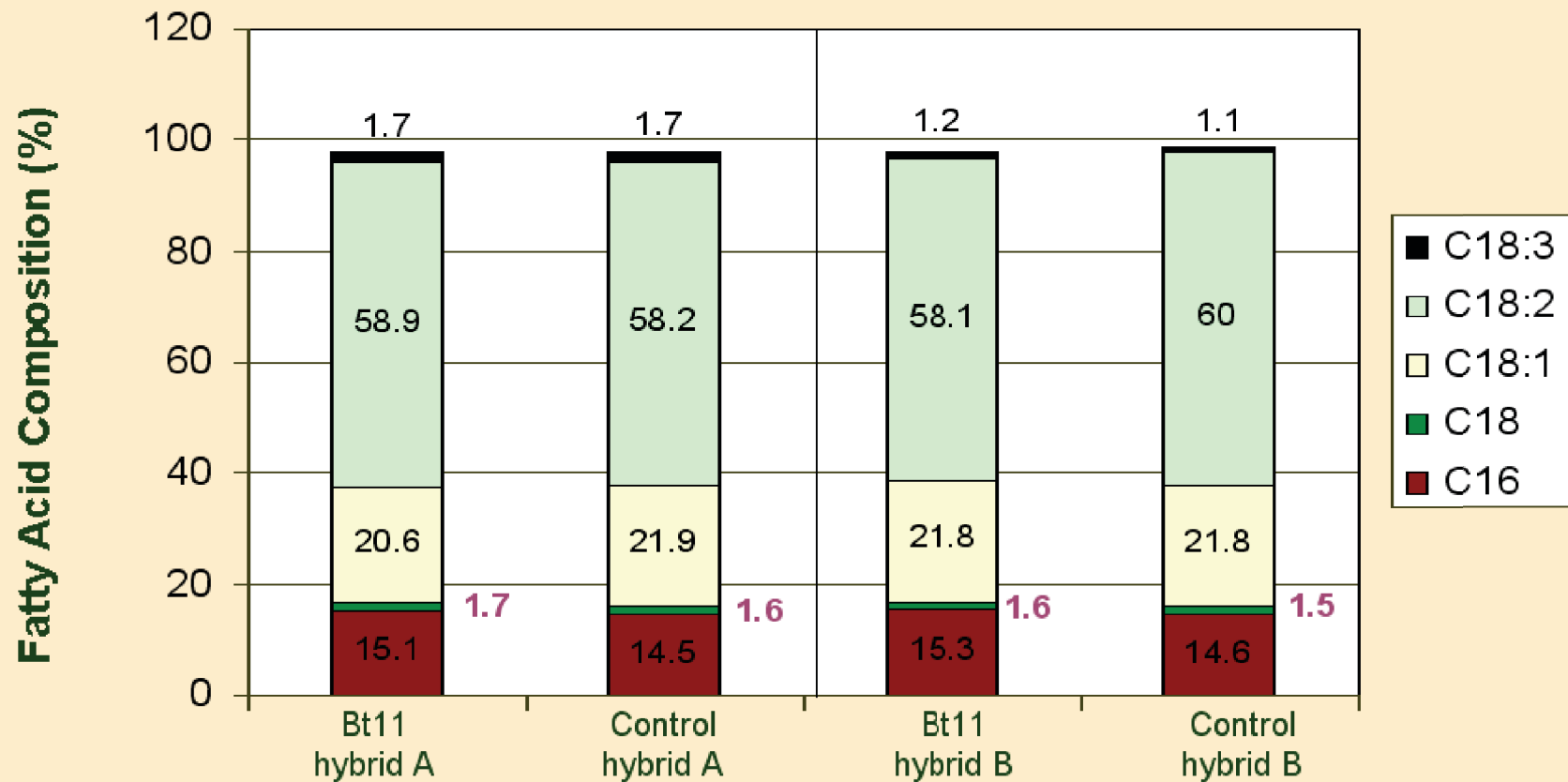


## *Substantial Equivalence: Amino Acids*



These results have been generated on event GA21. Data showing similar amino acid composition have been generated on the other corn events.

# Substantial Equivalence: Fatty Acids



These results have been generated on Event Bt 11. Data showing similar fatty acid composition have been generated on the other corn events.



# Are there any foods produced through biotechnology in the supermarket today?

	<u>1997</u>	<u>Jan. 2001</u>	<u>July 2006</u>	<u>July 2007</u>	<u>July 2008</u>
• Yes	40%	36%	36%	23%	23%
• No	37%	44%	30%	9%	10%
• Don't Know/Refused	23%	20%	34%	68%	66%

# What food or ingredients did you avoid or eat less of?

	<u>Jan. 2001</u>	<u>April 2003</u>	<u>July 2006</u>	<u>July 2008</u>
• <b>Sugars</b>	31%	65%	50%	51%
• <b>Fats/cholesterol</b>	41%	39%	33%	36%
• <b>Animal products</b>	28%	35%	28%	20%
• <b>Other</b>	9%	9%	11%	13%
• <b>Snacks/Fast food</b>	--	9%	16%	12%
• <b>Salt/spices</b>	11%	8%	12%	15%
• <b>Caffeine</b>	4%	4%	N/A	N/A
• <b>Genetically engineered</b>	0%	0%	0%	0%



# What, if anything are you concerned about when it comes to food safety?

	<u>Jan. 2001</u>	<u>Apr. 2003</u>	<u>July 2006</u>	<u>July 2008</u>
• <b>Packaging</b>	27%	15%	15%	3%
• <b>Food Handling/Preparation</b>	23%	41%	35%	29%
• <b>Other</b>	19%	9%	4%	2%
• <b>Disease/Contamination</b>	16%	28%	36%	50%
• <b>Chemicals/Pesticides in Food</b>	10%	7%	16%	6%
• <b>Altered/Engineered Food</b>	2%	1%	3%	1%
• <b>Nothing</b>	9%	5%	0%	0%

# What Are Some of the Issues with Food Safety of GE Foods?



# What are some food safety issues?

- No peer-reviewed food safety tests
- Creation of allergens or activation of toxins
- Pharma crops contaminate food supply
- Labeling
- Changes in nutritional content
- Gene flow from food to intestinal bacteria;  
increase in antibiotic resistance

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## Difficulties with food safety testing

### What to do and how to do it?

**“It is difficult if not impossible to test food safety of whole foods and feeds with animal tests. Despite what non-experts commonly think, animal tests are not the gold standard. Compositional analysis and toxicity testing of individual components is much more sensitive than whole foods testing.”**

*“Nutritional and Safety Testing of Foods and Feeds Nutritionally Improved through Biotechnology” 2004. *Comprehensive Reviews in Food Science and Food Safety*, ILSI*

# *Poultry and Egg Study: Bt Protein Analysis*

**Example of animal safety test**

- 14 day poultry feeding study
- Diet: contained 64% grain (Bt or non Bt)
- Eggs collected on days 13 & 14
- Muscle and liver samples collected on day 14

<u>Tissue</u>	<u>Bt Protein Analysis</u>
➤ white muscle (10)	Not detected
➤ dark muscle (10)	Not detected
➤ liver (10)	Not detected
➤ egg whites (10)	Not detected
➤ egg yolk (10)	Not detected

## Experiments comparing first generation GE crops with isogenic counterparts

Animal (Species/categories)	Number of experiments	Nutritional assessment
<b>Ruminants</b>		<b>No unintended effects in composition (except lower mycotoxins concentration in Bt plants)</b>
Dairy cows	23	
Beef cattle	14	
Others	10	
<b>Pigs</b>	21	
<b>Poultry</b>		<b>No significant differences in digestibility and animal health as well as no unintended effects on performances of animals and composition of food of animal origin</b>
Laying hens	3	
Broilers	28	
<b>Others (Fish, rabbits etc.)</b>	8	

SOURCE: Flachowsky, G. 2007. Feeds from Genetically Engineered Plants - Results and Future Challenges. ISB News Report, March 2007, pp. 4-7.



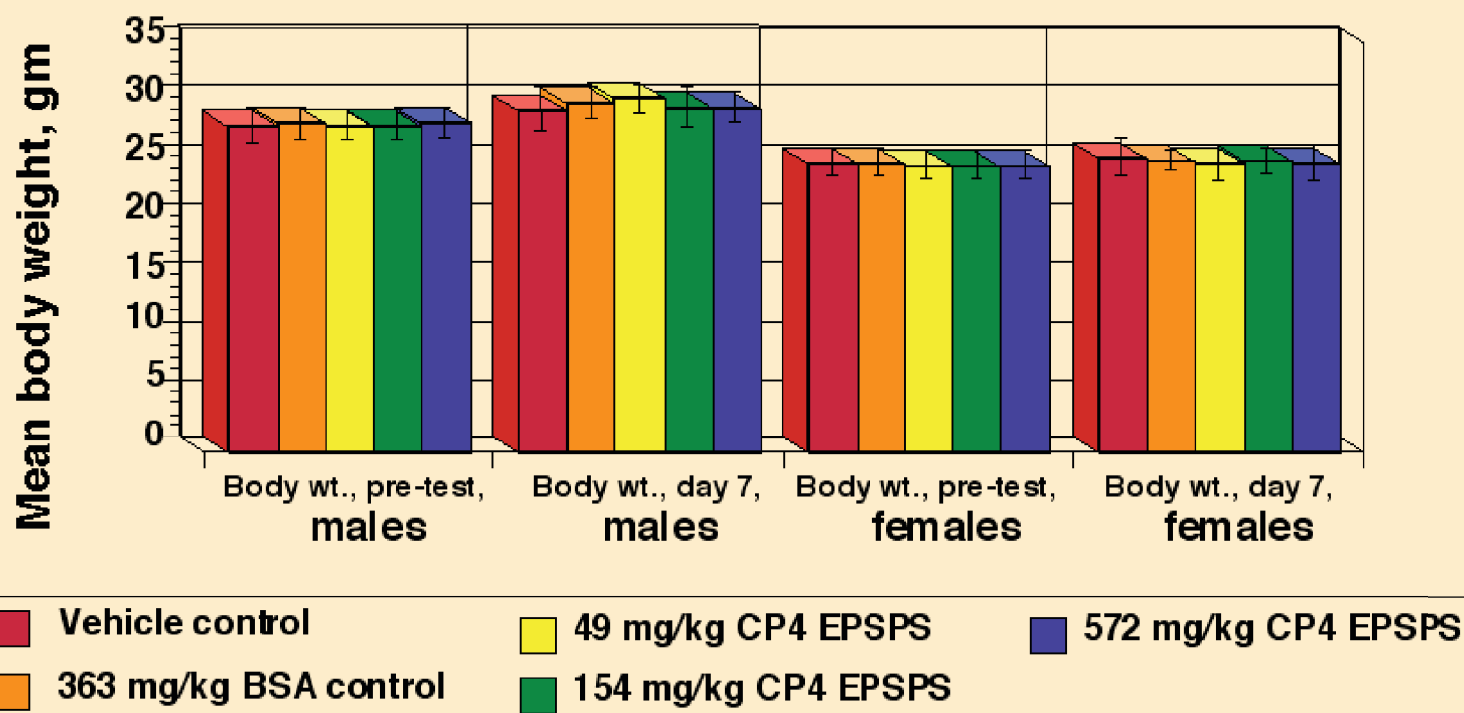
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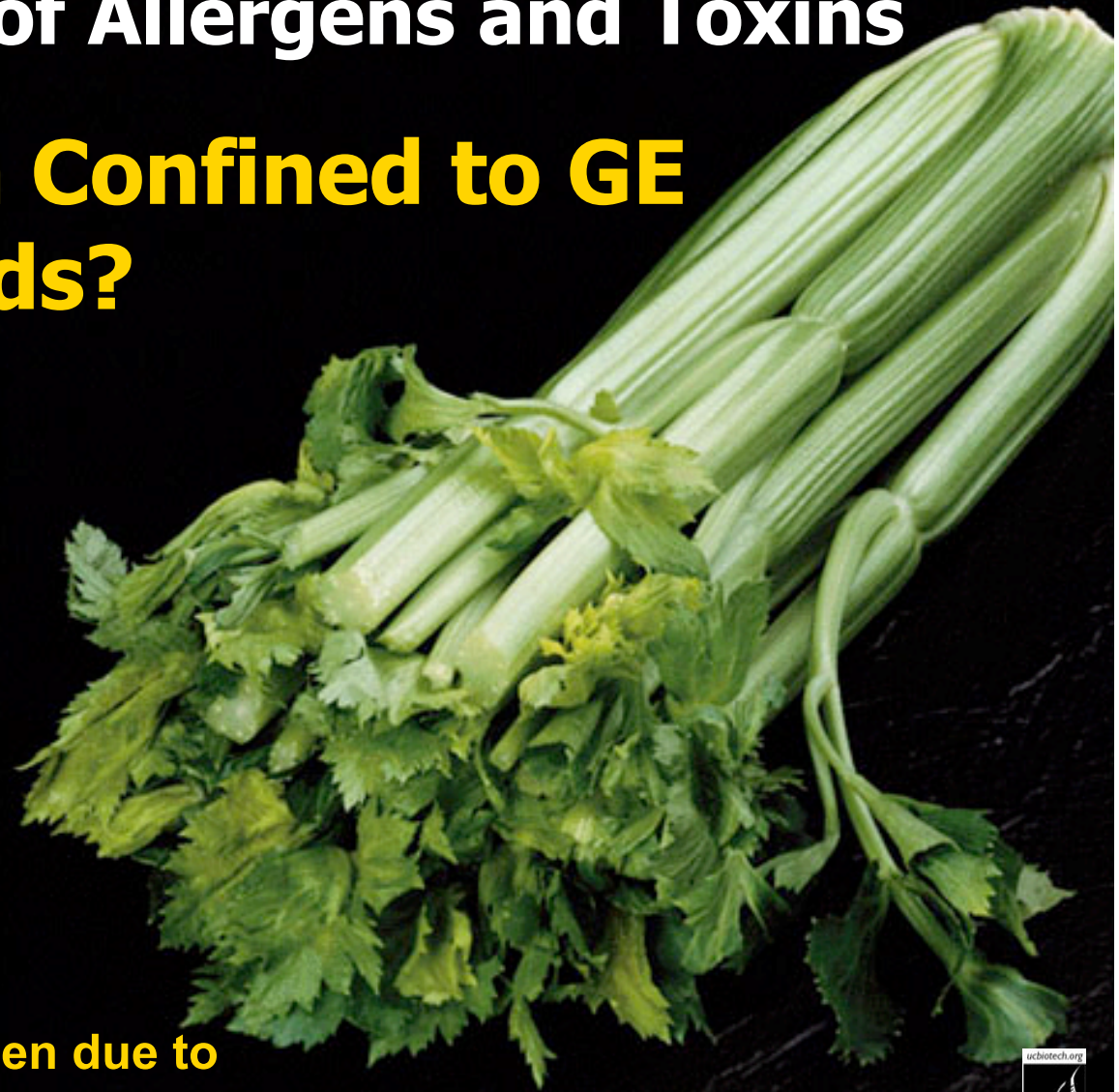
# Toxicity Assessment: Roundup Ready/CP4 EPSPS protein

*No deleterious effects at highest dose (572mg/kg)*



# Inadvertent Creation of Allergens and Toxins

## Is Toxin Creation Confined to GE Foods?



**No – naturally occurring toxins happen due to classical breeding efforts also, e.g., potato (glycoalkaloids) and celery (psoralens)**

# Allergy Creation Confined to GE Foods?

**Classically bred foods can cause allergy problems too –**

**Example: Kiwi**



**Long-term Food Safety Studies:  
Should They Be Done, How  
and on What Foods?**



# Fumonisin Reduction with Bt-maize



- **1989: High levels of fumonisin cause large-scale outbreaks of lethal lung edema in pigs, brain tumors in horses**
- **Fumonisin contamination caused by insect infestation**
- **20- to 30-fold fumonisin reduction with Bt-maize**

Modified from Drew L. Kershen  
University of Oklahoma

*SOURCE; Hammond, B. et al., (Feb. 2004), Lower fumonisin mycotoxin levels in the grain of Bt-corn grown in the United States in 2000-2002, J. Agric. Food Chem. 52: 1390-1397*



# What are some food safety issues?

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# Why Doesn't FDA Have a Labeling Policy for GM Foods?

**Actually it does...**

**Foods produced through biotechnology are subject to same labeling laws as all other foods and food ingredients**

**Govt-mandated label information relates to composition or food attributes not agricultural or manufacturing practices**

**No label needed if food essentially equivalent in safety, composition and nutrition**

**GM food labeled if:**

- 1. Different nutritional characteristics,**
- 2. Genetic material from known allergenic source e.g., peanut, egg**
- 3. Elevated levels of antinutritional or toxic cmpds**

# Should fresh produce items, packages or displays be labeled to identify...?

(Summary of "yes" responses)

<b>Nutritional value</b>	<b>77.1%</b>
<b>Country of origin</b>	<b>85.9%</b> ◀
<b>Chemicals used in production</b>	<b>90.7%</b> ◀
<b>Organically grown</b>	<b>86.0%</b> ◀
<b>Irradiated</b>	<b>77.8%</b>
<b>Use of biotechnology</b>	<b>78.4%</b>
<b>Use of waxes and/or coatings</b>	<b>84.5%</b> ◀

SOURCE: *Fresh Trends 2002* (courtesy of Roberta Cook, UC Davis)



# Why not just label?



**Putting a label on a whole food is relatively easy, but...**



**Processed foods are different.  
Tomato sauce can contain  
8 or more different varieties –  
each requires tracking to assure  
accurate content information.**



May contain  
genetically modified  
tomatoes



Contains  
genetically modified  
tomatoes



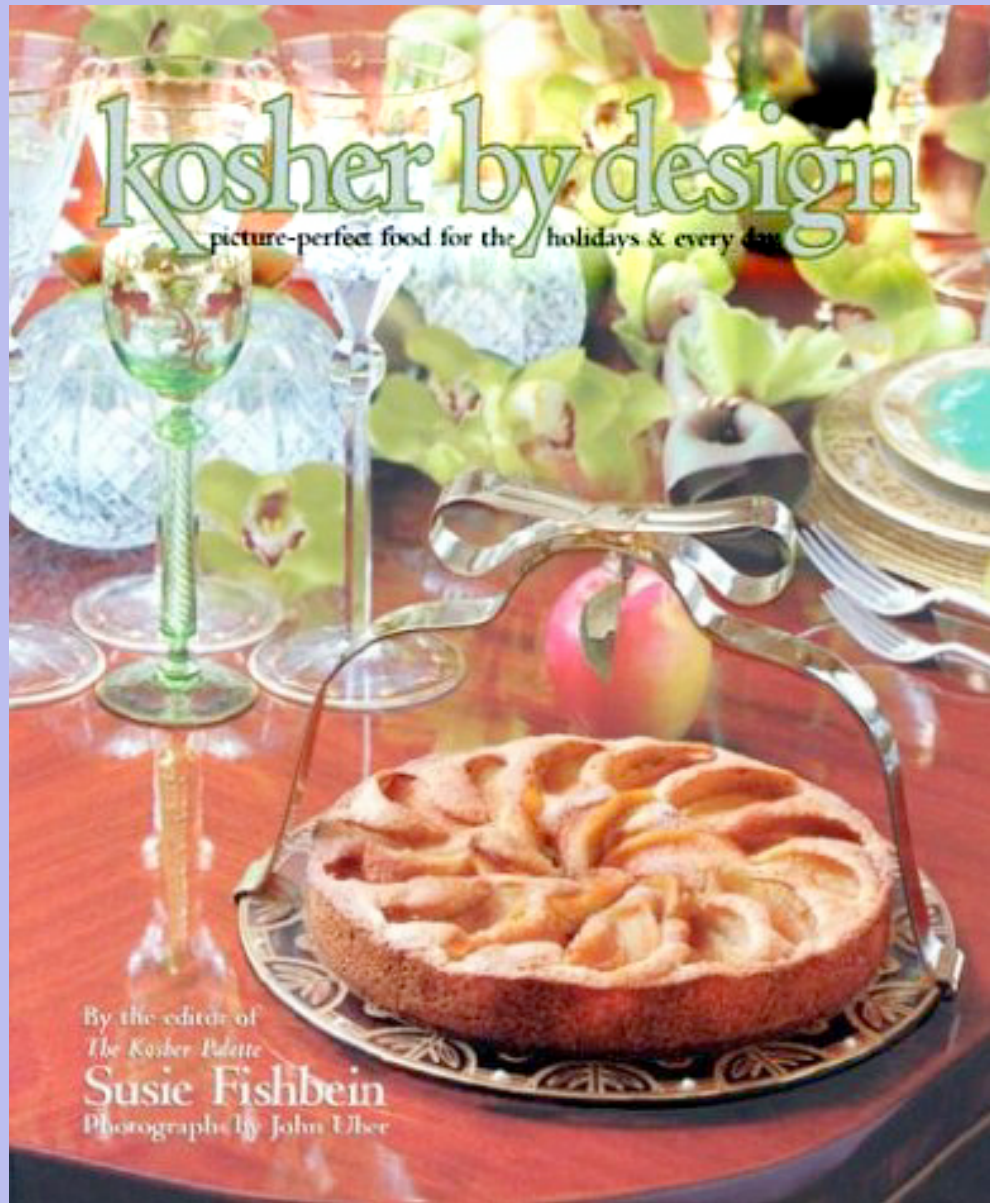
Contains tomatoes genetically modified with polygalacturonase gene from tomato, phosphinothricin acetyl transferase from *Streptomyces hygroscopicus*, crystal toxin from *Bacillus thuringiensis*, alpha amylase gene from barley, s-adenosyl methionine transferase gene from tobacco, N protein gene from tobacco, coat protein gene from tomato bushy stunt virus, phosphinothricin acetyl transferase from coat protein gene bushy stunt

**But there are foods that are tracked for consumer choice... like organic and...**



**...Kosher**

**For which  
people pay  
premium  
prices**



**Should  
everyone  
pay a  
premium  
price for  
GE- free  
foods?**

**Might another solution be to allow the creation of a specialty market for GE-free foods for which people pay a premium price and for which farmers are paid premium prices to grow them?**





**What is one of the major issues that drives many of the concerns?**

**Organic Agriculture  
Often seen as either/or**



SOURCE: <http://www.biotech.org>



# **What Exactly Is Organic Agriculture? It is a production system that...**

- **Places a priority on health of crops, animals, farmers, environment, and consumers**
- **Doesn't use synthetic pesticides and fertilizers**
- **Focuses on improving soil fertility through use of organic matter and cover crops**
- **Supports and enhances an abundance of beneficial insects**
- **Must have 3 years with no prohibited material and be inspected on an annual basis by a USDA accredited certifier to be certified organic**

# Why Do Consumers Prefer Organic Fresh Produce?

bananas, Fuji apples, broccoli, red leaf lettuce



*Based on 4 attributes:*

1. Absence of pesticides
2. No genetic engineering
3. Environmentally-friendly production methods
4. Price

## Regular organic buyers:

Willingness to pay for absence of pesticide, no genetic engineering and production methods.

## Non regulars:

Only willing to pay for absence of pesticides.

Different products yielded different willingness, broccoli & lettuce higher than bananas & apples.

\* Onozaka, Y., Bunch, D.S. and Larson, D.M. 2006. *What Exactly Are They Paying For? Decomposing the Price Premium for Organic Fresh Produce of Heterogenous Consumers.* Department of Agricultural & Resource Economics, University of California, Davis.


# Are Organic Foods Healthier? Safer?

AMERICAN SOCIETY OF AGRONOMY | CROP SCIENCE SOCIETY OF AMERICA | SOIL SCIENCE SOCIETY OF AMERICA

CROPS, SOILS, AGRONOMY APRIL 2007 V52 N04


## CSA NEWS

www.agronomy.org • www.crops.org • www.soils.org



Organic VS. Conventional

### FOODS



How do they measure up in terms of quality, safety?



## Los Angeles Times



THE CALIFORNIA COOK

### 'Organic' label doesn't guarantee quality or taste

**Just because it's organic  
doesn't mean it's the best. Let  
flavor dictate.**

By RUSS PARSONS  
July 1, 2009

» [Discuss Article](#)

I don't believe in organic.  
There, I've said it and I feel  
better. It's something that's  
been on my mind for years.

Now, don't get me wrong: I've got nothing against organic farmers. In fact, some of my favorite farmers are organic. I really admire them: Growing delicious food and doing it according to organic standards is adding a degree of difficulty that I wouldn't wish on anyone.

SOURCE: 'Organic' label doesn't guarantee quality or taste', July 1, 2009, Los Angeles Times.  
<http://www.latimes.com/features/food/la-fo-calcook1-2009jul01,0,2885942.story?track=rss>



# Are there differences between organic and conventional foods?

Qualitative differences (not all studies agree)

- Organic fruits/vegetables: lower pesticide residues and nitrates
- Higher levels of secondary metabolites:  
+ = antioxidants; - = naturally occurring toxins
- Potential increased microbiological hazards from organic produce

**“While some studies have demonstrated qualitative differences between organic and conventional foods, it is premature to conclude that either food system is superior to the other with respect to safety or nutritional composition.”**

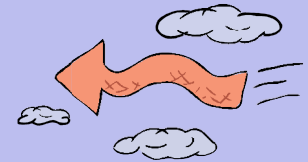
# Are There Tolerances for GE in Organic Products?

From NOP preamble...

- **Organic Production is a PROCESS certification NOT a PRODUCT certification – it allows for Adventitious Presence (AP) of certain excluded methods.**



☛ **Pesticides**: “When residue testing detects prohibited substances at levels that are greater than 5% of the EPA’s tolerance for the specific pesticide residue detected...the agricultural product must not be sold or labeled, or represented as organically produced.”



☛ **GMOs**: At the present time there are no specified tolerances for GMOs in organic products. Organic products are not ‘guaranteed’ GMO-free, although some organic farmers sign contracts guaranteeing GMO-free

**BUY FRESH  
BUY LOCAL**

## **Is Eating Local More Important than Eating Organic?**



**Central Coast**

COMMUNITY ALLIANCE WITH FAMILY FARMERS • [WWW.CAFF.ORG](http://WWW.CAFF.ORG)

# Organic or local?

- Willingness of consumer to pay for organic produce about same as for local produce.
- Frequency of purchases was different for organic and local produce.
- Consumers consider "freshness" and "safe to eat" as "very important" when purchasing locally grown produce.

“When you buy fruits and vegetables, how often do you buy locally grown (or organically grown) fresh produce when it is available”

	Local	Organic
Always	14%	6%
Most times	40%	15%
Sometimes	38%	38%
Seldom/Never	8%	40%

SOURCE: Yue, C. and Tong, C. 2009. *Organic or Local? Investigating Consumer Preference for Fresh Produce Using a Choice Experiment with Real Economic Incentives*. *HortScience* 44: 366-371.

## Nosestretcher alert: small farms produce safest food?

POSTED: MARCH 9TH, 2010 - 4:03AM BY DOUG POWELL

# Do small farms produce the safest food?

"Small farms produce the safest food available, without

**The idea that food grown...locally is somehow safer than other food...is the product of wishful thinking.**

safer than other food, either because it contacts fewer hands or any outbreaks would be contained. is the product of wishful

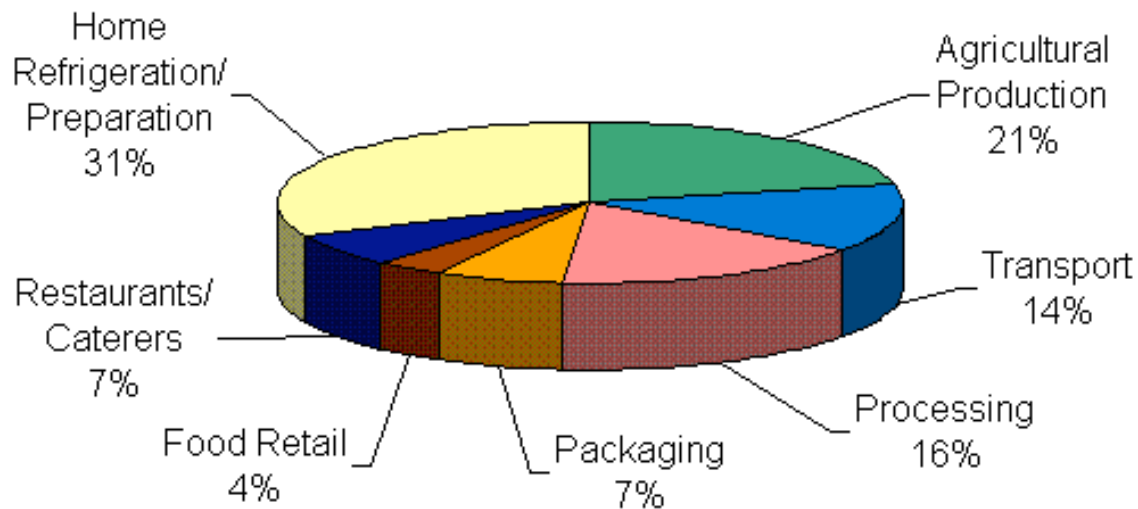
**Majority of foodborne outbreaks come from large farms because vast majority of food consumed comes from food produced on large farms.**

SOURCE: <http://www.barfblog.com/blog/141228/10/03/09/nosestretcher-alert-small-farms-produce-safest-food>



## United States Food System Energy Use

Total = 10.25 Quadrillion Btu



Source: Heller and Keoleian

**Agricultural production accounts for only ~20% of the energy use for food production...**

**“The other four-fifths goes to moving (14%), processing (16%), packaging (7%), selling (11%) and storing (31%) food after it leaves the farm”**

SOURCE: Murray, D. 2005. *Oil and Food: A Rising Security Challenge*. Earth Policy Institute report, May 9, 2005-4. [http://www.earth-policy.org/Updates/2005/Update48\\_printable.htm](http://www.earth-policy.org/Updates/2005/Update48_printable.htm)





# Where to get more information on the issues?



SCIENCE-BASED INFORMATION & RESOURCES  
ON AGRICULTURAL BIOTECHNOLOGY

HOME | IN THE NEWS | BIOTECHNOLOGY INFORMATION | SCIENTIFIC DATABASE | RESOURCES | LINKS | GLOSSARY | CONTACTS

## know GMOS

*This website, developed for the University of California Division of Agricultural and Natural Resources Statewide Biotechnology Workgroup, provides educational resources focused broadly on issues related to agriculture, crops, animals, foods and the technologies used to improve them. Science-based information related to these issues is available, as well as educational tools and information, which can be used to promote informed participation in discussions about these topics.*

## FEATURED PRESENTATION

"Biotechnology 101:  
(Some of what you  
need to know  
in a few minutes)"

ASA Plant & Soil Conference,  
Fresno, CA, February 3, 2009

### BIOTECHNOLOGY INFORMATION



#### ANNUAL REVIEWS

**Review articles:** Focused on food, environmental and socioeconomic issues of GE crops and foods.

**Issues and Responses:** Searchable list of issues related to agriculture, foods, technologies linked to responses.

### RESOURCES FOR OUTREACH & EXTENSION, RESEARCHERS & TEACHERS



**Slide Archive:**  
Extensive collection of PP slides on agriculture & biotechnology.

Available on loan:

**Educational displays:** "Genetics and Foods" and Genetic Diversity and Genomics" available with companion educational cards and teacher worksheet in English and Spanish.

**Gene-IE Juice Bar:** Interactive activity to isolate DNA from common fruits and vegetables.

**Tic Tac Grow:** Educational game to teach what foods come from what crops.

### HELPFUL SITES



**Seed Biotechnology Center**  
Mobilizes research, education & outreach efforts in partnership with seed & biotechnology industries.

**Animal Genomics & Biotechnology Cooperative Extension Program, UC Davis**



Provides education on use of animal genomics & biotechnology in livestock production.

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## Genetically Engineered Plants and Foods: A Scientist's Analysis of the Issues (Part I)

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## Genetically Engineered Plants and Foods: A Scientist's Analysis of the Issues (Part II)

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### Key Words

benefits, biotechnology, crops, food safety, genetic engineering, risks

### Abstract

Through the use of the new tools of genetic engineering, genes can be introduced into the same plant or animal species or into plants and animals that are not sexually compatible—the latter is a discipline with classical breeding. This technology has led to the commercial production of genetically engineered (GE) crops on approximately 250 million acres worldwide. These crops generally are herbicide and pest tolerant, but other GE crops in the pipeline focus on traits such as improved nutrition, enhanced drought tolerance, and improved disease resistance. For some farmers and consumers, planting and eating GE crops are acceptable; for others they raise issues about safety and the environment. In Part I of this review, we discuss the benefits and risks of GE crops and the environment.

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### Abstract

Genetic engineering provides a means to introduce genes into plants via mechanisms that are different in some respects from classical breeding. A number of commercialized, genetically engineered (GE) varieties, most notably canola, cotton, maize and soybean, were created using this technology, and at present the traits introduced are herbicide and/or pest tolerance. In 2007 these GE crops were planted in developed and developing countries on more than 280 million acres (113 million hectares) worldwide, representing nearly 10% of rainfed cropland. Although the United States leads the world in acres planted with GE crops, the majority of this planting is on large acreage farms. In developing countries, adopters are mostly small and resource-poor farmers. For farmers and many consumers worldwide, the benefits of planting GE crops and eating GE foods are still being debated.

**Also in peer-reviewed articles:**  
**Lemaux P.G. *Annual Review of Plant Biology* 2008**  
**and 2009 and ANR Fact Sheets 2006**

