FEAST, FAMINE and the FUTURE of FOOD

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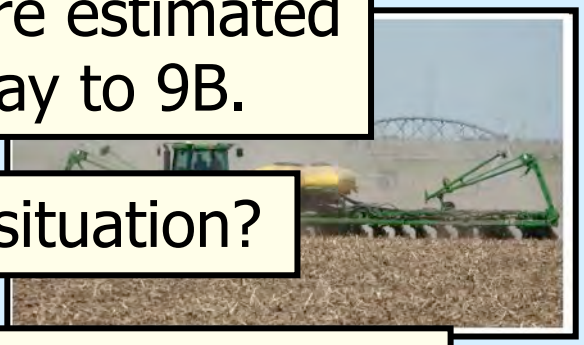
http:/ucbiotech.org
http://pmb.berkeley.edu/~lemauxlab

Images of our world raise issues of population explosion and the food production that will be required – in the face of climate change.

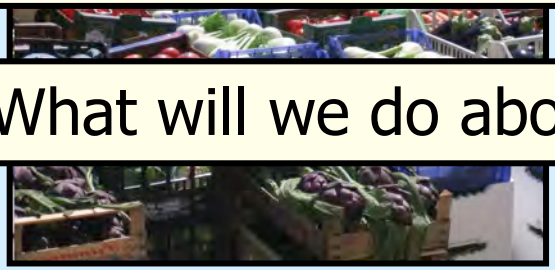
By 2050 number of people are estimated to increase from 7.2B today to 9B.

How did we get into this situation?



Increased food demand will require world ag production to rise by 50% in less than 20 years

What will we do about it?



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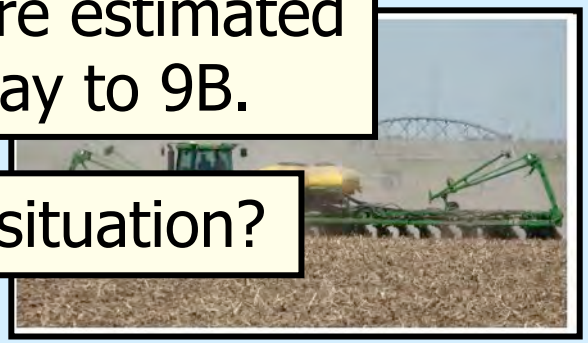
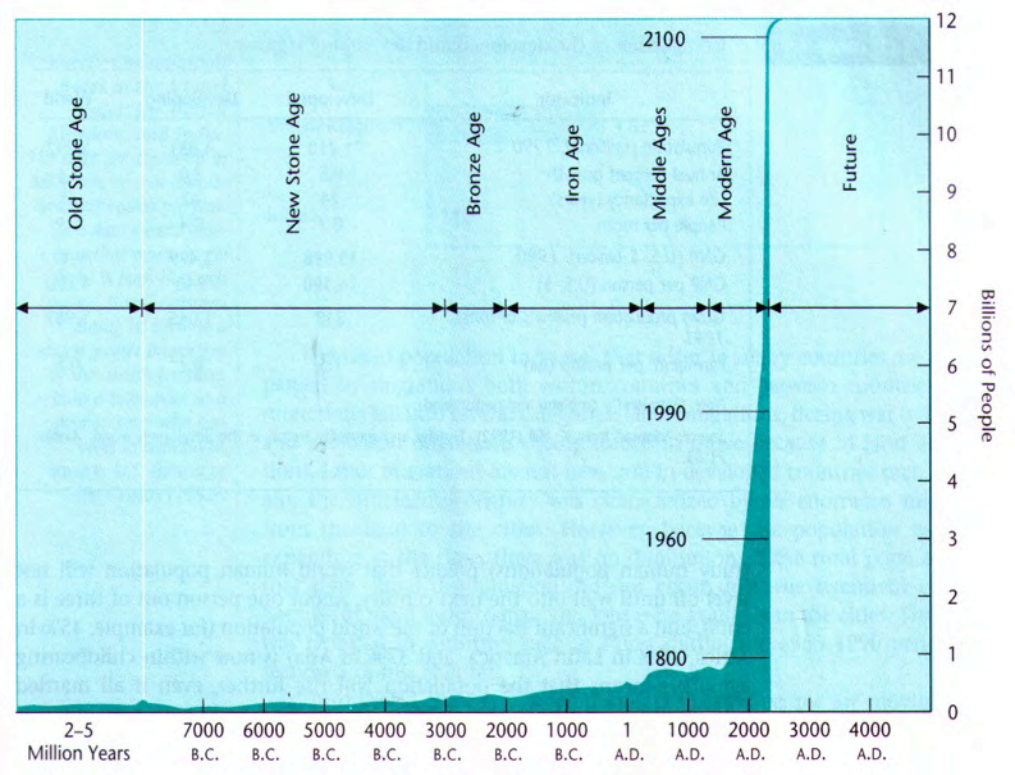


2,000 years ago – 300 million people worldwide – approximately as it is in just the U.S. today!



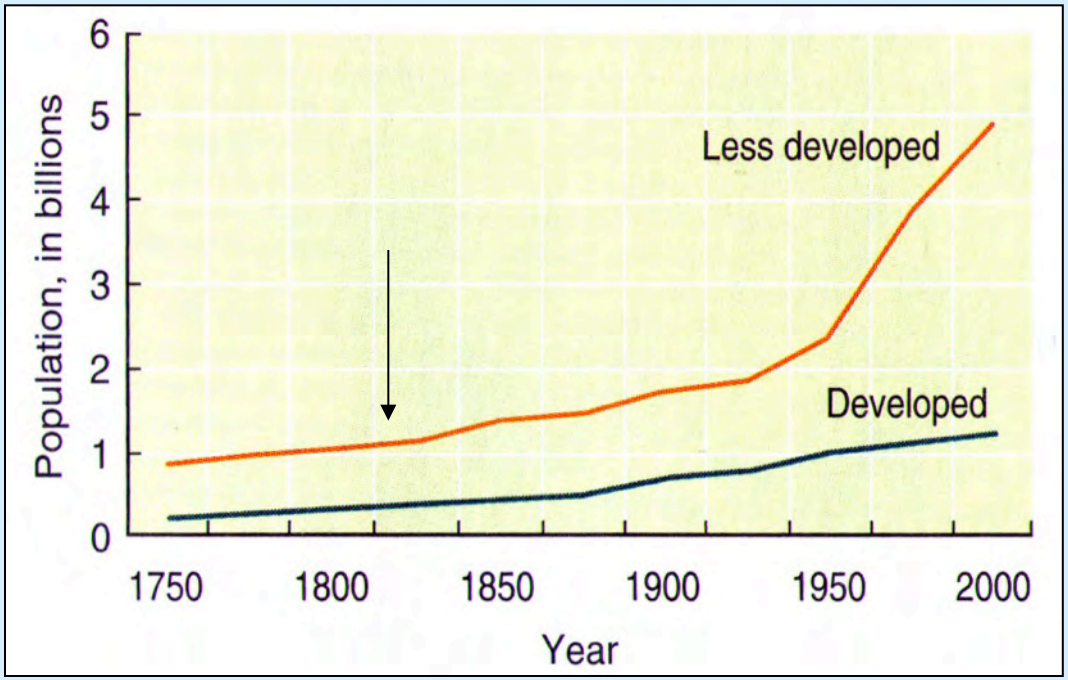
2000 years ago:
500 people were added to the world each day.

Today: 400 times more people per day are added: 200,000!

SOURCE: "Plants, Genes, and Agriculture", Chrispeels, M.J. and Sadava, D.E. (editors) 1994.

Early in civilization hunter/gatherer lifestyles led to both moderately high birth and death rates.

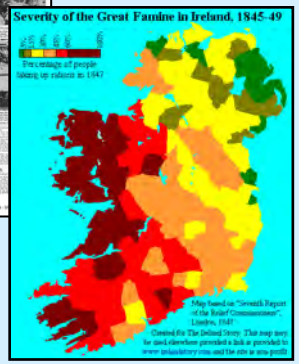
~10,000 years ago, agriculture began replacing hunting and gathering.



Reliable food supplies plus a settled existence led to dramatic birth rate increases up to 1800 – but…

SOURCE: "Plants, Genes, and Crop Biotechnology", Chrispeels, M.J. and Sadava, D.E. (editors), 2003

FAMINE,



WAR,

and

DISEASE

kept populations down

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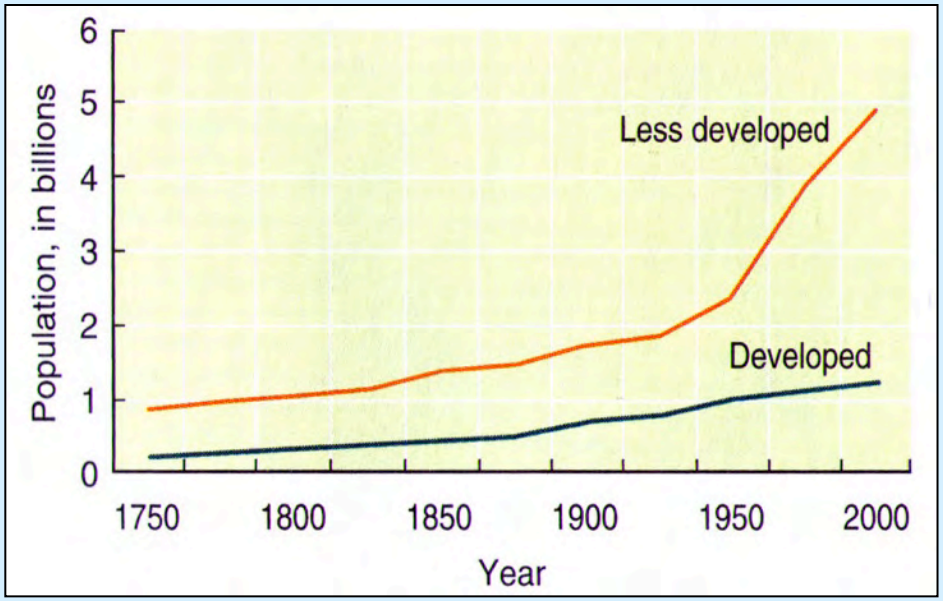
Dramatic population explosion in last 80 years.

Why?

Rising income = more people could buy food

Improved housing/ public hygiene = decrease in infectious disease



Food production more dependable due to improved transportation

Medical advances due to disease agent identification / treatments to control diseases

SOURCE: "Plants, Genes, and Crop Biotechnology", Chrispeels, M.J. and Sadava, D.E. (editors), 2003

In Europe and North America, industrialization occurred over hundreds of years

In Asia, Africa, Latin America, improvements happened "overnight" (the last 50 years) with populations growing extremely rapidly

This led to 16-fold increases in population in less developed countries

But grain production did not keep up - only 1.5-fold

Comparison of developed and less developed regions

Indicator	Developed	Less Developed	World
Population (millions), 2002	1,193	4,944	6,137
Annual percent growth	0.1	1.6	1.3
Life expectancy, years	75	64	67
People per room	0.7	2.4	1.9
Mortality under 5, per 100 births	0.8	6.1	5.6
GNP per person, US$	20,520	3,300	6,650
Grain production, millions of tons	810	1,259	2,069
Farmland/person, hectares	1.5	0.6	0.7

s), 2003

WHY?

Lack of increases in grain production was due in part to the mass exodus from rural areas (and farming)…

to urban areas, as a result of industrialization.
This put increased pressure on agricultural systems

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But that's not the whole story: types of foods consumed also affect agricultural production

Comparison of the diets in India and United States

Food	Source of calories		Source of protein	
	India	United States	India	United States
Cereals, starchy foods	65%	25%	64%	21%
Sugars	6	12	—	—
Beans, lentils	10	4	18	3
Fruits, vegetables	2	6	1	4
Fats, oils	4	19	—	—
Milk, milk products	7	14	11	26
Meat, poultry, eggs, fish	6	20	6	46

Sources: Data from Food and Agriculture Organization and U.S. Department of Agriculture.

Less developed countries 'protein needs were satisfied by cereals and beans. Now shifting to milk and meat – affecting ag production. Why?

Transfer of energy efficiency from plants to humans through beef is ~1%!!

SOURCE: "Plants, Genes, and Agriculture", Chrispeels, M.J. and Sadava, D.E. (editors) 1994.

In the past how were increases in the food supply able to keep up with increases in population?

From 1860 to 1978 land used for food production increased.

But since 1978 land size has remained steady, causing amount of cultivated land per person to drop by 25%.

This loss was compensated for by increased crop productivity.

SOURCE: "Plants, Genes, and Crop Biotechnology", Chrispeels, M.J. and Sadava, D.E. (editors), 2003

What do farmers produce?

Globally **300** crops provide food…
24 supply most of the food and feed...
8 crops supply 85%!

Three account for over half of our food - directly or indirectly.

Corn

Wheat

Rice

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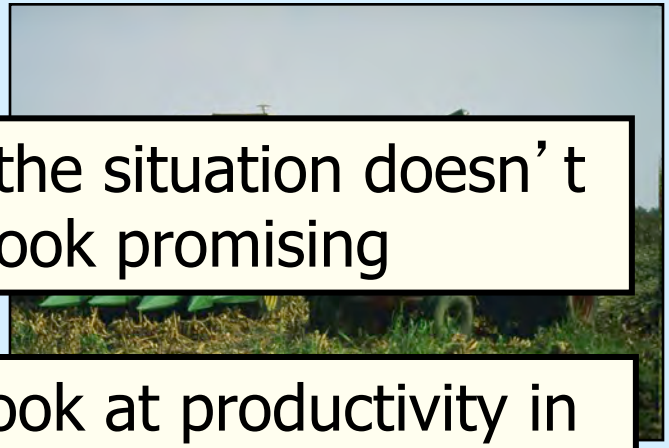
	1930	2009
% of people involved in farming:	21%	~0.7%
Number of farms:	6,295,000	2,200,000

BOTH DECREASED

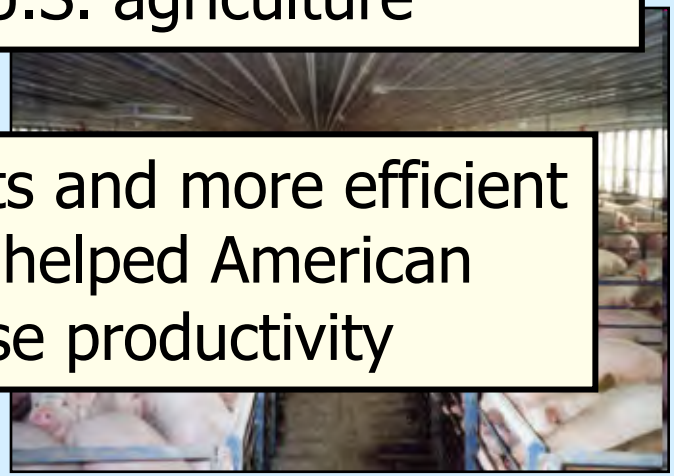
But productivity of average US farmer INCREASED…

In 1930 fed 10
In 1960, 24
In 1990, 100
In 2009, 155



At first the situation doesn't look promising

Let's look at productivity in U.S. agriculture



Genetic improvements and more efficient farming practices helped American farmers increase productivity

http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_US/st99_1_063_063.pdf

http://prb.org/Datafinder/Geography/Data.aspx?category=6&region=72&region_type=3

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But is this bounty of food production universally true? Compare the amount of food Americans have on their table for an entire week…

Versus that same week in Africa

USA (Texas)

MALI

Just something to think about!

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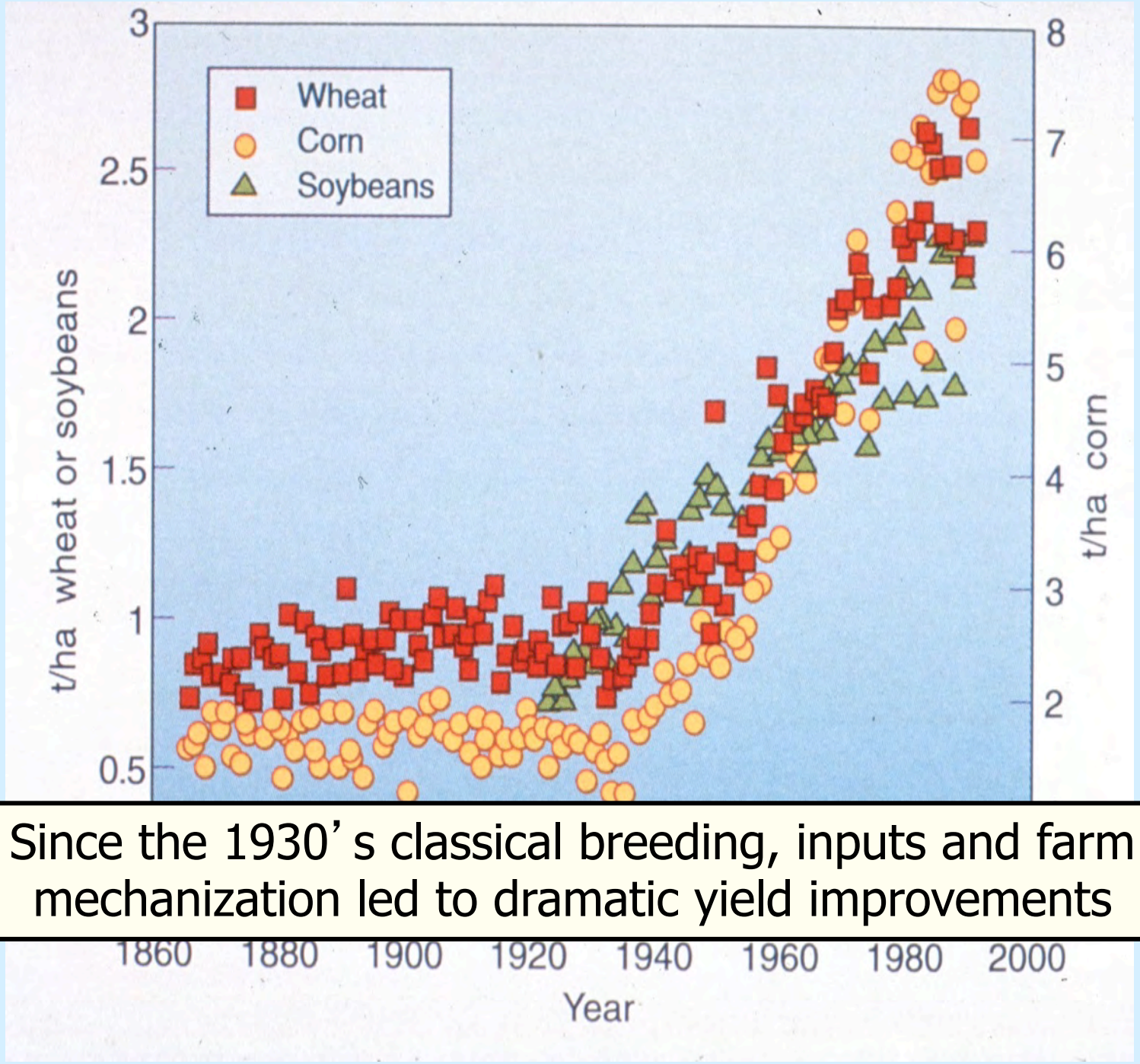

Since the 1930's classical breeding, inputs and farm mechanization led to dramatic yield improvements

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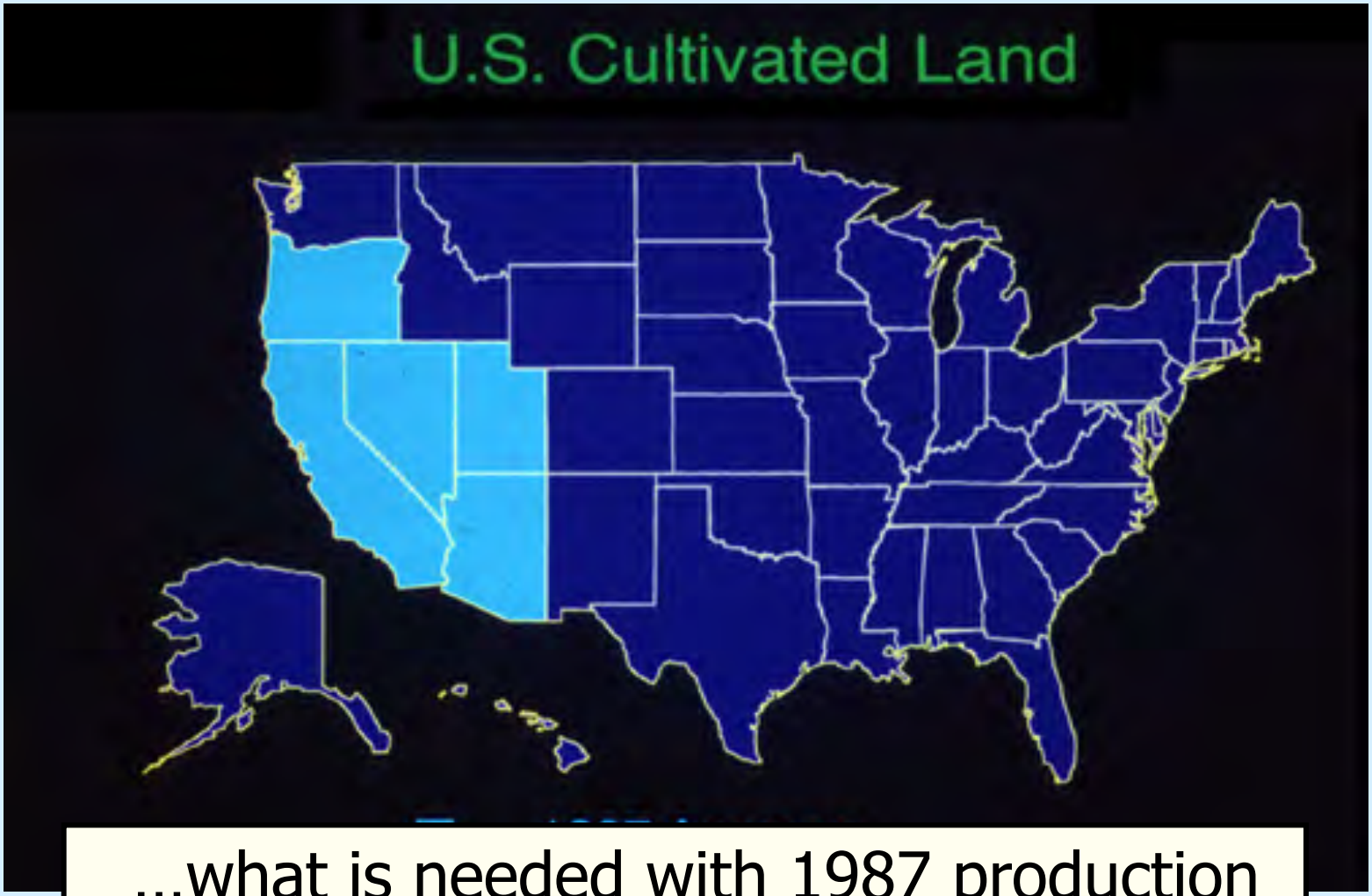
From the acreage that would have been needed in 1987 to feed the U.S. at 1929 production levels to…



…what is needed with 1987 production levels – the situation in 2014 would be even better!

The problems are complex and require the best of a diverse number of approaches.

It is important to realize there is no one magic bullet for these challenges!

In the past how did we use genetics to create higher yielding varieties?

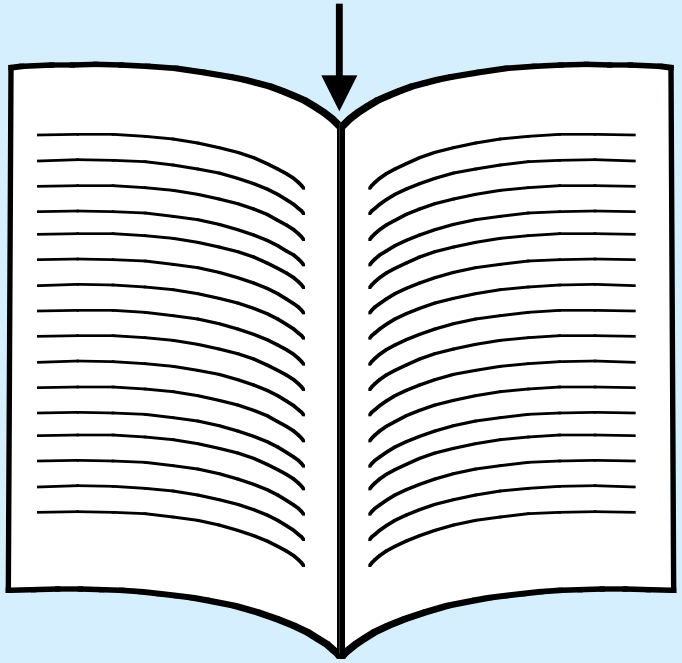
Triticum aestivum
Modern bread variety

Triticum monococcum
Ancient variety

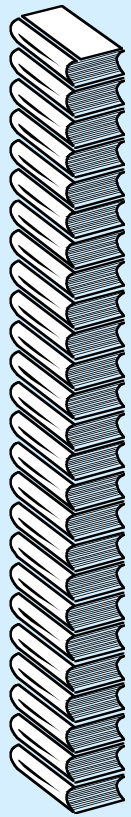
Information in the wheat genome

Chemical units represented by alphabetic letters

...CTGACCTAATGCCGTA...

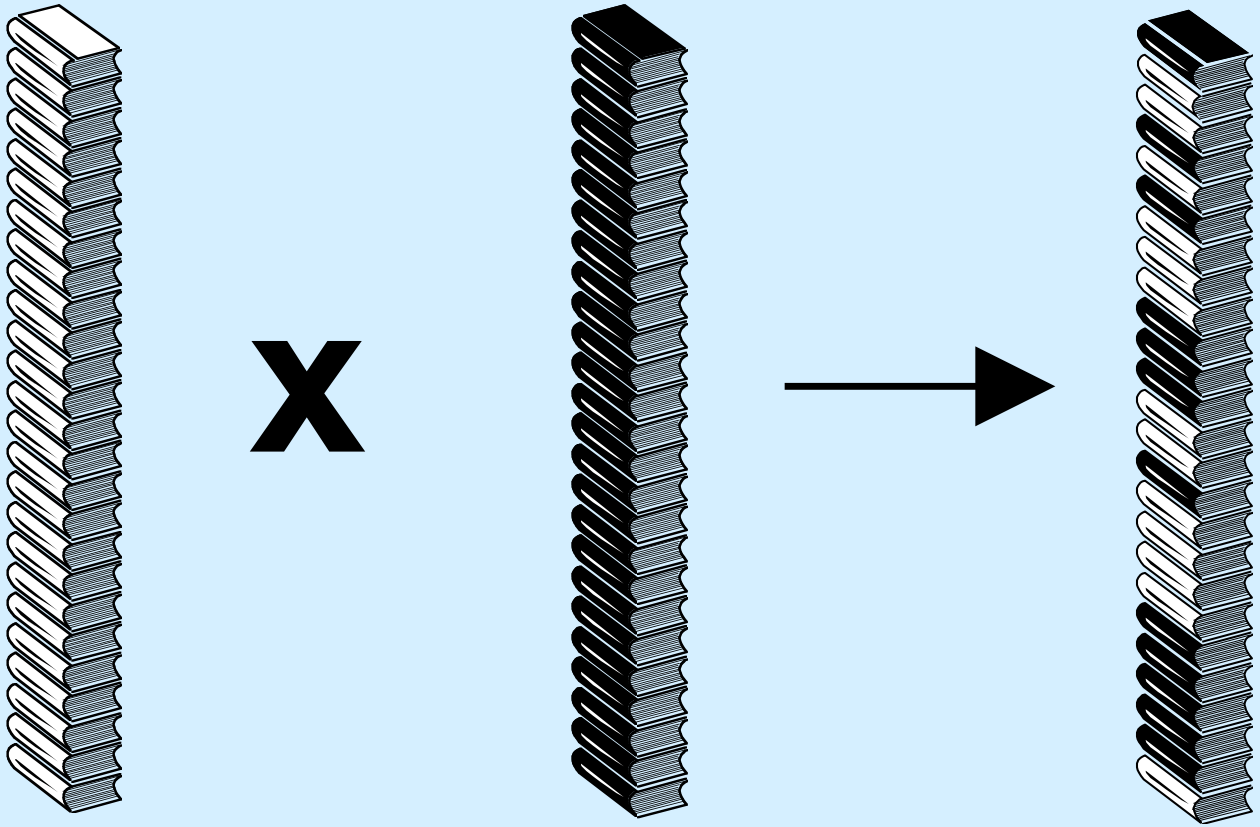


1700 books
1000 pages each



1700 books
(or 1.7 million pages)

Hybridization or cross breeding of wheat



Random retention of information from each parent

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(or 1.7 million pages)

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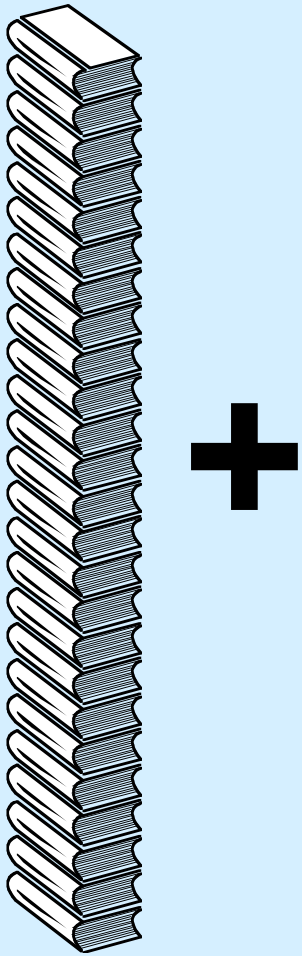
What about new genetic approaches that are being used to create crops?

Genetic Engineering Methods



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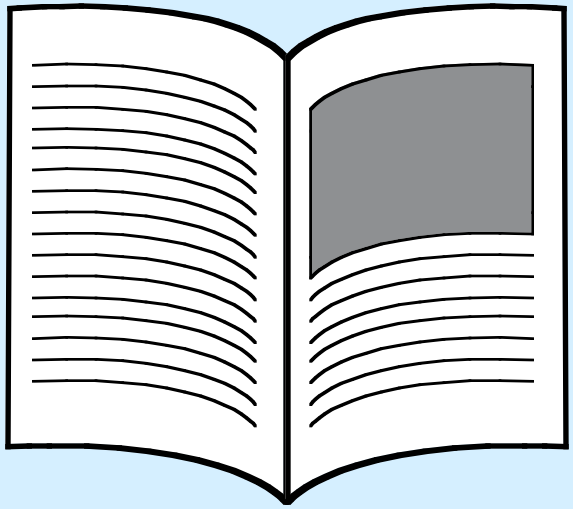
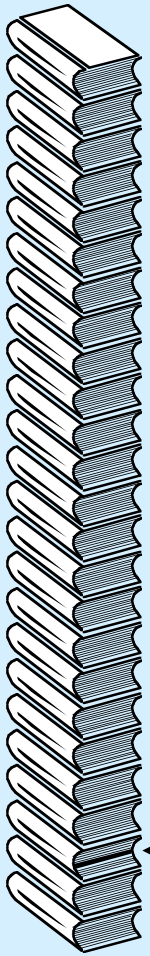


One-half page
equivalent to a gene



Inserts randomly in genome

Inserted gene(s)

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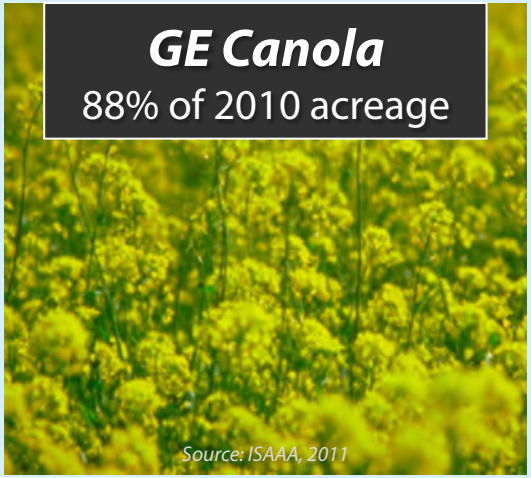
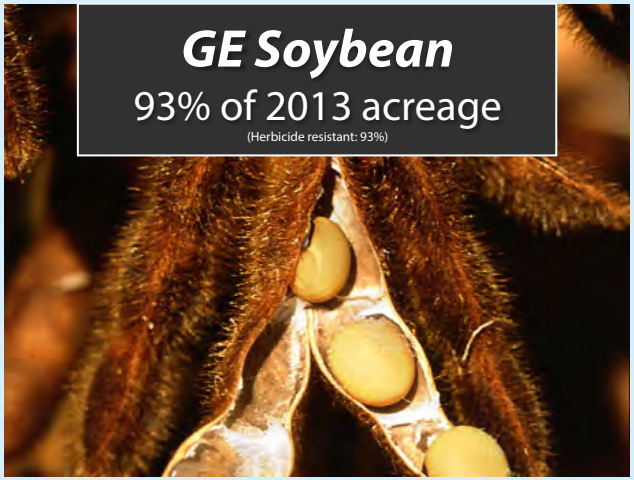
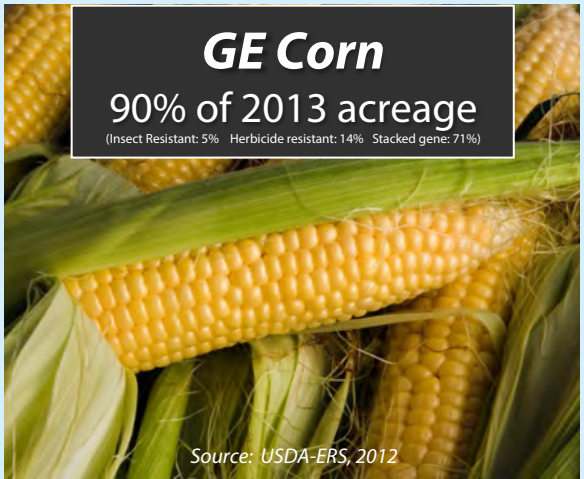
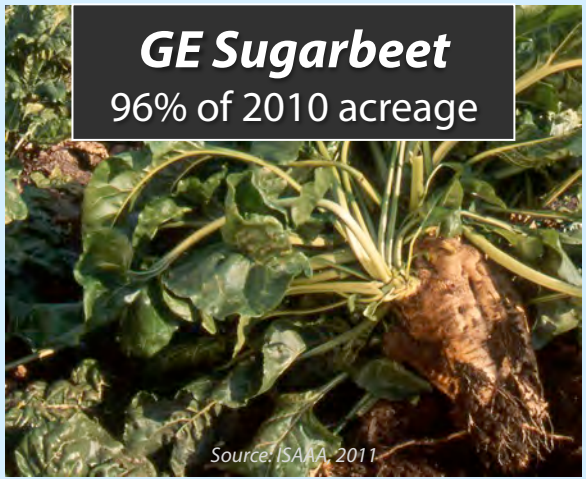
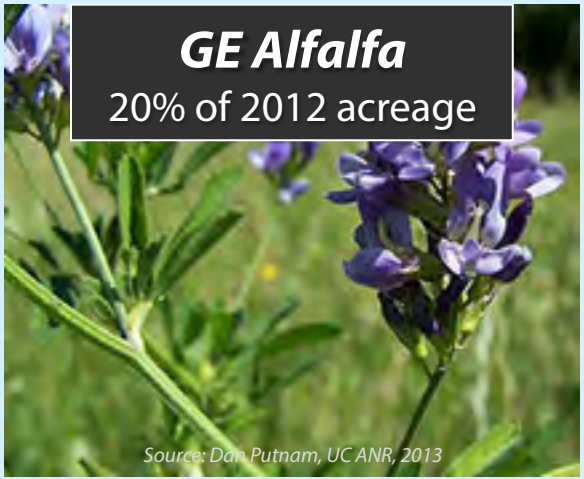
What's in the commercial field in the U.S.?











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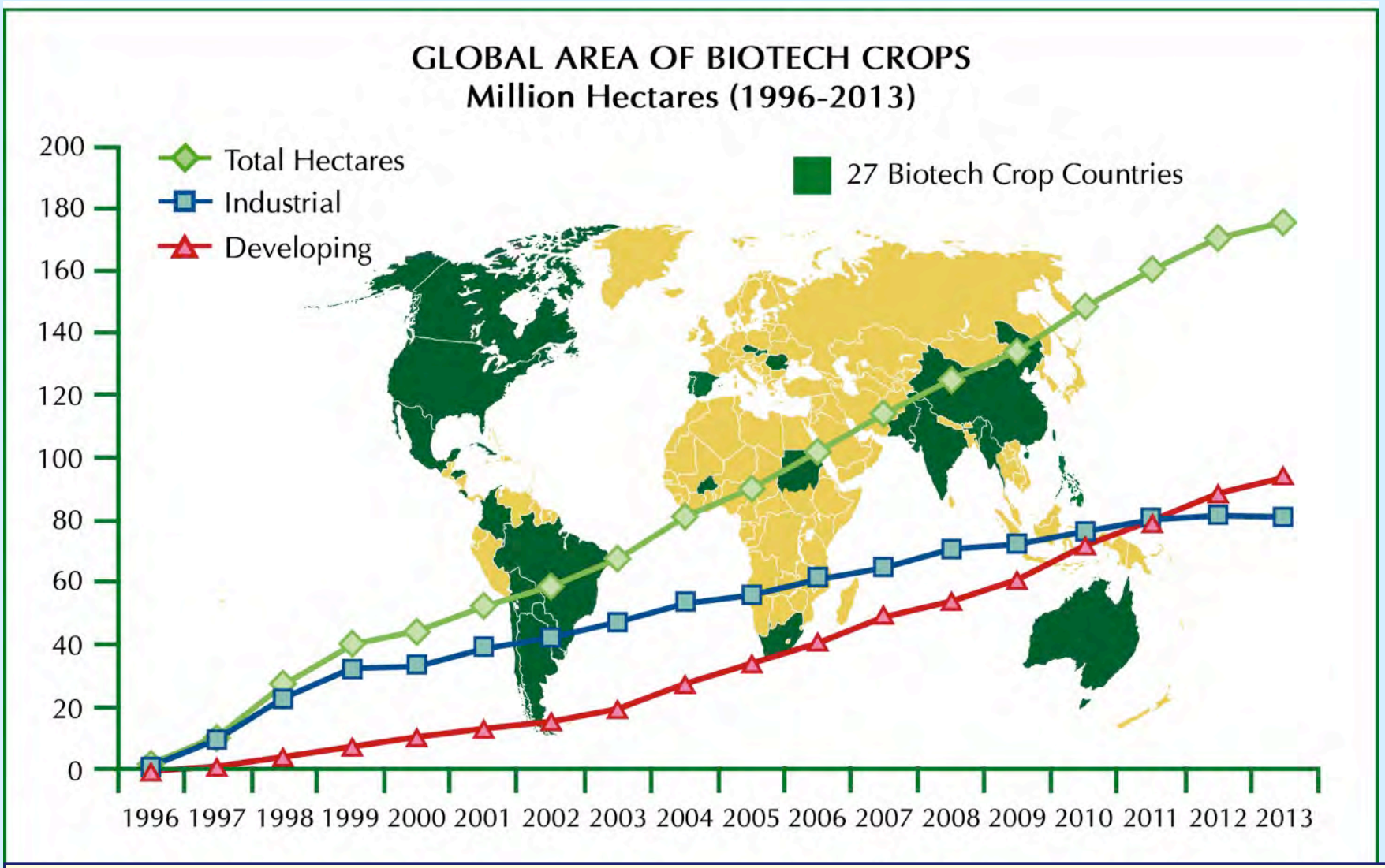
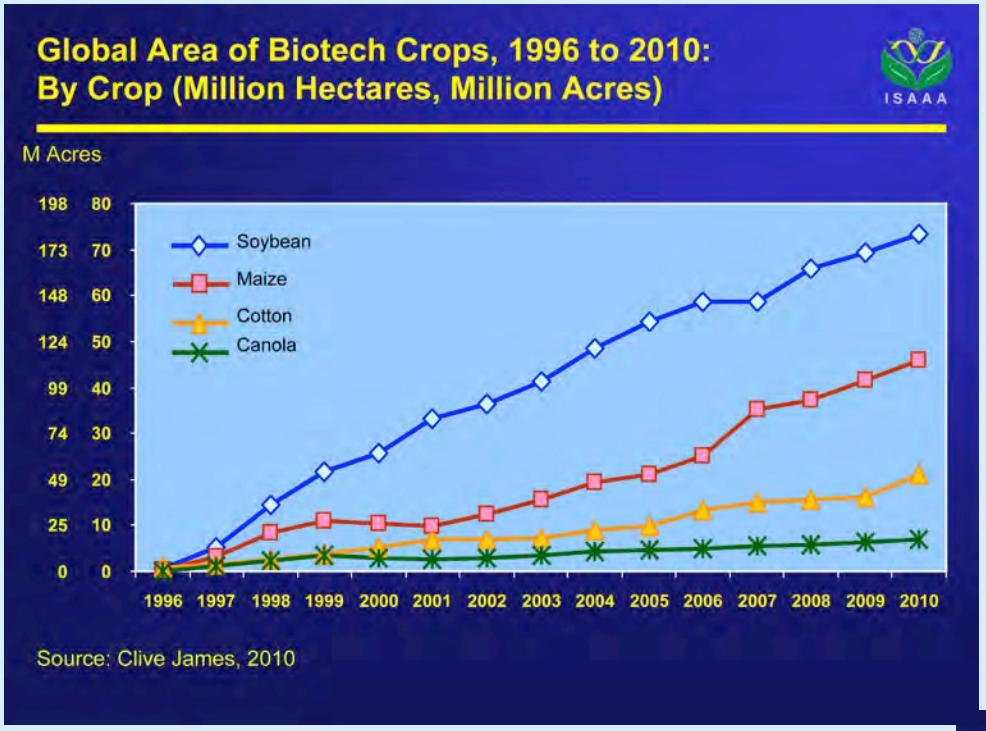
Only a few whole foods on the market are genetically engineered

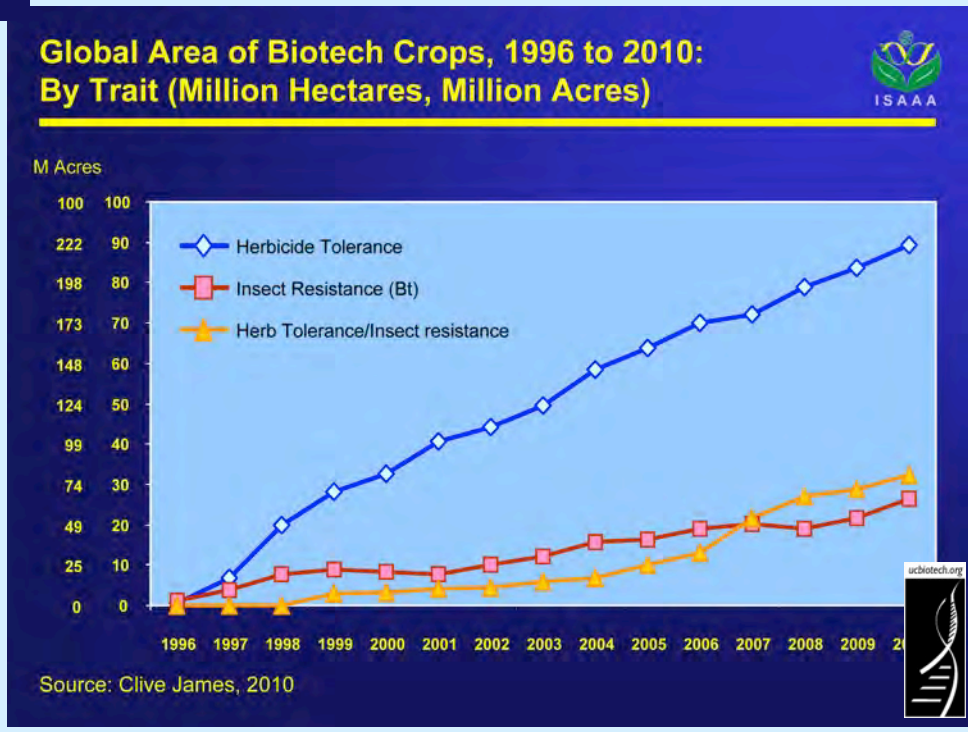
What is the situation with GE crops worldwide?



2013 figures indicate 15.4 million farmers in 27 countries planted 433M acres (>3X size of California) – over 90% were small



But advances for these farmers are only in a few crops – not necessarily those of most value to developing countries and…



…they have a limited number of traits. Does this really serve the needs of developing countries?

More of world's crops are genetically engineered

By Elizabeth Weise, USA TODAY

February 23, 2011

The amount of land devoted to genetically engineered crops grew 10% last year, and 7% in the year before, as

Lemaux says "because of the expenses involved, creating engineered crops for developing countries requires humanitarian contributions by philanthropists like (Bill) Gates and the Rockefeller Foundation, or perhaps by companies who see value in such endeavors."

And, although many academic scientists would like to play a meaningful role, they have limited resources to do so.

SOURCE: "More of world's crops are genetically engineered", USA Today, February 23, 2011.
http://www.usatoday.com/tech/news/biotech/2011-02-22-biotech-crops_N.htm

The situation with agricultural production in less developed countries requires a different perspective. Why?
Let's look at the situation in Africa.

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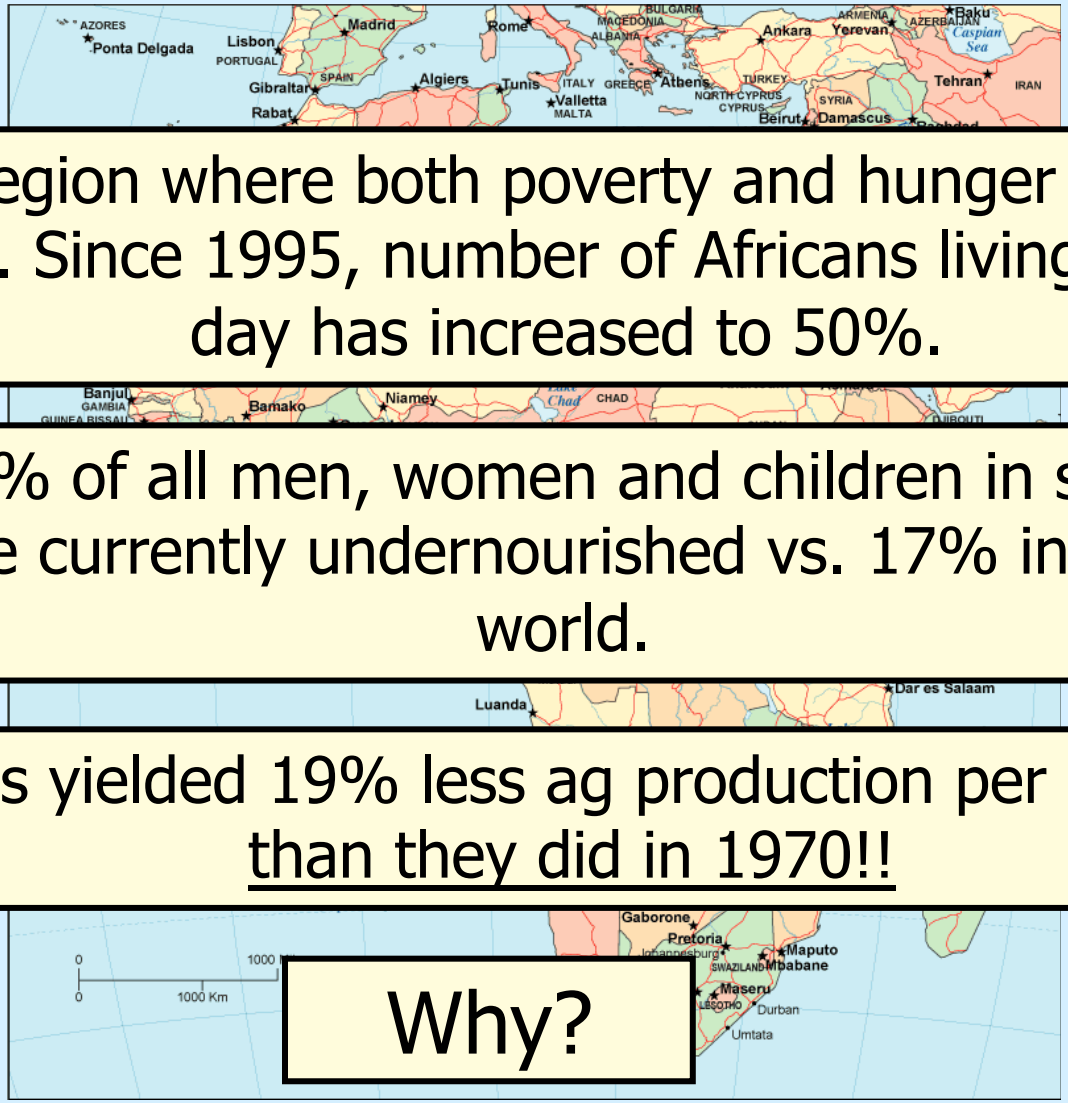

Only region where both poverty and hunger continue increasing. Since 1995, number of Africans living on <$1 per day has increased to 50%.

Nearly 33% of all men, women and children in sub-Saharan Africa are currently undernourished vs. 17% in developed world.

African farms yielded 19% less ag production per person in 2005 <u>than they did in 1970!!</u>

Why?

From "Starved for Science: How Biotechnology Is Being Kept out of Africa" by R. Parlberg 2008

Senegal

United States

Technologies used for agriculture in Africa and other developing countries are different from those in the developed world…

Also crop productivity is lower in Africa and India vs. developed countries because yields are lower.

CROP	YIELD (kilograms per hectare)				
	Kenya	Ethiopia	India	Developed World	
Maize	1,640	2,006	1,907	8,340	5X
Sorghum	1,230	1,455	797	3,910	5X
Rice	3,930	1,872	3,284	6,810	~3X
Wheat	2,310	1,469	2,601	3.110	2X
Chickpea	314	1,026	814	7,980	25X

And most Africans do not have access to the diversity of foods available in the developed world to satisfy their dietary needs.

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This leads to a difficult situation in Africa today?

- One billion of the world's poorest people depend on their own agriculture for food
- 820 million people go to bed hungry each day
- Malnutrition leads to stunted physical and mental development, increased disease susceptibility

Global Development Program, Gates Foundation: http://www.gatesfoundation.org;

Starved for Science. 2008. Robert Parlberg, Harvard University Press.

Can biological improvements in crops help? Focus on a couple of examples

Public sector:
Development of Nutritionally Enhanced Rice and Banana

Public-Private sector:
Development of SuperSorghum

Micronutrient deficiencies

- According to World Health Organization, micronutrient deficiencies are the third most important worldwide public health problem after HIV/AIDS and malaria!
- Deficiencies disproportionately affect people in developing countries.
- Major deficiencies in order of importance: vitamin A, iron, zinc, iodine and folic acid.

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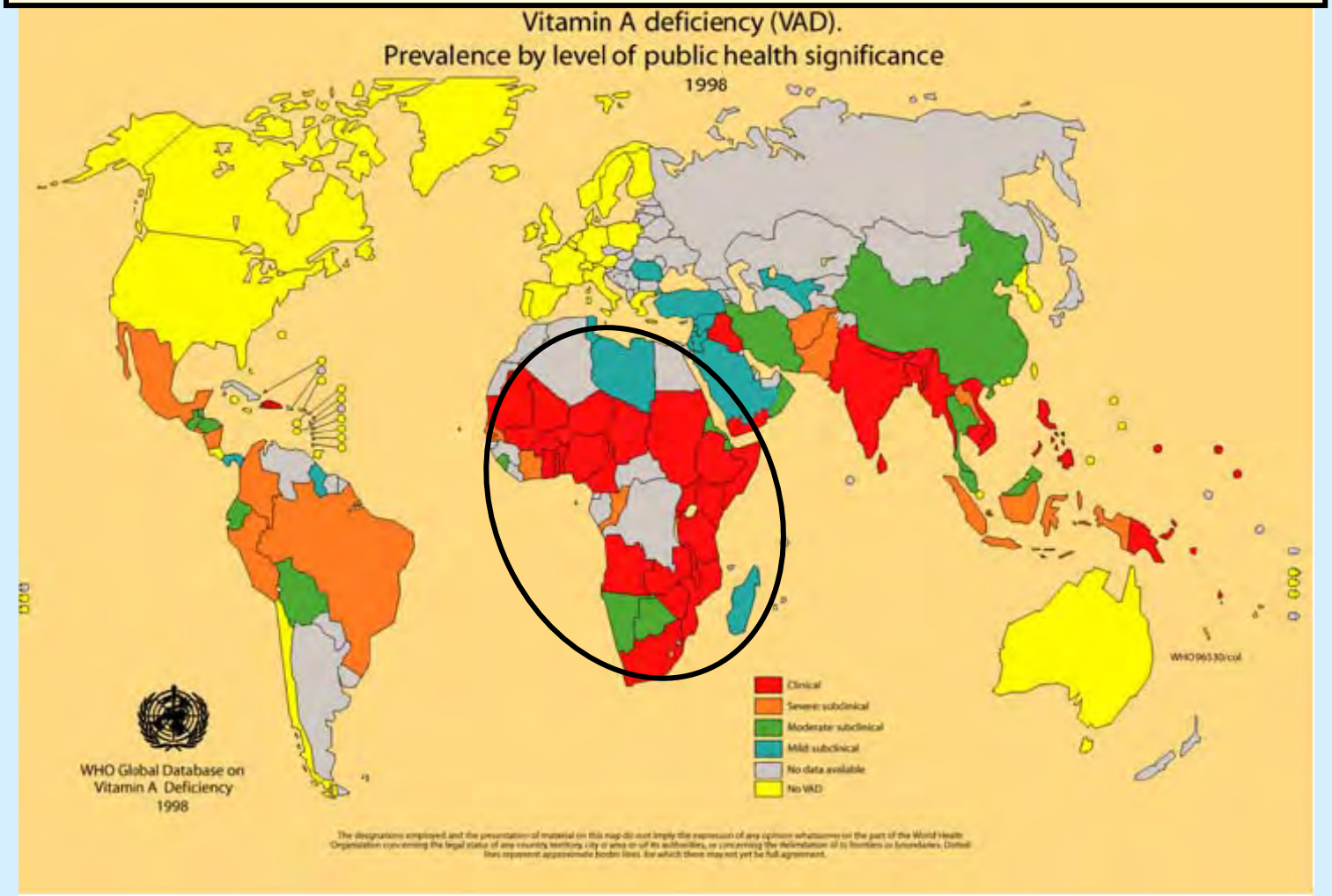
Vitamin A deficiency

Causes severe health problems, vision loss, poor brain development, immune system failure.



Modified from G. Barry, IRRI

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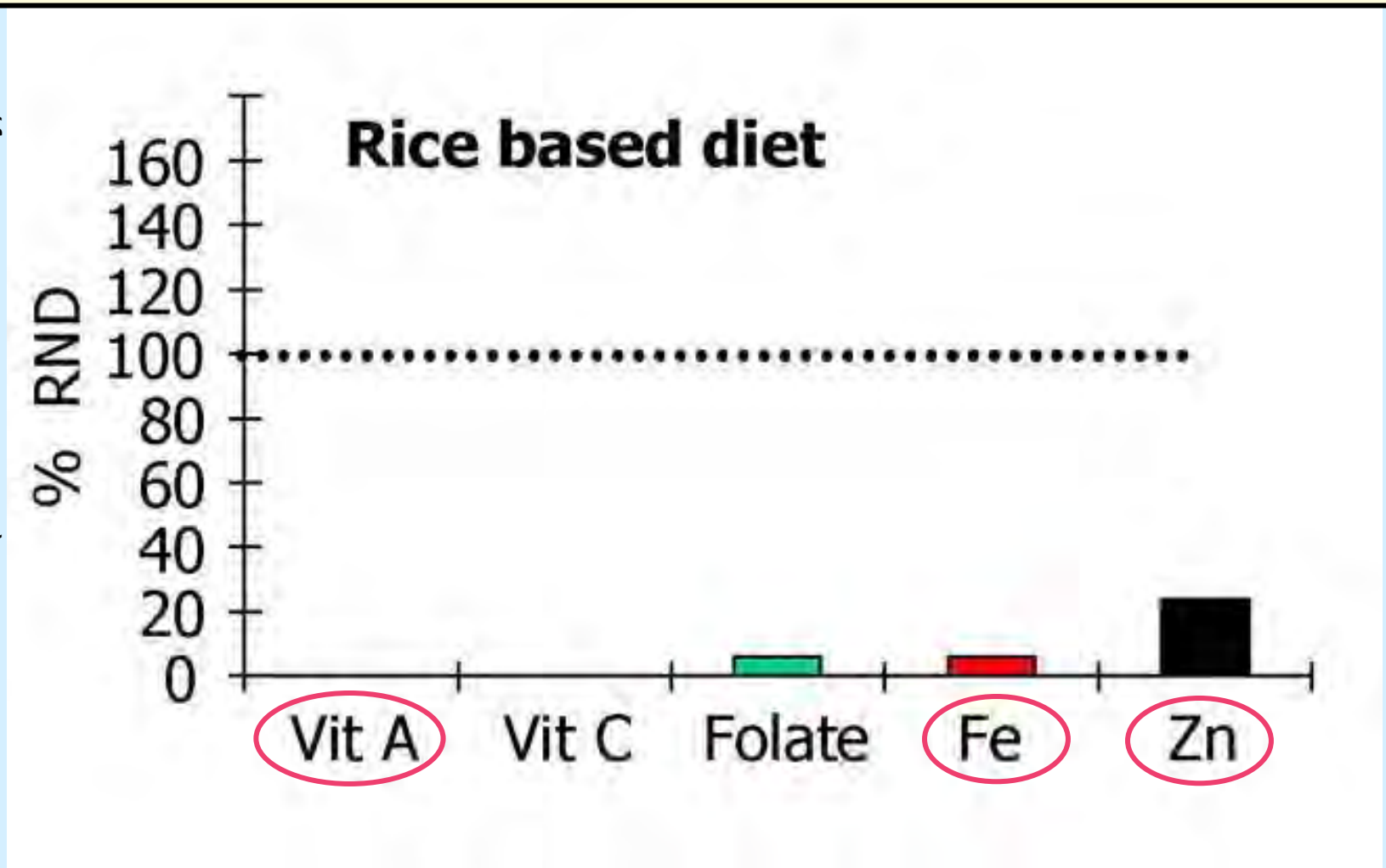
In many less developed countries rice often serves as the main, or only, source of calories. Rice, like most cereal crops, is a poor source of vitamins and minerals



From: "Nutrition: A Cornerstone for Human Health and Productivity", Richard J. Deckelbaum. Seminar, Earth Institute of Columbia University, April 14, 2005

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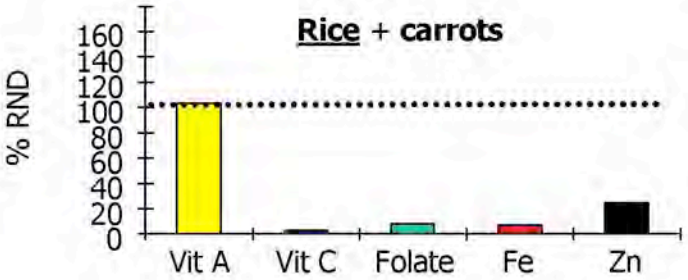
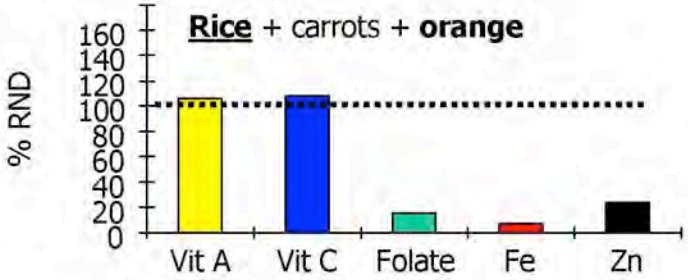
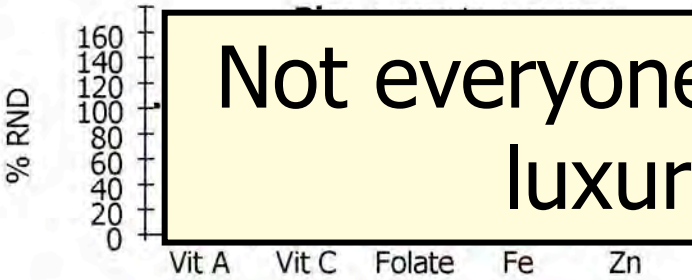
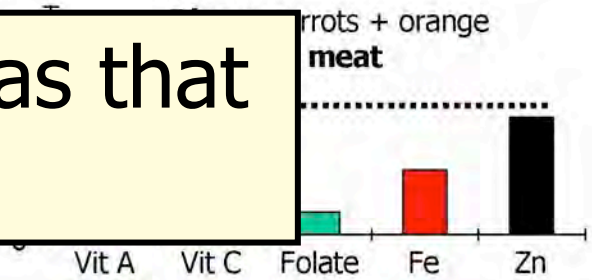
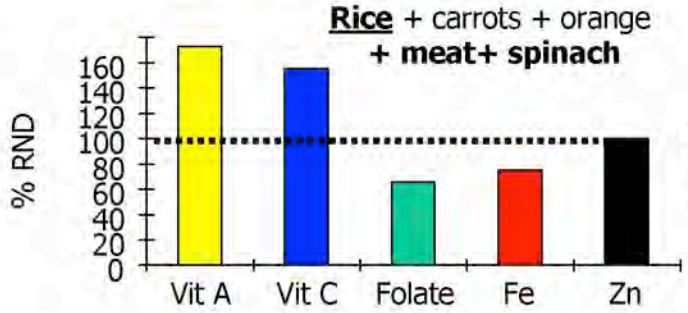


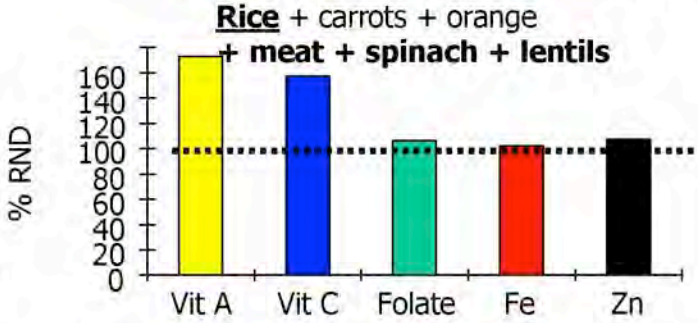






Not everyone has that luxury!





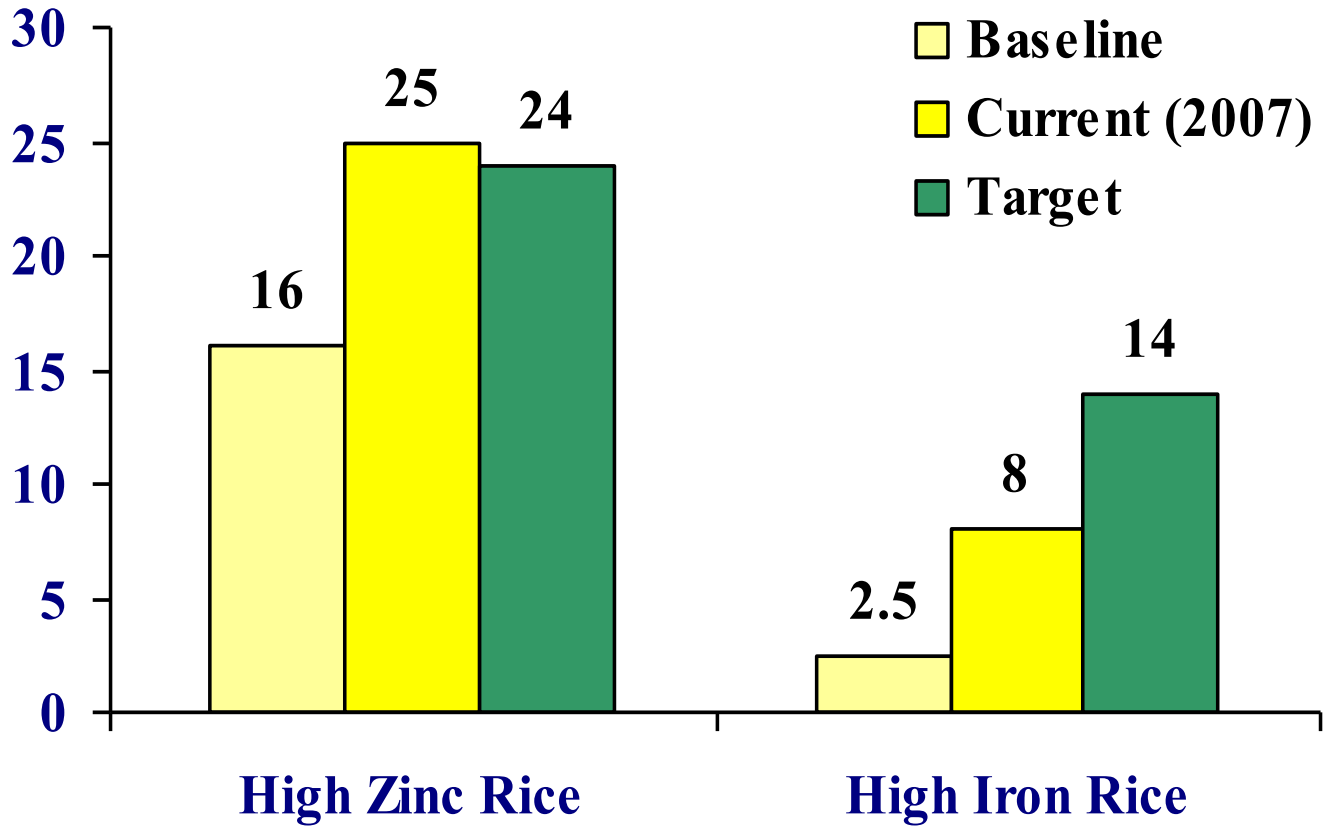
Can’t rice diets just be supplemented with other fruits, vegetables and meat to add these nutrients?

Modified from G. Barry, IRRI

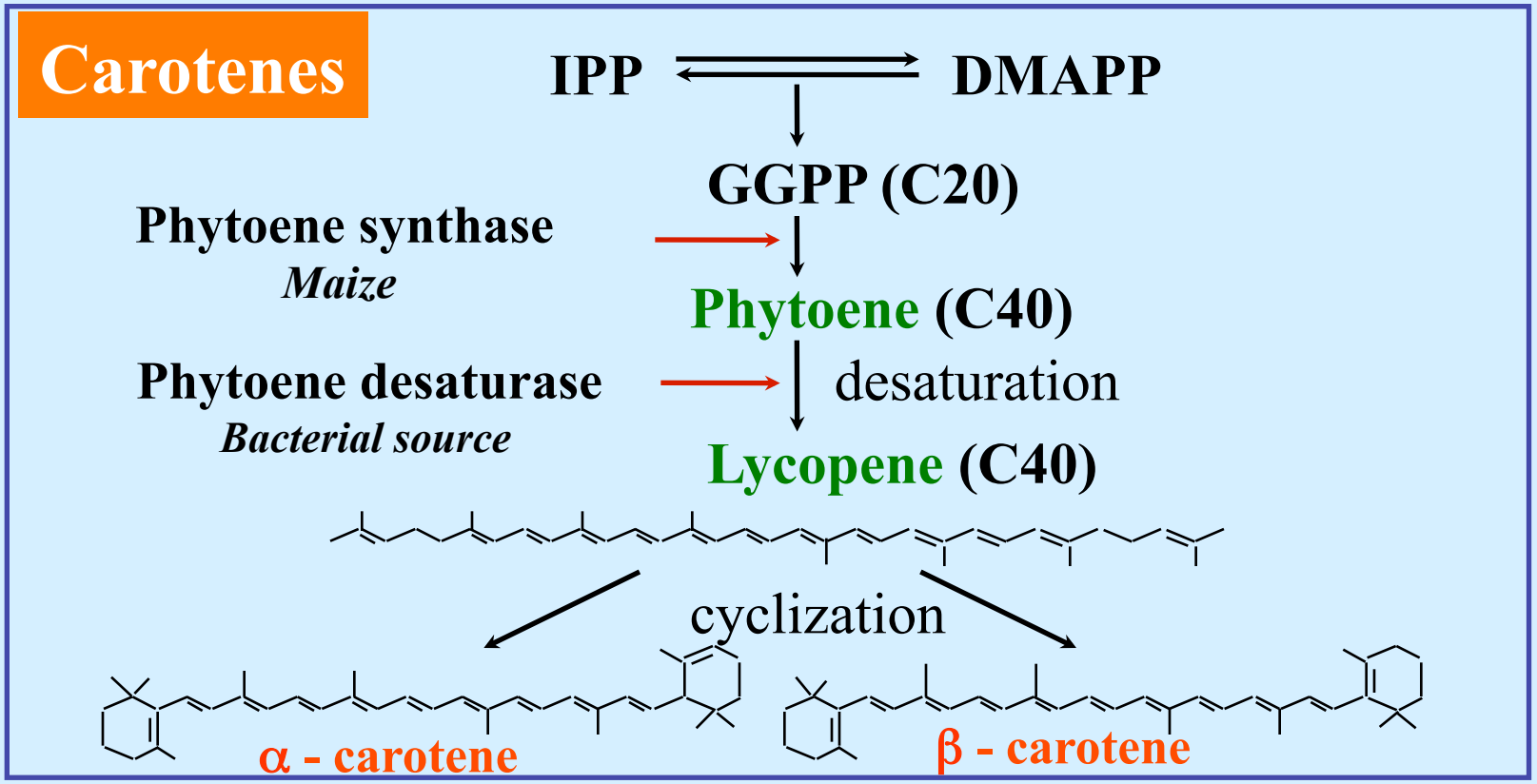
: "Nutrition: A Cornerstone for Human Health and Productivity", Richard J. Deckelbaum. Seminar at The Earth Institute of Columbia University, April 14, 2005

Progress has been made fortifying rice with iron and zinc using classical breeding crosses with other varieties…

But this is not feasible for Vitamin A since there are no compatible varieties with high levels of this vitamin.



Basic Carotenoid Biosynthetic Pathway



Genes from corn and a bacterium were used to engineer rice to make provitamin A, converted to Vitamin A in the body

Golden Rice was created

Normal portion of Golden Rice 2 provides half of a child's Vitamin A needs

NO MAGIC BULLET

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NEW YORK TIMES

SUNDAY, AUBUST 25, 2013

NEWS ANALYSIS

Golden Rice: Lifesaver?

By AMY HARMON

Published: August 24, 2013 408 Comments

STEVE CARELL
TONI COLLETTE

ONE bright morning this month, 400 protesters smashed down the high fences surrounding a field in the Bicol region of the Philippines and uprooted the genetically modified rice plants growing inside.

Enlarge This Image

Joe Aznar for The New York Times

Genetically engineered Golden Rice grown in a facility in Los Baños, Laguna Province, in the Philippines.

Despite potential positive health effects, activists destroyed field trial of engineered Golden Rice in the Philippines in 2013

What leads individuals to destroy field trials of Golden Rice? Listen: GMOs, like Golden Rice, threaten continuation of life on our planet - <u>far worse than nuclear war</u>. GMOs are the new thalidomide!

Public sector: Development of Nutritionally Enhanced Banana

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Worldwide bananas are the world's most important fruit crop

- Staple food crop in parts of Asia and Africa, e.g., Uganda
- Key dietary food in nearly all countries in the wet tropics
- Serious micronutrient deficiencies in these areas
- Banana also source of fibre and shelter
- Major source of income as exports

Enhancing vitamin A in banana using Golden Rice strategy

Control
1.25 ug/g dwt
β-Carotene

Exp1>APsy2a
9.96 ug/g dwt
B-Carotene

Ubi>APsy2a
16.10 ug/g dwt
B-Carotene

Courtesy: J. Dale Queensland Technological University Australia

Almost 13X increase Vit A!

Second cereal that is important in developing countries and also nutritionally deficient in:

Vitamins
Minerals
Amino acids
(like most cereals)

but, uniquely, is also

Poorly Digested

What is this crop?

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University of California, Berkeley joins Africa Biofortified Sorghum (ABS) project

Berkeley, California

University of California, Berkeley Scientists join Africa Biofortified Sorghum Project

The Africa Biofortified Sorghum (ABS) project is funded by a $17.6 million grant from the Grand Challenges in Global Health initiative to Africa Harvest Biotechnology Foundation International, a non-profit organization dedicated to fighting hunger and poverty in Africa.

"Our goal is to develop sorghum that will provide increased calories and needed protein in the diet of African consumers," said Bob B. Buchanan, UC Berkeley professor of plant and microbial biology and one of the lead scientists on the project. "We are extremely happy to offer our expertise and materials for this important project for the public good."

The announcement of UC Berkeley's participation was made from Nairobi, Kenya, today (Monday, April 10) by project leader Florence Wambugu. "All the project consortium members are delighted that researchers from UC Berkeley will be joining the team," said Wambugu, who is a plant pathologist and CEO of Africa Harvest. "Their contribution will provide a second avenue to ensure success in achieving the important goal of increasing digestibility of sorghum."

Peggy G. Lemaux, UC Berkeley Cooperative Extension specialist in plant and microbial biology, and Bob Buchanan, professor of plant and microbial biology, inspect sorghum plants in a controlled temperature growth room. (Rosemary Alonso photo)

The Grand Challenges in Global Health initiative is supporting nutritional improvement of four staple crops - sorghum, cassava, bananas and rice - as one of its 14 "grand challenges" projects that focus on using science and technology to dramatically improve health in the world's poorest countries. The initiative is funded by the Bill & Melinda Gates Foundation, the Wellcome Trust, and the Canadian Institutes of Health Research.

In June 2005, the initiative awarded $16.94 million to Africa Harvest to head a consortium of public and private research institutes for the ABS project. The Gates Foundation has just supplemented this amount with $627,932

Sorghum was one target for nutritional improvement for Bill and Melinda Gates Foundation Grand Challenges for Global Health – a project in which my lab and Bob Buchanan's participated.

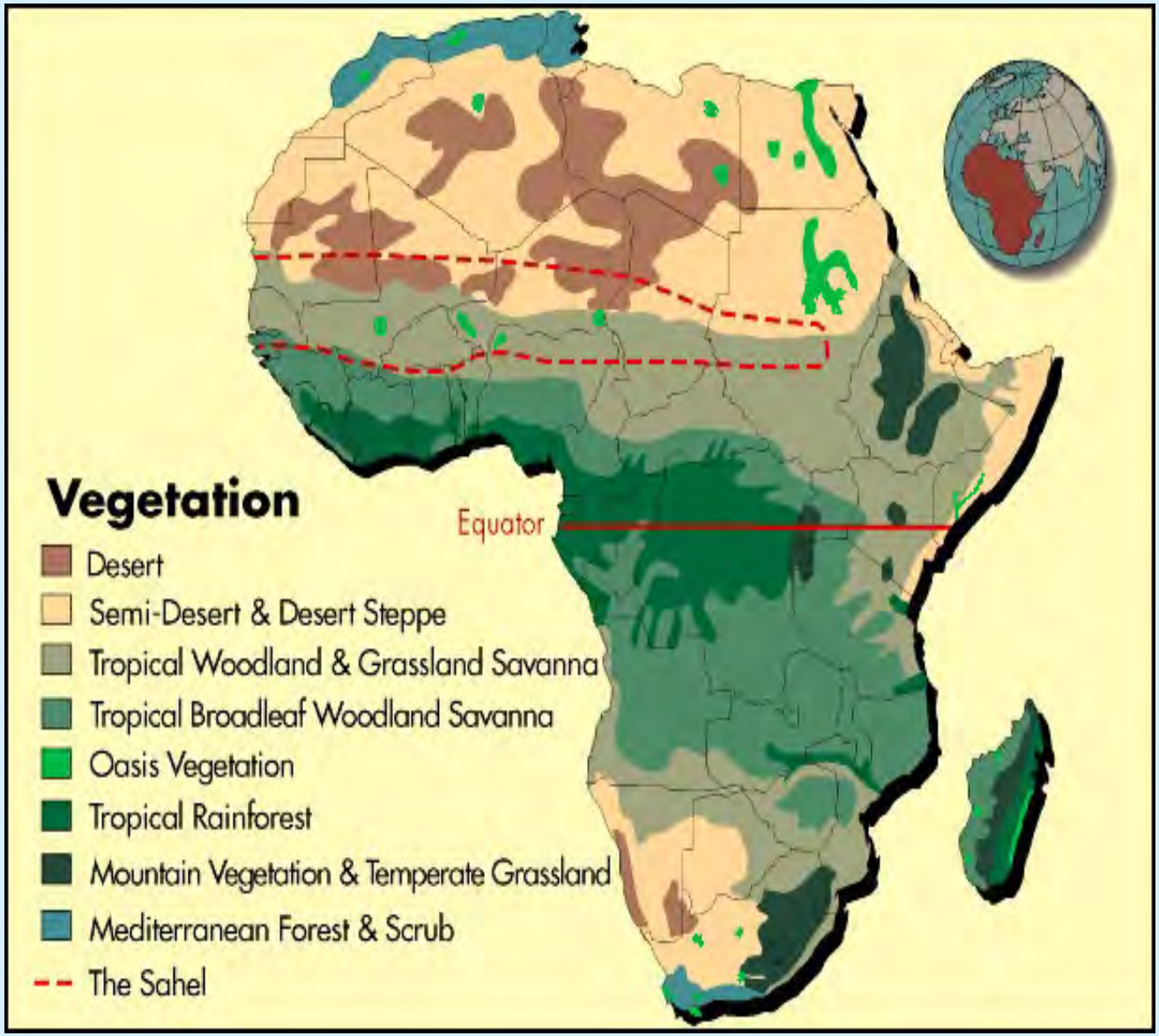
Why Sorghum?

- Fifth most important food grain worldwide
- 90% grown in Africa and Asia in arid and semi-arid regions
- Staple food for 300 million in Africa and, like rice, is nutritionally deficient

Cultivated sorghum

Wild outcrossing species

Sorghum uniquely adapted to Sub-Saharan Africa's climate – withstands both too much and too little water



First successful nutritional improvement in sorghum was engineering it to make provitamin A, converted to vitamin A in the body.

My lab continues to work on increasing iron and zinc levels in sorghum grain.

The ABS Project has produced the world's first golden sorghum enabling pro-vitamin A to be used as the visible marker for final ABS product

ABS Project Produces

World's First Golden Sorghum

Africa Harvest CEO and Coordinator of the Africa Biofortified Sorghum (ABS) Project, Dr. Florence Wambugu, told a recent Bio2Biz SA Forum in South African that the Project had produced the world's first golden sorghum "enabling pro-vitamin A to be used as the visible marker for final ABS product".

Making her presentation "ABS Project: Networking African & International Biotech Capacities to Deliver a Nutrient Rich Product to the Needy", Dr. Wambugu said the new development was made by Pioneer scientists. She said the project has been able to significantly increase transformation efficiency, paving the way for it to transit into the Product Development & Deployment phase.

Dr. Wambugu told scientists drawn from South African research institutions and the private sector that the ABS Project had trained 11 African scientists and breeders in a short period of less than five years. She said the project had conducted six field trials in four years and contained greenhouse work was continuing in Kenya and South Africa.

Bio2Biz SA is hosted by South Africa's Biotechnology Innovation Centres (BICs) comprising of BioPAD, Cape Biotech, LIFElab and PlantBio, together with the Innovation Fund and eGoli Bio. It brings together biotechnology researchers and industry to create mutually beneficial relationships. This year, the meeting was held at the Durban International Conference Centre (ICC) from September 20th to 23rd.

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Digestibility also remains a problem

In Africa, 74% of sorghum is consumed by people at home as cooked porridge

Elderly woman making cooked sorghum porridge

Of major cereals, sorghum is the least digestible, especially following cooking

Cereal	% Digestibility Uncooked	Cooked	Decrease	
Sorghum	80.8	56.3	24.5	←
Maize	83.4	79.3	4.1	←
Barley	93.2	80.2	13.0	
Rice	91.1	82.1	9.1	
Wheat	91.3	85.9	5.4	

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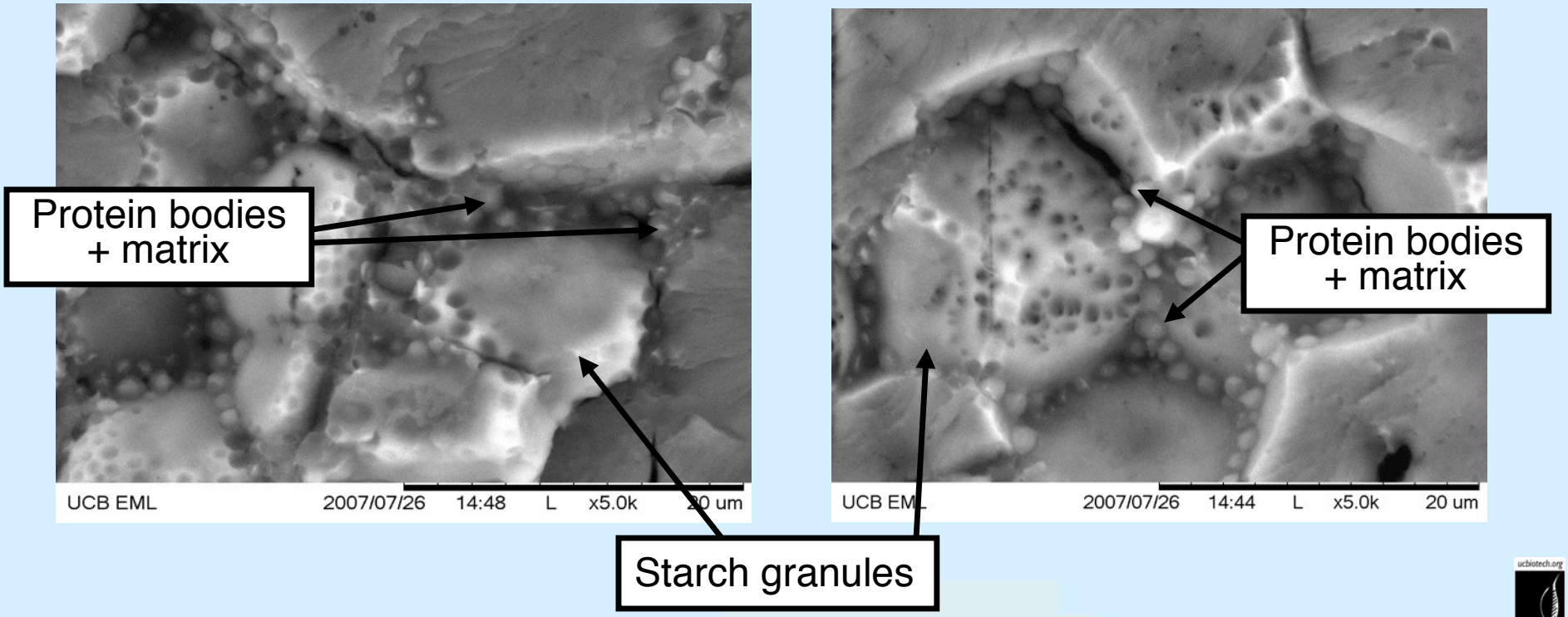
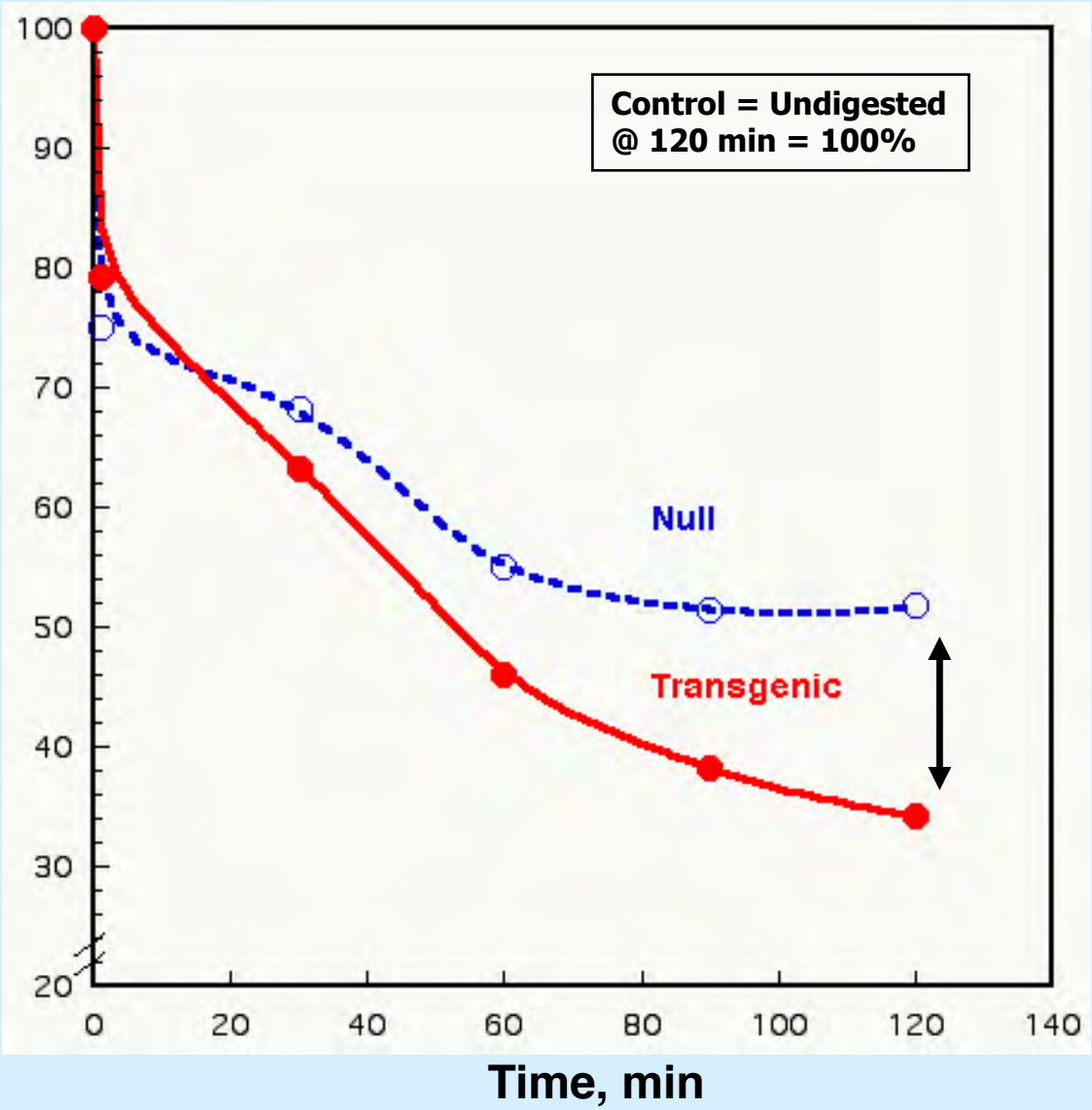
Our efforts continue to improve digestibility by interfering with the chemical linkages between proteins that interfere with starch and protein digestibility.



In vitro Digestion of Seed Storage Proteins in Sorghum Engineered with Innate Redox Protein, Thioredoxin



25% increase in digestibility in engineered line

Are Genetically Engineered Crops a Magic Bullet?

Is Farming Using Organic Practices a Magic Bullet?

Is Farming Conventionally a Magic Bullet?

No. Future farming will be complex, requiring all skills and technologies available. Wise use of the best of each approach offers the best way of achieving sustainable food production to feed future populations.

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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.

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HELPFUL SITES

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

Animal Genomics & Biotechnology

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

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