Genetic Improvements in Agriculture

From Hunter Gatherer to Green Revolution and Beyond

www.plantcell.org/cgi/doi/10.1105/tpc.111.tt0511

Cro magnon skull
Homo sapiens
~ 30,000 years old

- **Life on earth is about four billion years old**
- ***Homo sapiens* emerged as a species about 300,000 years ago**

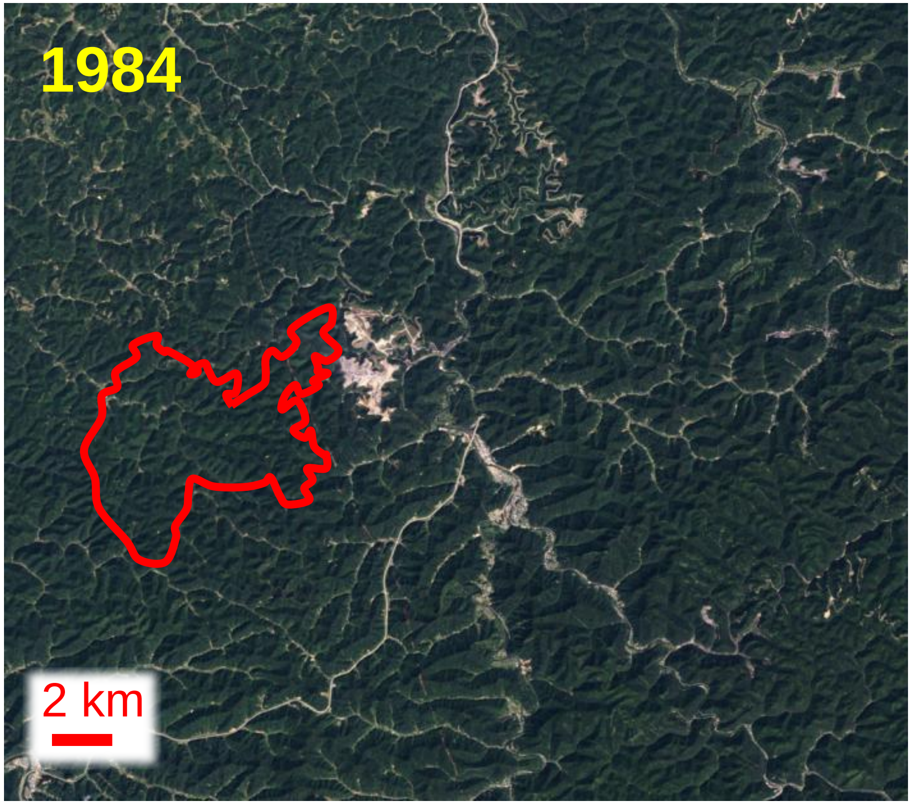
Image credit: Smithsonian Institution Human Origins Program

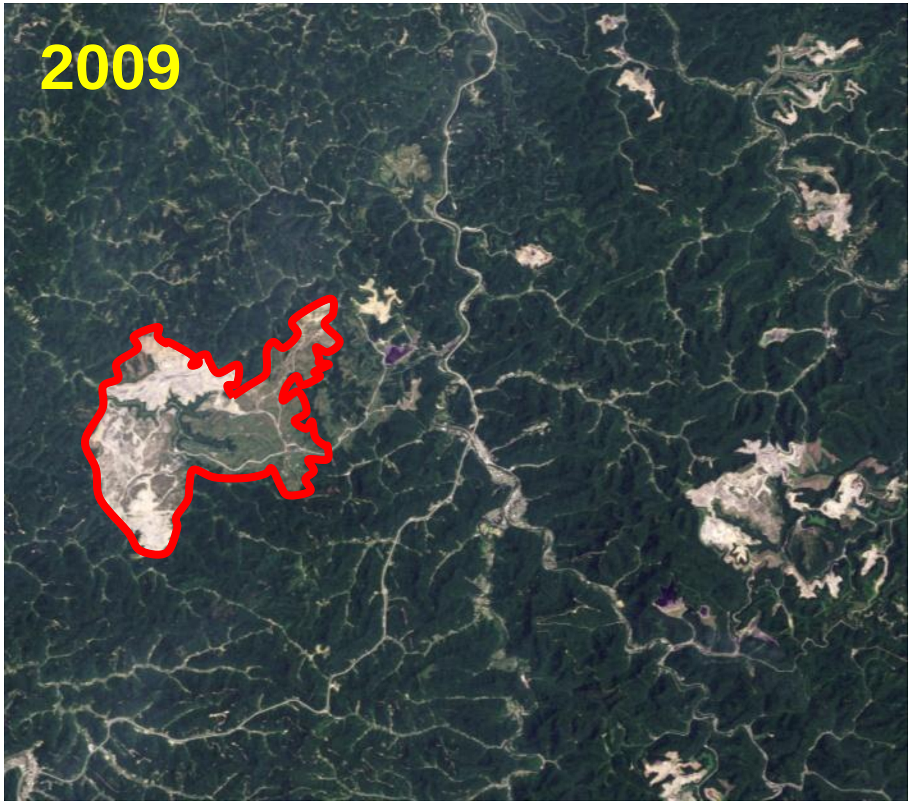
Cro magnon skull
Homo sapiens
~ 30,000 years old

- Human activities have caused vast changes in the physical, chemical, geological, atmospheric and biological realm of our planet

Image credit: Smithsonian Institution Human Origins Program

We’ve removed mountains



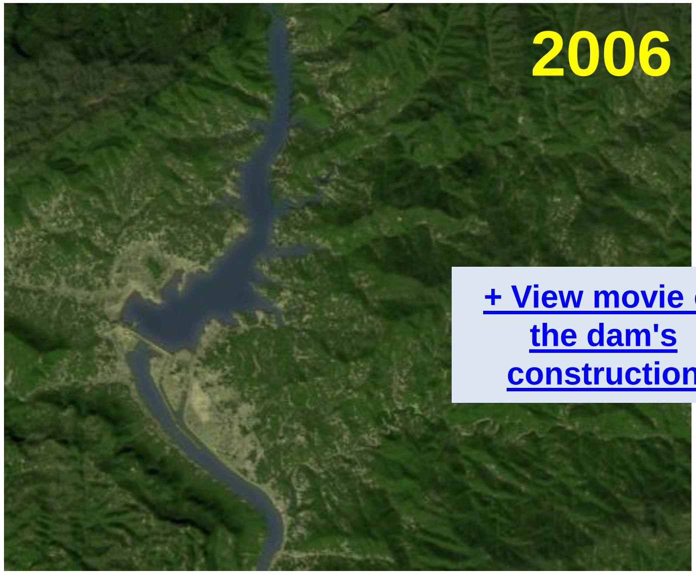


The Hobet coal mine in Boone County, West Virginia spreads over 10,000 acres (15.6 square miles)

NASA images by Robert Simmon, based on Landsat 5 data from the USGS Global Visualization Viewer.

...dammed rivers...

Three Gorges Dam, the world's largest hydroelectric power generator. The reservoir just upstream of the dam is more than 2 miles (3 km) across



[+ View movie of the dam's construction]

Photo credit: NASA/Goddard Space Flight Center Scientific Visualization Studio United States Geological Survey and Le Grand Portage

....caused extinctions.....

The dodo (*Raphus cucullatus*) was a large flightless bird indigenous to Mauritius. The arrival of humans led to the dodo's extinction by the end of the 17th century.

Dodo by Edouard Poppig, 1841

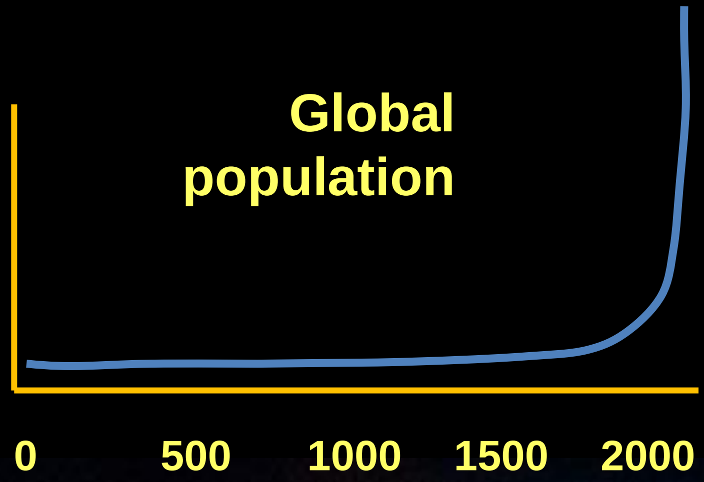
...modified other species in extraordinary ways

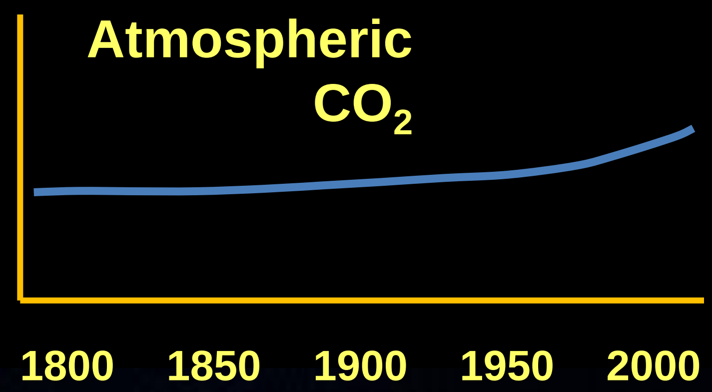
... and modified plant genomes for thousands of years......



Image credits: P. Cos, Cacaphony, USDA, CIMMYT

Now we face our biggest challenges





How do we feed more people without further damaging our planet?

Photo courtesy Earth Observatory NASA

What is the role of plant breeding in addressing global challenges?

Photo credits: Xochiquetzal Fonseca/[CIMMYT]() and [IRRI]()

GENETIC IMPROVEMENTS IN AGRICULTURE

The Distant Past

Crop plant domestication and beyond

The Recent Past

Hybrid seed

The (First) Green Revolution

Advances in breeding technologies

Now and Into The Future

Breeding for improved human health

Breeding for drought tolerance

Agricultural innovation in Africa

The Second Green Revolution

The Distant Past (>10,000 years ago to 1900)

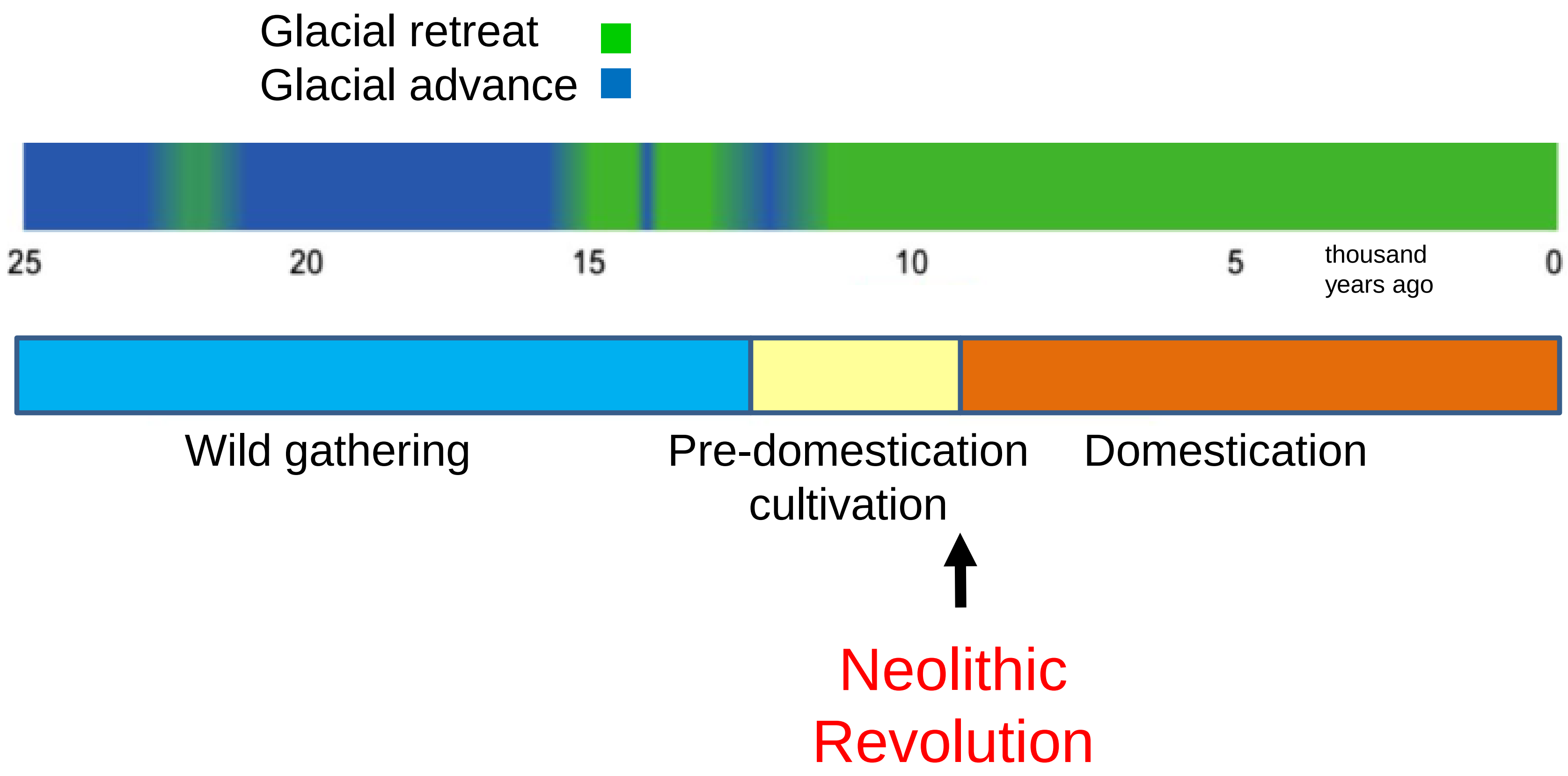
Homo sapiens originated 400,000 – 250,000 years ago

Major crops were domesticated ~ 10,000 – 5000 years ago

The development of human civilizations is correlated with the development of agriculture

Karol Schauer

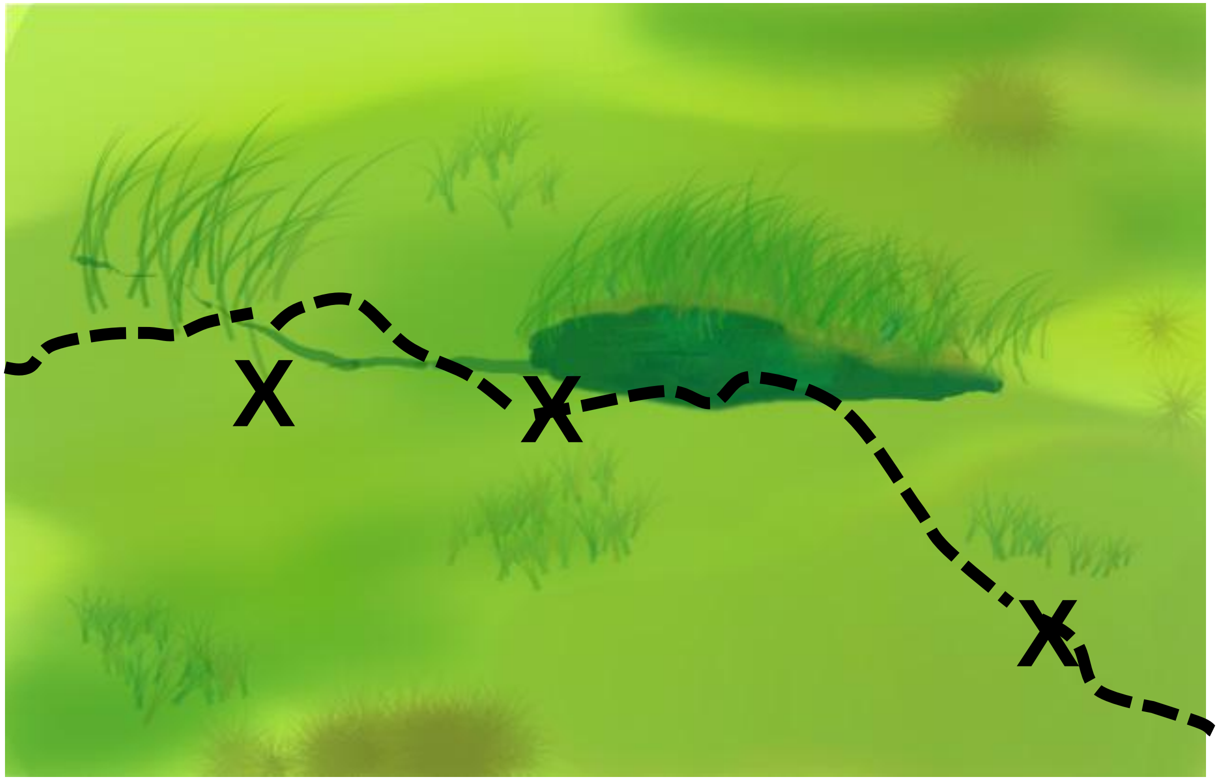
Plant domestication followed the end of the most recent glacial period



Allaby, R.G., Fuller, D.Q., and Brown, T.A. (2008) The genetic expectations of a protracted model for the origins of domesticated crops. Proc. Natl. Acad. Sci. USA 105: 13982-13986, copyright National Academy of Sciences USA

How did people begin to cultivate plants?

It is thought to have been a gradual change from seeking and following food sources



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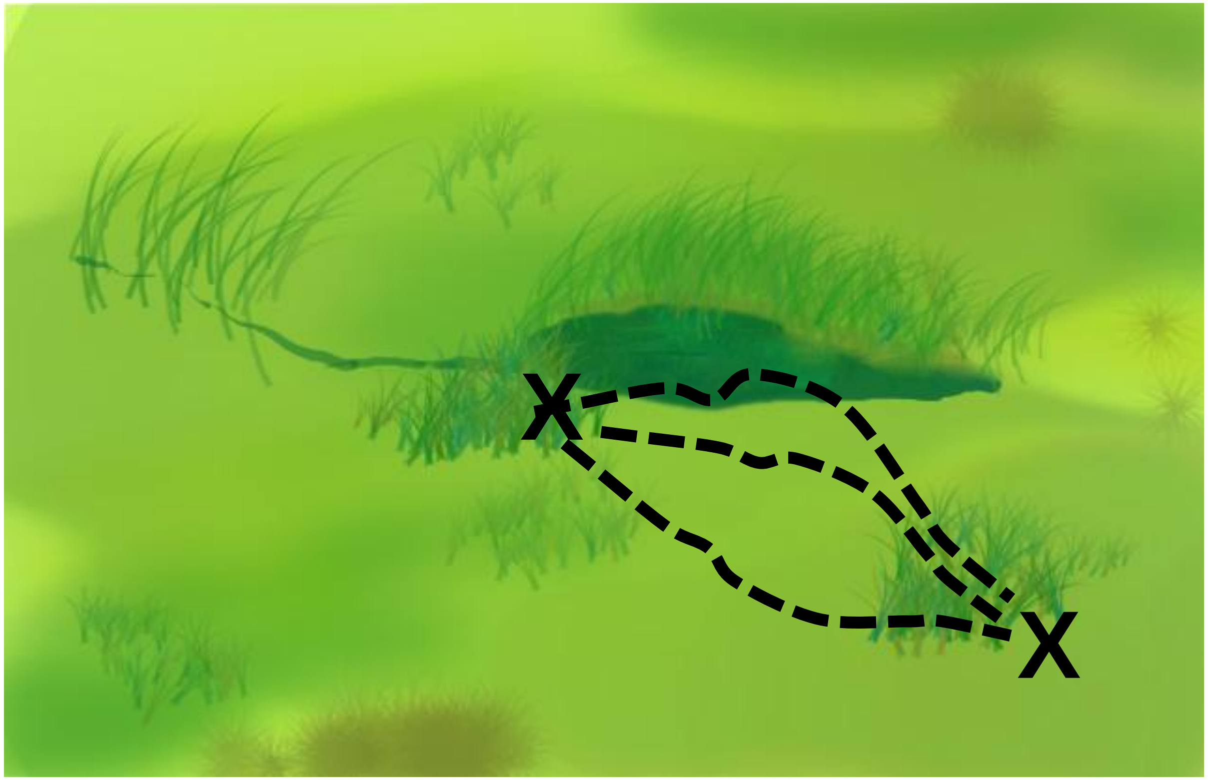
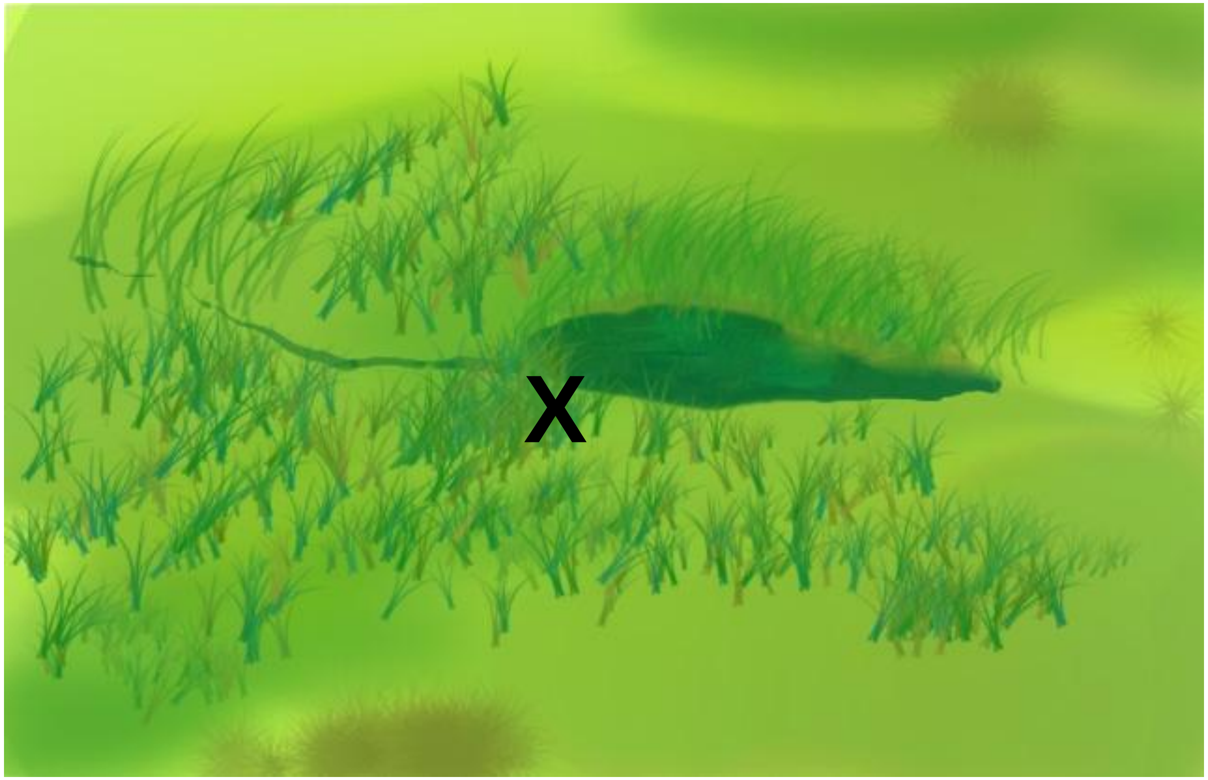


How did people begin to cultivate plants?

It is thought to have been a gradual change from seeking and following food sources to semi settled migration and finally permanent settlements.



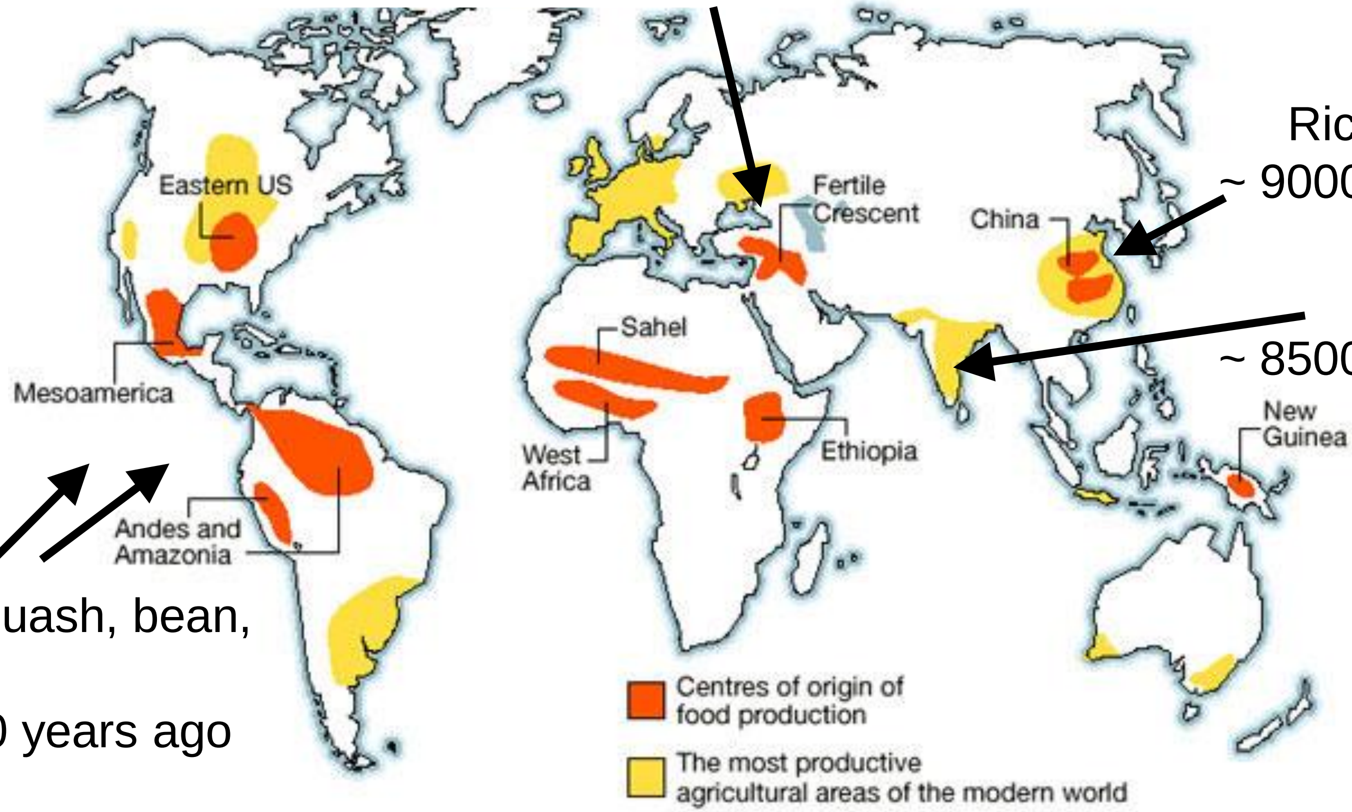
Plants were domesticated in parallel in several regions

Wheat, barley, pea, lentil
~ 13,000 years ago

Rice, soybean
~ 9000 years ago

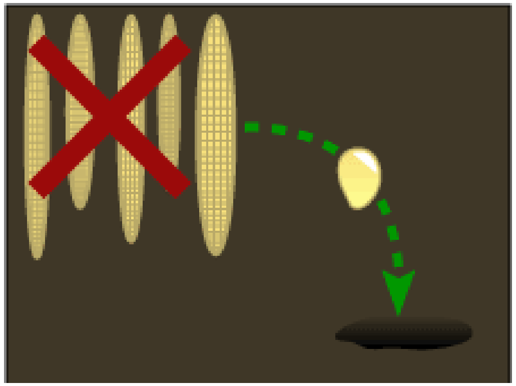
Rice, bean
~ 8500 years ago

Corn, squash, bean, potato
~ 10,000 years ago



Genetic modification arose as a consequence of cultivation

Natural variation within population



Planting seeds from "good" plants increased their representation in subsequent generations

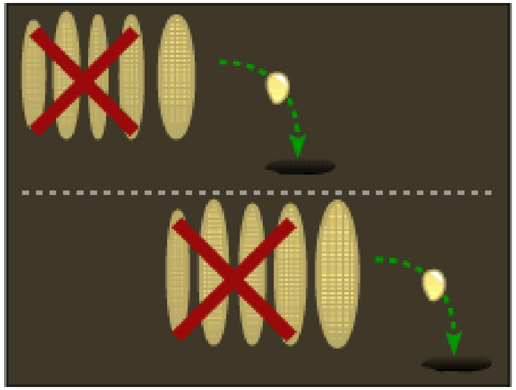
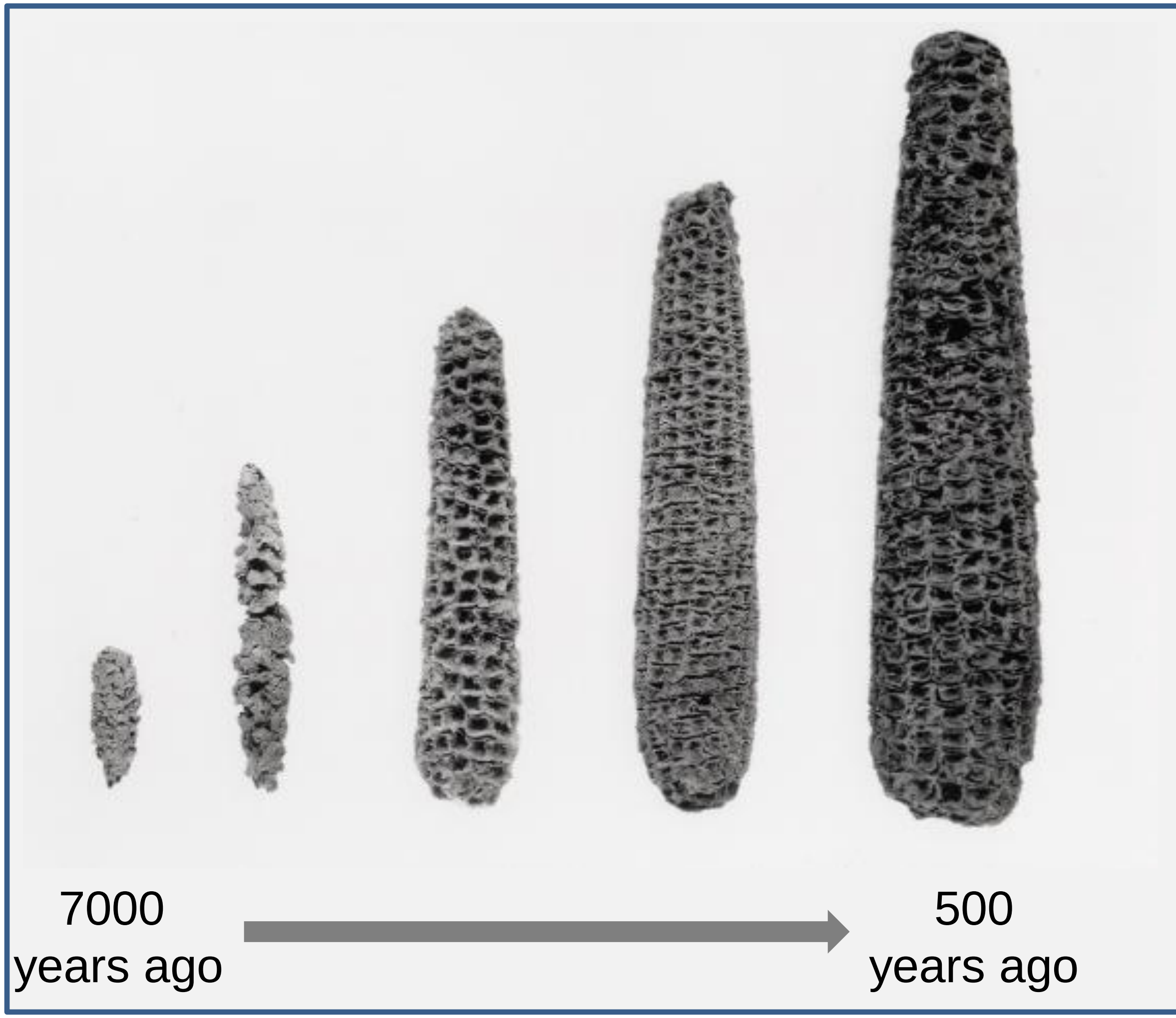


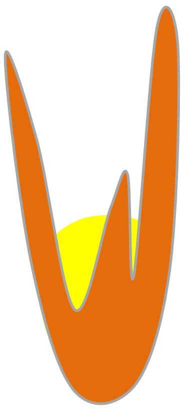
Image courtesy of University of California Museum of Paleontology, Understanding Evolution - www.evolution.berkeley.edu

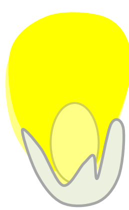
During maize domestication cob size increased

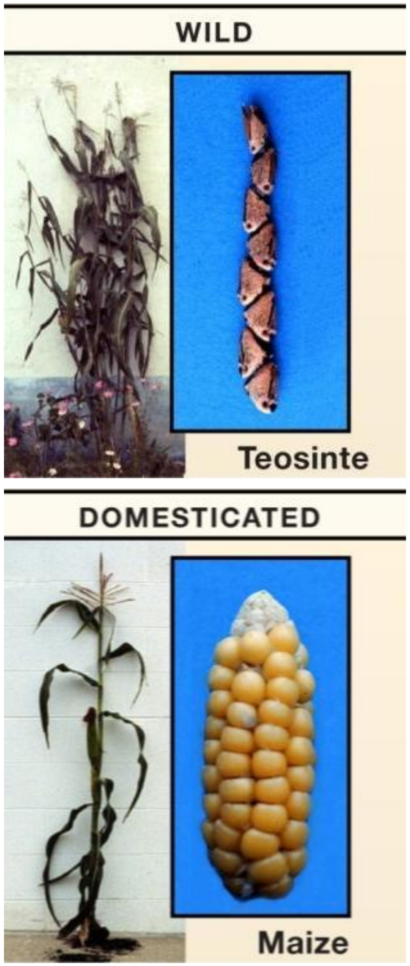
Cobs from archeological sites in the Valley of Tehuacan, Mexico



The hard casings around many grains were eliminated







Teosinte, the wild relative of maize, has hard coverings over each grain. Humans selected against these during maize domestication.

Photo by Hugh Iltis; Reprinted from Doebley, J.F., Gaut, B.S., and Smith, B.D. (2006). The Molecular Genetics of Crop Domestication. Cell 127: 1309-1321, with permission from Elsevier.

Decrease in branching and increase in seed size were also selected for

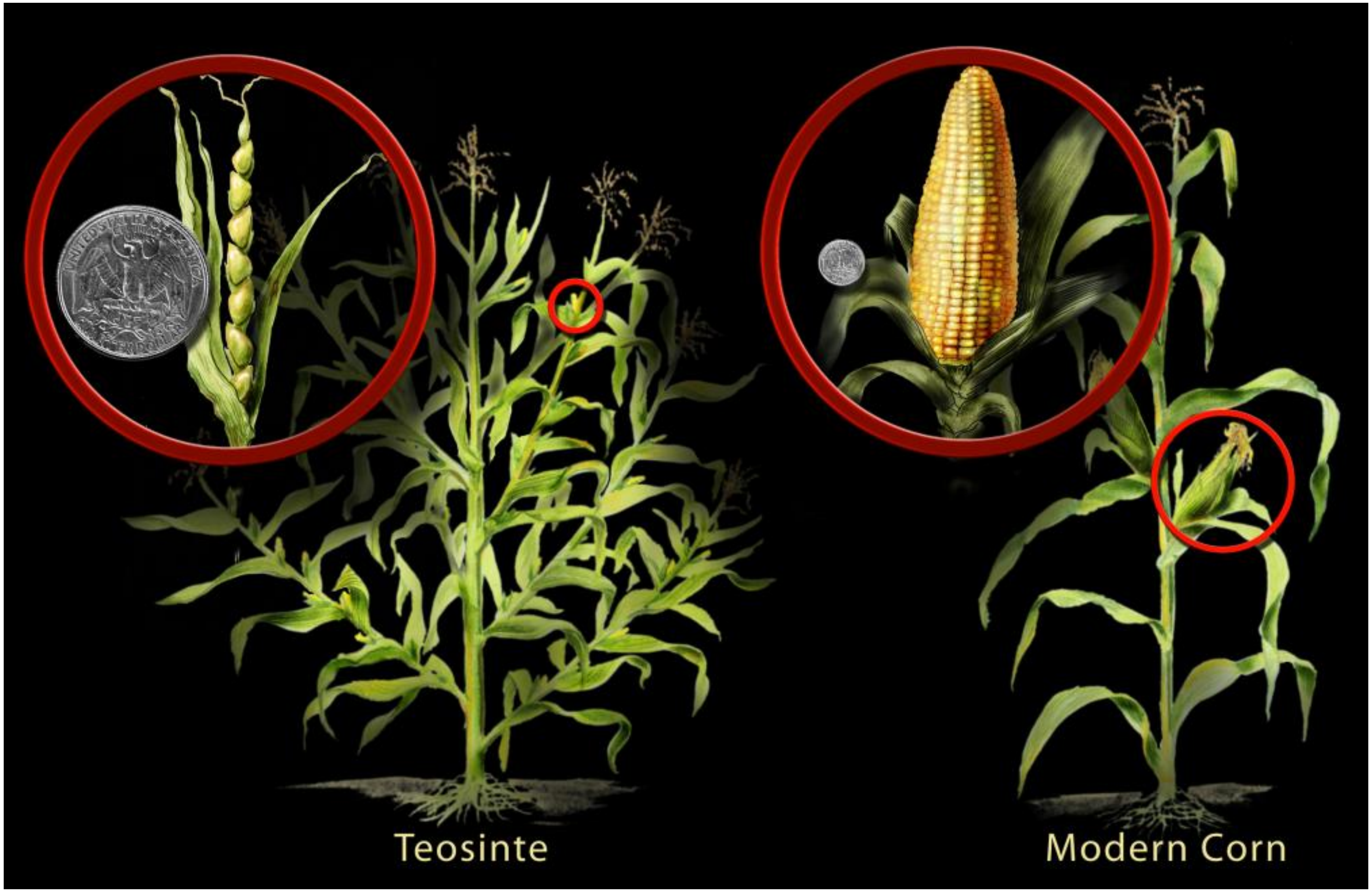


Image credit Nicolle Rager Fuller, National Science Foundation

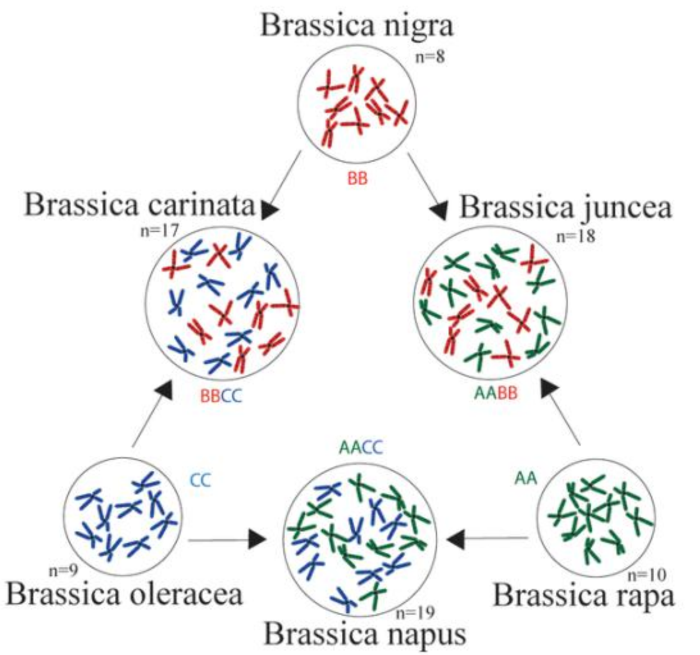
Seeds that don't break off were selected

Wild
Shattering grain
"Brittle rachis"
Advantage – maximizes seed dispersal

Domesticated
Non-shattering grain
"Tough rachis"
Advantage – facilitates harvesting

From Konishi, S., Izawa, T., Lin, S.Y., Ebana, K., Fukuta, Y., Sasaki, T., and Yano, M. (2006). An SNP caused loss of seed shattering during rice domestication. Science 312: 1392-1396. Reprinted with permission from AAAS.

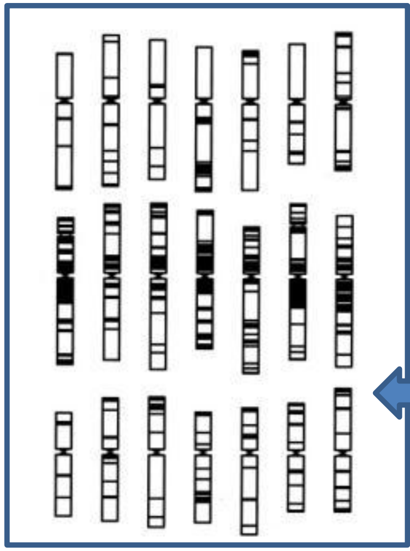
Many of our crops are products of extensive genomic rearrangements



The brassicas share three genomes recombined in various ways

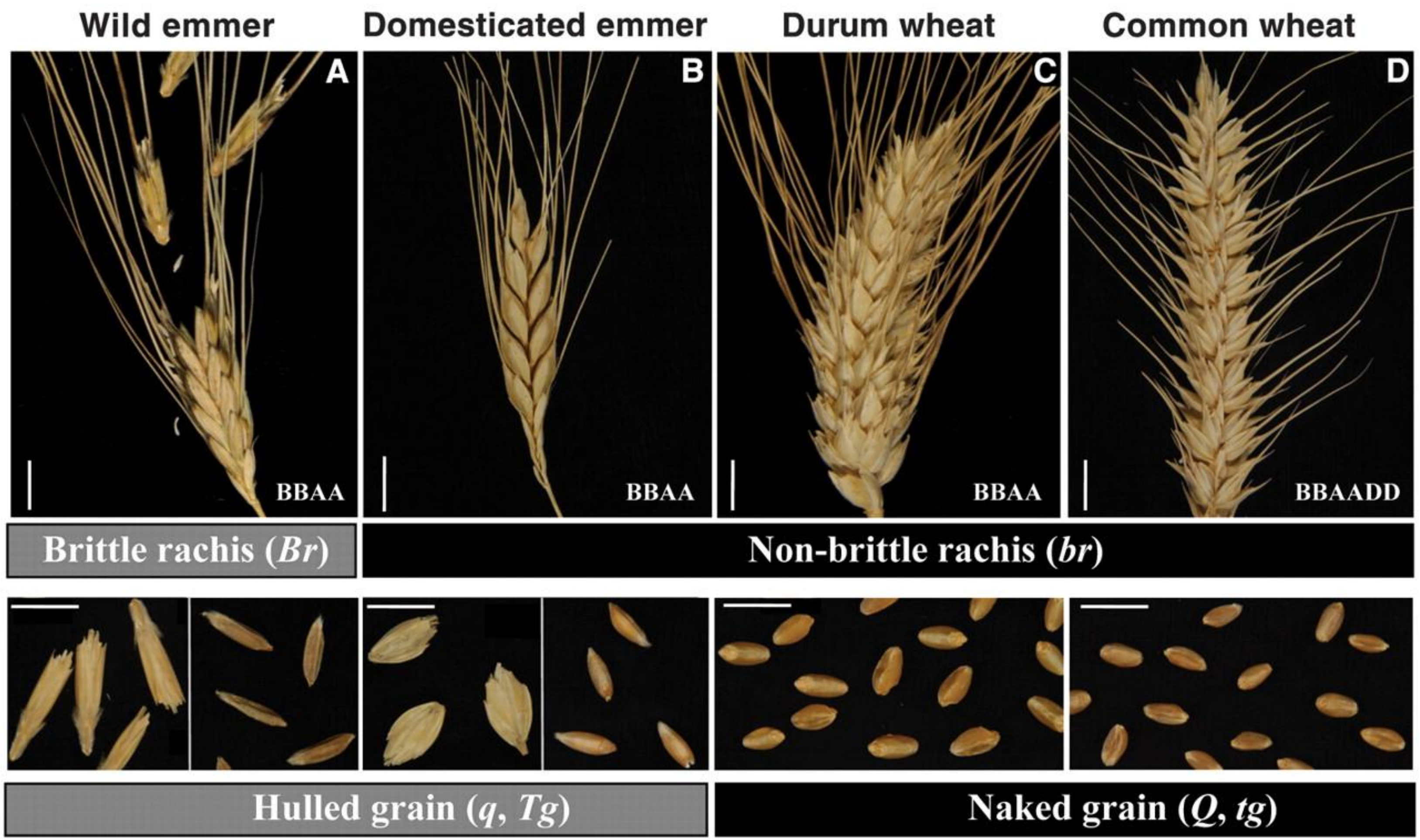
Polyploid (multi-genome) plants are often bigger and so selected for propagation

Common wheat is the result of interspecific hybridization between three ancestors



From Dubcovsky, J. and Dvorak, J. (2007). Genome Plasticity a Key Factor in the Success of Polyploid Wheat Under Domestication. Science. **316:** 1862-1866. Reprinted with permission from AAAS. Brassica figure from Adenosine

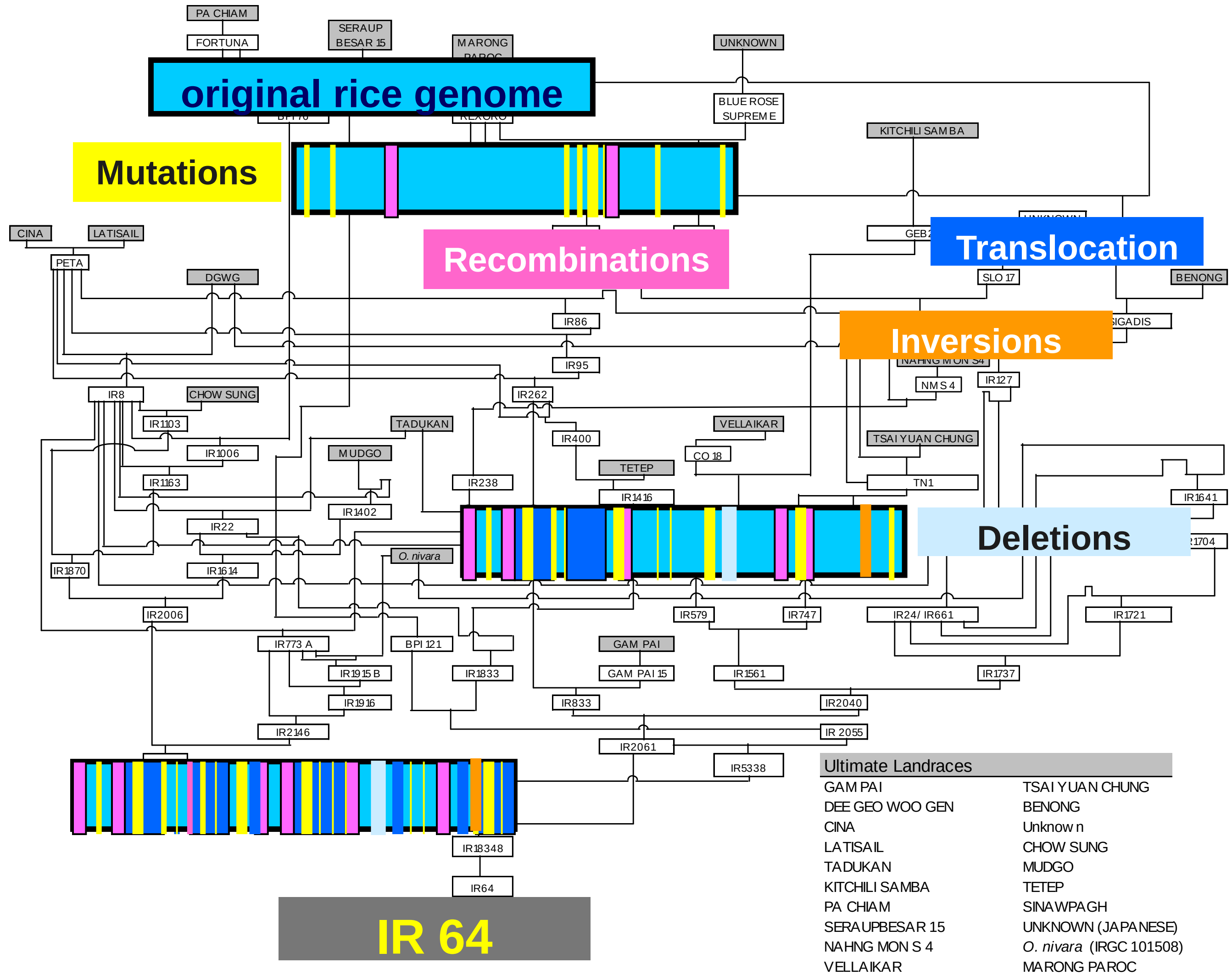
Domestication through genome modification gave us modern crops



From Dubcovsky, J. and Dvorak, J. (2007). Genome Plasticity a Key Factor in the Success of Polyploid Wheat Under Domestication. Science. **316:** 1862-1866. Reprinted with permission from AAAS.

Breeding tree of Indica Rice IR64

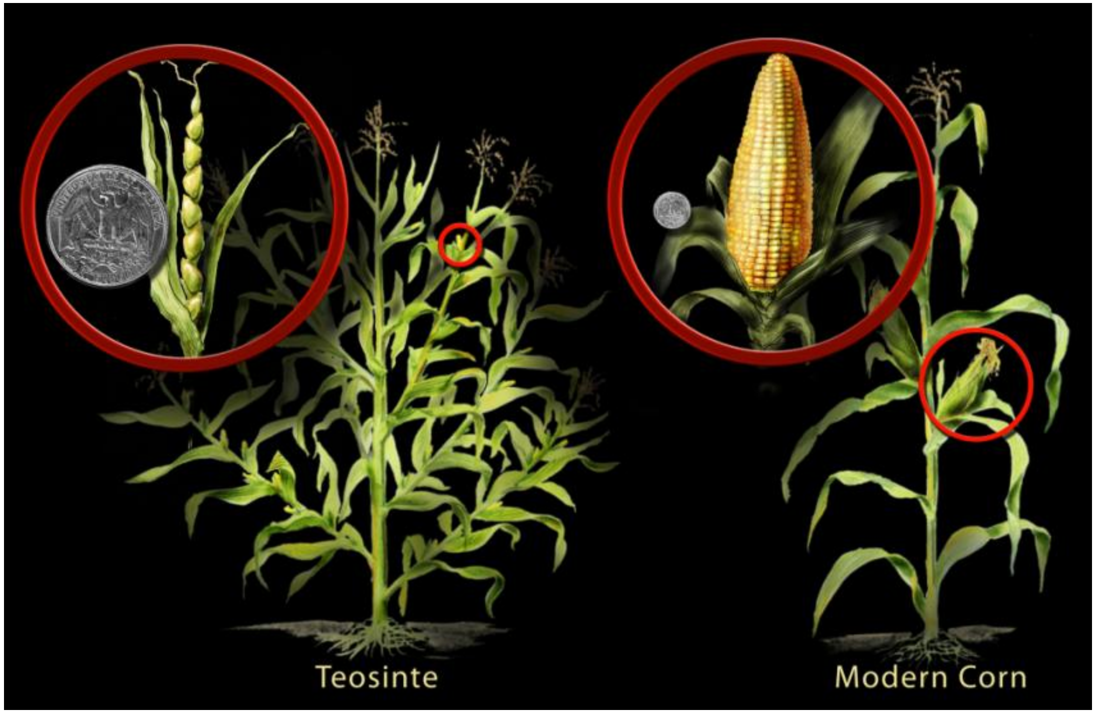
One of the most widely grown crops, indica rice IR64 is the product of a complex breeding program that has caused extensive genomic modification, mutation, deletion and rearrangement



Slide courtesy of Ingo Potrykus

The myth of natural food

The food we eat comes from plants already extensively modified from their original form. Even heritage varieties are extensively genetically modified.

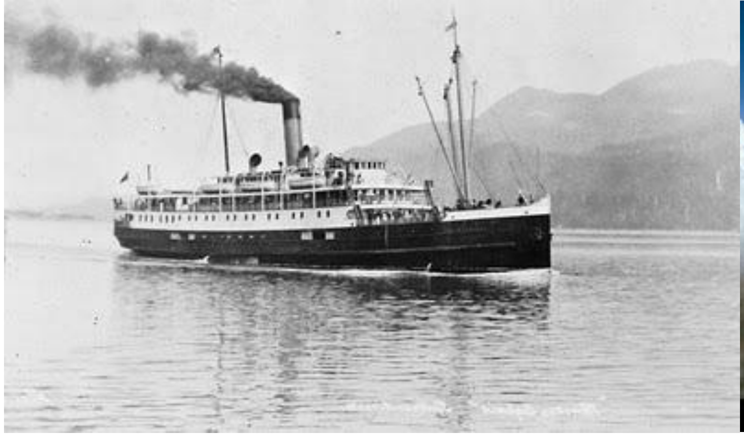


Credit: Nicolle Rager Fuller, National Science Foundation

The Recent Past –
Scientific Plant Breeding

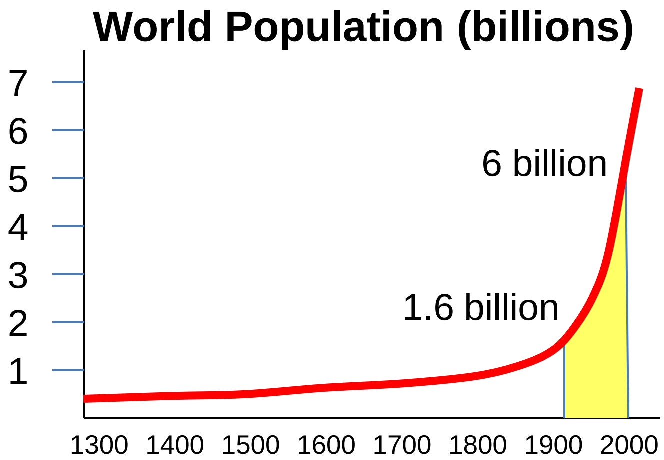
Google™

The twentieth century took us from gas lamps to Google and steamships to space shuttles



The Recent Past – Scientific Plant Breeding

And the world population quadrupled in just over 100 years



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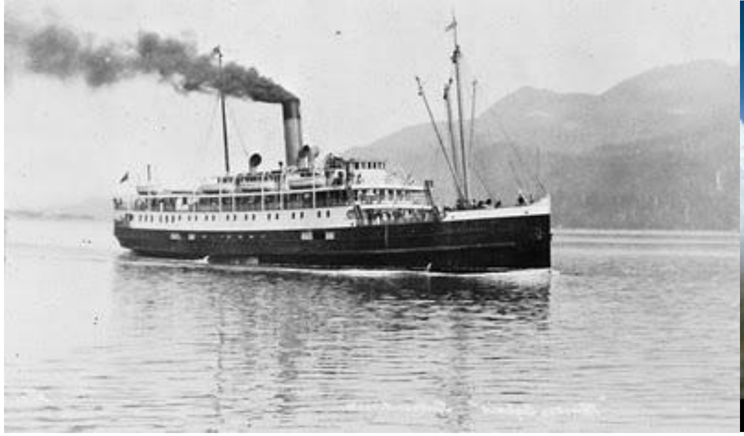
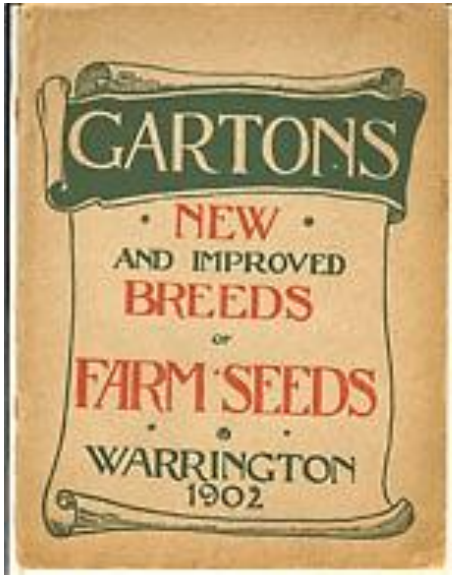
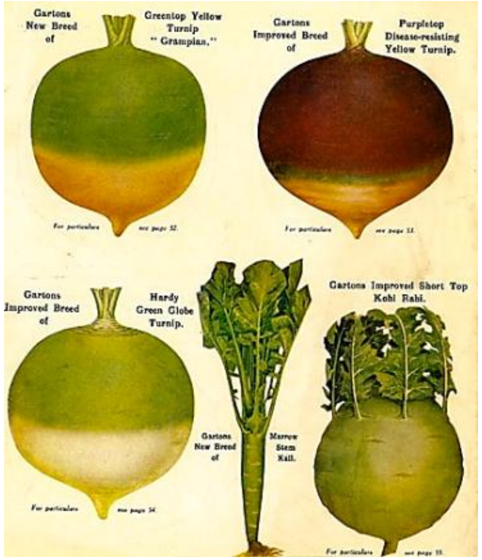


The Recent Past – Scientific Plant Breeding

Improvements in plant propagation and breeding were needed to keep up with population growth





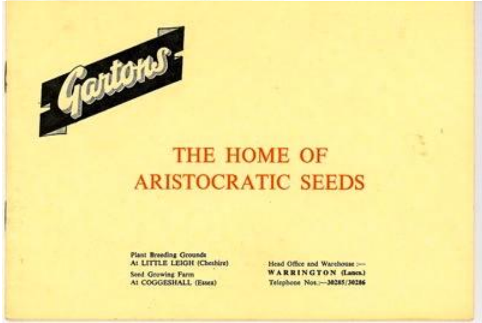
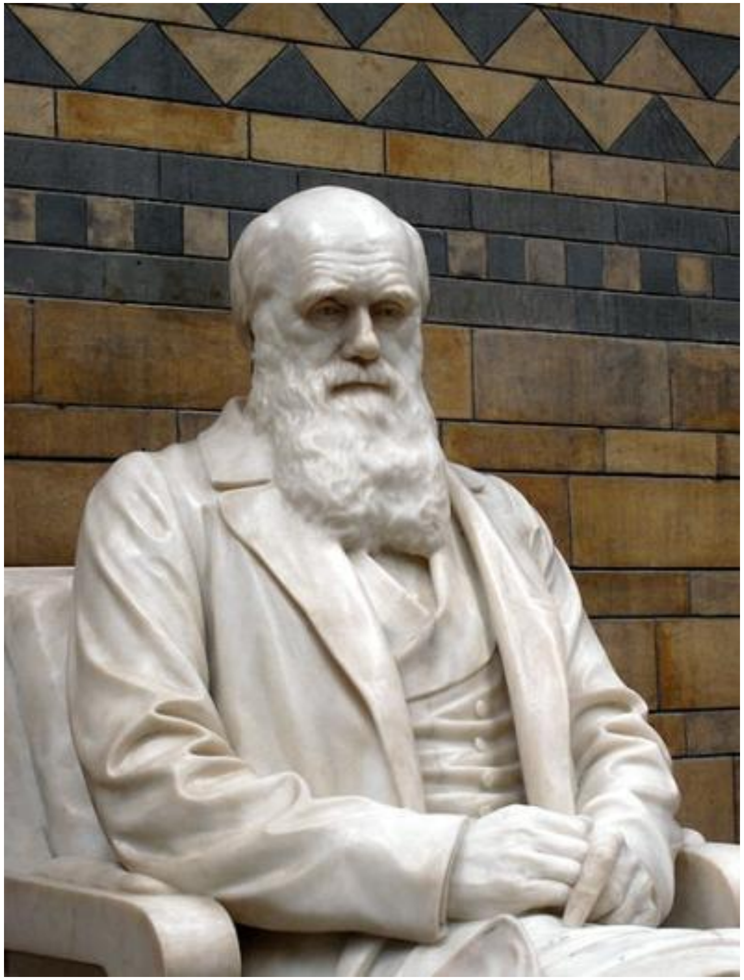
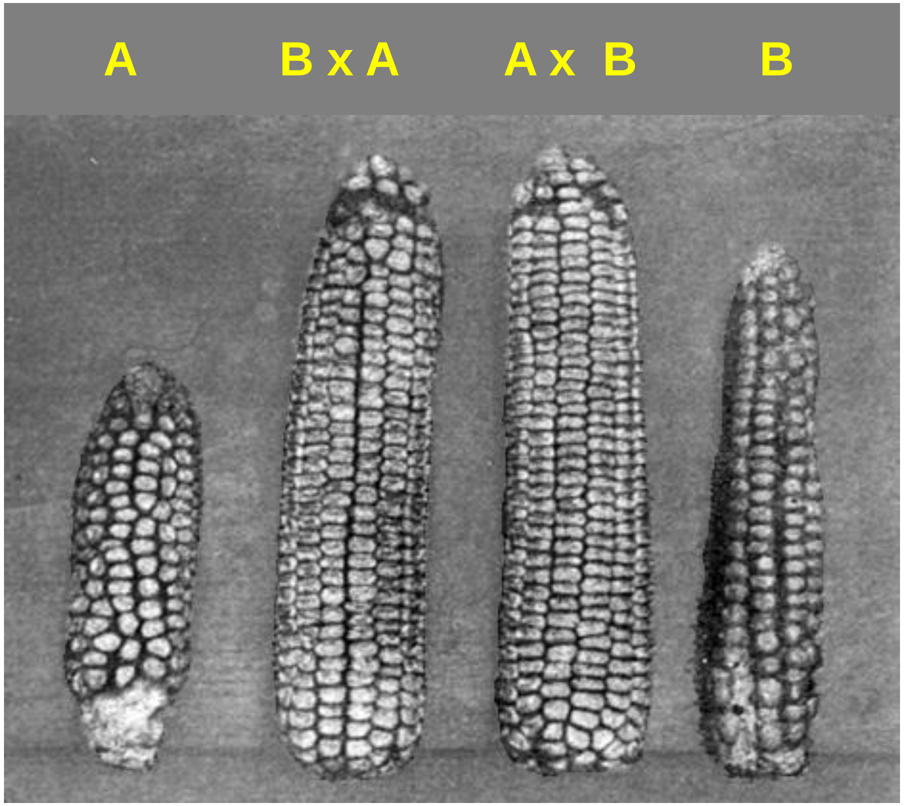


Photo credits: Gartons Plant Breeders

Mendel and Darwin paved the way for scientific plant breeding



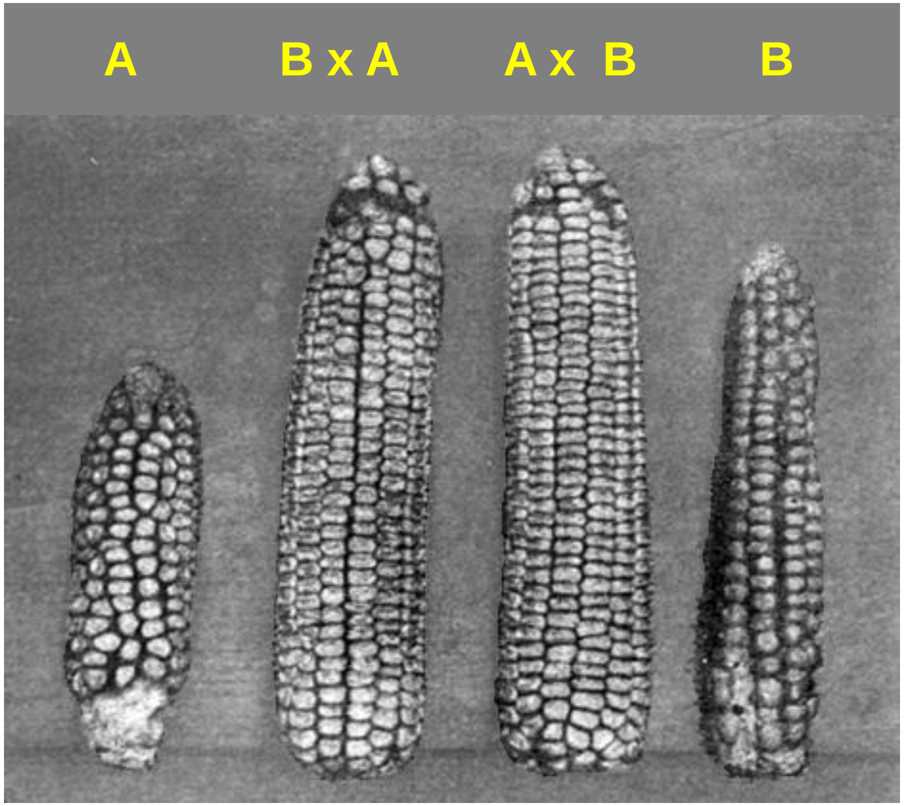
The development of hybrid corn led to a big increase in yields



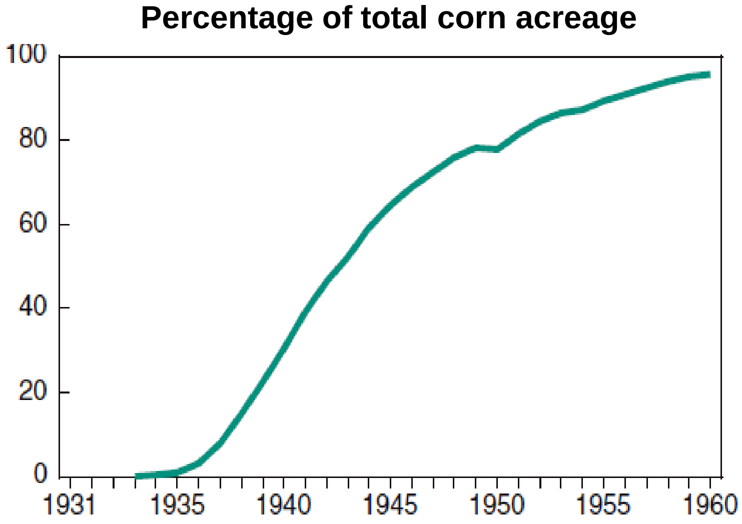
The progeny of two genetically different parents often show enhanced growth – this effect is termed “hybrid vigor”

Shull, G.H. (1909) A pure line method in corn breeding. Am. Breed. Assoc. Rep. 5, 51–59 by permission of Oxford University Press.

Hybrid corn was rapidly adopted because of its increased yields



Even though farmers had to purchase seed every year, increased yields more than offset increased costs



Source: *Agricultural Statistics*, NASS, USDA, various years.

Shull, G.H. (1909) A pure line method in corn breeding. Am. Breed. Assoc. Rep. 5, 51–59 by permission of Oxford University Press; Economic Research Service / USDA

Norman Borlaug was a plant breeder, and “father of the green revolution”

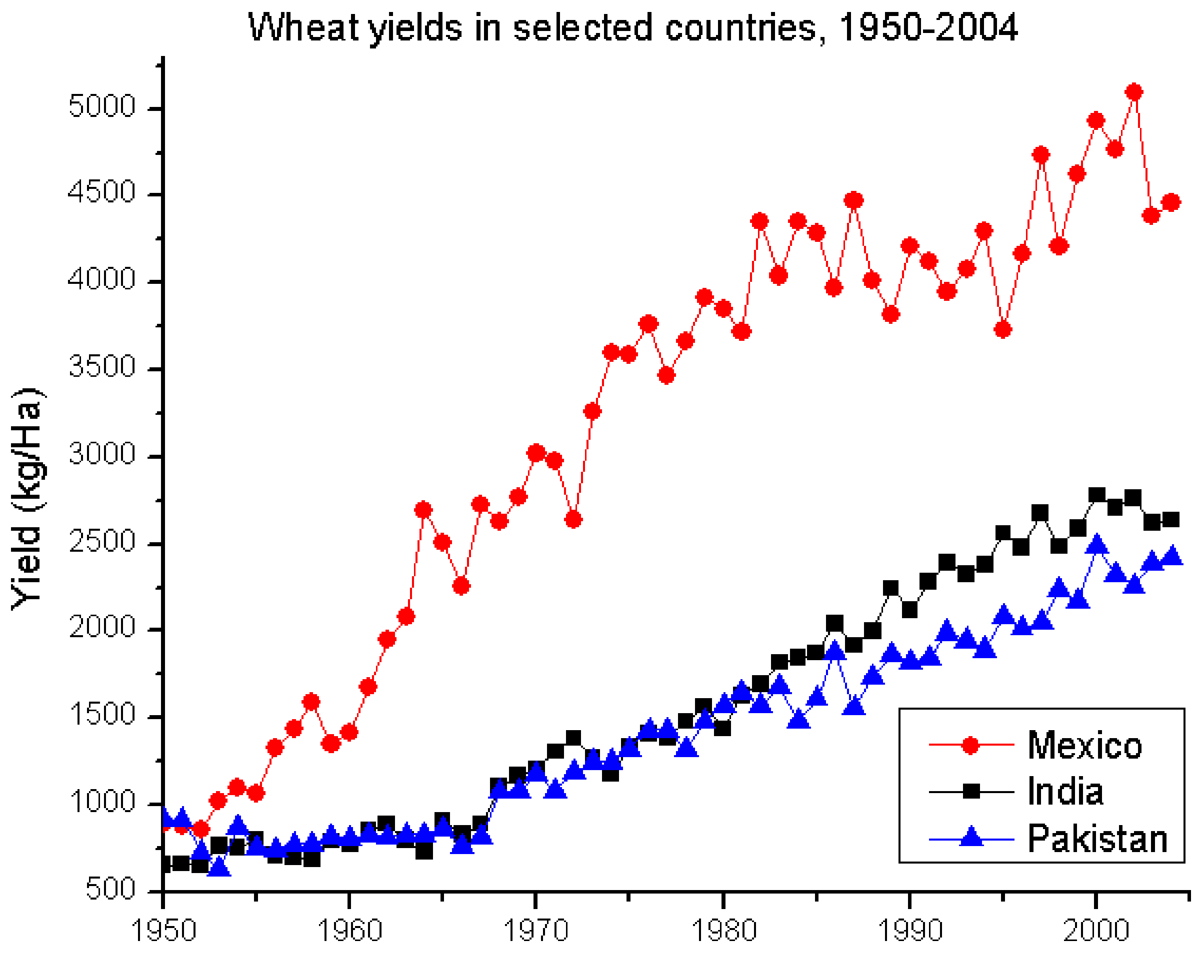
Distinguished plant breeder and Nobel Laureate
Norman Borlaug **1914-2009**

One of the most significant accomplishments of 20th century science was the development of lodging-resistant, high-yielding semi-dwarf grain varieties

Improved green-revolution plants led to dramatically increased crop yields

The introduction of disease-resistant, semi-dwarf varieties turning countries from grain importers to grain exporters

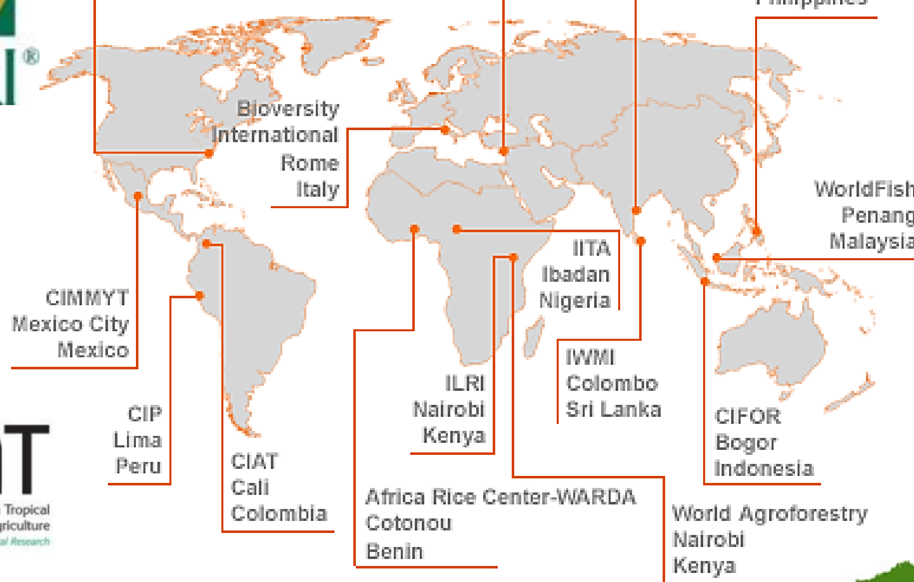
Dwarf wheat was developed at **CIMMYT** – the International Maize and Wheat Improvement Center



Source: FAO via [Brian0918]

Consultative Group on International Agricultural Research CGIAR

CGIAR is an international organization of agricultural research groups



International Center for Agricultural Research in the Dry Areas ICARDA

ICRISAT Science with a human face

IFPRI

Bioversity International

IRRI International Rice Research Institute

WorldFish Center

CIMMYT International Maize and Wheat Improvement Center

CIFOR

Centro Internacional de la Papa CIP

CIAT Centro Internacional de Agricultura Tropical International Center for Tropical Agriculture Consultative Group on International Agricultural Research

IITA Research to Nourish Africa

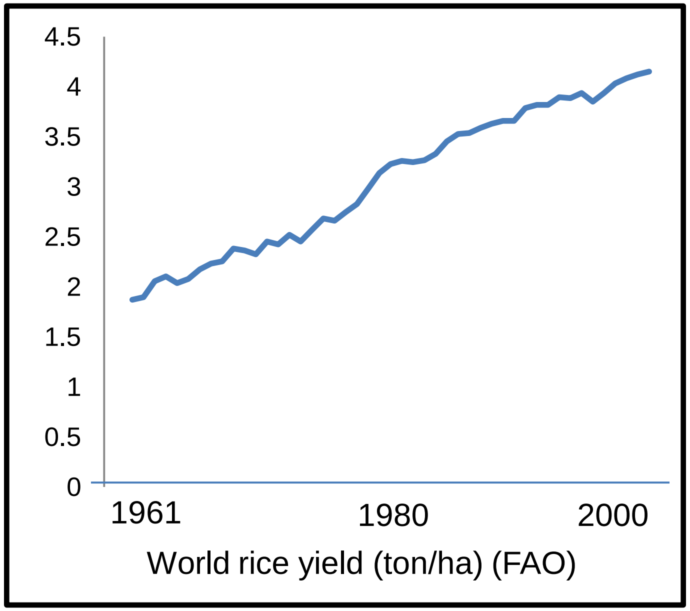
IWMI International Water Management Institute

AfricaRice

ILRI International Livestock Research Institute

World Agroforestry Centre TRANSFORMING LIVES AND LANDSCAPES

Rice breeding at IRRI also brought huge yield increases



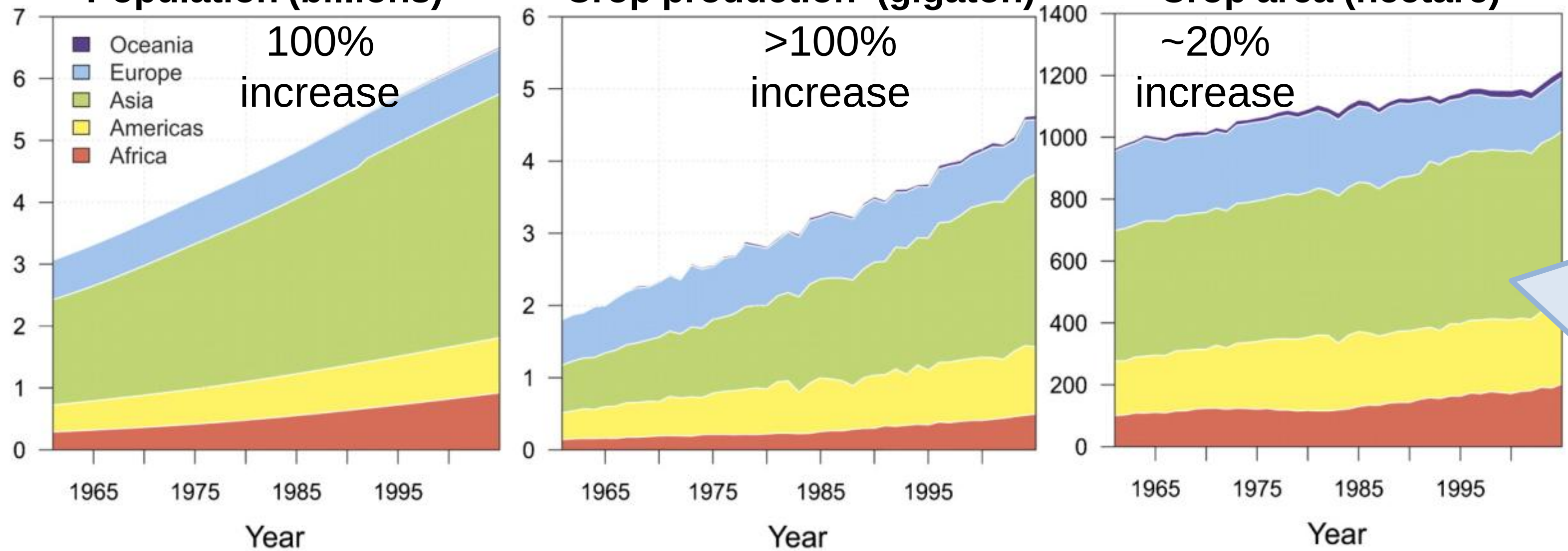
IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

IR8, released in 1966, *"…was to tropical rices what the Model T Ford was to automobiles*." It was known as "miracle rice" because of its high yields.

Photo courtesy [IRRI]

Crop productivity has kept pace with population because of increased yields

Population (billions) | Crop production (gigaton) | Crop area (hectare)



Crop **area** has not increased as rapidly as crop production, because yields (food per hectare) have increased

Growing more food without using more land helps mitigate climate change and slow the loss of biodiversity

Burney, J.A., Davis, S.J., and Lobell, D.B. (2010). Greenhouse gas mitigation by agricultural intensification. Proc. Natl. Acad. Sci. 107: 12052-12057.

Modern plant breeders use molecular methods including DNA sequencing and proteomics as well as field studies

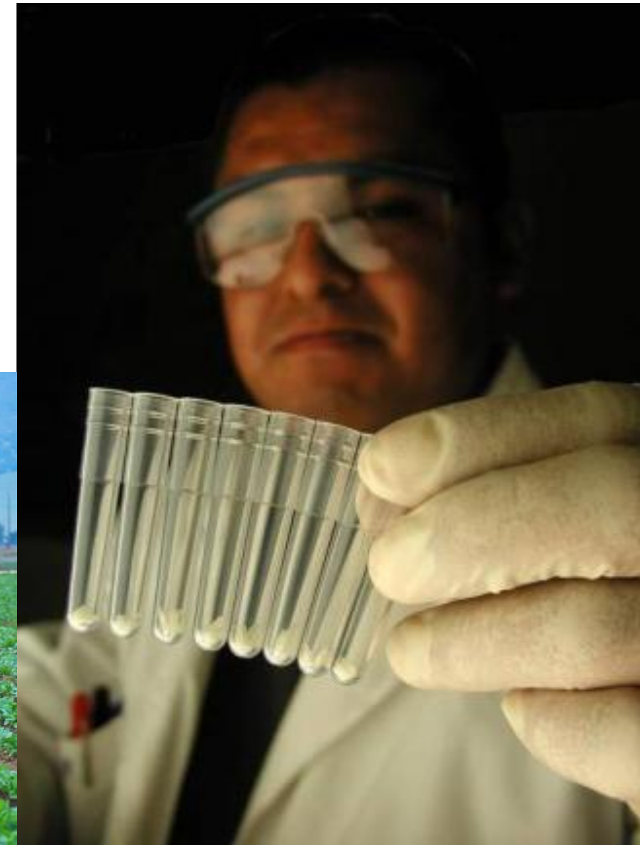


Photo credits Scott Bauer USDA; CIMMYT; IRRI; RCMI; Duke Institute for Genome Sciences and Policy

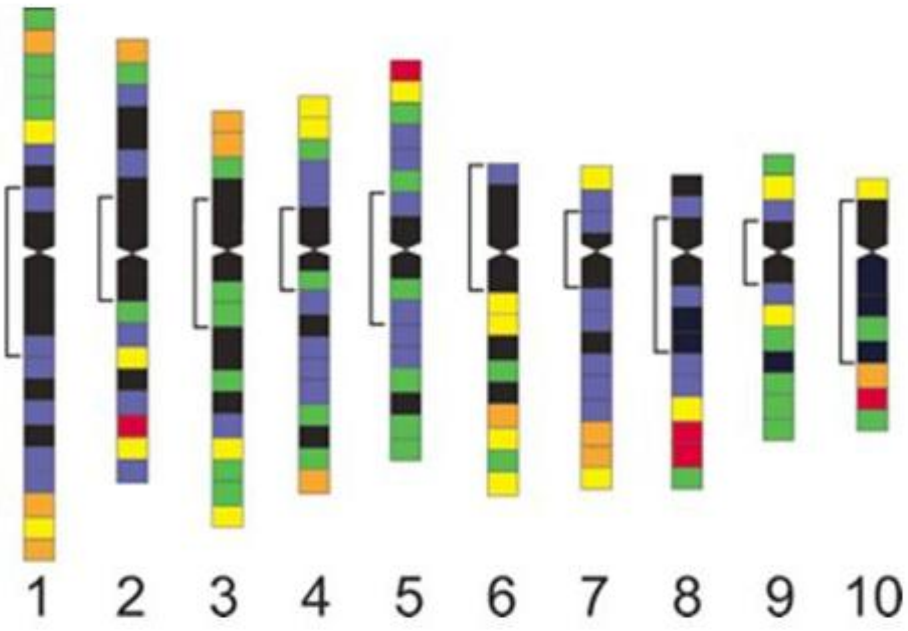
Advances in genetic technologies contribute to improved plants

- Marker assisted selection
- Genome-wide association studies
- Recombinant DNA technology and transgenic plants

Photo credit: IRRI

Marker assisted selection (MAS)

Phenotype: physical expression of traits



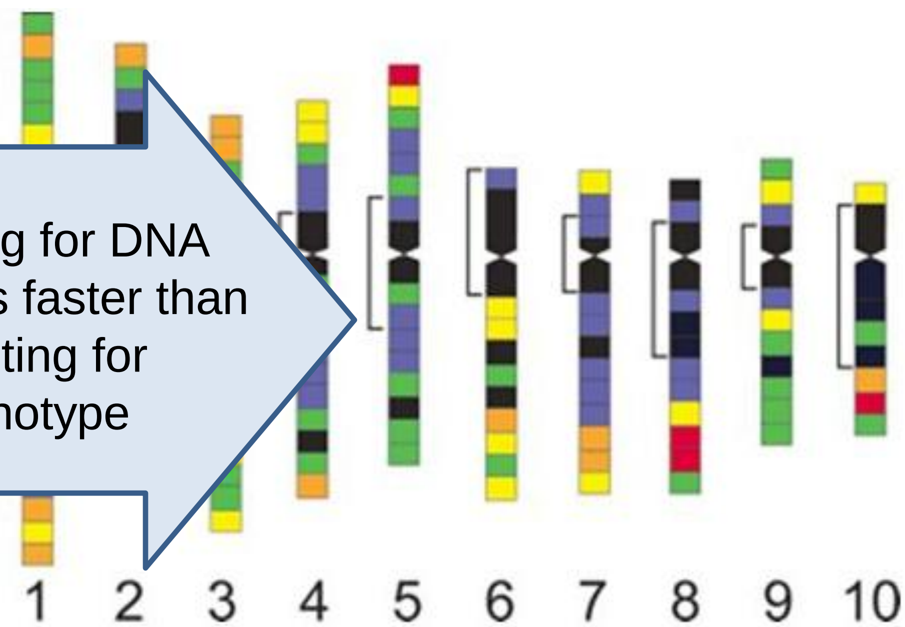
Genotype: sequence of all the genes in a genome

Photo credit LemnaTec; Anderson, L.K., Lai, A., Stack, S.M., Rizzon, C. and Gaut, B.S. (2006). Uneven distribution of expressed sequence tag loci on maize pachytene chromosomes. Genome Research. 16: 115-122.

Marker assisted selection (MAS)

Phenotype: physical expression of traits

Selecting for DNA markers is faster than selecting for phenotype



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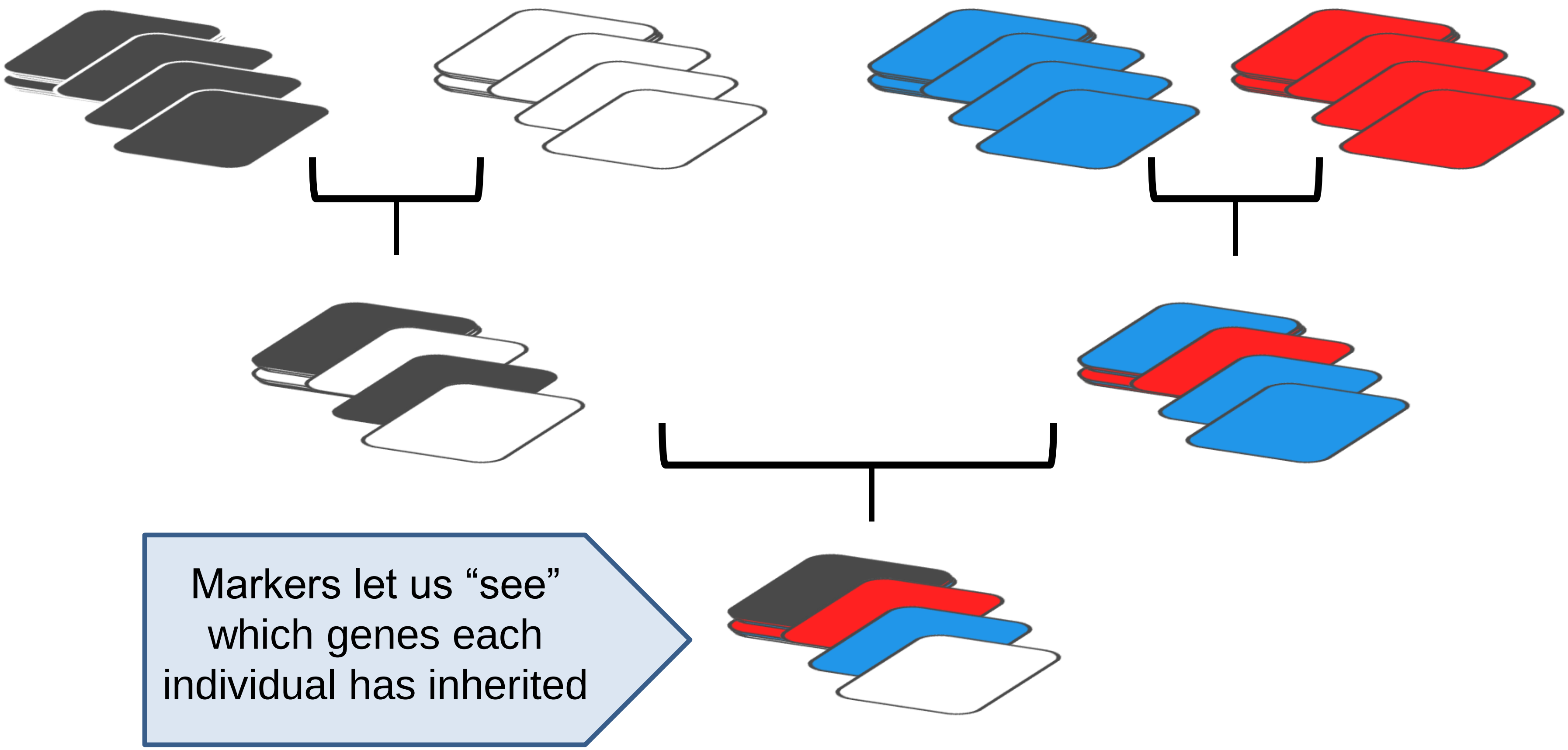
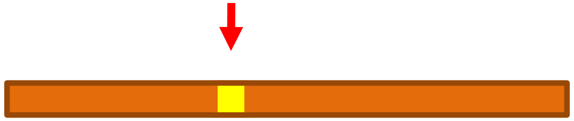
How markers work: Each generation, genes reassort or shuffle



Example: Introgression of a disease resistance gene

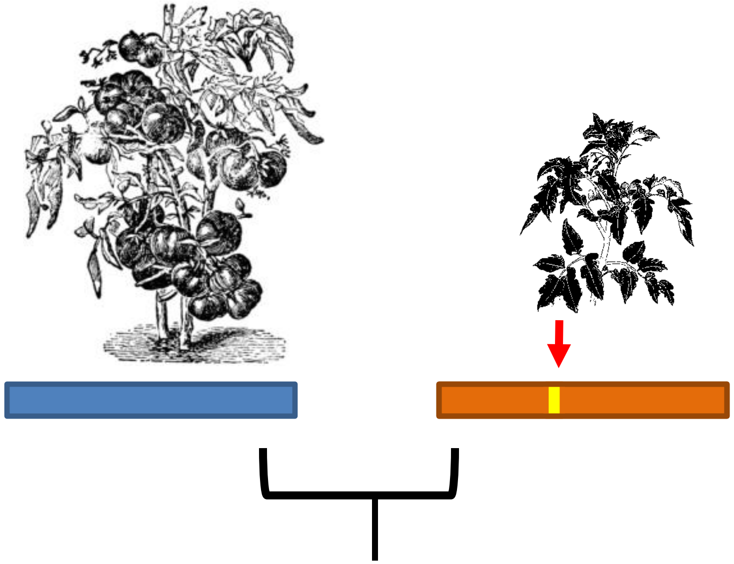
We want to add a disease resistance trait to an “elite” tomato plant.



Elite tomato

Poor tomato but disease resistant
(resistance gene indicated)

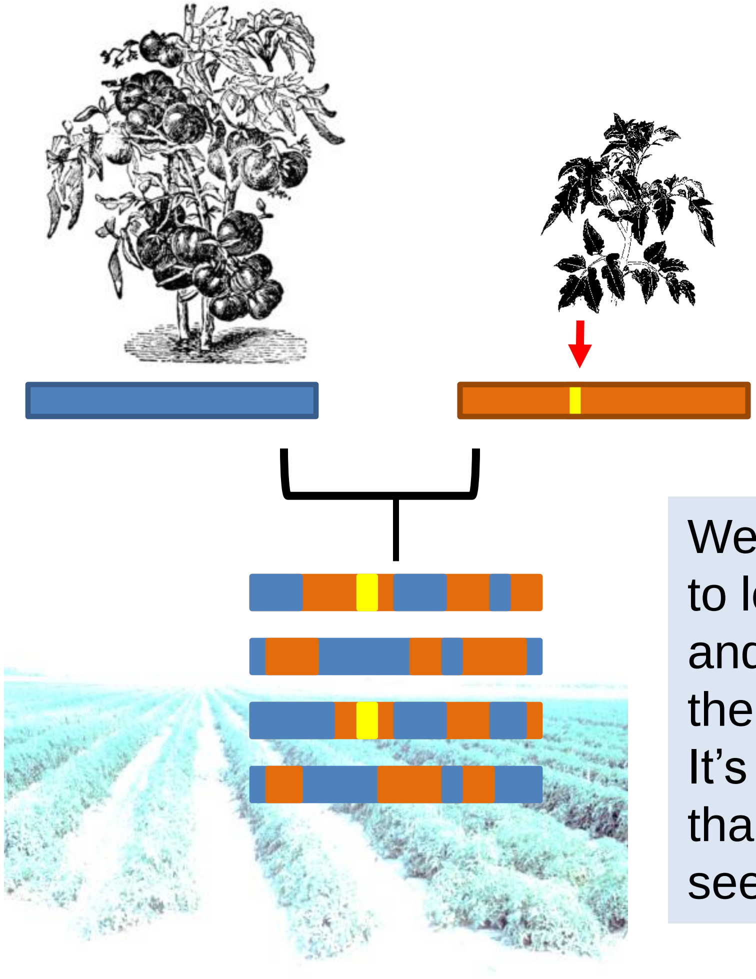
Example: Introgression of a disease resistance gene



We cross the two plants. Some of their progeny inherit the disease resistance trait, some don't – how can we tell the difference?

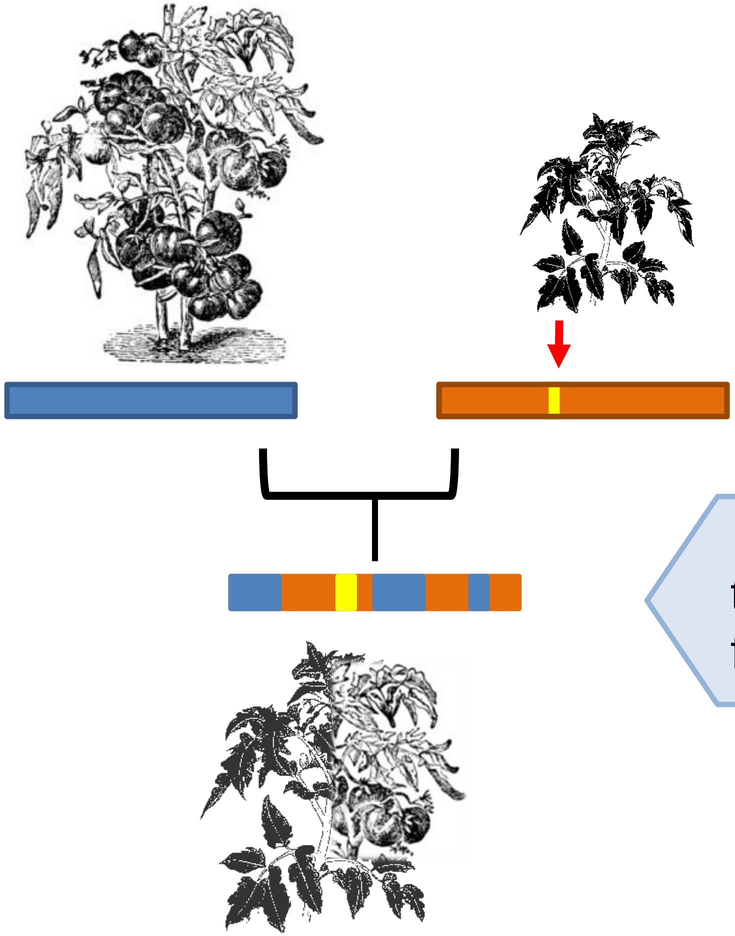
Photo by Stephen Ausmus USDA

Example: Introgression of a disease resistance gene



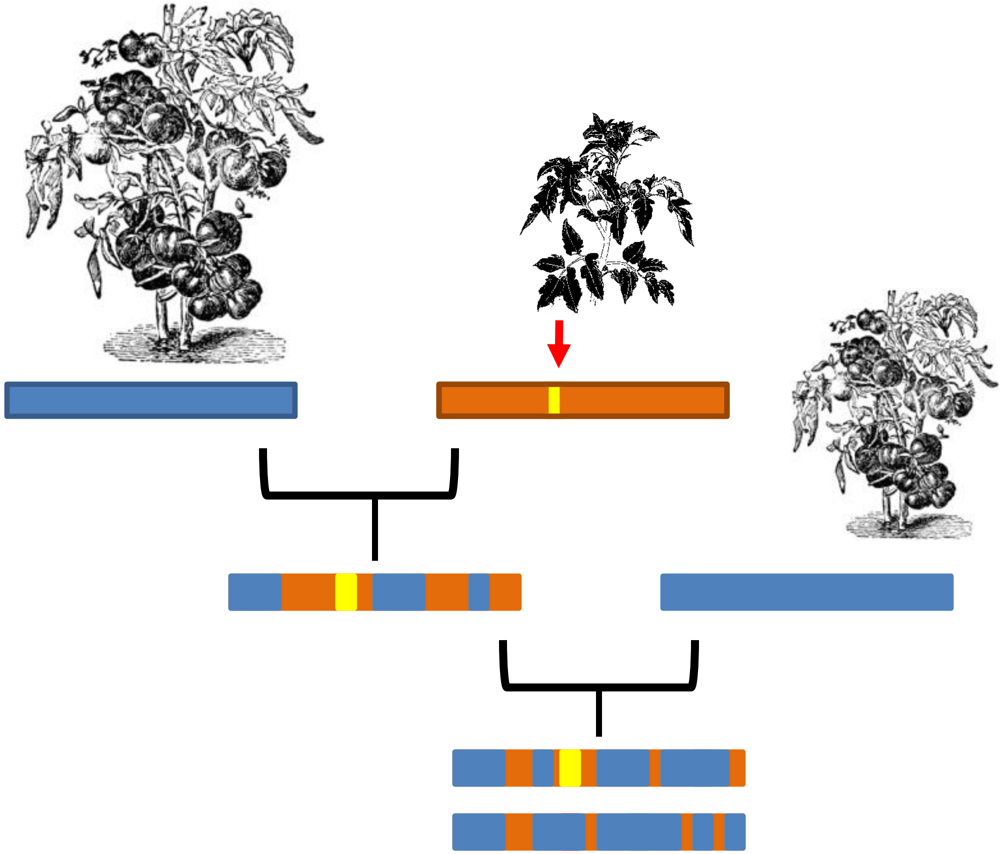
We can use markers to look at their DNA and identify those with the resistance gene. It's faster and easier than infecting them to see the phenotype

Example: Introgression of a disease resistance gene



Is this an elite, disease-resistant tomato? No, half of its genes are from the poor tomato

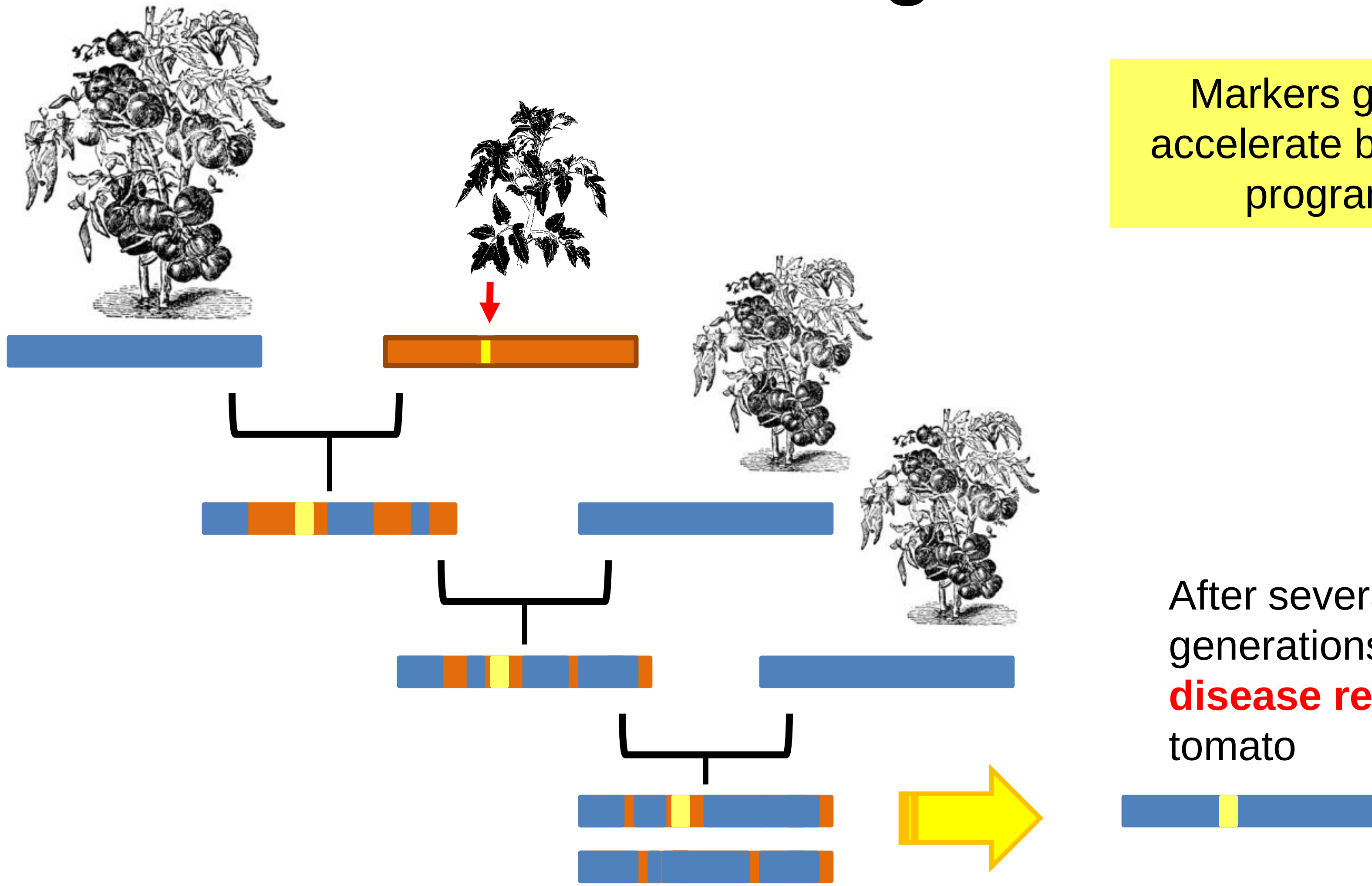
Example: Introgression of a disease resistance gene



We have to repeatedly cross back to the elite tomato, using markers to identify plants with the disease resistance gene

Example: Introgression of a disease resistance gene

Markers greatly accelerate breeding programs



After several generations, **elite**, **disease resistant** tomato

MAS as a tool in production of submergence tolerant rice (*Sub1*)

Many rice-growing regions are prone to flooding. In Pakistan a 2010 a huge, deadly, flood submerged 17 million acres (69,000 km^2) and destroyed much of the harvest

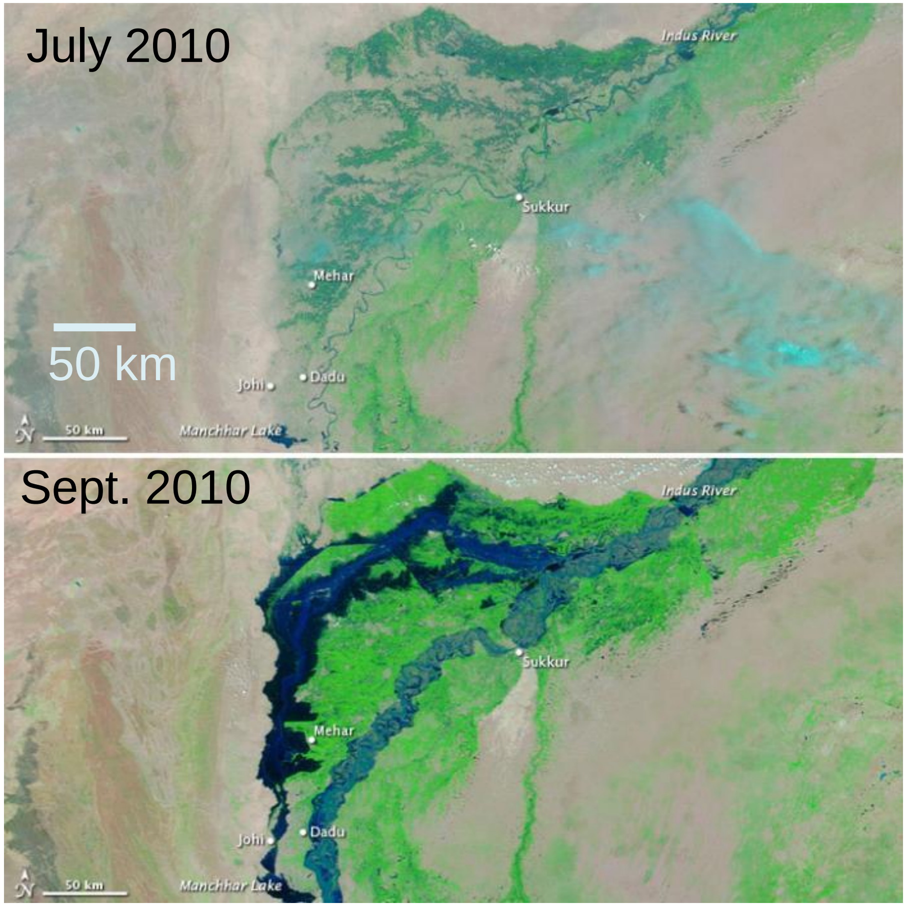
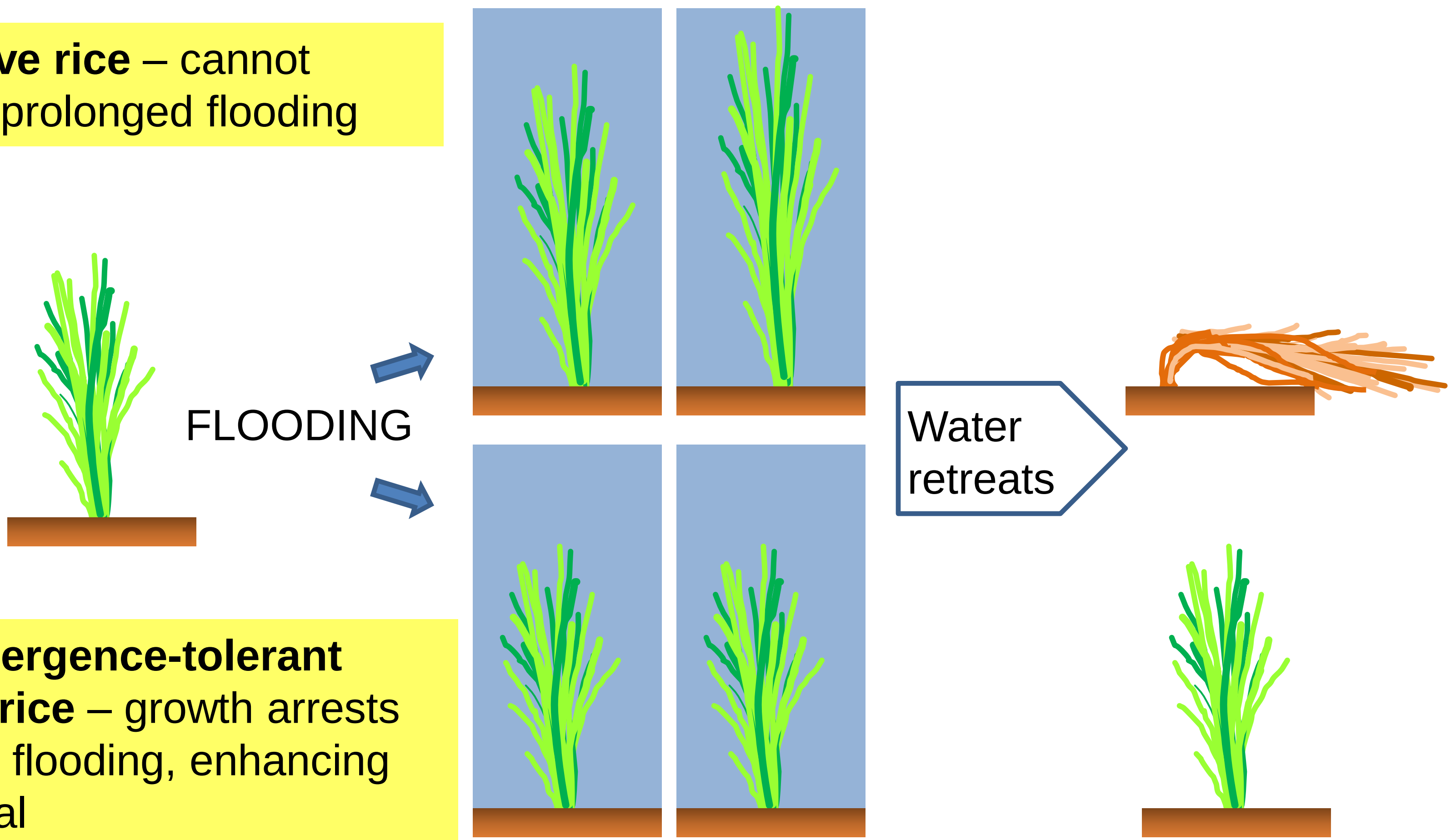


Photo credits: Abdul Majeed Goraya / IRIN; NASA Goddard

Submergence-tolerant rice can survive floods as long as 17 days

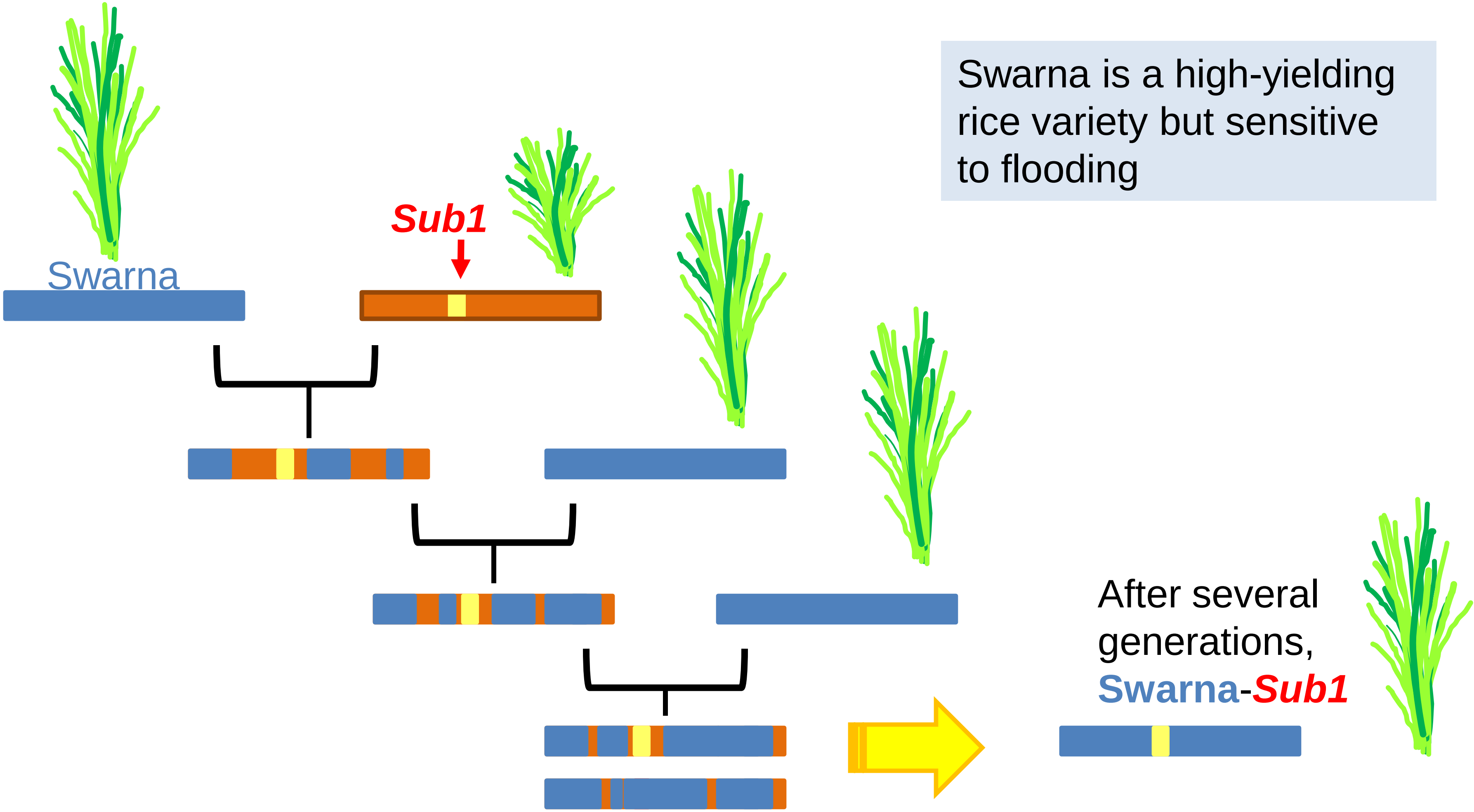
Sensitive rice – cannot survive prolonged flooding

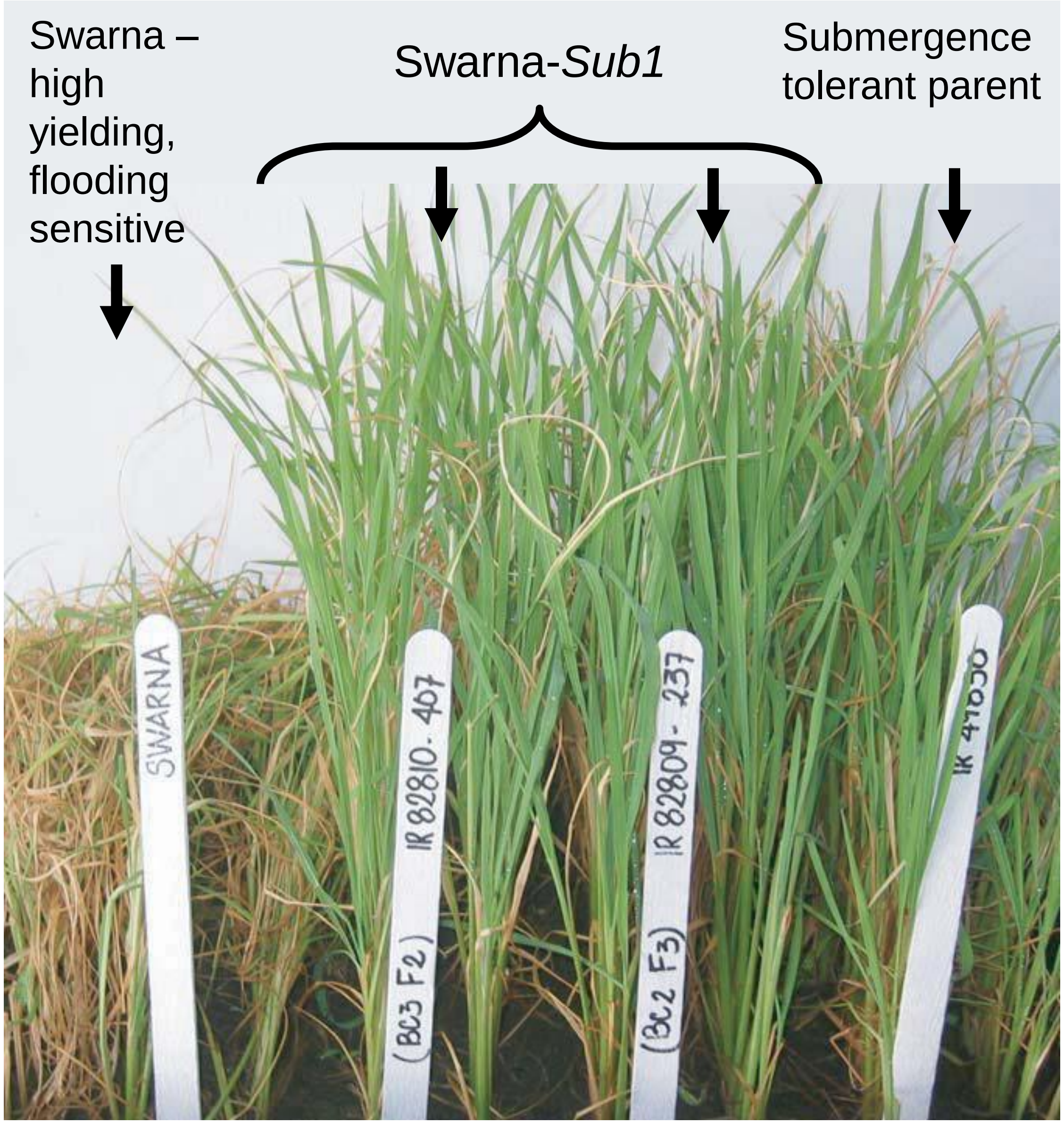


Submergence-tolerant *Sub1* rice – growth arrests during flooding, enhancing survival

Production of Swarna–*Sub1*: Cross Swarna with *Sub1* donor

Swarna is a high-yielding rice variety but sensitive to flooding



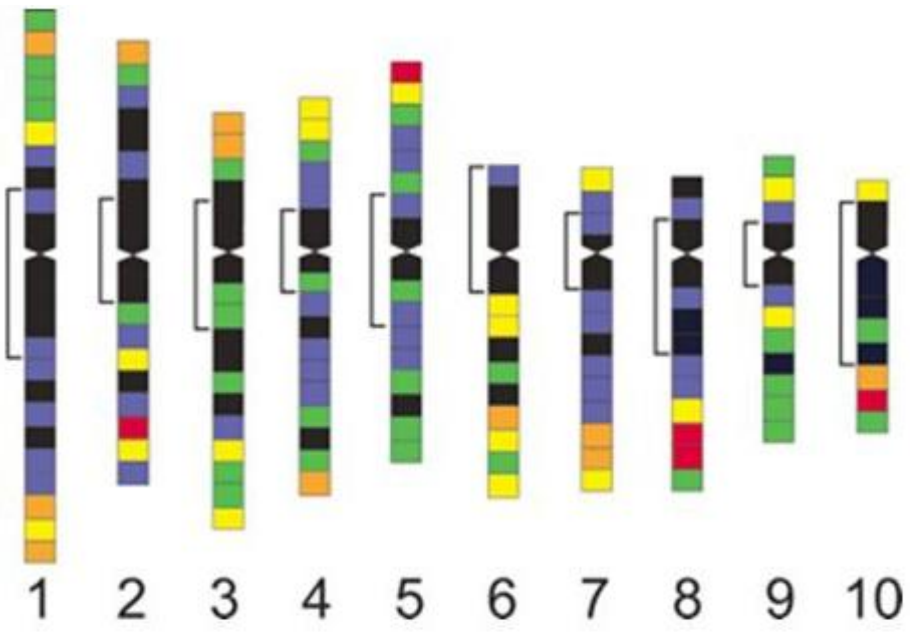


MAS allowed the *Sub-1* trait to be rapidly introgressed into Swarna. The Swarna-*Sub1* rice accounted for over ¼ of the rice planted in India in 2010.

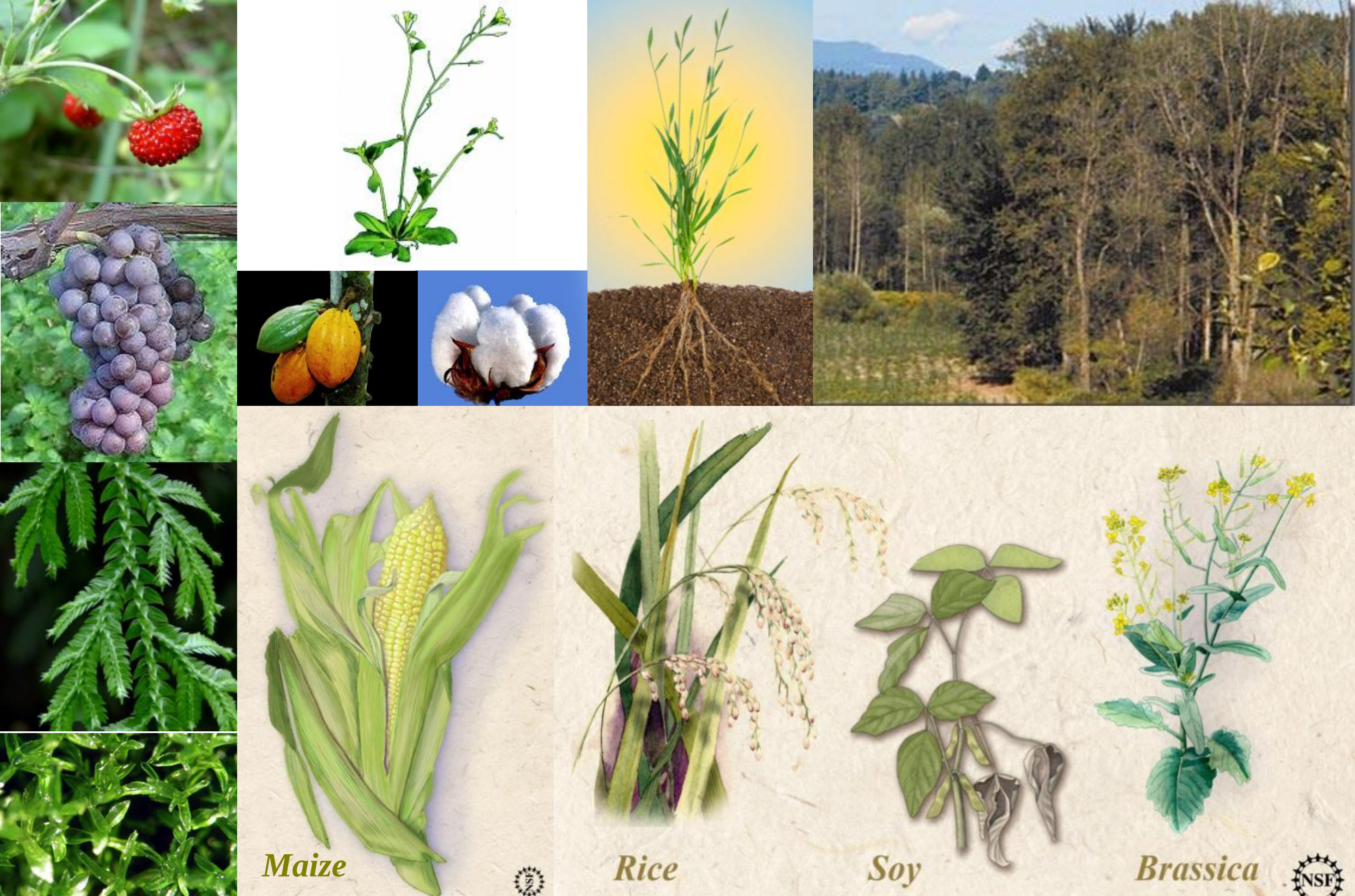
Reprinted by permission from Macmillan Publishers Ltd. (NATURE) Xu, K., Xu, X., Fukao, T., Canlas, P., Maghirang-Rodriguez, R., Heuer, S., Ismail, A.M., Bailey-Serres, J., Ronald, P.C., and Mackill, D.J. (2006). Sub1A is an ethylene-response-factor-like gene that confers submergence tolerance to rice. Nature 442: 705-708. Photo couresy of Adam Barclay CPS, IRRI Photo.

Advances in gemonics technologies facilitate breeding for complex traits

- •Genome sequence data are available for more than 20 plant species
- •Molecular breeding and mapping tools are developed for many species
- •Genome-wide association studies help match genes to traits

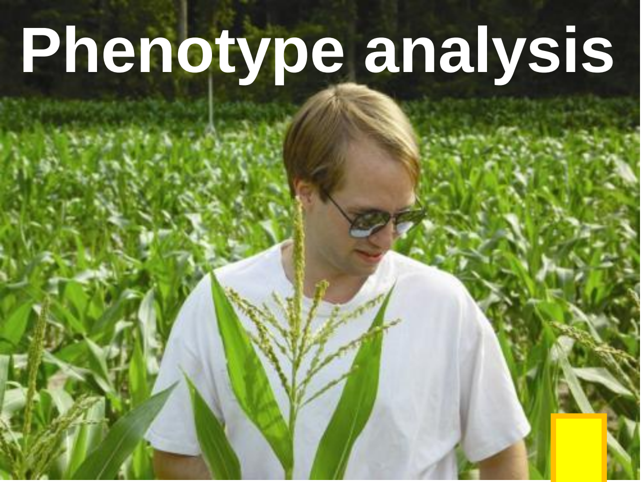


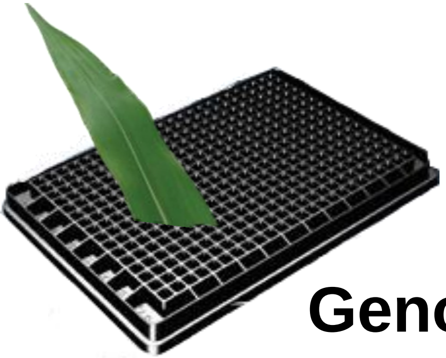
Anderson, L.K., Lai, A., Stack, S.M., Rizzon, C. and Gaut, B.S. (2006). Uneven distribution of expressed sequence tag loci on maize pachytene chromosomes. Genome Research. 16: 115-122.



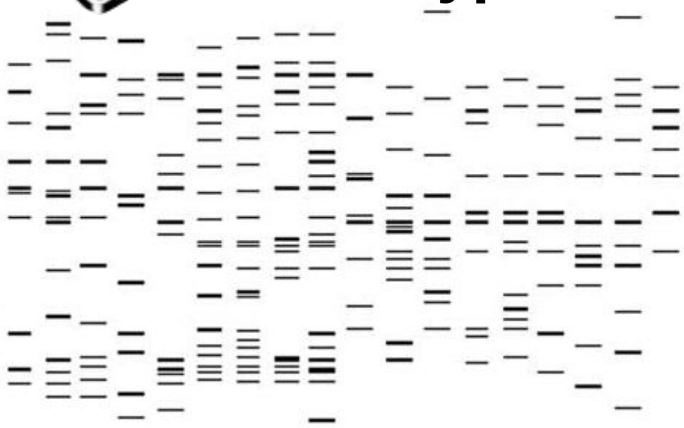
Genome sequence data are available for many important plants

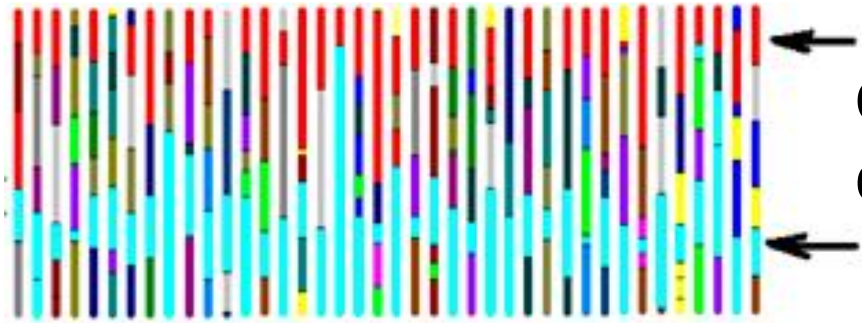
Genome-wide methods make it possible to identify genes associated with complex traits, like yield or water use efficiency





Genotype analysis



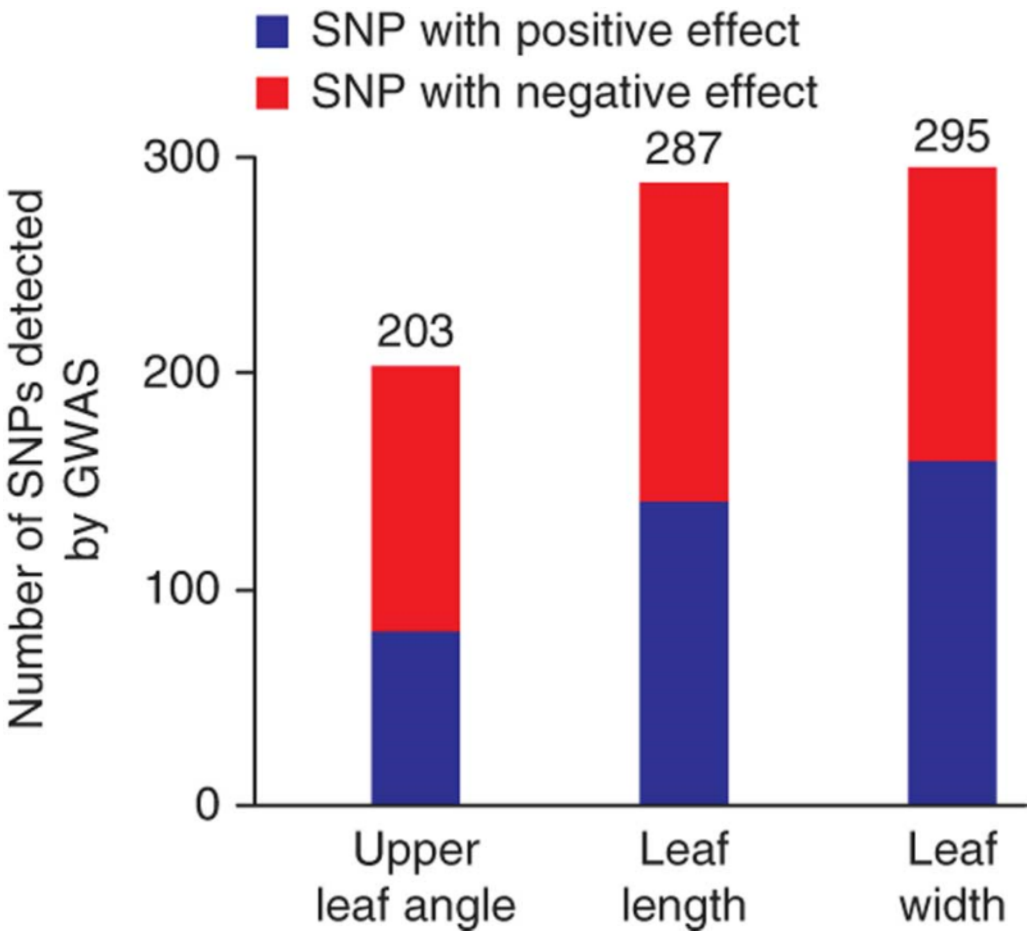


Gene discovery

Association analysis

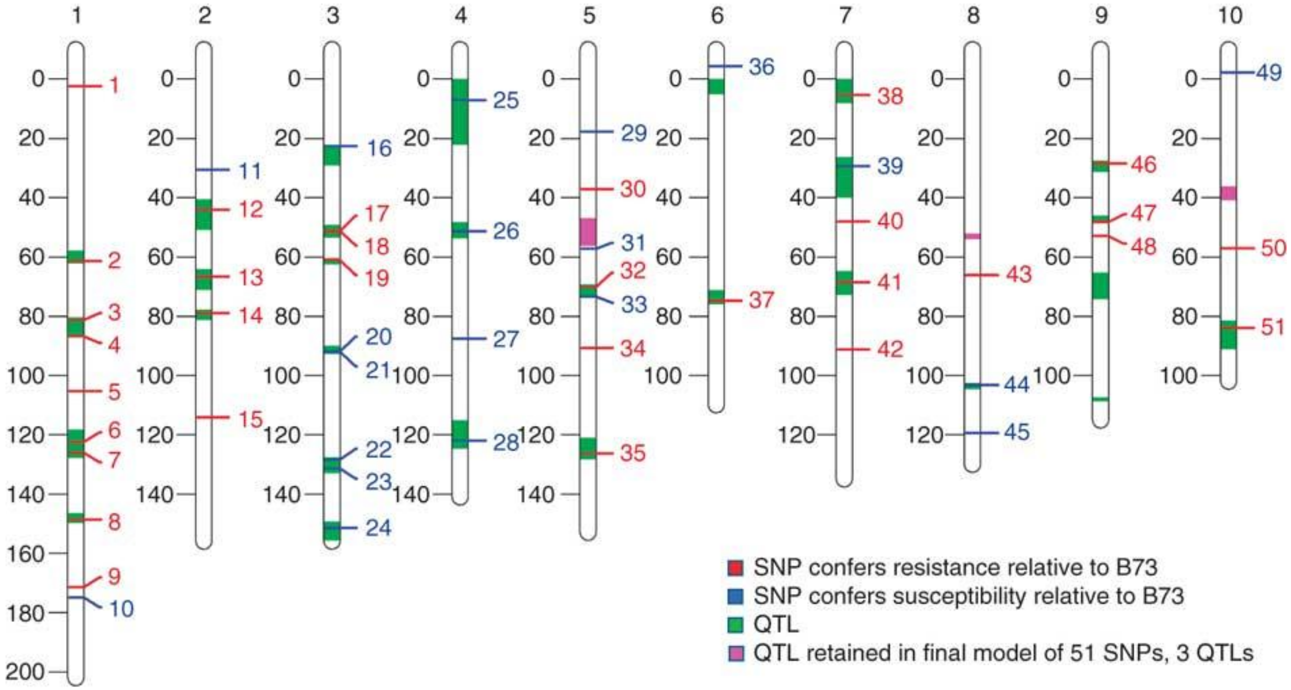
This approach allows hundreds of genes with small effects to be identified

In maize, grain yields are correlated with leaf angle and size. A genome-wide association survey (GWAS) revealed hundreds of single-nucleotide polymorphisms (SNPs) associated with these traits, providing invaluable information for breeders.



Reprinted by permission from Macmillan Publishers Ltd. Tian, F., Bradbury, P.J., Brown, P.J., Hung, H., Sun, Q., Flint-Garcia, S., Rocheford, T.R., McMullen, M.D., Holland, J.B., and Buckler, E.S. (2011). Genome-wide association study of leaf architecture in the maize nested association mapping population. Nat Genet 43: 159-162.

GWAS reveals SNPs that contribute to disease resistance



Similar studies have led to the identification of genes contributing to other agronomically important traits including drought tolerance

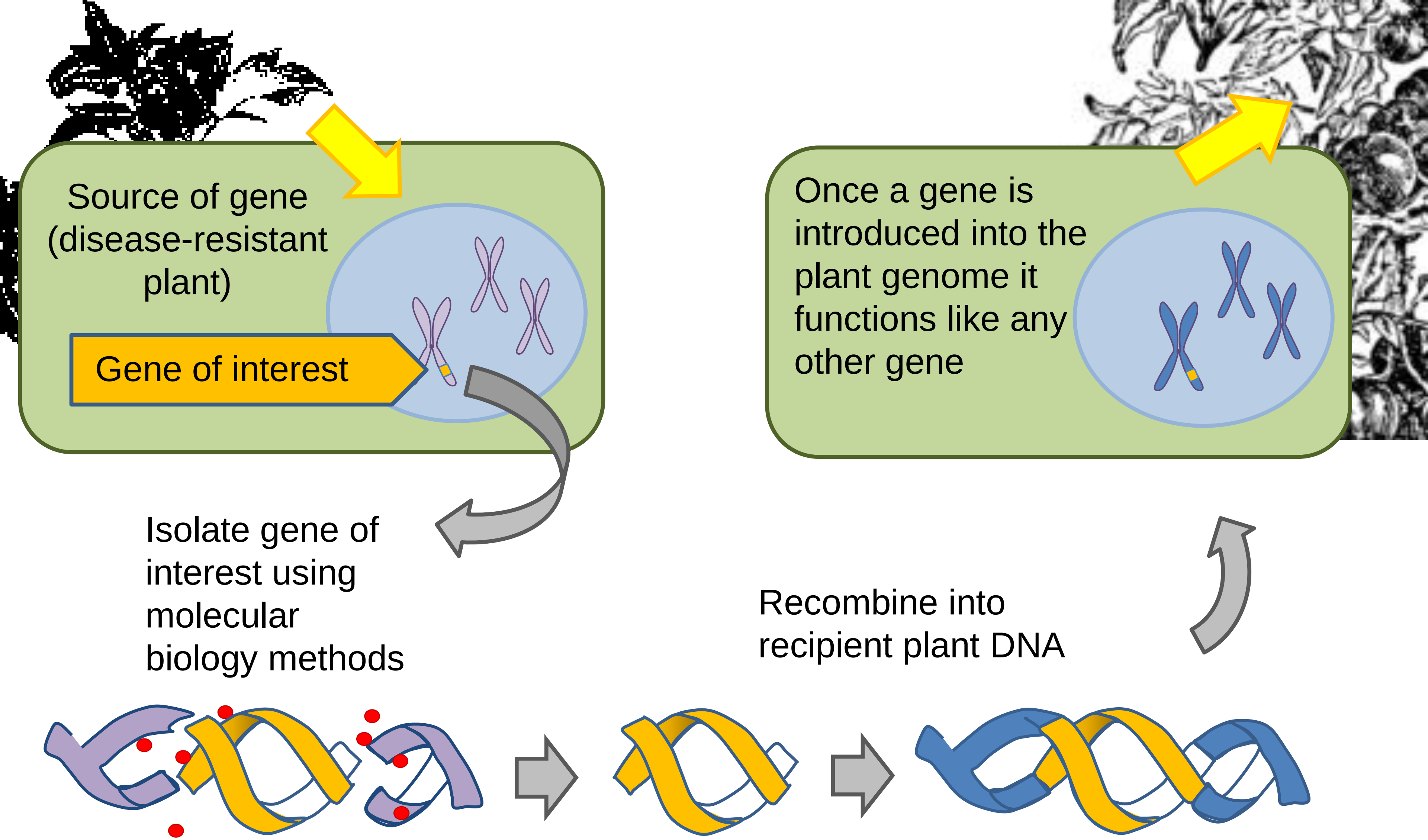
Genetic Modification (GM) is another breeding method

Recombinant DNA (or GM) allows a single gene to be introduced into a genome. This method can be faster than conventional breeding

Elite tomato

Poor tomato but disease resistant

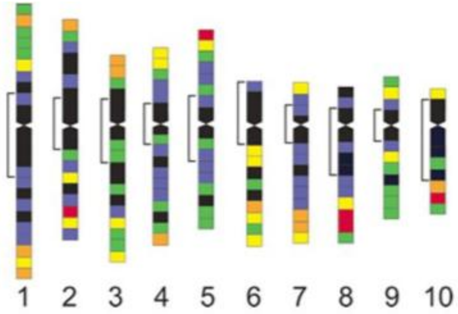
Elite, disease resistant tomato


Source of gene (disease-resistant plant)
Gene of interest
Once a gene is introduced into the plant genome it functions like any other gene
Isolate gene of interest using molecular biology methods
Recombine into recipient plant DNA

Why are GM methods used sometimes and molecular breeding others?

Molecular breeding

1. Desired trait must be present in population



2. Genetic resources must be available

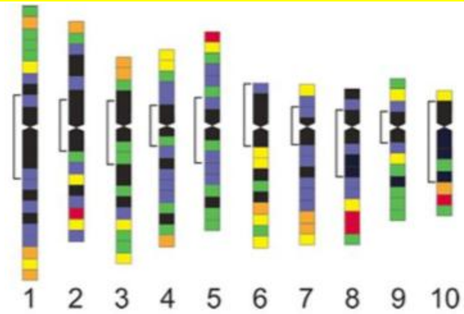
3. Plant should be propagated sexually

Photo credits: Gramene.org

Why are GM methods used sometimes and molecular breeding others?

Molecular breeding

1. Desired trait must be present in population

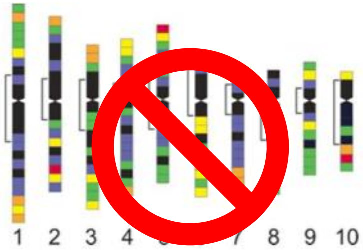


2. Genetic resources must be available

3. Plant should be propagated sexually

GM

1. Gene can come from any source

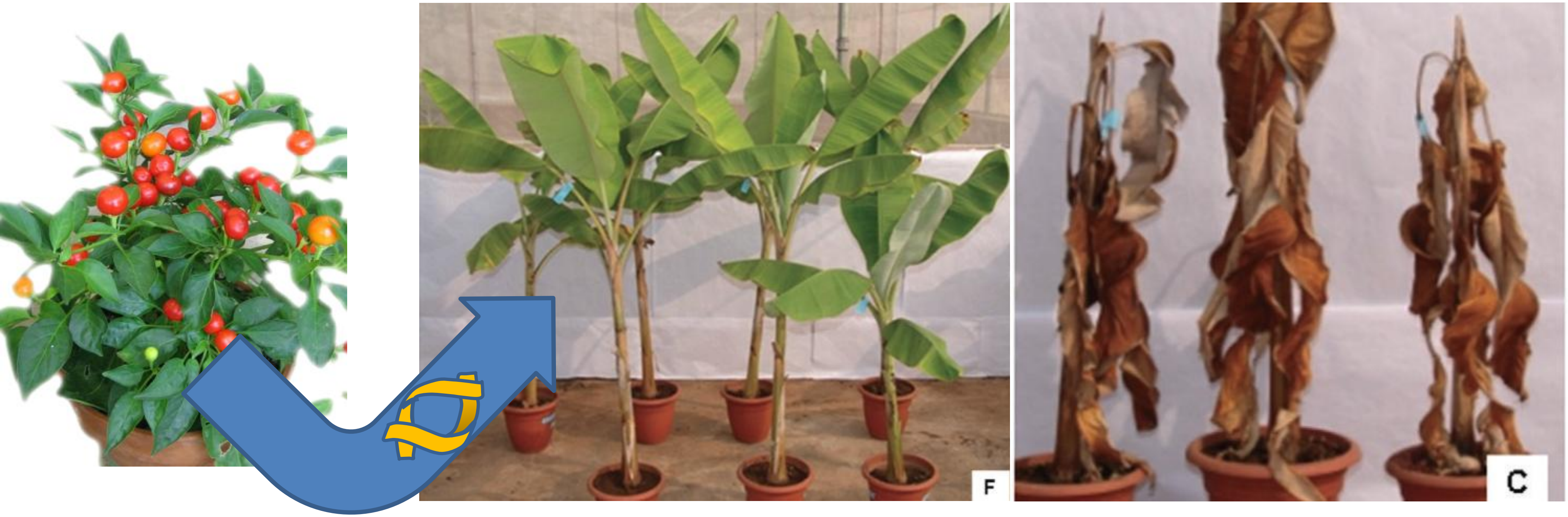


2. Genetic resources not required

3. Plant can be propagated vegetatively

Photo credits: Gramene.org ETH Life International

GM Example: Disease resistant banana by introduction of a gene from pepper



Resistant **Susceptible**

Banana bacterial wilt is destroying plants in eastern Africa. Transgenic plants carrying a resistance gene from pepper are resistant to the disease

Tripathi, L., Mwaka, H., Tripathi, J.N., and Tushemereirwe, W.K. (2010). Expression of sweet pepper Hrap gene in banana enhances resistance to Xanthomonas campestris pv. musacearum. Molecular Plant Pathology 11: 721-731.

GM Example: Insect resistance through introduction of the *Bt* gene

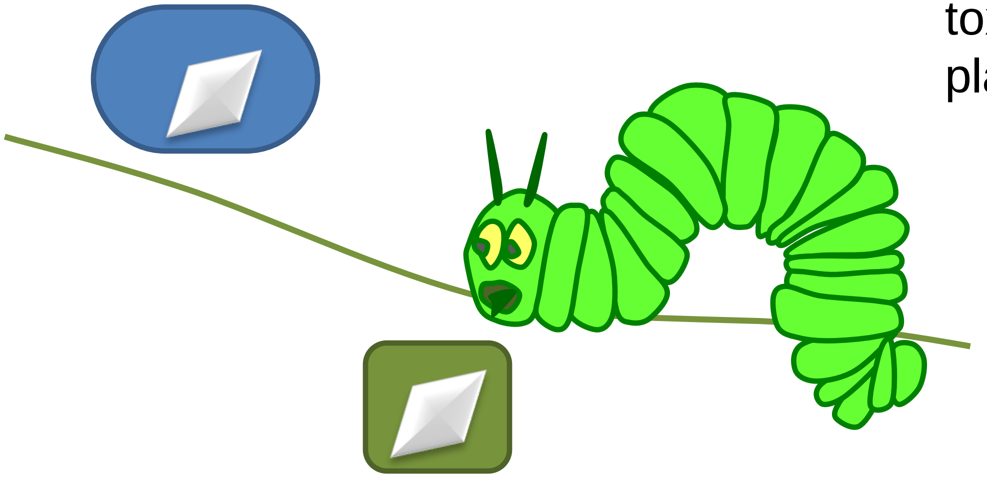
Wild-type peanut plant

Peanut plant expressing the *Bt* gene

Photo by Herb Pilcher USDA

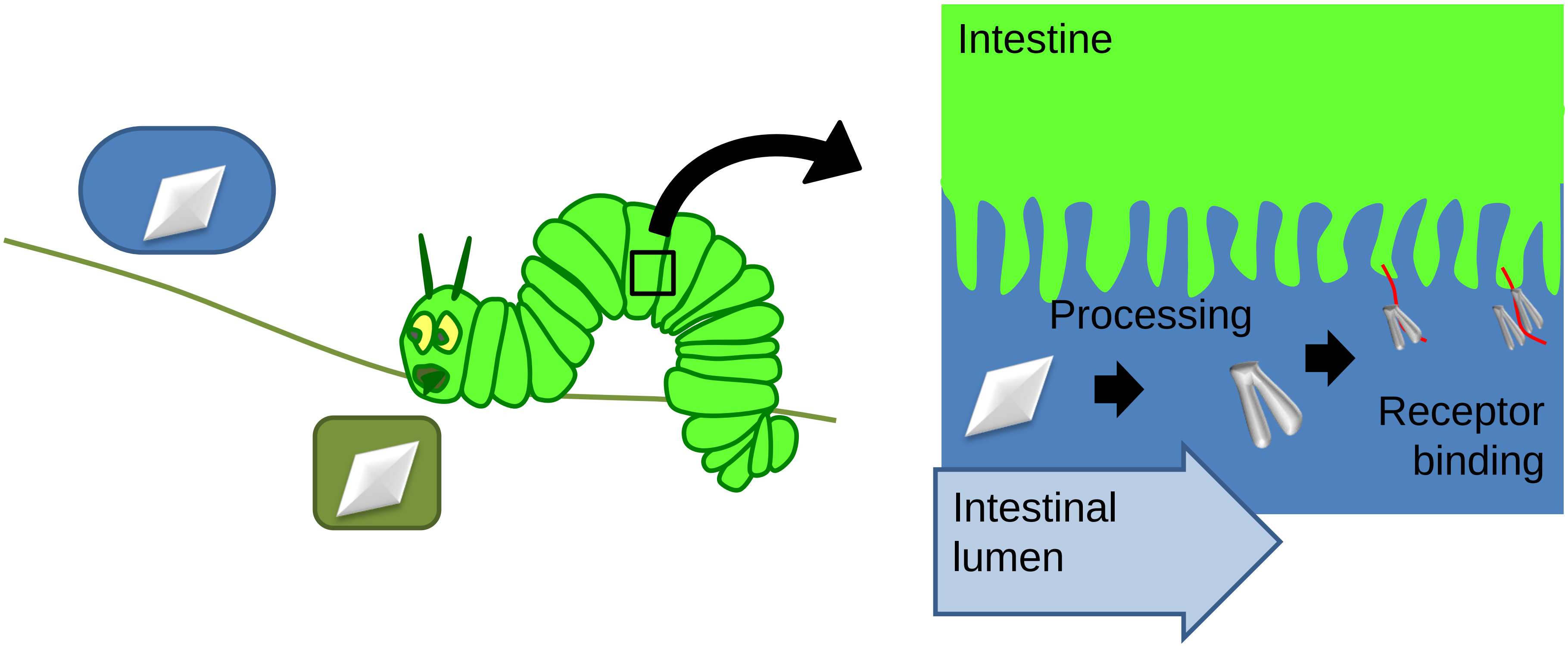
Bacillus thuringiensis (Bt) bacteria produce insecticidal proteins

Bacillus thuringiensis expressing insecticidal Bt toxin can be sprayed onto plants



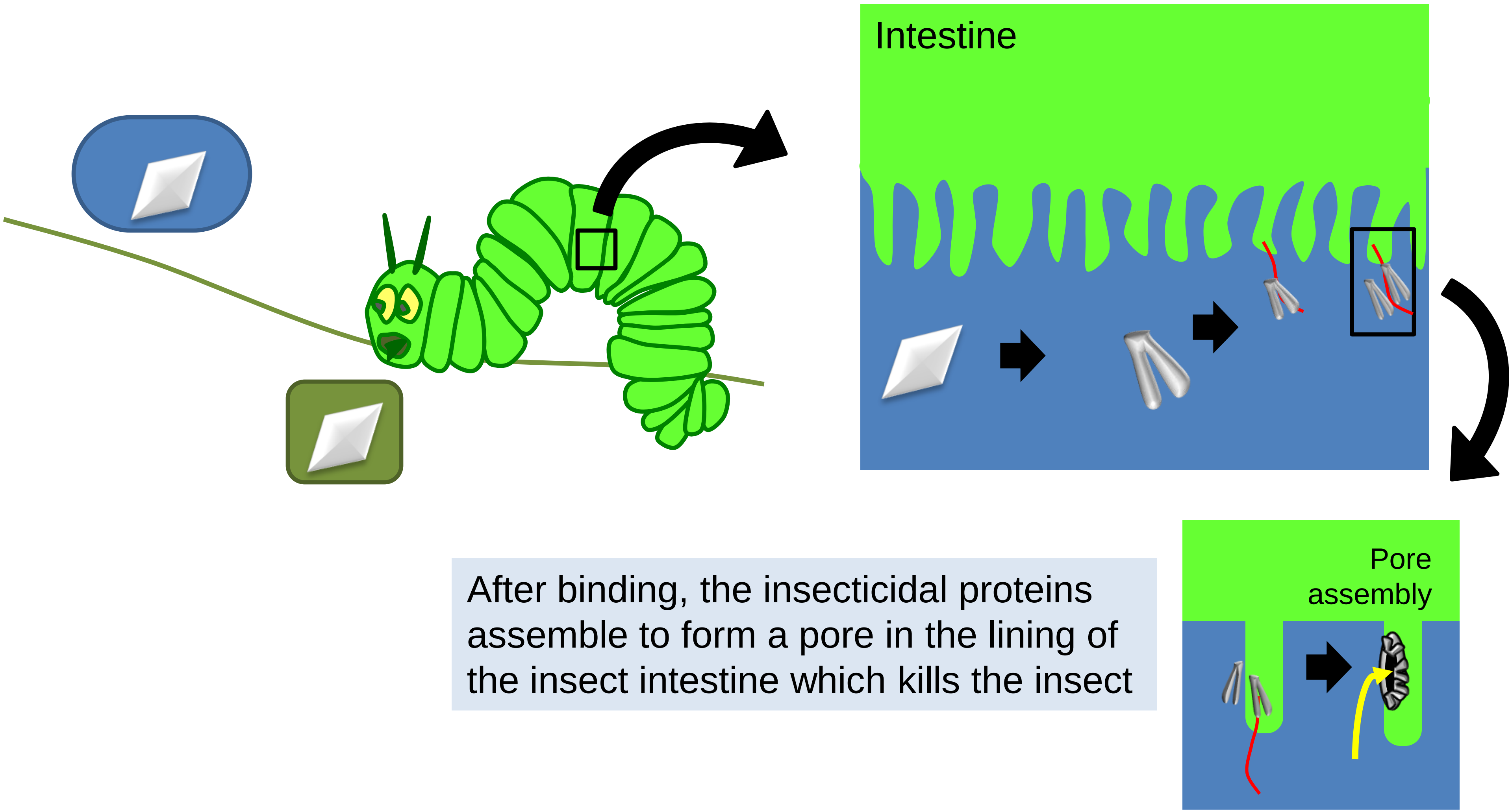
Or the plants can be engineered to express the *Bt* gene coding for Bt toxin

The effect of Bt toxin is highly specific



The Bt toxin affects only some insects because to be effective it has to be processed and bind to a specific receptor protein

The effect of Bt toxin is highly specific



After binding, the insecticidal proteins assemble to form a pore in the lining of the insect intestine which kills the insect

GM Example: Herbicide resistance

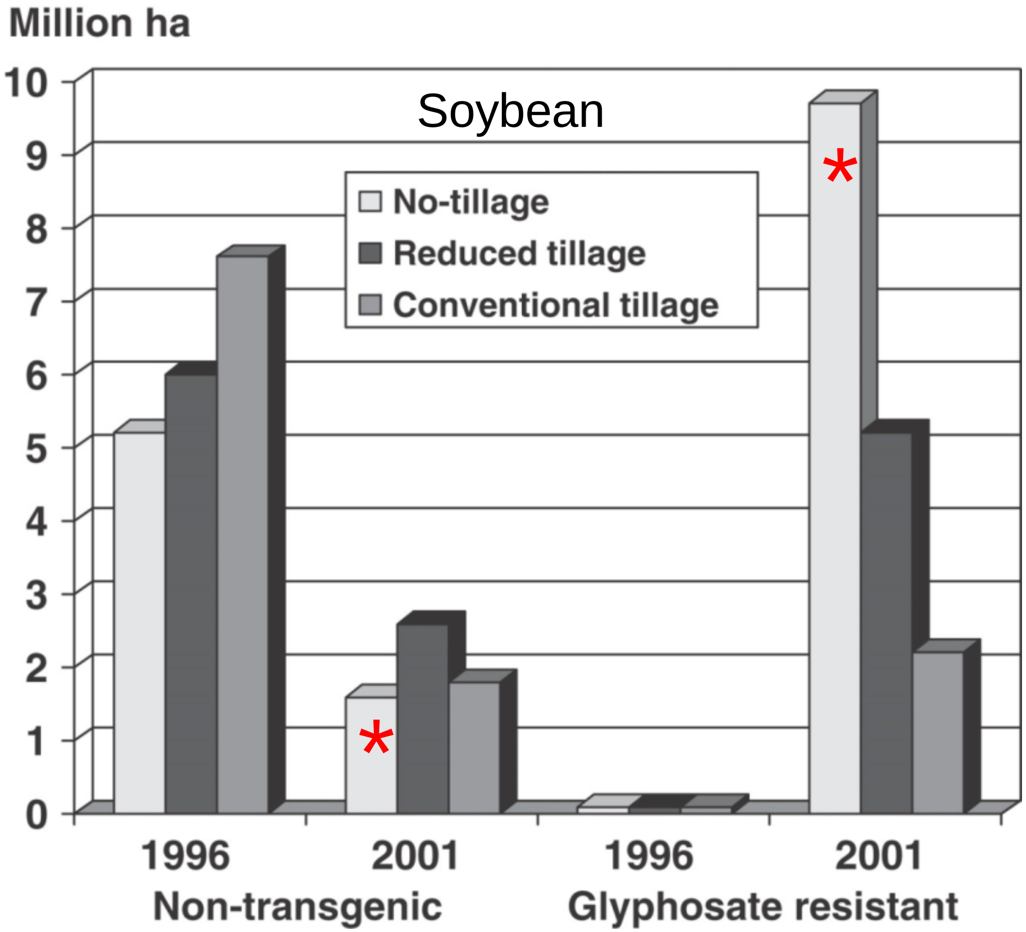
Plants compete with other plants for sunlight and nutrients. Many farmers use herbicides to eliminate weeds (undesired plants) from their fields.

Left – corn rows sprayed with herbicide to eliminate competing plants
Right – corn being choked by giant foxtail (*Setaria faberi*)

Photo credit: Doug Buhler, Bugwood.org

Herbicide tolerant plants are environmentally friendly

Farmers that plant herbicide-tolerant crop plants use *less herbicide*, herbicides that are *less toxic*, and *till (plow) less*, saving soil and fuel.



Cerdeira, A.L. and Duke, S.O. (2006). The Current Status and Environmental Impacts of Glyphosate-Resistant Crops. J. Environ. Qual. 35: 1633-1658. Photo credit Hunt Sanders, University of Georgia, bugwood.org.

Gene flow through pollen movement has to be monitored and controlled

There have been confirmed cases of gene transfer from crops to weeds and vice versa.

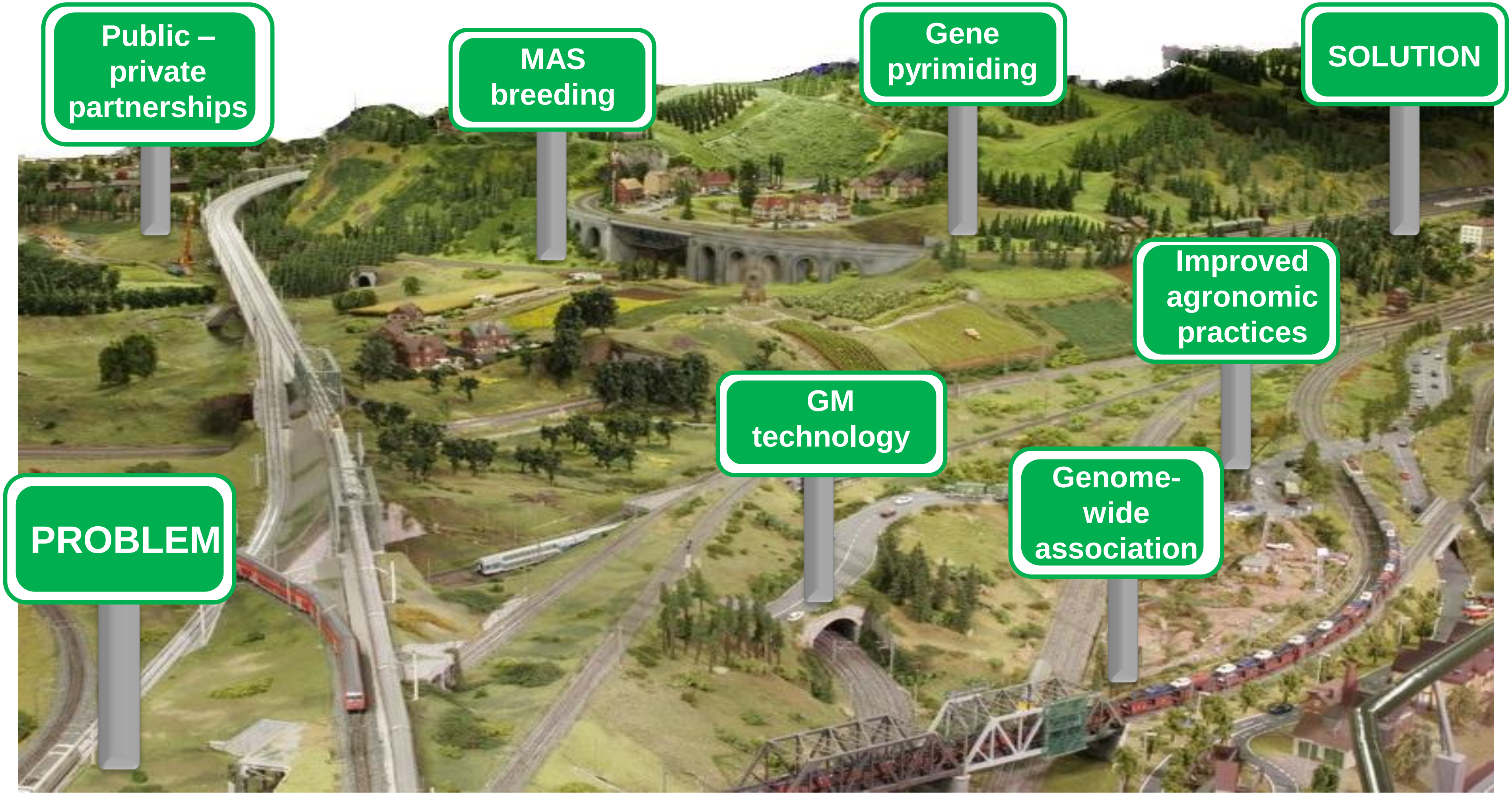
- What consequences are expected from gene flow?
- How can gene flow be minimized?
- How can consequences be mitigated?

Howard F. Schwartz, Colorado State University, Bugwood.org

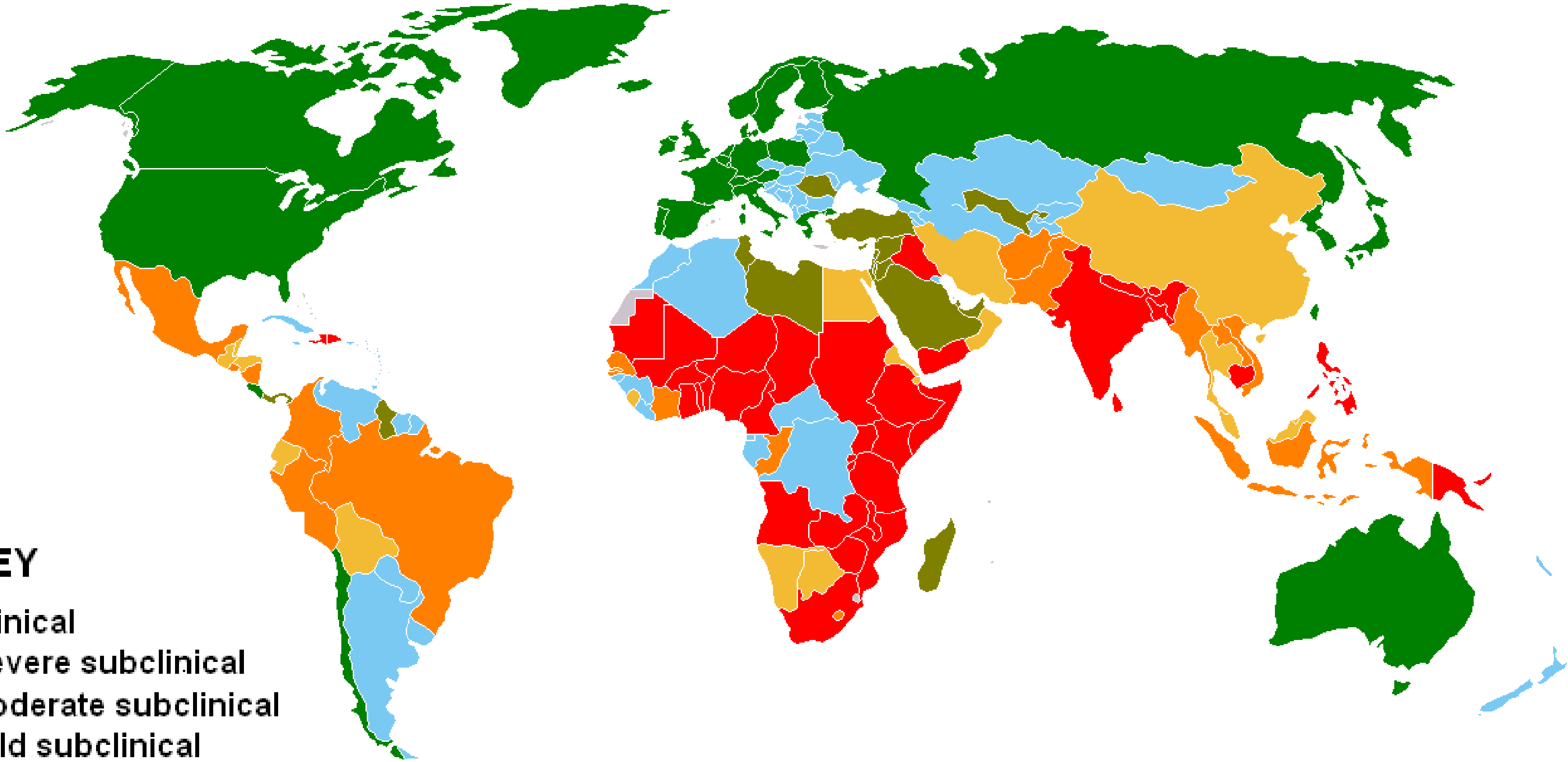
Future Challenges

Photo credit: IRRI

Breeders can use more than one technology to address a challenge



Breeding plants for β-carotene (pro-vitamin A) enrichment



KEY

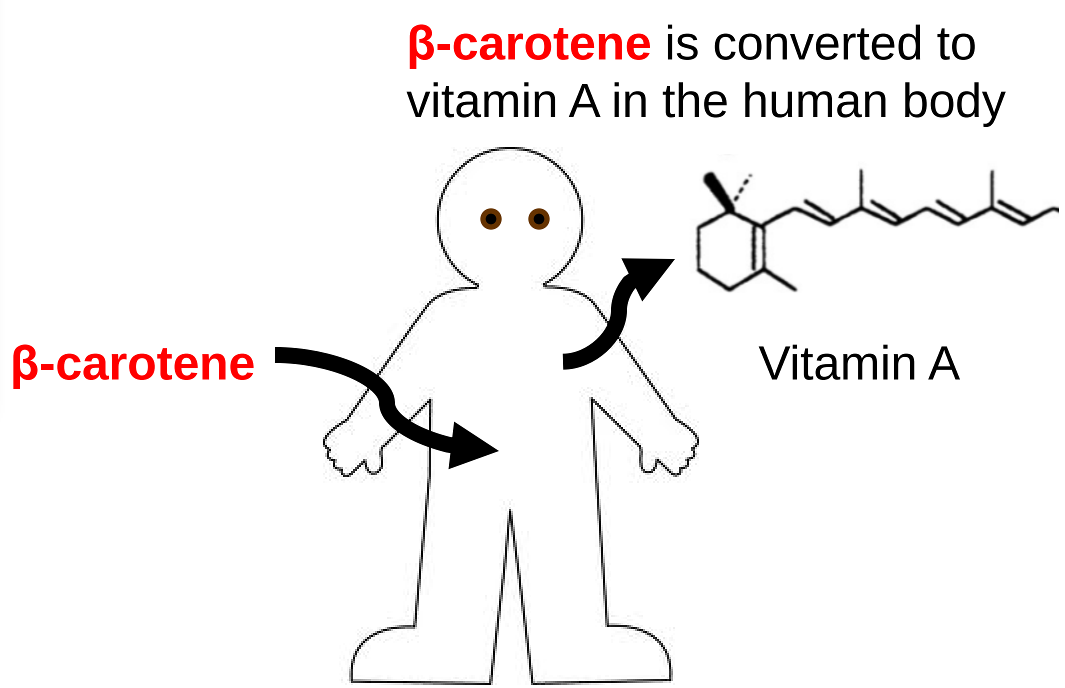
- Clinical
- Severe subclinical
- Moderate subclinical
- Mild subclinical
- VAD under control
- No data available

Vitamin A deficiency is a leading cause of blindness

Image sources: Petaholmes based on WHO data;

Enhanced β-carotene content in food can prevent vitamin A deficiency

•Many staple foods are poor sources of β-carotene so many people do not get adequate vitamin A in their diet



Synthesis, storage and breakdown all affect β-carotene content

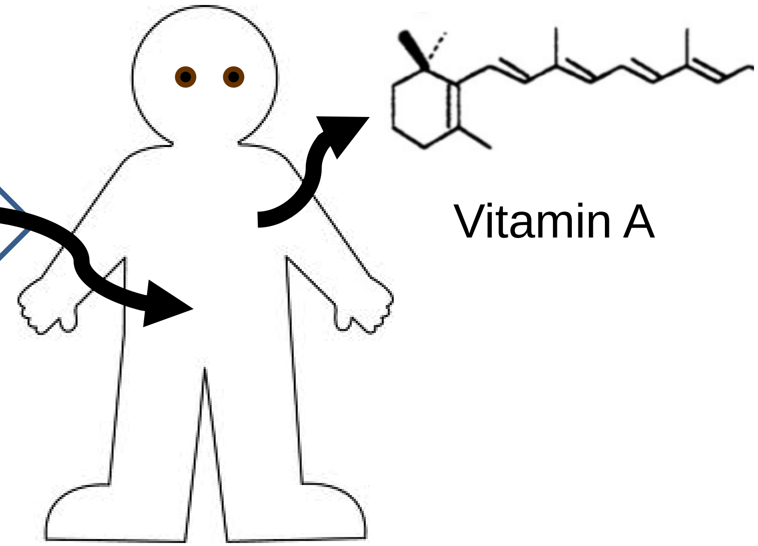
To increase beta-carotene levels in plants, you need **more synthesis, more storage** or **less catabolism**

Synthesis
GGPP
↓
phytoene
↓
lycopene
↓
β-carotene

← **Storage**

↓ **Catabolism or conversion to other forms**

Chromoplasts – organelles that store carotenoids

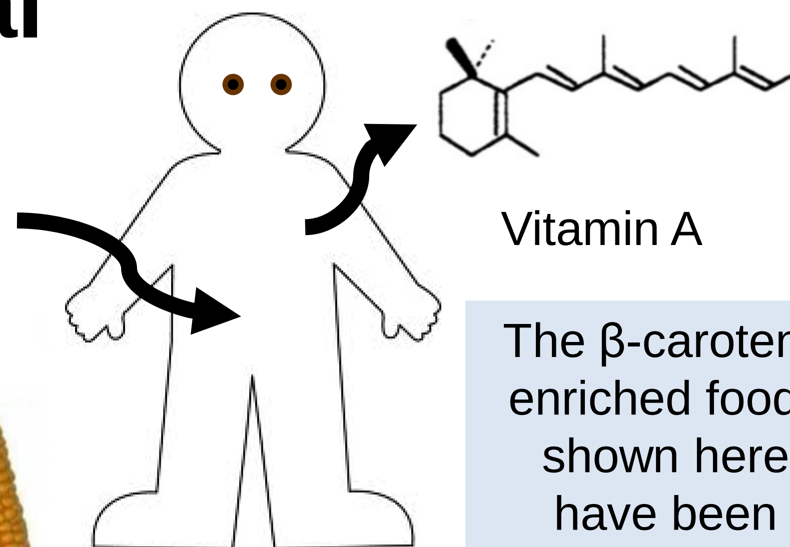


Vitamin A

β-carotene makes the rice look golden

There is no inherently right or wrong way to enhance plant nutritional quality

β-carotene



Vitamin A

The β-carotene enriched foods shown here have been produced using GM and non-GM approaches

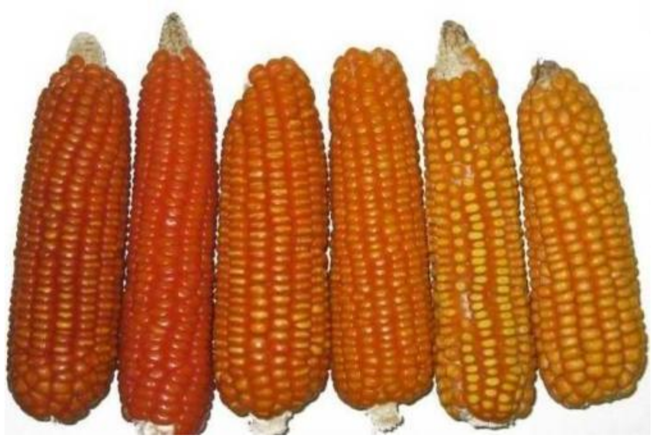


Photo credit: Golden rice humanitarian board

Biofortified plants are improving nutrition for many

HarvestPlus
Breeding Crops for Better Nutrition

The non-profit organization HarvestPlus focuses on the development of biofortified crops for the developing world, including a provitamin A enriched sweet potato that is currently being grown by **half a million** families. Other biofortification projects are underway to increase levels of protein, iron, zinc, antioxidants and other beneficial components in food.

Sources: HarvestPlus; CIMMYT

Breeding for drought tolerance

Water use efficiency is a complex trait that involves hundreds of genes

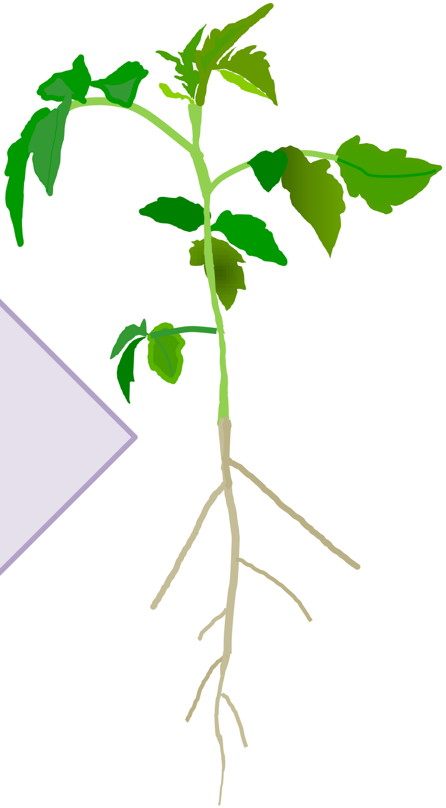
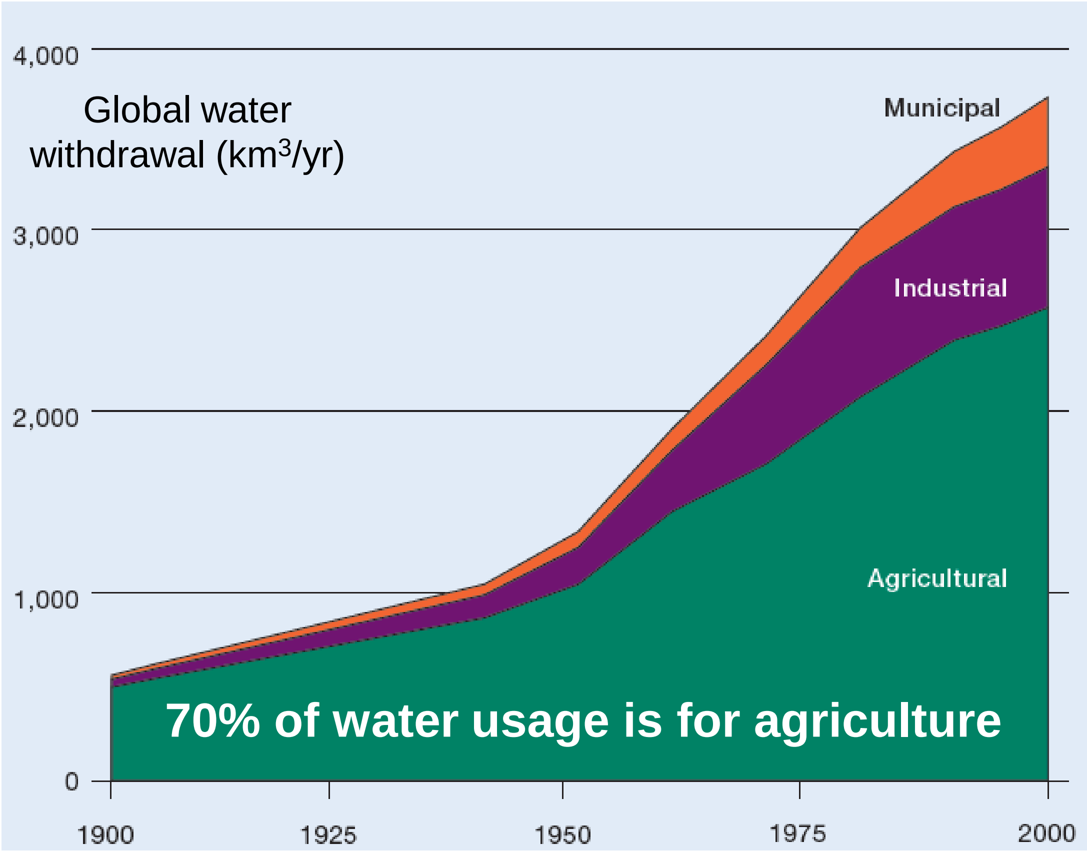


Photo credit: J.S. Quick, Bugwood.org

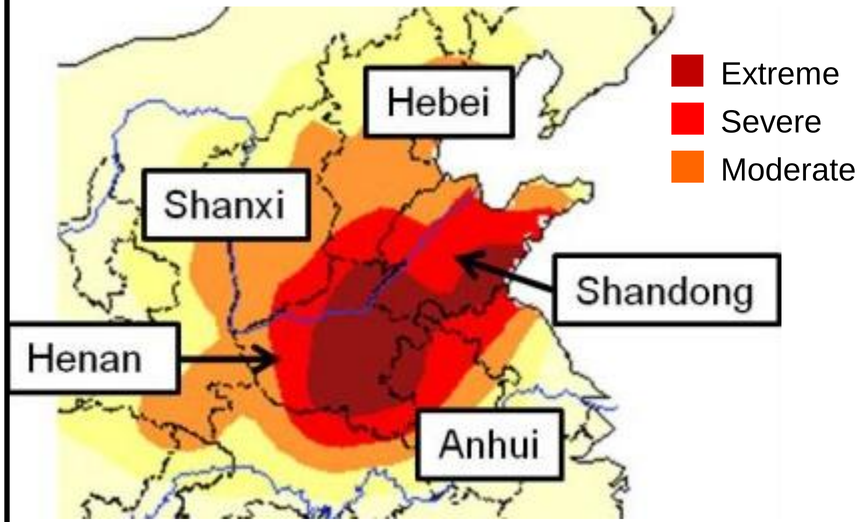
Food production for one person for one day requires 3000 liters of water



Comprehensive Assessment of Water Management in Agriculture. 2007. Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earthscan, and Colombo: International Water Management Institute.

The incidence of major droughts is on the rise

China experienced a major drought in 2011



Major droughts and heat waves in China, Russia and Australia have impacted food production and raised prices

Russia experienced heat waves, drought and wildfires in 2010

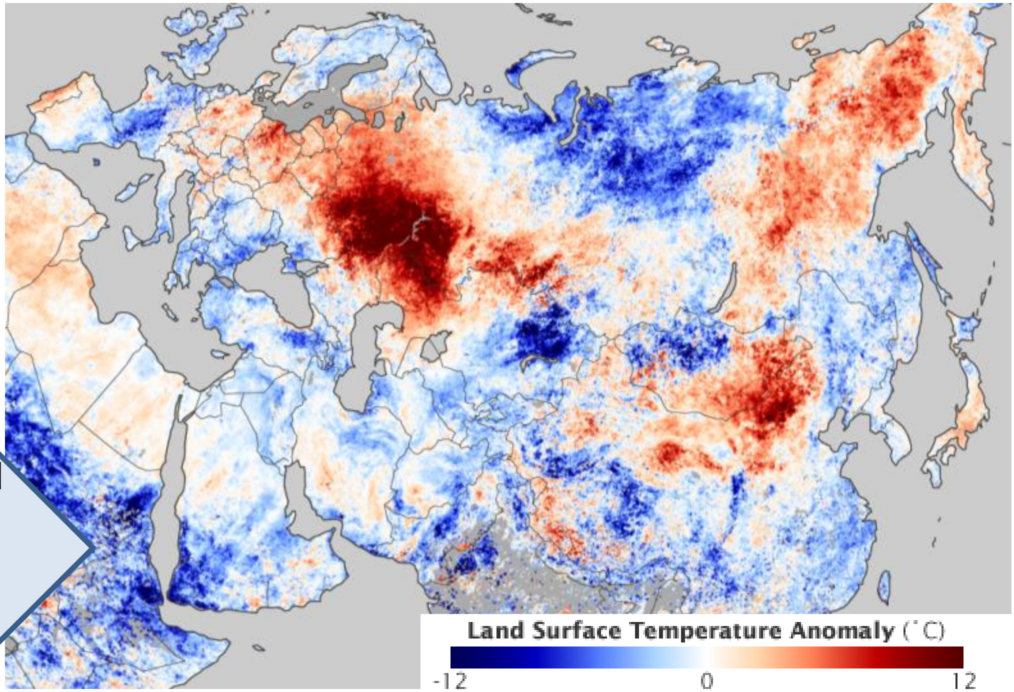


Image credits: USDA Foreign Agricultural Service; IRRI; NASA earth observatory

In 2011 seed companies released water-optimized corn

Both of these varieties were developed using modern molecular breeding methods without the use of recombinant DNA

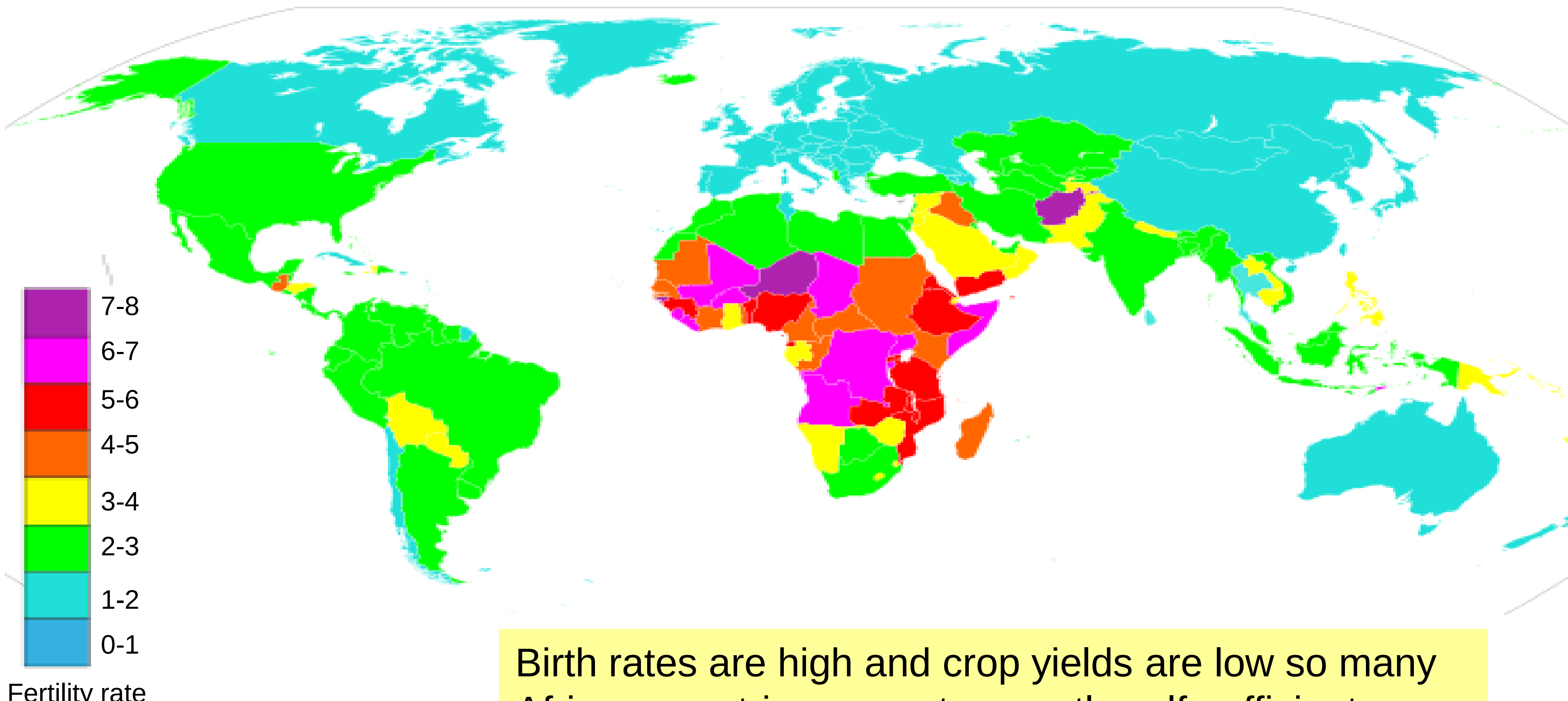
Agrisure Artesian

Optimum AQUAmax™

syngenta

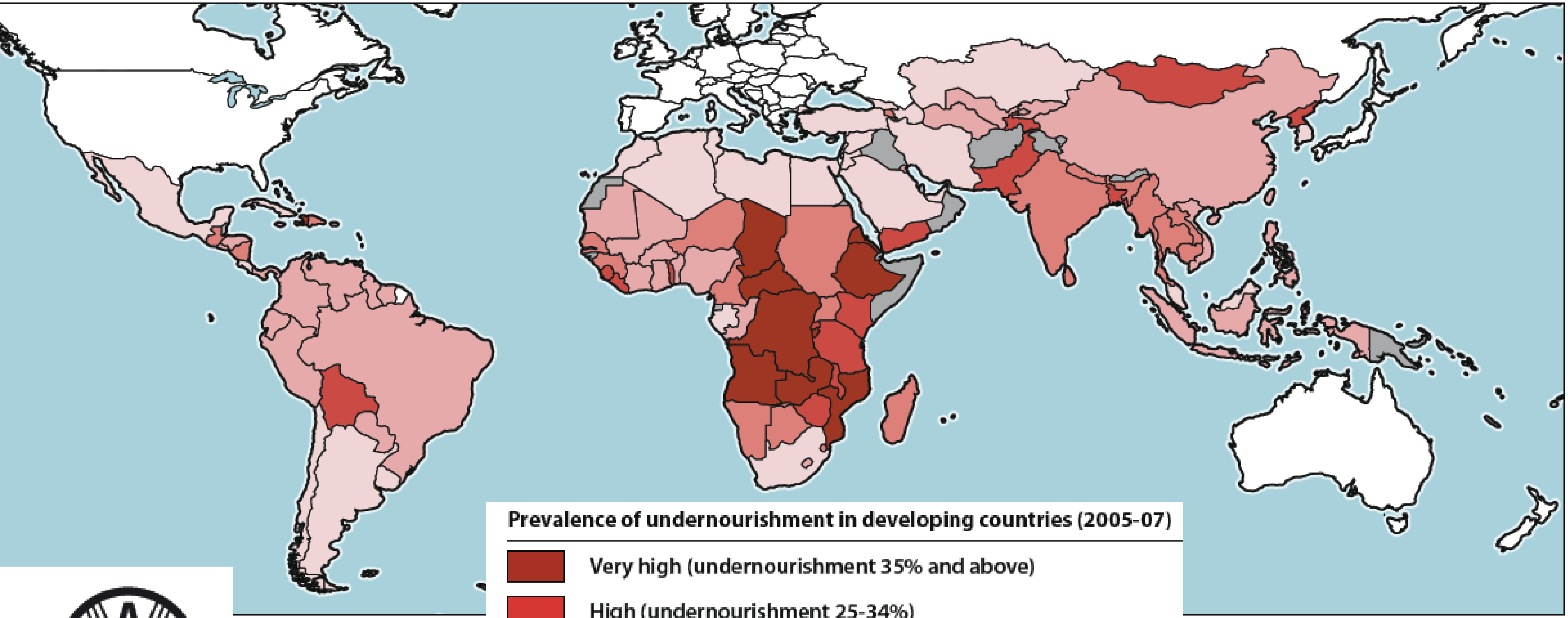
PIONEER

Agricultural innovation in Africa – breeding crops for sub-Saharan Africa



Birth rates are high and crop yields are low so many African countries are not currently self-sufficient

Many African countries experience a very high rate of undernourishment



Prevalence of undernourishment in developing countries (2005-07)

- Very high (undernourishment 35% and above)
- High (undernourishment 25-34%)
- Moderately high (undernourishment 15-24%)
- Moderately low (undernourishment 5-14%)
- Very low (undernourishment below 5%)
- Missing or insufficient data

www.fao.org

Source: FAOSTAT

The challenges to food production in Africa are immense

- Lack of infrastructure, especially irrigation and access to transportation networks
- High incidence of diseases
- Lack of available fertilizers
- Lack of education and support for farmers
- Lack of economic supports and market stability
- Agricultural subsidies in other countries affect market value

Maize is a staple crop in Africa but very sensitive to drought damage

Less than 10% of crop land in sub-Saharan Africa is irrigated, making agriculture production highly susceptible to drought

Irrigation as percentage of cultivated area

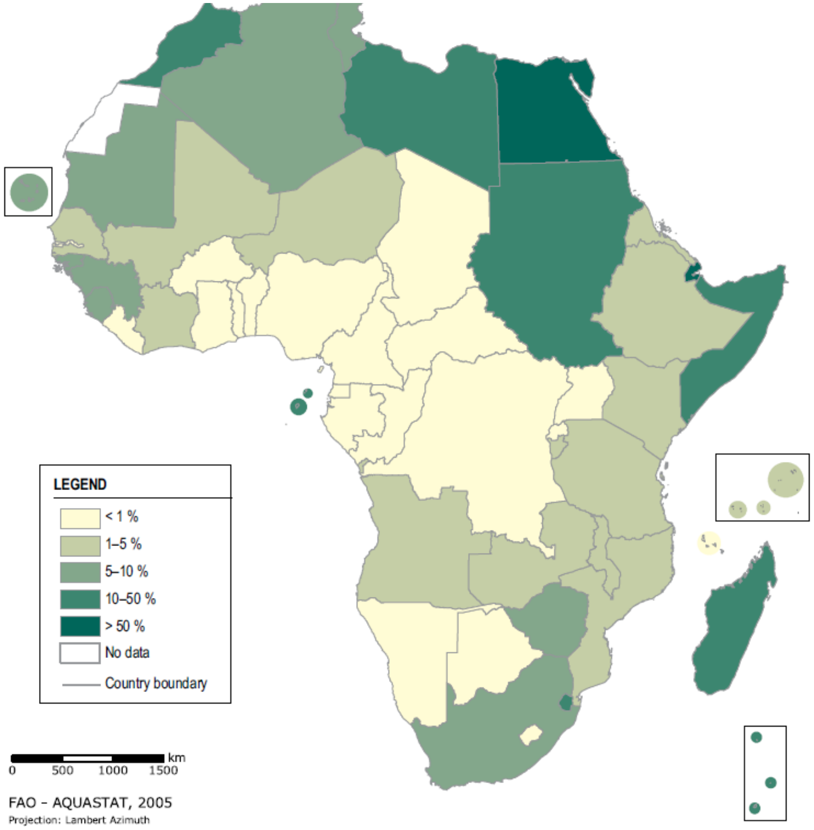


Photo credit: Anne Wangalachi/CIMMYT Map Source – FAO Aquastat 2005

As a consequence of climate changes, droughts are expected to increase

In some African countries, yields from rain-fed agriculture, which is important for the poorest farmers, ***could be reduced by up to 50% by 2020***.

-(FAO 2010)

Drought events per country from 1970 to 2004 within Sub-Saharan Africa

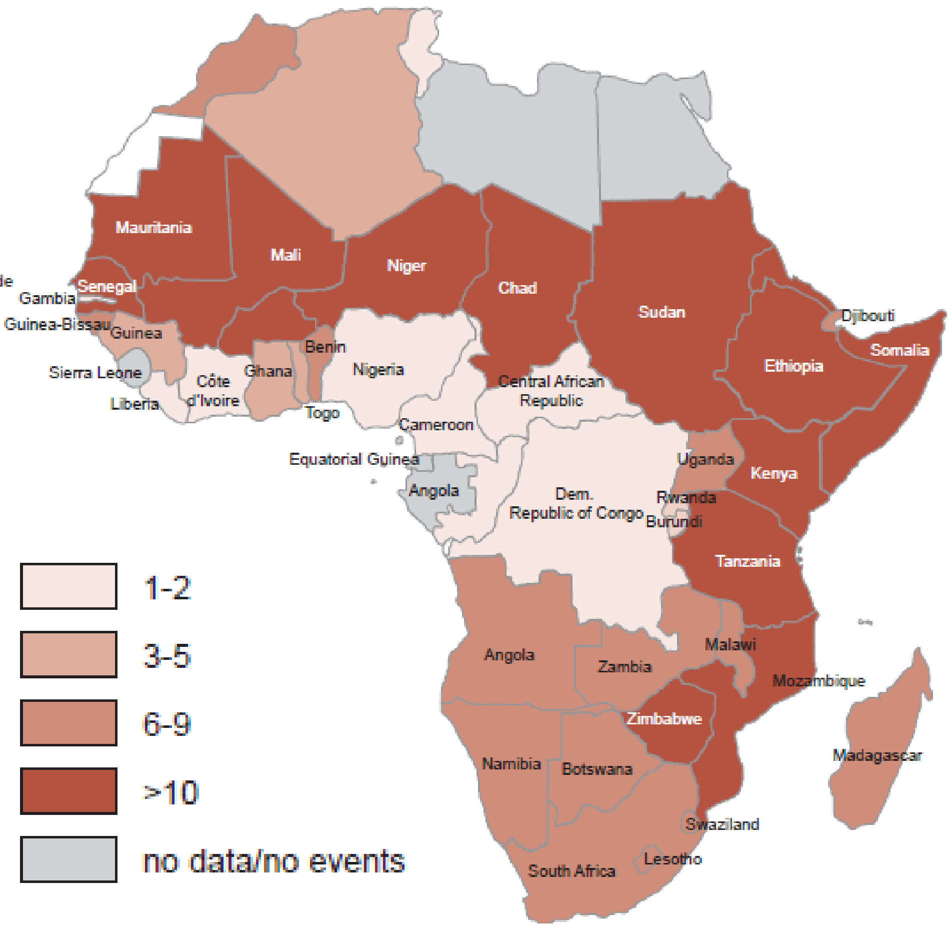


Image credit: United Nations Economic Commission for Africa, 2008 *Africa Review Report on Drought and Desertification*

Water Efficient Maize for Africa was developed through a public-private partnership

Water-efficient maize optimized for growth in sub-Saharan Africa has been developed through a combination of breeding and GM methods

AFRICAN AGRICULTURAL TECHNOLOGY FOUNDATION
FONDATION AFRICAINE POUR LES TECHNOLOGIES AGRICOLES

CIMMYT

BILL & MELINDA GATES foundation

MONSANTO

THE HOWARD G. BUFFETT FOUNDATION

WEMA is being developed as a public-private partnership that includes international and regional plant breeding institutes, philanthropic groups and Monsanto

Photo credits: Anne Wangalachi/CIMMYT

Plant breeding can support African agriculture

African farmers need access to high yielding, drought tolerant, disease resistant plants. Most food is grown by small-scale farmers with little mechanization. Cassava, cowpea and banana are important crops and the focus of intensive breeding programs.

Photos courtesy if IITA

African governments are working together to support agriculture

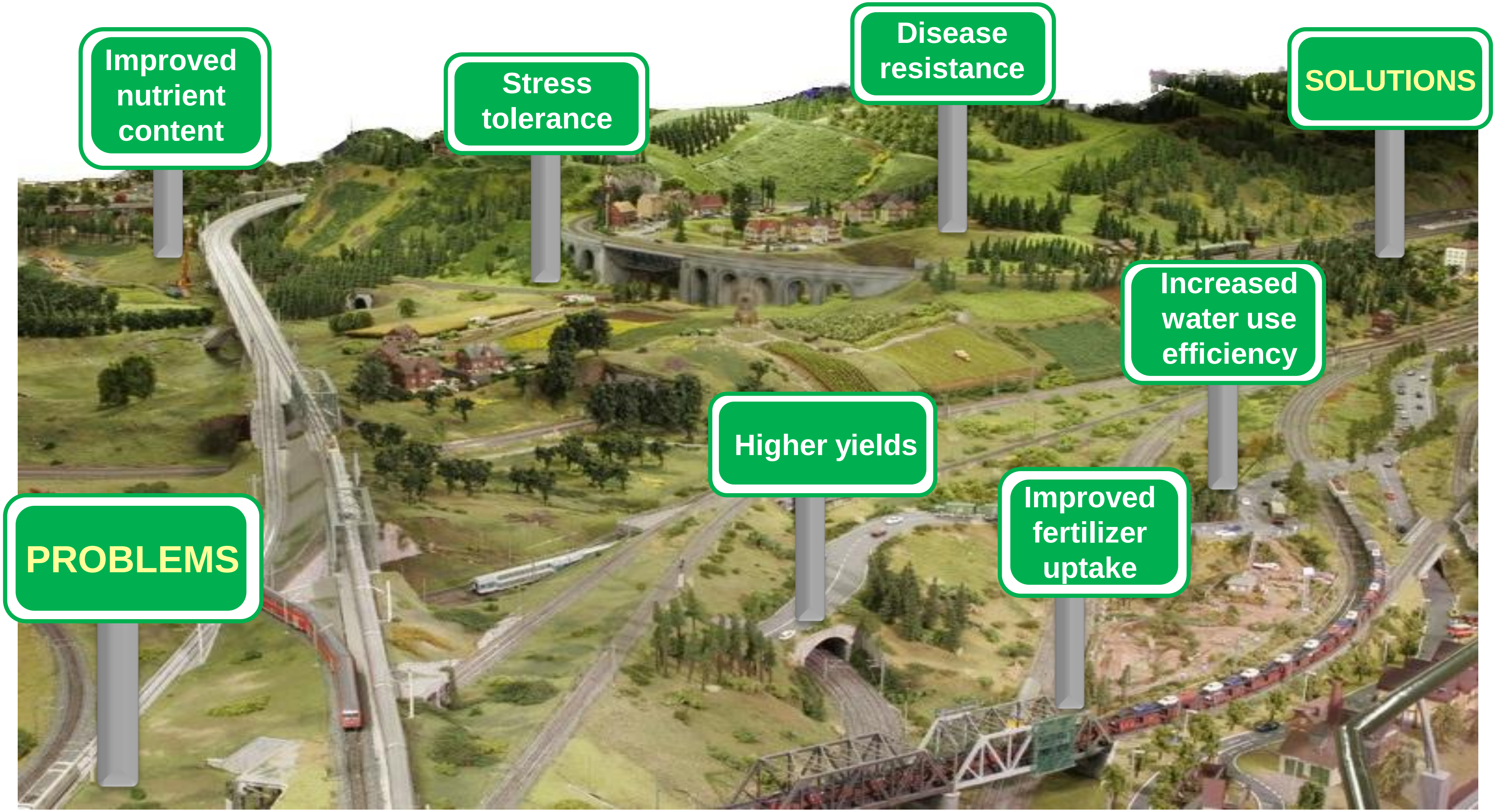
Alliance for a Green Revolution in Africa

"*AGRA is a dynamic, African-led partnership working across the African continent to help millions of small-scale farmers and their families lift themselves out of poverty and hunger*".
A major thrust of these efforts is to develop Africa's human capacity through education, innovation and technology transfer.

Source: AGRA

In the next 50 years, we will have to produce as much food as we have yet produced in human history

We have many paths to follow



Breeding crops for a second green revolution

Good Genes

Many people are calling for a second green revolution, to develop plants that minimize environmental degradation while enhancing human health.

Advances in genetics make that possible.

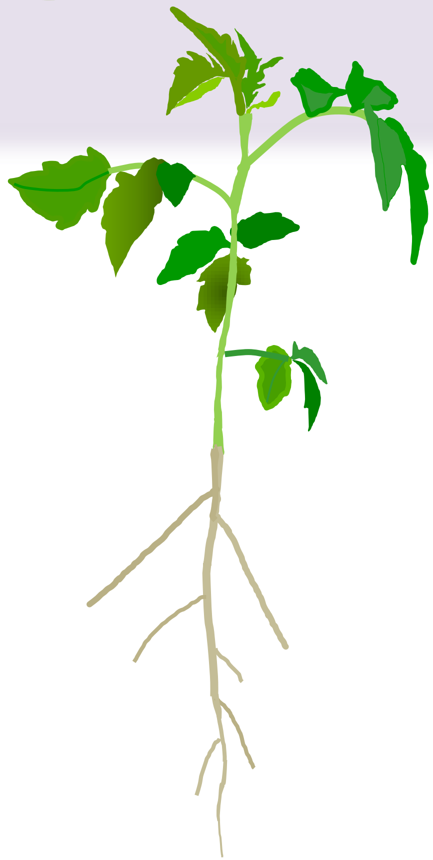


Photo credit: IRRI

Questions

What risk assessments are performed on GM crops?

Before release into the environment, GM crops are subject to risk-assessment and risk-management measures to evaluate:

- Risks to human health (including toxicity and allergenicity)
- Risks of evolution of resistance in target pathogens or pests
- Risks to non-target organisms
- Risks from movement of transgenes

Will genes from GMOs contaminate wild populations?

John William Waterhouse: Pandora - 1896

Pollen can move DNA between plants. To minimize this possibility, GM crops have to be grown prescribed distances away from closely related plants. Technological methods to reduce this risk are being developed.

Will anti-insecticidal genes harm unintended targets?

The evidence shows that the planting of GE crops has largely resulted in less adverse or equivalent effects on the farm environment compared with the conventional non-GE systems that GE crops replaced (National Academies 2010)

Image credit jons2

Will GMOs take away choice and exploit small farmers?

> 45% of corn yields are often lost to insects

Partnerships including national agricultural research institutions, non-government and community-based organizations, regional research networks, and private companies work together to develop seeds that are suited to local conditions and are affordable for local farmers

Photo credit: CIMMYT.

Are GM crops safe to eat?

YES

All GM plants are subject to extensive testing and regulatory oversight and no detrimental health effects have been identified

Bt corn is less prone contamination by fungi which produce toxins linked to cancer and birth defects

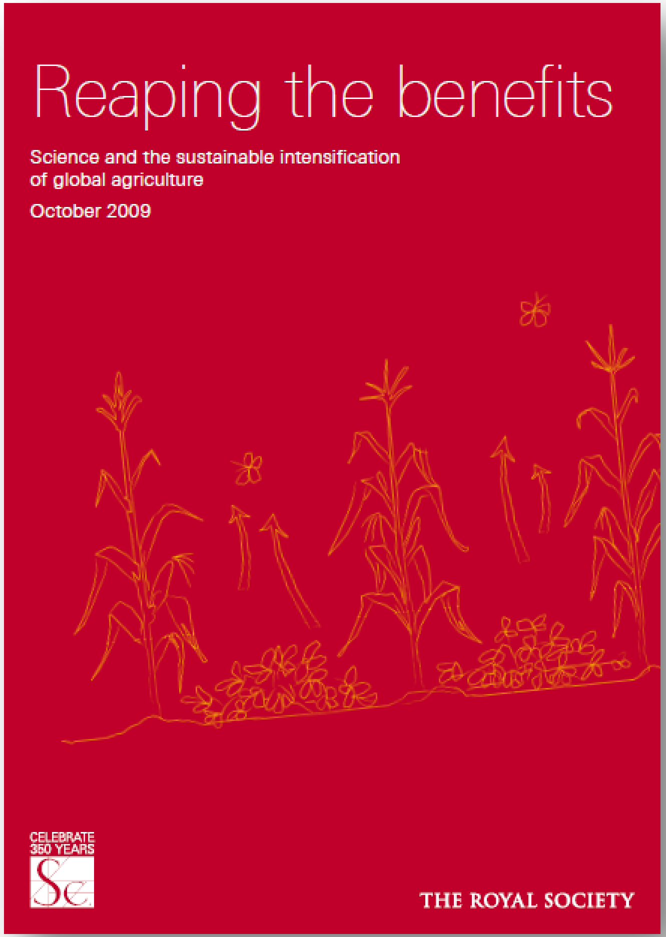
GM biofortification can ensure that *all* children get adequate levels of protein, vitamins and mineral nutrients.

GM is a safe and beneficial tool in the quest to sustainably feed the growing population

Photo credit: Neil Palmer/ CIAT

Scientists worldwide endorse GM as an important tool for breeding

“Both genetic improvement and better crop management are vital and both should be resourced in parallel.” - 2009



“The ASPB believes strongly that, with continued responsible regulation and oversight, GE will bring many significant health and environmental benefits to the world and its people.” - 2006