Making crops more resilient to environmental change

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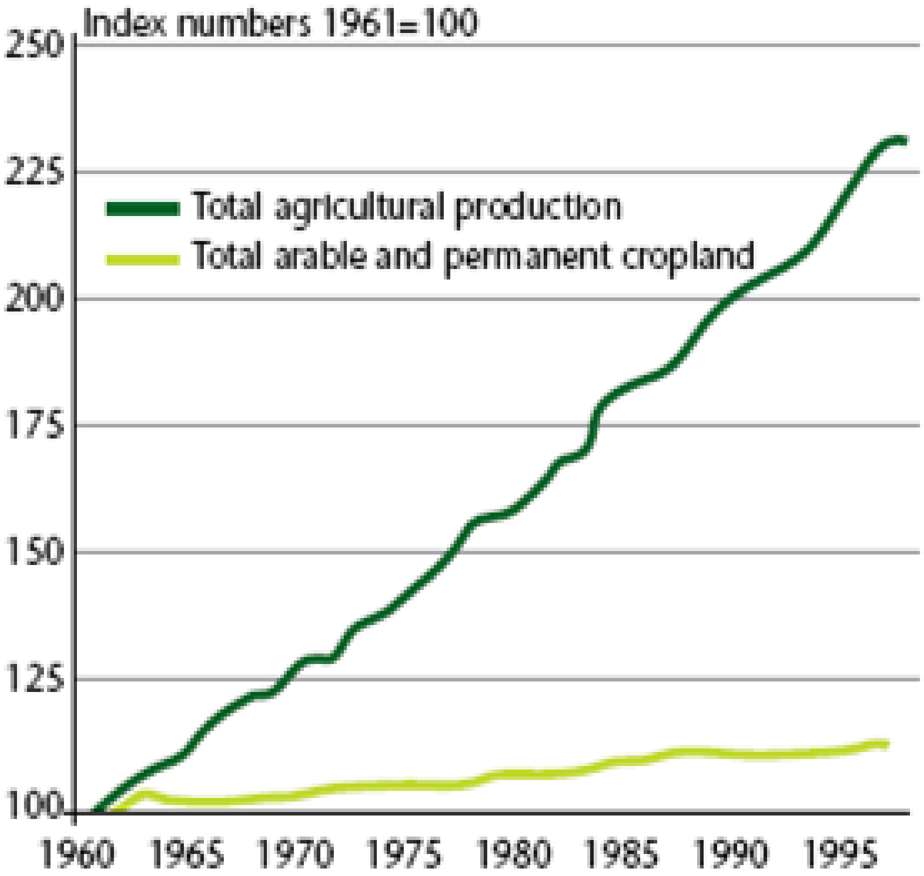
www.cnap.org.uk

An agricultural technology timeline

Technology	Era	Genetic interventions
Traditional	About 10 000 years BC	Civilizations harvested from natural biological diversity, domesticated crops and animals, began to select plant materials for propagation and animals for breeding
	About 3 000 years BC	Beer brewing, cheese making and wine fermentation
Conventional	Late nineteenth century	Identification of principles of inheritance by Gregor Mendel in 1865, laying the foundation for classical breeding methods
	1930s	Development of commercial hybrid crops
	1940s to 1960s	Use of mutagenesis, tissue culture, plant regeneration. Discovery of transformation and transduction. Discovery by Watson and Crick of the structure of DNA in 1953. Identification of genes that detach and move (transposons)
Modern	1970s	Advent of gene transfer through recombinant DNA techniques. Use of embryo rescue and protoplast fusion in plant breeding and artificial insemination in animal reproduction
	1980s	Insulin as first commercial product from gene transfer. Tissue culture for mass propagation in plants and embryo transfer in animal production
	1990s	Extensive genetic fingerprinting of a wide range of organisms. First field trials of genetically engineered plant varieties in 1990 followed by the first commercial release in 1992. Genetically engineered vaccines and hormones and cloning of animals
	2000s	Bioinformatics, genomics, proteomics, metabolomics

Source: Adapted from van der Walt (2000) and FAO (2002a).

Four innovations brought about the change in agriculture and increased yield in the twentieth century



- Productivity steadily increased with only a 10% increase in land use :
  - Mechanisation and irrigation
  - Synthetic fertilisers
  - Crop protection chemicals
  - Plant Breeding and Genetics-
    the 'Green revolution'
- **The effect of these four innovations was to allow more food to be produced from less land and keep pace with a doubling of the population since 1960**
- **The developed world became complacent!!**
- **What are the innovations which will change agriculture in this century?**





Food supply must match demand

We face a “perfect storm” of food insecurity:
by 2030, we need >50% more food,
from ~ same land,
with less water, and more expensive energy,
and with climate change (Beddington, 2009)

Increasing crop yields will be difficult, and requires major investment

We need every tool in the toolbox

The scientific basis of crop improvement is identification of the genes that encode and regulate specific phenotypic characteristics or traits of use to the farmer.

REDUCED STRESSES
Biotic and Abiotic

- Pests and Diseases
- Weeds
- Saline or acid soils
- Increased greenhouse gases- Tolerance to climate change
- Drought or Flooding
- High or low Temperature
- Phyto-remediation

MORE SUSTAINABLE PRODUCTION

Environment

Plant Gene Technology

IMPROVED PLANT PERFORMANCE

- Nutrient use efficiency
- Water use efficiency
- Control of flowering
- Plant architecture
- Heterosis
- Yield

IMPROVED NUTRITION AND HEALTH

Quality Traits

- Vitamins & Minerals
- Biofortification
- Post harvest quality
- Taste
- Proteins
- Oils and Fats - PUFAs
- Carbohydrates
- Fibre & Digestible energy
- Bloat Safety

NEW INDUSTRIES

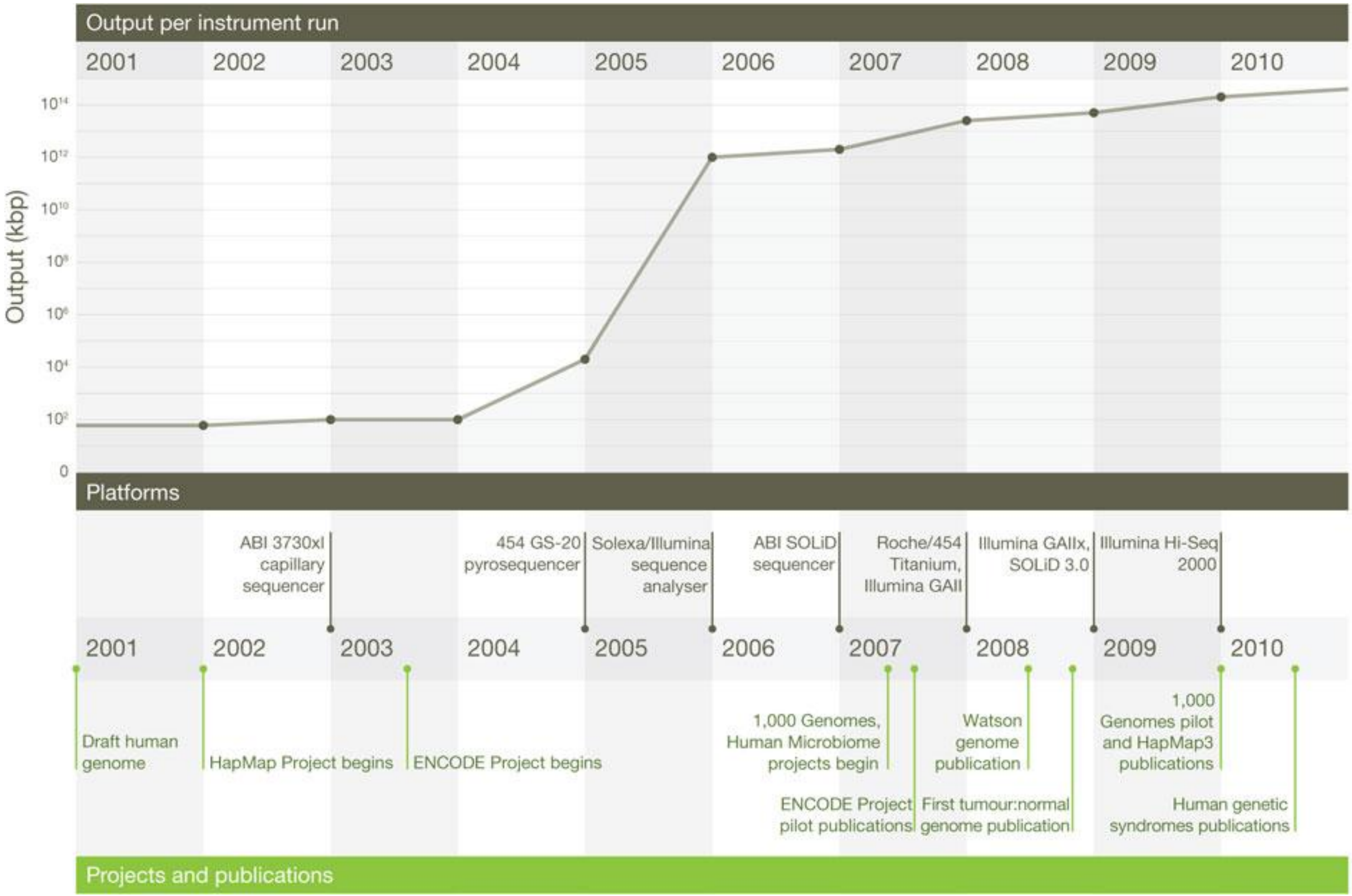
CHEMICAL FEEDSTOCKS

- Biodegradable Plastics
- Biofuels

PHARMACEUTICALS

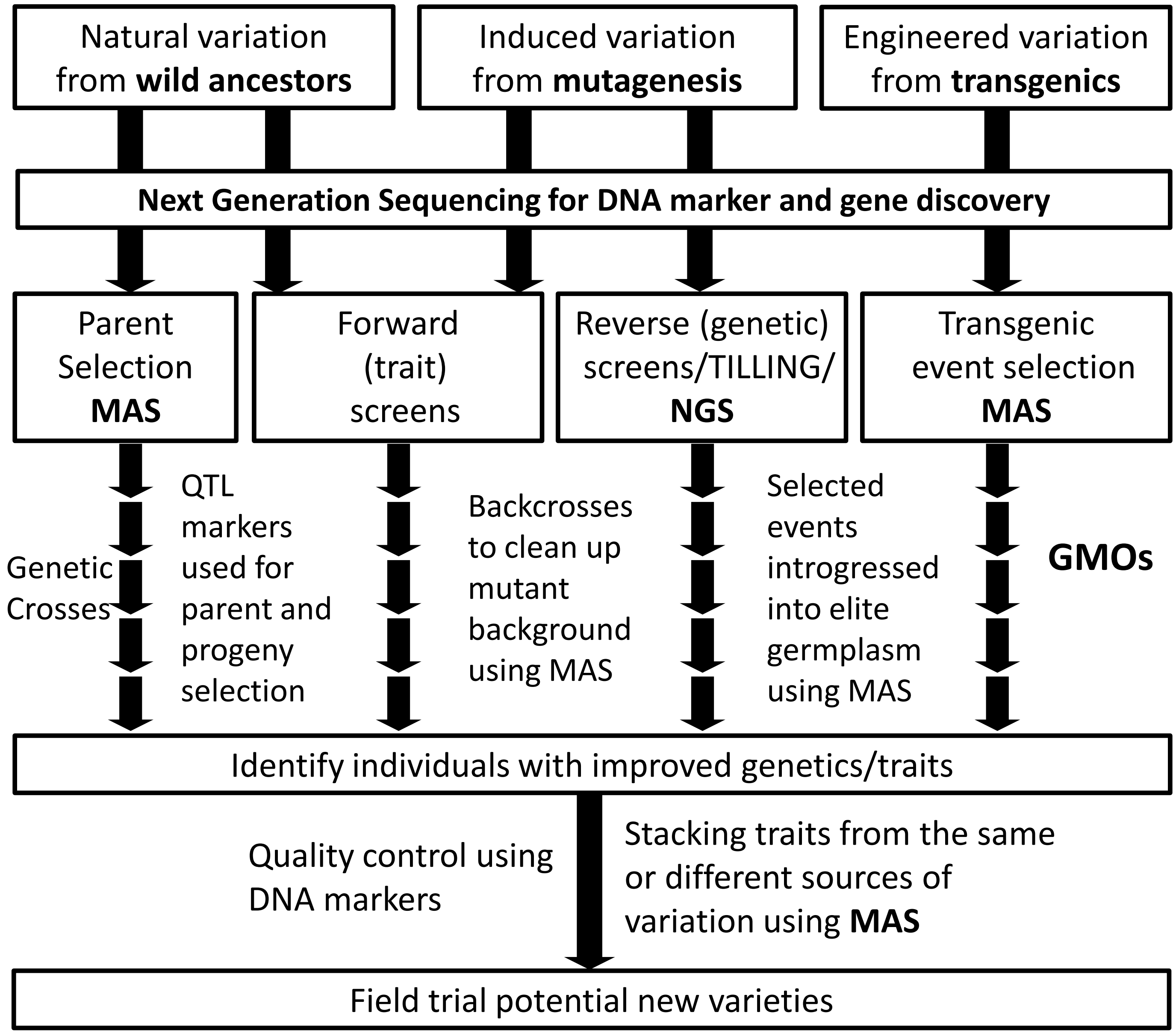
- Drugs
- Vaccines
- Antibodies
- Diagnostics

Step change in DNA sequencing technologies in the last decade has lowered the barrier for development of tools for trait improvement in any crop



ER Mardis. *Nature* **470**, 198-203 (2011)

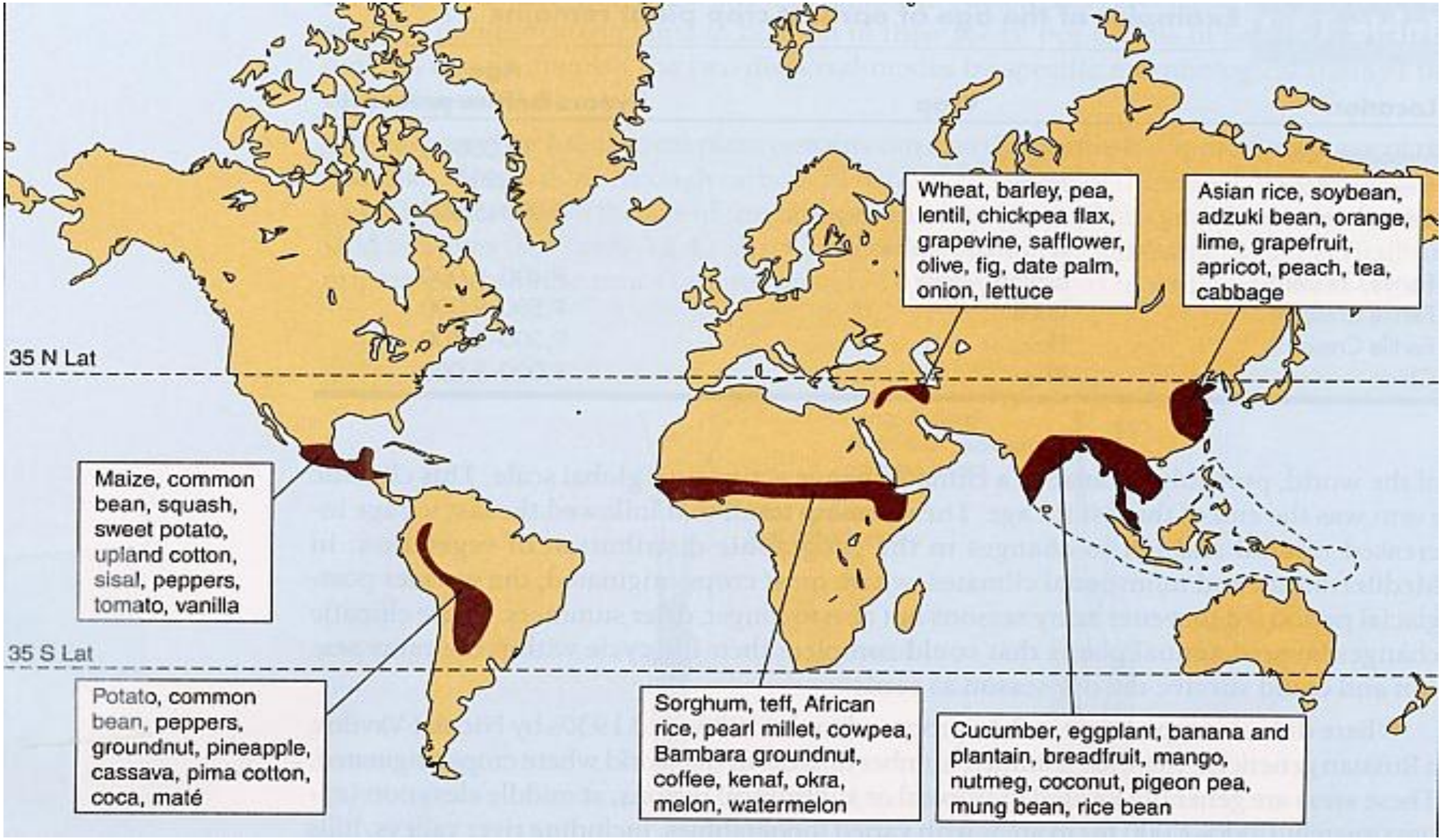
Knowledge translation - Molecular Plant Breeding



GMOs in the context of plant breeding

- From 1930–2007 more than 2540 mutagenic derived plant varieties have been released, 75% of which are crops (Schouten and Jacobsen, 2007).
- Conventional and mutation breeding can introduce hundred to thousands of uncharacterised changes in DNA, many of which remain in the final product
- Not aware of any biosafety problem caused by an induced mutation of a released variety in last 80 years
- Common thorough evaluation of induced mutants at the phenotypic level by plant breeders has been sufficient
- GMO crops are required to go over much higher hurdles for regulatory approval – necessary with respect to foreign protein impact on food safety and environmental impact
- However, costs can be prohibitive and politics plays a big part in final approval
- Public acceptance dominated by perceived risks in absence of personal benefits

Map of the world showing the major centres of origin of crops, distributed mainly in tropical regions

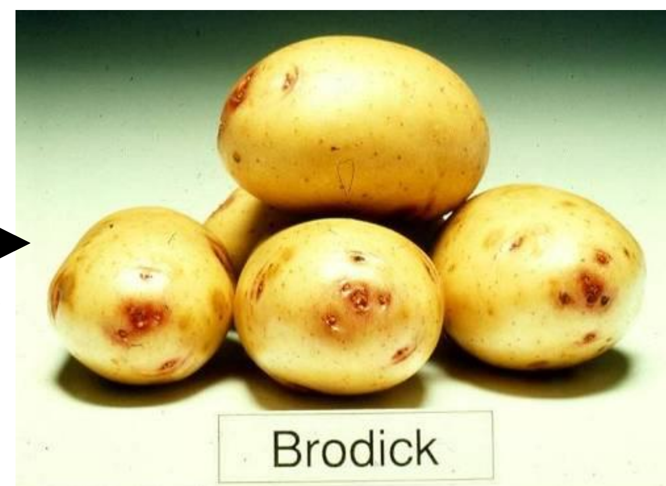


Products of Conventional Breeding

Tomatoes

Peppers

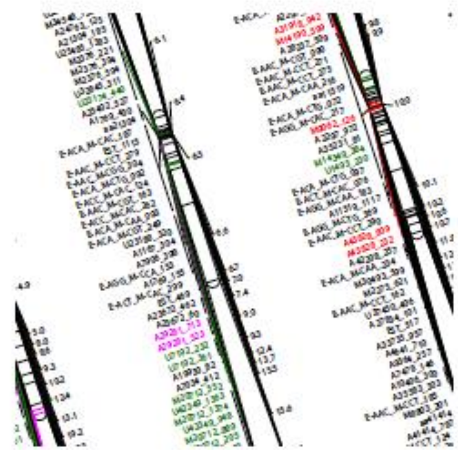
Potato



Marker Assisted Breeding

Molecular markers are DNA sequences that lie so close to the locus/gene responsible for a trait of interest that they are usually inherited along with it.

They are reliable DNA indicators that a plant carries the gene for the trait of interest



Because they are easily detected in young plants, molecular markers can be predictive as regards mature plant performance

They greatly speed up the plant breeding process because multiple markers can be selected for in parallel

Trait Stacking with markers: a new tool for forward breeding

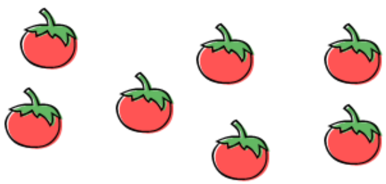
Example: Tomato breeder initiates ~12 new crosses for a target market; each cross segregates for three disease resistances

Old way:

100 F2 seeds

X 12 pops

Grow 100 plants and select 7 based on fruit size



select based on first resistance marker

select based on second marker

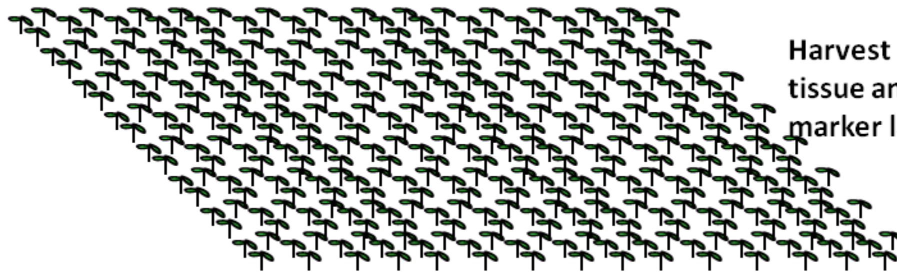
None of the selections from any of the 12 populations contain triple resistance

Outcome: 4.2×10^{-13} Probability of Success

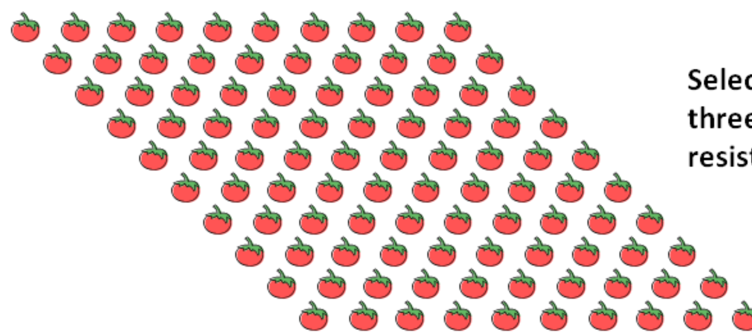
New way:

6,400 F2 seeds

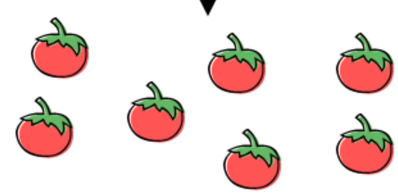
X 12 pops



Harvest seedling tissue and send to marker lab



Select 100 with all three disease resistance



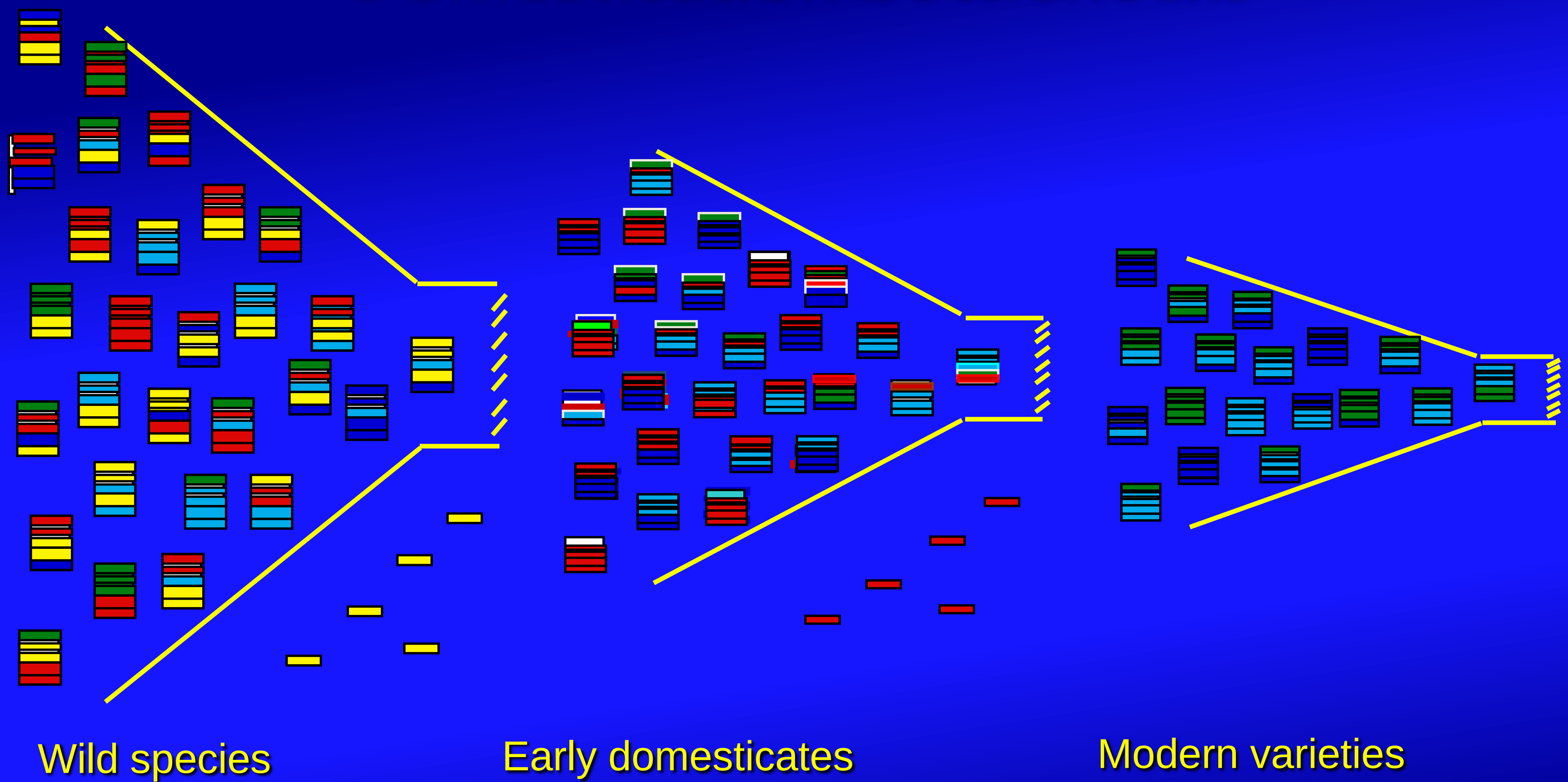
Grow F3 and select 7 from each population based on fruit size – all have triple resistance!

Outcome: 98% Probability of Success

Professor Harry Klee, University of Florida

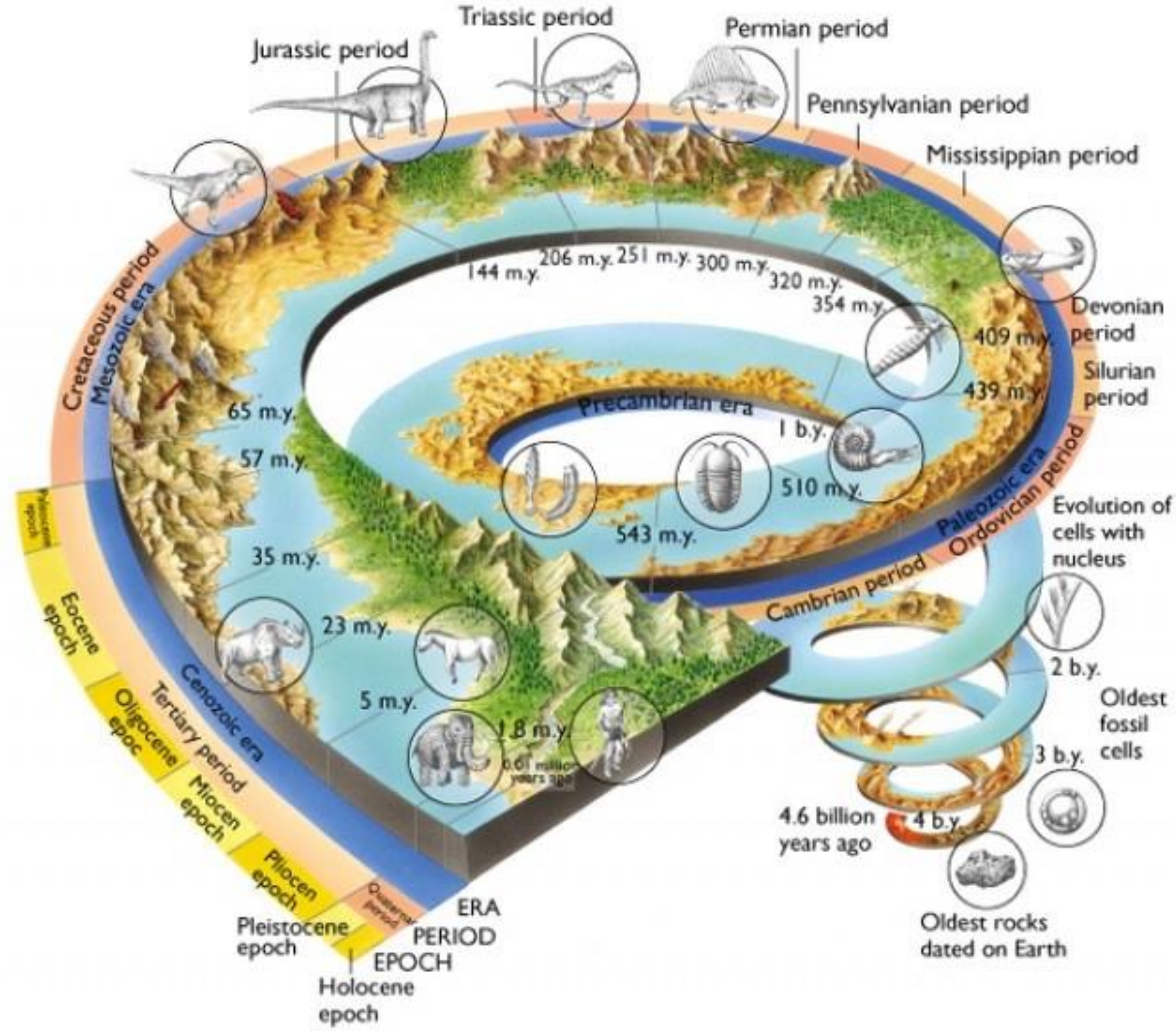
Where do we look for novel genetic variation?

Domestication bottlenecks

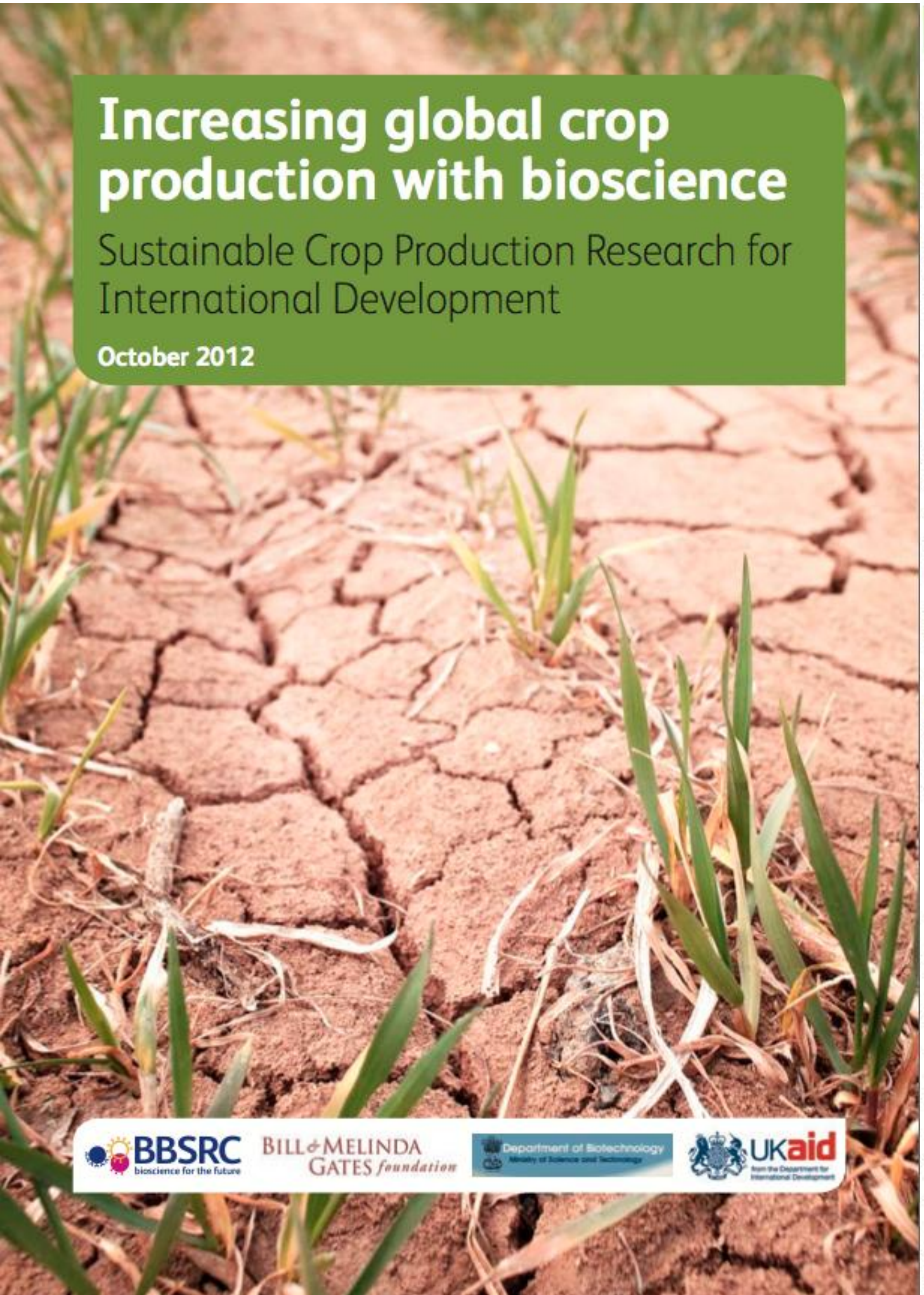


Tanksley & McCouch, 1997. Science

Timeline of life evolution on earth



O. rufipogon F1 Cultivar (IR64)



Increasing global crop production with bioscience

Sustainable Crop Production Research for International Development

October 2012

BBSRC bioscience for the future | BILL & MELINDA GATES foundation | Department of Biotechnology Ministry of Science and Technology | UKaid from the Department for International Development

Unlocking ancient rice secrets to overcome rainfall extremes

Rice is the staple food for over two billion people, but more rice is needed to feed a growing global population. A quarter of global rice production, rising to 45 per cent in India, is in rain-fed environments, so the challenge of producing more rice, is further complicated by climate change, which is predicted to cause more drought and flooding in the future.

Researchers from the UK, USA and India will work together to access valuable genetic information about variation in ancestral wild species of rice to try and identify beneficial segments of the genome that help plants survive drought. These small segments from ancestral rice genomes can then be transferred into commercial rice varieties by breeding.

In parallel, researchers in India will conduct field trials using hundreds of lines of rice carrying chromosome segments of DNA from wild varieties to see how different varieties grow. Using this field information, scientists back in the lab will study the different varieties to build up a detailed genetic picture of what causes increased resistance to drought in specific lines of rice.

At the end of the four-year project, the international team hope to produce improved drought tolerant rice varieties that are accepted and adopted by local communities in rain-fed areas of India, as well as new breeding tools to enable rapid further development of new rice varieties.

UK collaborators
University of York

Overseas collaborators
Central Rice Research Institute, India and Cornell University, USA

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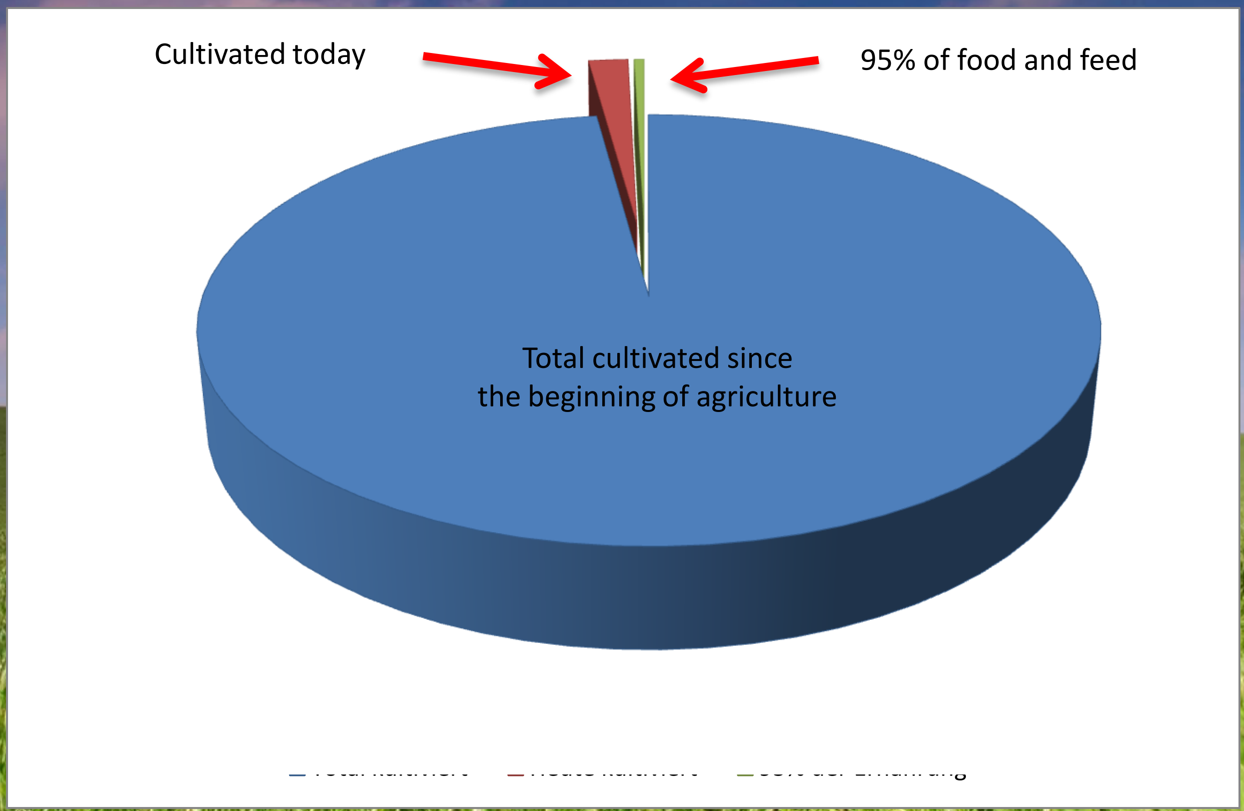
Rice growing in lab conditions at the University of York

© Phil Roberts, Centre for Novel Agricultural Products, Department of Biology, University of York

Sustainable food security is facing a major bottleneck

- Since the beginning of agriculture, humans have cultivated 7,000 plant species
- Today only 150 plant species (2%) are agriculturally relevant for food and clothing
- Only 10 plant species are cultivated today to provide 95% of food and feed



'A group of crops that are vital
to the economy of developing countries due
to their suitability
to the agro-ecology and socio-economic
conditions, but remain largely unimproved'.
Africa Technology Development Forum 2009,
Vol 6: 3&4.

Orphan Food Crops

Orphan Industrial/Medicinal Crops

Orphan Fuel Crops

Tef Cereal Improvement for Ethiopia

http://www.syngentafoundation.org

Most important cereal in Ethiopia

Low input and stress tolerant but Yield is very low – 0.9t/Ha

A big problem is Lodging – stem displacement

Genome Sequencing Program

TILLING for mutations in 'Green Revolution' Genes to obtain **semi-dwarf trait**

Institute of Plant Sciences, University of Bern, Switzerland

syngenta foundation for sustainable agriculture

Ho

Improving the livelihood of smallholder farmers

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PROJECTS

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  - Smallholders - Bangladesh
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  - Seed markets - East Africa
  - Rice intensification - West Africa
  - Jatropha biofuel - Central America
  - Agriculture insurance - Kenya

Tef cereal improvement for Ethiopia

Syngenta Foundation supports the University of Berne in the development of dwarf *tef* plants. The aim is to raise the yields of this important cereal for Ethiopia.

Tef (*Eragrostis tef*, sorghum/millet family) is an African "orphan" crop, meaning that it has not been the subject of much research and development work.

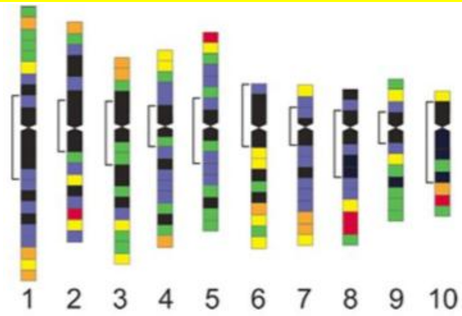
Tef is the most important cereal in Ethiopia, where about 85% of the population lives in rural areas. The crop adapts excellently to the climatic and soil conditions there. Tef grows better than other cereals both in drought and water-logged conditions. The seeds contain high protein levels and are free of gluten, which is very important for people with a gluten allergy.

However, average tef yield is much lower than for most other cereals. "Lodging" is the major problem: tef has tall, tender stems which easily fall over. The Foundation is thus working with the University of Berne, Switzerland, to develop shorter, "dwarf "plants. The breeding of semi-dwarf cultivars in major crops like wheat and rice contributed to their huge yield increases during the "Green Revolution" of the 1960's and 1970's.

Why are GM methods used sometimes and molecular breeding others?

Molecular breeding

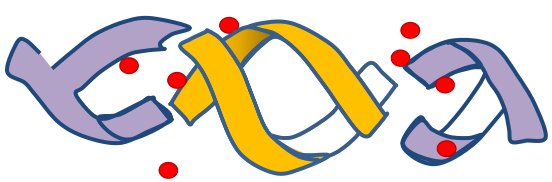
1. Desired trait must be present in population



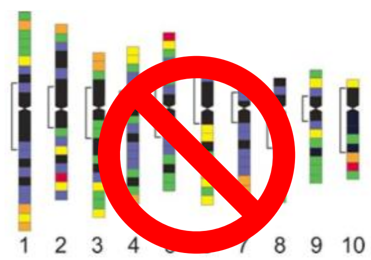
2. Genetic resources must be available

3. Plant should be propagated sexually

GM



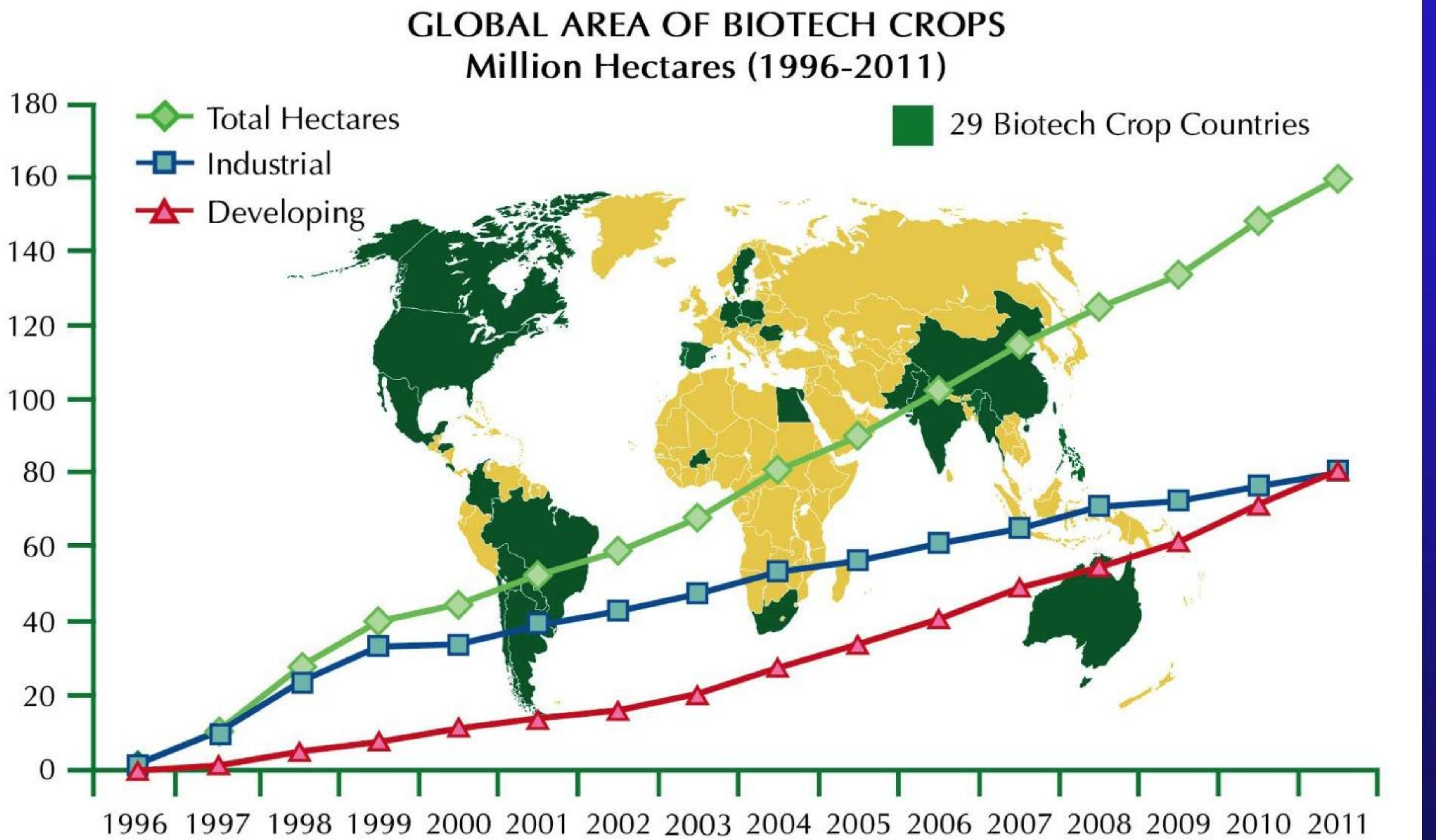
1. Gene can come from any source



2. Genetic resources not required

3. Plant can be propagated vegetatively

Photo credits: Gramene.org ETH Life International



A record 16.7 million farmers, in 29 countries, planted 160 million hectares (395 million acres) in 2011, a sustained increase of 8% or 12 million hectares (30 million acres) over 2010.

Source: Clive James, 2011.

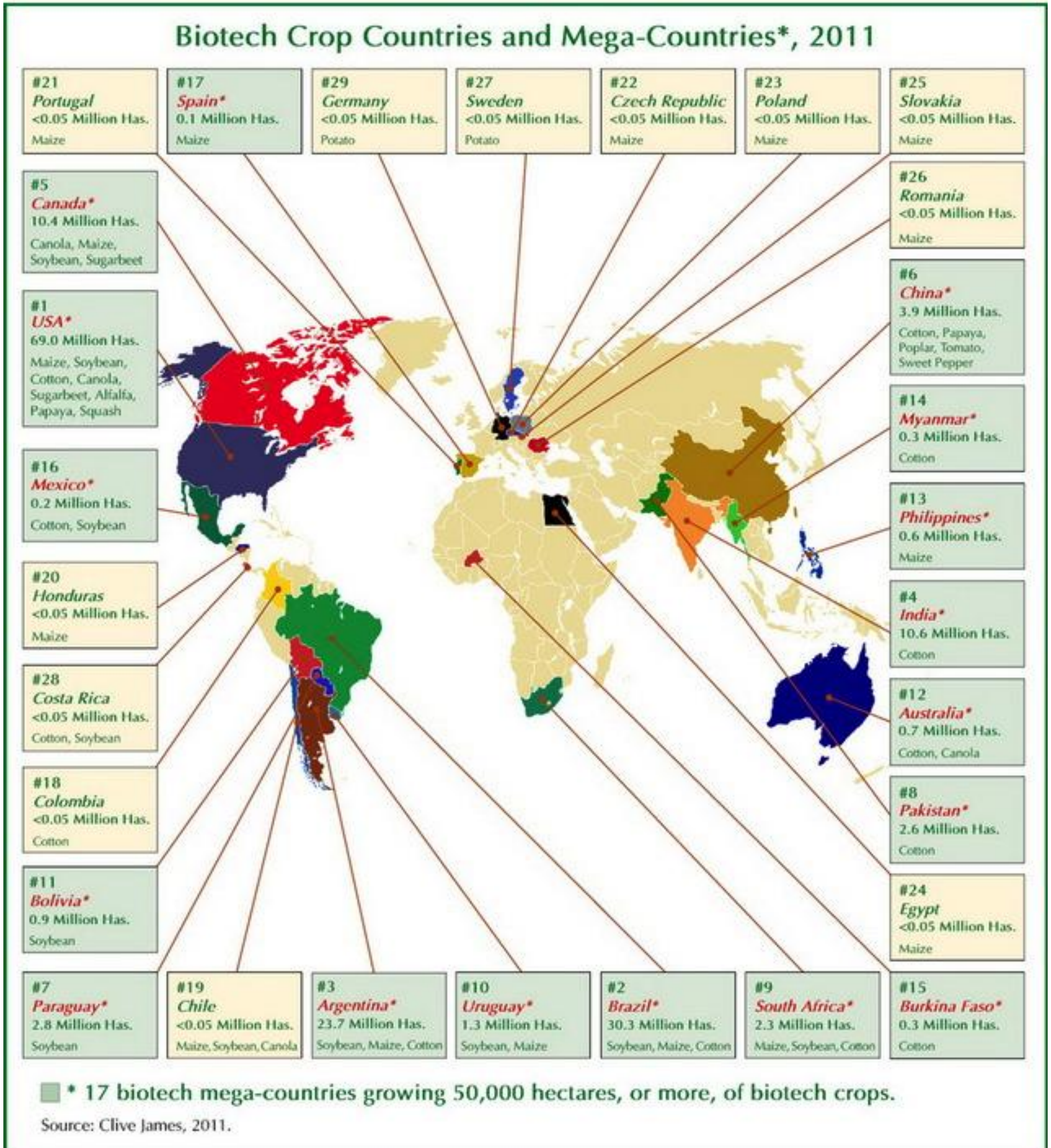


Figure 1. Global Map of Biotech Crop Countries and Mega-Countries in 2011

Major genetically Modified Crops in Agriculture Today

The first generation of GM traits were designed to complement the use of agrichemicals and provide better insect and weed control-from chemical to biological solutions

These input traits were of obvious benefits to producers (agrochemical companies and farmers) but not obvious to the consumer. These traits are now being introduced together (stacked) in Corn ,Soybean, Cotton, Canola and now Rice and other crops-----

Corn

Glyphosate tolerance

- Foliar insect control
- Corn root worm

How many more traits in one crop?

Cotton and Soybean

- Insect resistance
- Glyphosate tolerance

Virus control

Papaya

Canola (Oil Seed Rape)
Sugar Beet

- Glyphosate tolerance

Conventional cotton **Bt Protected Cotton**

Economic impacts and impact dynamics of Bt (*Bacillus thuringiensis*) cotton in India

Proc Nat Acad Sci 2012

Jonas Kathage[1] and Matin Qaim[1]

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Edited by Calestous Juma, Harvard University, Cambridge, MA, and approved May 15, 2012 (received for review March 2, 2012)

Despite widespread adoption of genetically modified crops in many countries, heated controversies about their advantages and disadvantages continue. Especially for developing countries, there are concerns that genetically modified crops fail to benefit smallholder farmers and contribute to social and economic hardship. Many economic studies contradict this view, but most of them look at short-term impacts only, so that uncertainty about longer-term effects prevails. We address this shortcoming by analyzing economic impacts and impact dynamics of Bt cotton in India. Building on unique panel data collected between 2002 and 2008, and controlling for nonrandom selection bias in technology adoption, we show that Bt has caused a 24% increase in cotton yield per acre through reduced pest damage and a 50% gain in cotton profit among smallholders. These benefits are stable; there are even indications that they have increased over time. We further show that Bt cotton adoption has raised consumption expenditures, a common measure of household living standard, by 18% during the 2006–2008 period. We conclude that Bt cotton has created large and sustainable benefits, which contribute to positive economic and social development in India.

successful farmers may have higher crop yields and profits anyway, this can result in inflated benefit estimates. Third, most available studies focus on agronomic impacts of Bt, such as yield and pesticide use effects, but economic effects, such as profit changes, are not analyzed at all or only based on simplistic comparisons. Fourth, and related to the previous point, many existing studies concentrate on impacts at the plot level, without considering possible broader welfare effects for farm households.

We address these shortcomings by using comprehensive panel data collected in India in four waves between 2002 and 2008. Estimation of panel data models allows us to account for selection bias and also analyze impact dynamics. In particular, we estimate fixed-effects specifications of yield, profit, and consumption expenditure models to derive net impacts of Bt adoption on cotton yield per acre, profit per acre, and household living standard. To our knowledge, this economic impact assessment of any GM crop technology that builds on more than 2 y of panel data is unique.

Results

Also big impact from Bt maize for cornborer and root worm resistance

Why not Bt aubergine, potato, Brassicas .....?

Nature 2012 487: 362-367

LETTER

doi:10.1038/nature11153

Widespread adoption of Bt cotton and insecticide decrease promotes biocontrol services

Yanhui Lu[1], Kongming Wu[1], Yuying Jiang[2], Yuyuan Guo[1] & Nicolas Desneux[3]

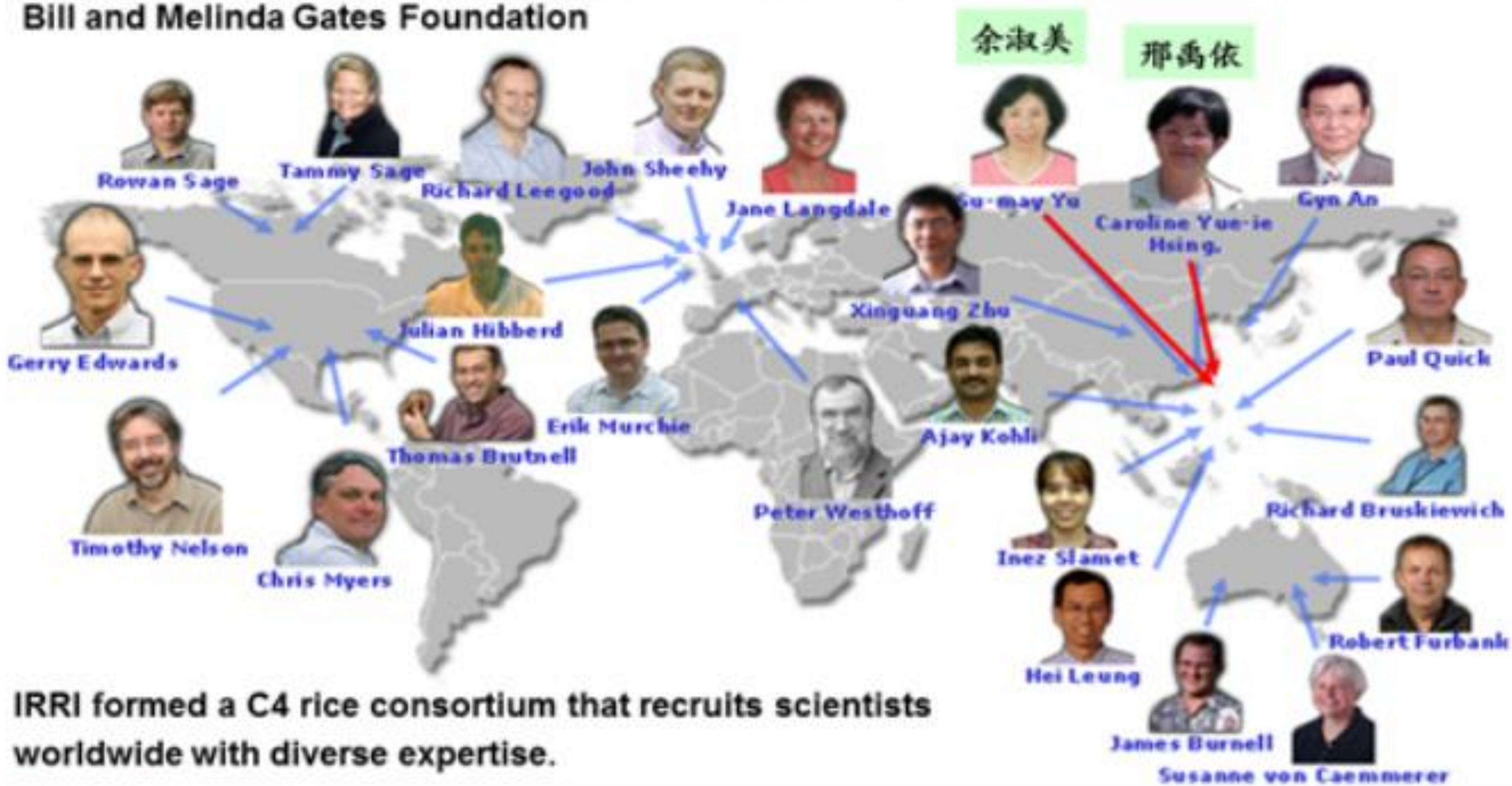
Over the past 16 years, vast plantings of transgenic crops producing insecticidal proteins from the bacterium *Bacillus thuringiensis* (Bt) have helped to control several major insect pests[1–5] and reduce the need for insecticide sprays[1,5,6]. Because broad-spectrum insecticides kill arthropod natural enemies that provide biological control of pests, the decrease in use of insecticide sprays associated with Bt crops could enhance biocontrol services[7–12]. However, this hypothesis has not been tested in terms of long-term landscape-level impacts[10]. On the basis of data from 1990 to 2010 at 36 sites in six provinces of northern China, we show here a marked increase in abundance of three types of generalist arthropod predators (ladybirds, lacewings and spiders) and a decreased abundance of aphid pests associated with widespread adoption of Bt cotton and reduced insecticide sprays in this crop. We also found evidence that the predators might provide additional biocontrol services spilling over from Bt cotton fields onto neighbouring crops (maize, peanut and soybean). Our work extends results from general studies evaluating ecological effects of Bt crops[1–4,6,12,13] by demonstrating that such crops can promote biocontrol services in agricultural landscapes.

rapidly planted on a large scale, rising to 2.4×10^6 ha by 2011 (more than 95% of the cotton crop in northern China). It managed CBW effectively, which led to decreased insecticide use on this pest[3,21].

The widespread adoption of Bt cotton may have favoured an increase in generalist natural enemy populations and promoted their associated biocontrol services. We therefore performed two assessments: first, whether implementing Bt cotton on a large scale induced an increase in populations of three groups of key generalist predators in China (ladybirds, lacewings and spiders) in both Bt cotton and three common neighbouring crops, namely maize, peanut and soybean; and second, whether this trend resulted in increased biocontrol services in agricultural landscapes in China. Aphids were selected as a pest model because they are common prey for generalist predators. During 1990–2011, research was conducted in six major cotton-growing provinces (Henan, Hebei, Shandong, Shanxi, Anhui and Jiangsu) in northern China, where about 2.6×10^6 ha of cotton and 3.3×10^7 ha of other crops (notably maize, peanut and soybean) are cultivated annually by more than ten million small-scale farmers.

BMGF-C4 Rice Project Consortium Members

Bill and Melinda Gates Foundation



IRRI formed a C4 rice consortium that recruits scientists worldwide with diverse expertise.

Various approaches are taken to identify genetic factors that control the C4 syndrome.

Science 29 June 2012:
Vol. 336 no. 6089 pp. 1671-1672
DOI: 10.1126/science.1220177

PERSPECTIVE

The Development of C_4 Rice: Current Progress and Future Challenges

Susanne von Caemmerer[1,*], W. Paul Quick[2], Robert T. Furbank[3]

+ Author Affiliations

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ABSTRACT

Another "green revolution" is needed for crop yields to meet demands for food. The international C_4 Rice Consortium is working toward introducing a higher-capacity photosynthetic mechanism—the C_4 pathway—into rice to increase yield. The goal is to identify the genes necessary to install C_4 photosynthesis in rice through different approaches, including genomic and transcriptional sequence comparisons and mutant screening.

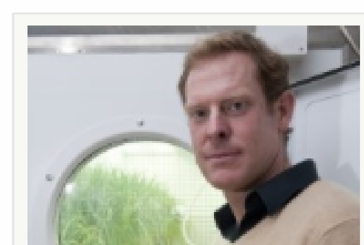
Major investment to persuade bacteria to help cereals self-fertilise

JULY 15, 2012 10 COMMENTS

The John Innes Centre will lead a $9.8m research project to investigate whether it is possible to initiate a symbiosis between cereal crops and bacteria. The symbiosis could help cereals access nitrogen from the air to improve yields.

The five-year research project, funded by the Bill & Melinda Gates Foundation, could have most immediate benefit for subsistence farmers.

> "During the Green Revolution, nitrogen fertilisers helped triple cereal yields in some areas," **said Professor Giles Oldroyd from JIC.** "But these chemicals are unaffordable for small-scale farmers in the developing world."



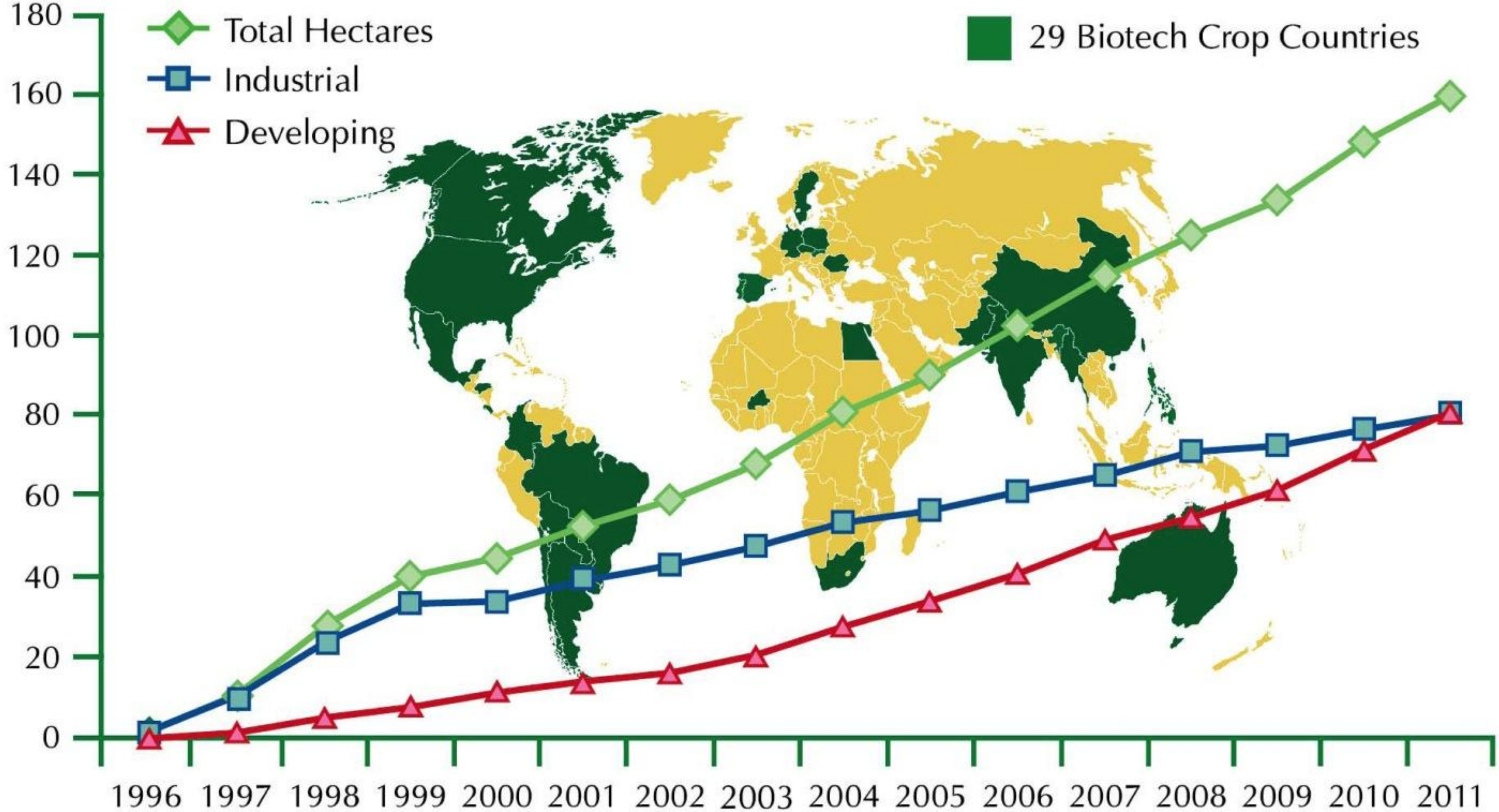
Decreasing post-harvest spoilage with biotechnology

Figure 11.22 Genetic manipulaton can have a profound effect on ripening. Normal tomatoes (right) and Flavr Savr™ tomatoes (left) were picked when both were nearly ripe (light red) and held at room temperature for four weeks. By this time normal fruit had softened and rotted but Flavr Savr™ fruit was still firm and edible. This genetically modified fruit lacked polygalacturonase and had a much better shelf life, as well as improved flavour and handling qualities. Scale bar = 2 cm.

(Photograph courtesy A.J. Conner)

1994 - 1997

GLOBAL AREA OF BIOTECH CROPS
Million Hectares (1996-2011)



A record 16.7 million farmers, in 29 countries, planted 160 million hectares (395 million acres) in 2011, a sustained increase of 8% or 12 million hectares (30 million acres) over 2010.

Source: Clive James, 2011.

Conclusions

- Molecular Breeding technologies – marker assisted breeding **and** genetic engineering - have a massive contribution to make if we are to double food production on the same amount of land by 2050 in the face of climate change **and** decrease environmental impact
- Understanding the molecular basis of complex traits is essential if we are to improve them in a time efficient manner
- This requires foresight and commitment from policy makers as well as scientists

Thank you!