GMO crops: Their use, impacts, and evolution

Webinar presented to
Regulatory Framework Information Forum of Biotechnology in Mexico at Tecnológico de Monterrey / April 28, 2016

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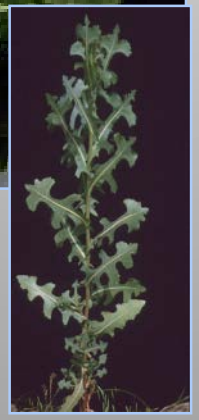
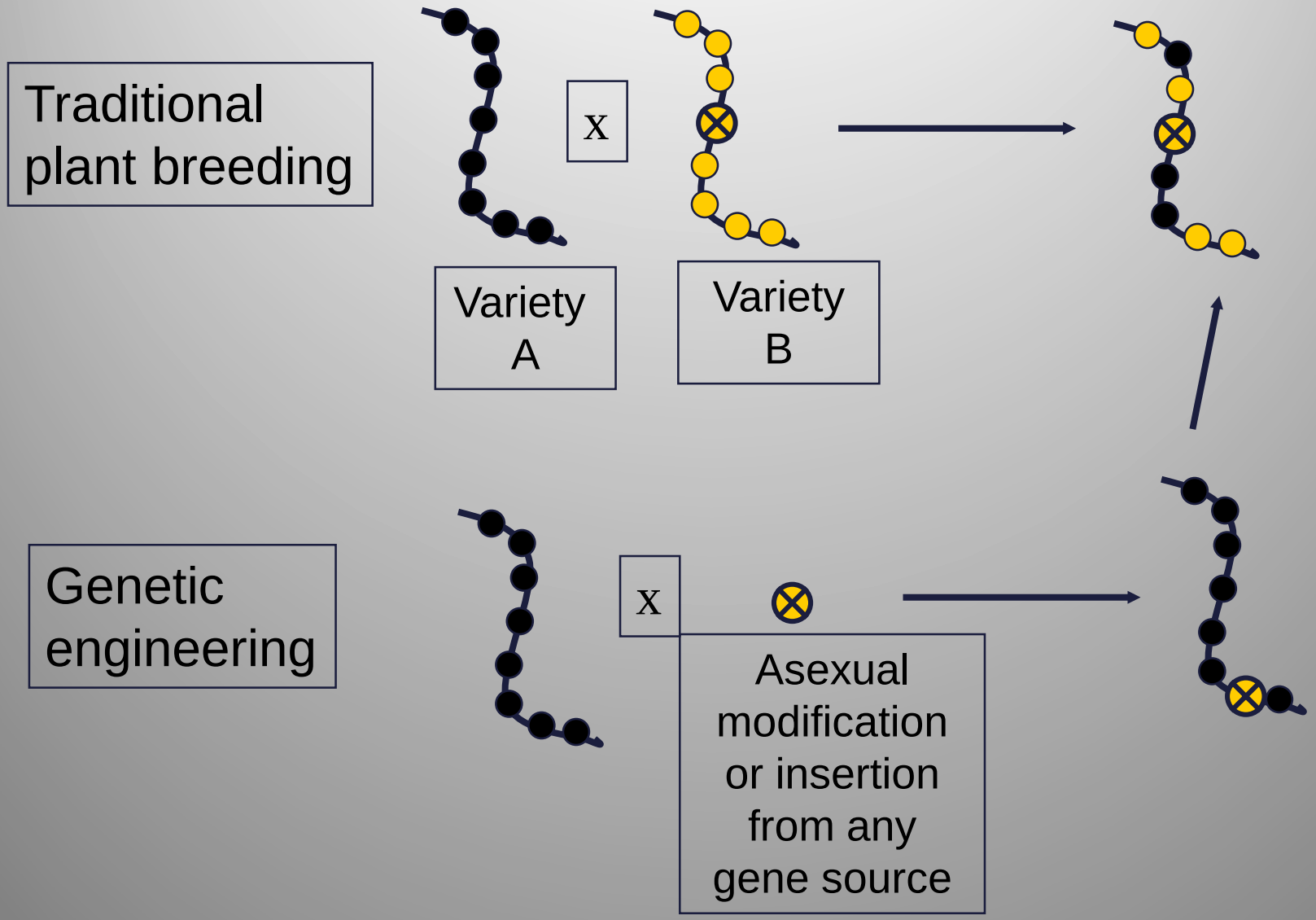
Agenda

- What are they – a brief reminder
- Extent in the world
- Some impacts
- Examples of new traits in pre-commercial pipeline (many more in research)

Most crops intensively bred, moved globally prior to GMOs

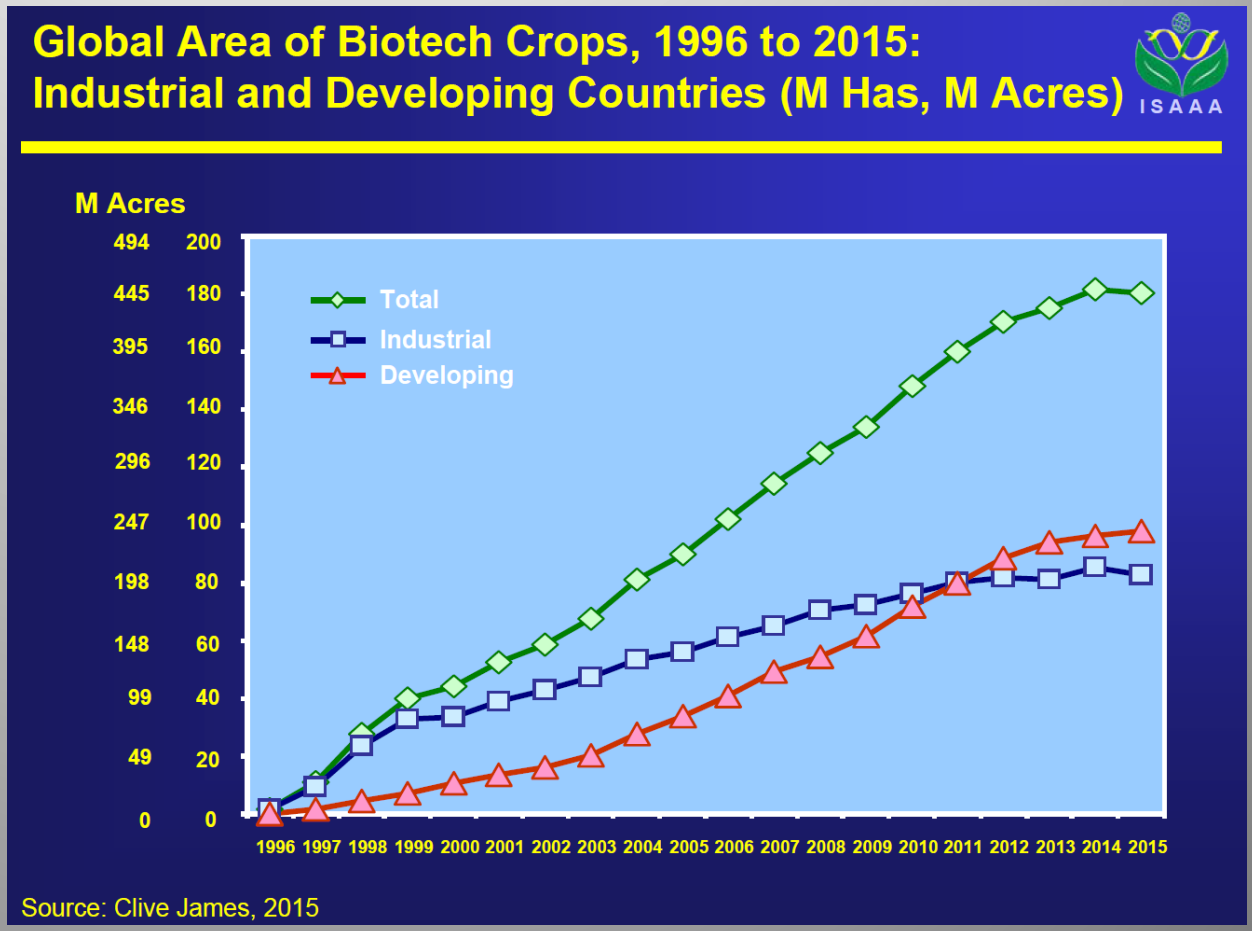


GMO refers to a method of breeding, not particular kinds of products

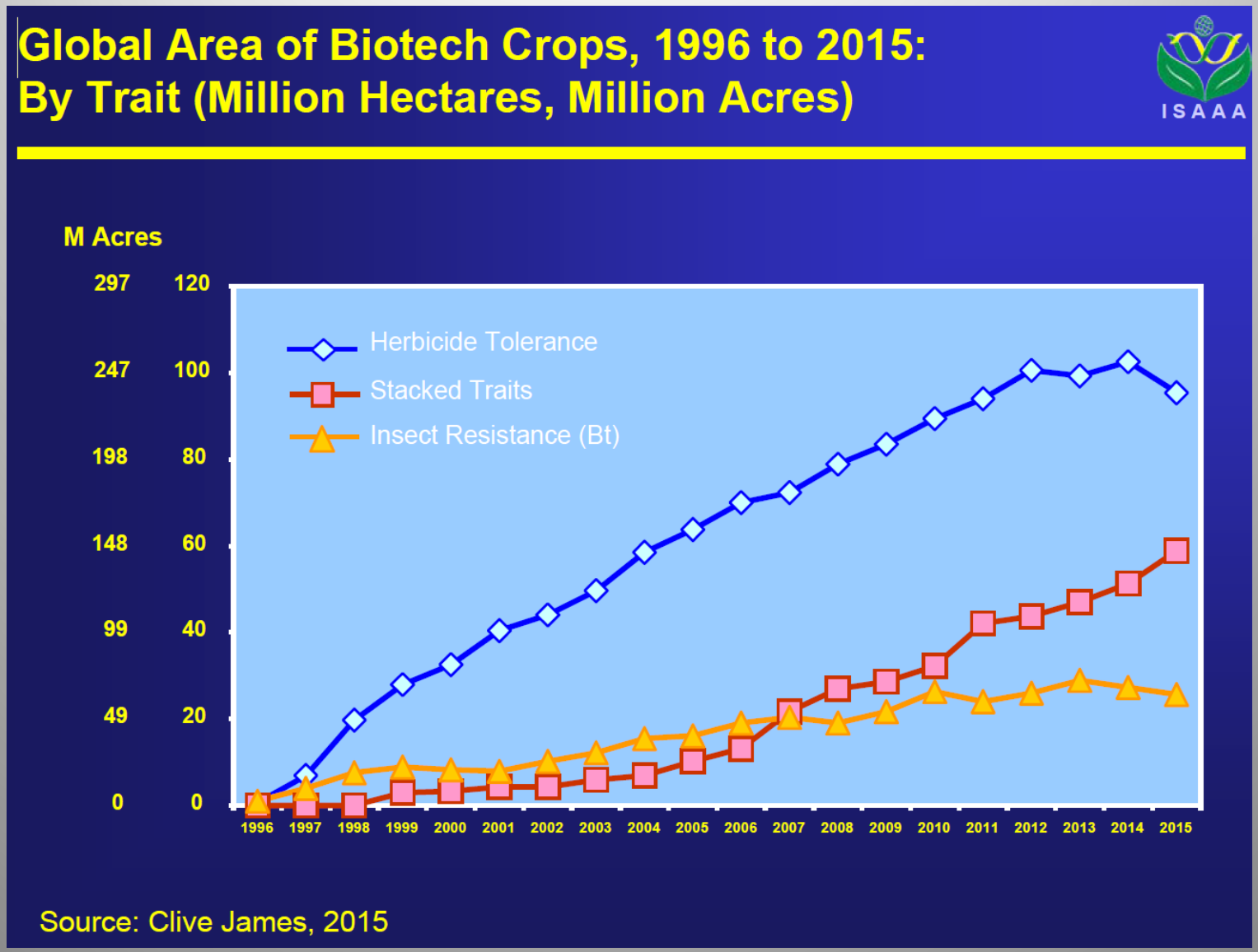


After cells are modified, they are induced to regenerate into whole plants

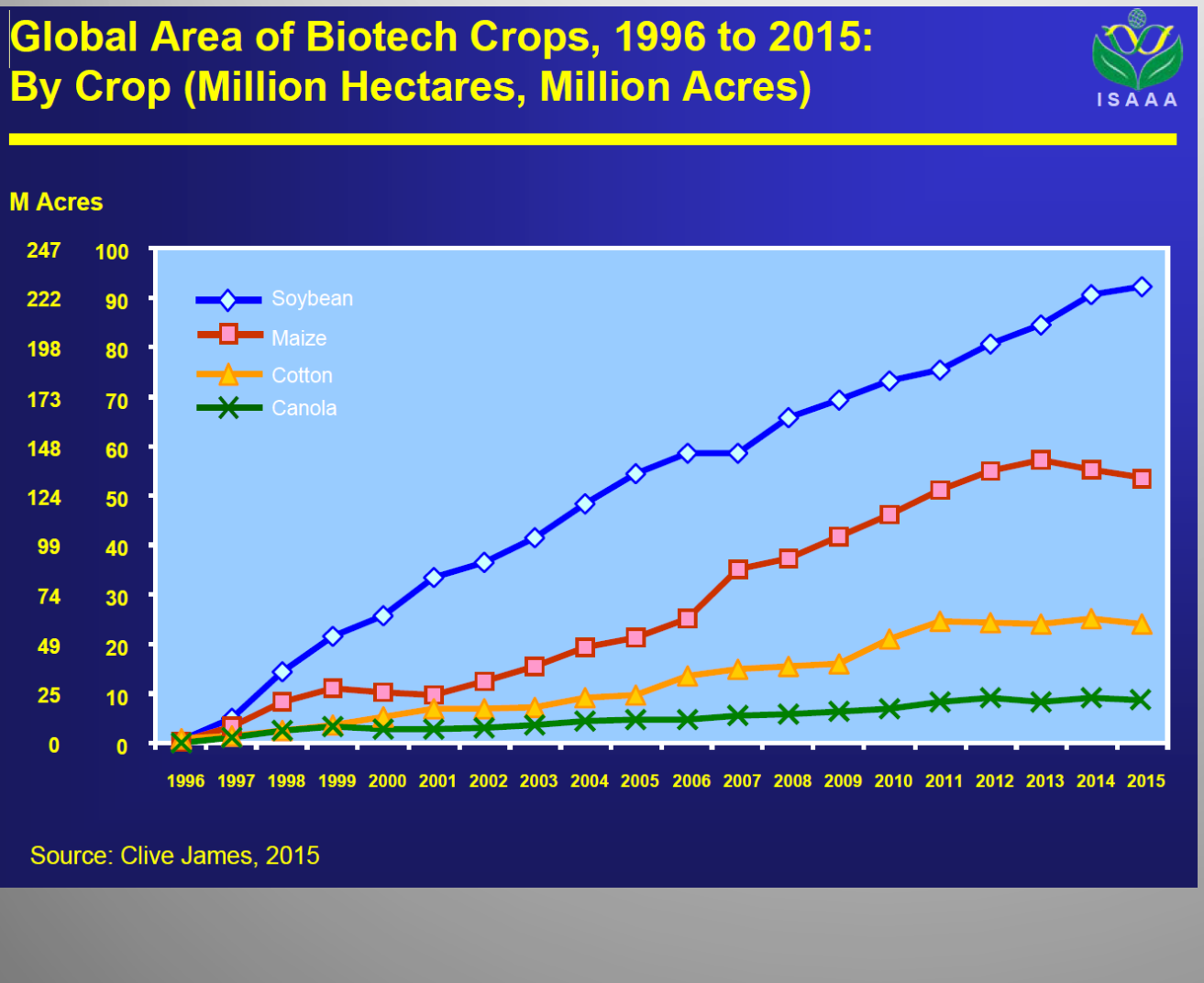
First generation herbicide and insect resistant crops were rapidly adopted by farmers, both in the developed and developing world



Two traits dominate worldwide, increasingly “stacked” in combinations



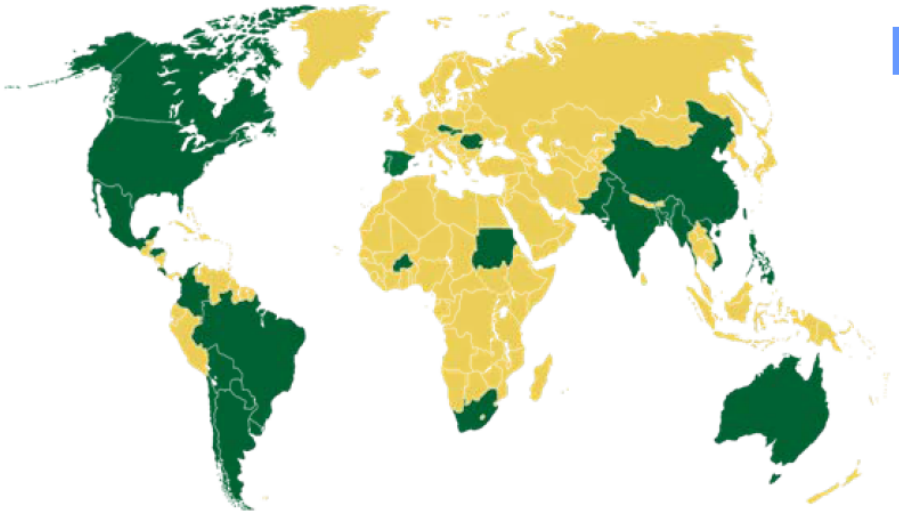
Four crops dominate, 8+ crops in USA



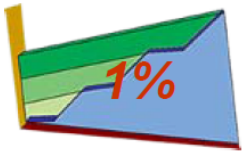
Adoption by 28 countries, but rates highly variable

Global Area (Million Hectares) of Biotech Crops, 2015: by Country

ISAAA



Marginal Decrease from 2014



28 countries which have adopted biotech crops

In 2015, global area of biotech crops was 179.7 million hectares, representing a marginal decrease of 1% from 2014, equivalent to 1.8 million hectares.

Source: Clive James, 2015.

Biotech Mega Countries

50,000 hectares (125,000 acres), or more

		Million Hectares
1.	USA	70.9
2.	*Brazil**	44.2
3.	*Argentina**	24.5
4.	*India**	11.6
5.	Canada	11.0
6.	*China**	3.7
7.	*Paraguay**	3.6
8.	*Pakistan**	2.9
9.	*South Africa**	2.3
10.	*Uruguay**	1.4
11.	*Bolivia**	1.1
12.	*Philippines**	0.7
13.	Australia	0.7
14.	*Burkina Faso**	0.4
15.	*Myanmar**	0.3
16.	*Mexico**	0.1
17.	Spain	0.1
18.	*Colombia**	0.1
19.	*Sudan**	0.1

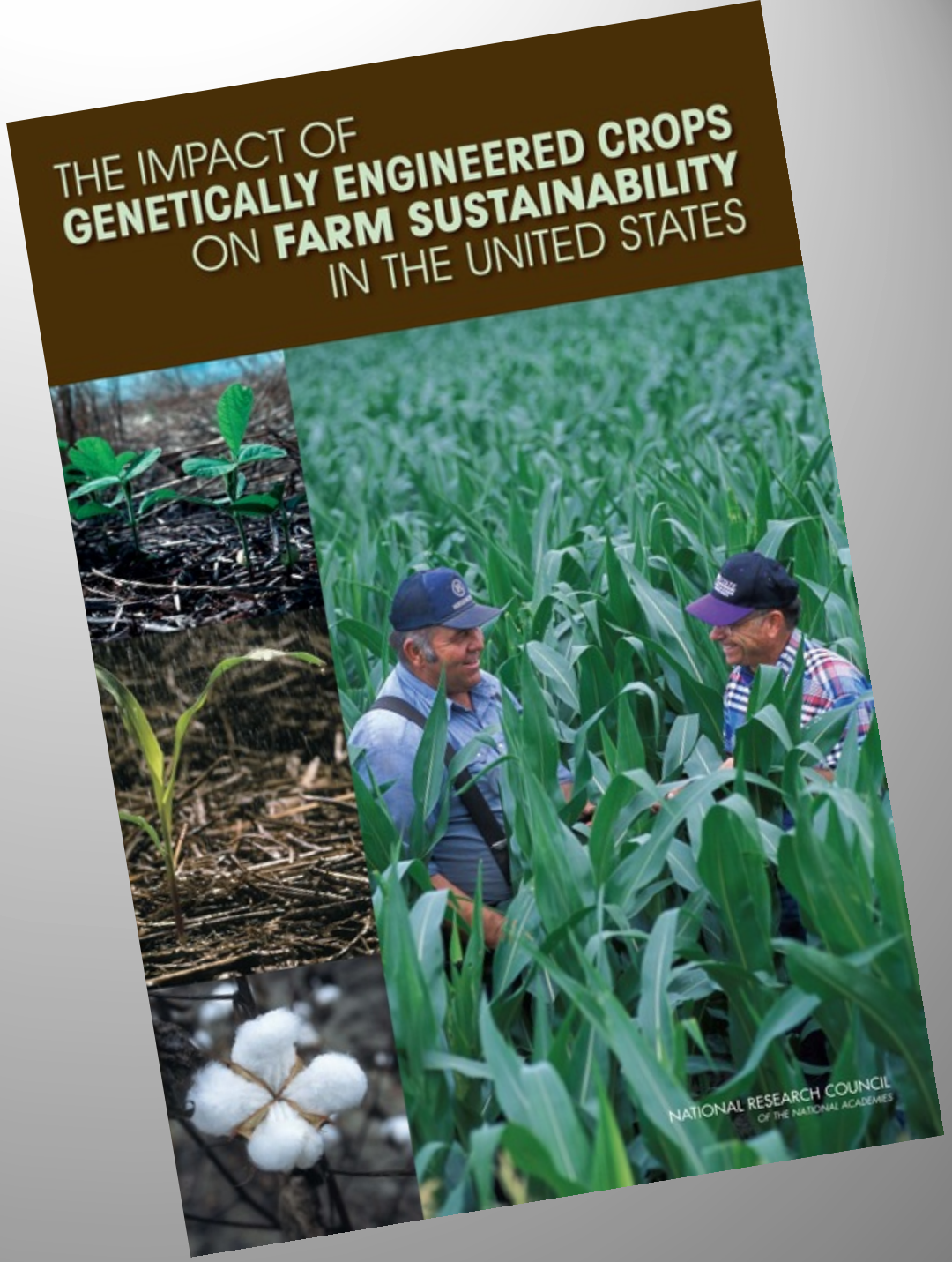
Less than 50,000 hectares

*Honduras**
*Chile**
Portugal
*Vietnam**
Czech Republic
Slovakia
*Costa Rica**
*Bangladesh**
Romania

** Developing countries*

Many National Research Council and other reports on GMOs

Major pesticide reductions, conservation tillage expansion, need for more sustainable pest management



Global “meta-analysis” in 2014

“147 original studies were included.”
“On average, GM technology adoption has reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%.”

Herbicide tolerant plants promote conservation tillage – With many environmental benefits thereof

Conservation Technology Information Center

- Lowers greenhouse gas emissions
- Improves soil organic matter
- Reduces erosion and fertilizer runoff into water

Poor weed management has led to rapid development of herbicide-resistant weeds

And motivated development of new kinds of herbicide tolerant crops

nature biotechnology

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NATURE BIOTECHNOLOGY | NEWS

Glyphosate resistance threatens Roundup hegemony

Emily Waltz

Nature Biotechnology **28**, 537–538 (2010) | doi:10.1038/nbt0610-537
Corrected online **13 October 2010**
Corrigendum (October, 2010)

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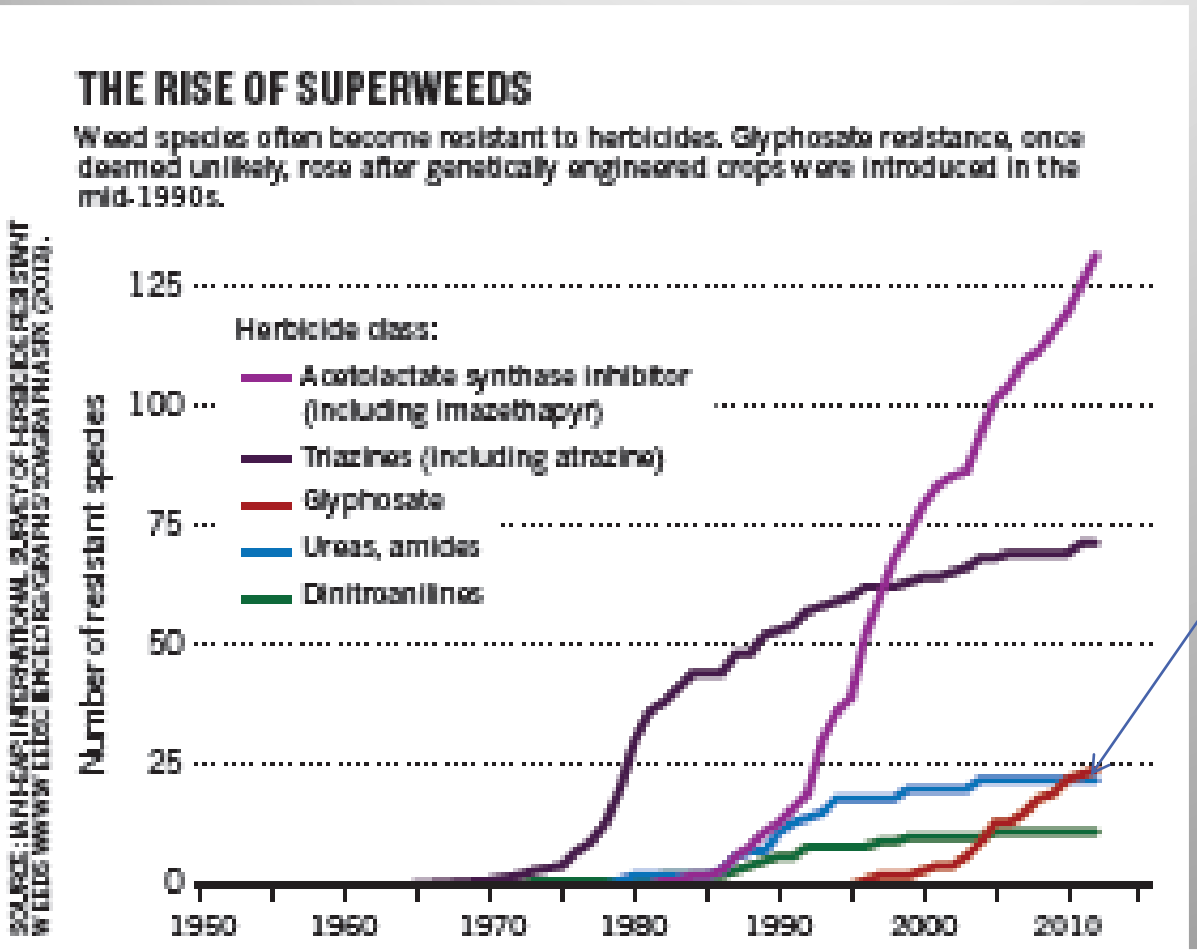
Weeds are becoming increasingly resistant to glyphosate, a report from the US National Academy of Sciences (NAS) released in April has found. The driving force, according to the report, is farmers' dependence on the weed killer accompanied by the widespread adoption of genetically modified (GM) herbicide-tolerant crops. Seed makers are hoping to forestall the problem by developing GM crops with 'stacked' traits that tolerate multiple herbicides. But weed scientists warn that if farmers manage these new crops in the same way as they managed their glyphosate-tolerant predecessors, weeds will simply become resistant to the new technologies.

"The number of weed species evolving resistance to glyphosate

BILL BARKSDALE / AGSTOCKUSA /

Herbicide-resistant weeds are an old problem in agriculture, but exacerbated by GE herbicide tolerant crops



Accelerated by GE Roundup-tolerant crops

24 | NATURE | VOL 497 | 2 MAY 2013

Newly approved GE crop varieties in USA

- Soybean – insect resistant (Apr. 2014)
- Alfalfa – reduced lignin (Nov. 2014)
- Potato – reduced black spot bruise and low acrylamide production (Nov. 2014), reduced browning and disease resistant as well (August 2015)

- Soybean and cotton – new herbicide tolerances (Jul. 2014 – Jan. 2015)
- Apple – non-browning (Feb. 2015)
- Plum – virus resistant (2014)

RNA interference (RNAi) for gene suppression

Nobel Prize for it's impact and mechanism

The Nobel Prize in Physiology or Medicine 2006

Andrew Z. Fire, Craig C. Mello

Share this: 28

The Nobel Prize in Physiology or Medicine 2006

Photo: L. Cicero

Andrew Z. Fire

Prize share: 1/2

Photo: J. Mottern

Craig C. Mello

Prize share: 1/2

The Nobel Prize in Physiology or Medicine 2006 was awarded jointly to Andrew Z. Fire and Craig C. Mello *"for their discovery of RNA interference - gene silencing by double-stranded RNA"*

Virus-resistant GM papaya

Saved the Hawaiian industry in the mid-1990s, ~70% of crop today

Like a vaccine –
"RNAi immunization" via implanting a viral gene in the papaya genome

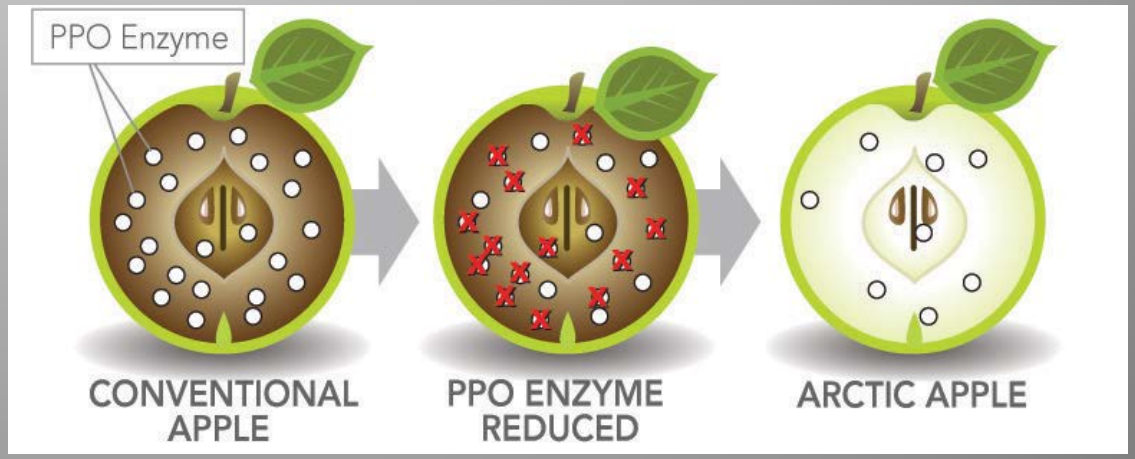
GMO, virus-resistant trees

Courtesy of Denis Gonsalves, formerly of Cornell University

Non-browning “Arctic Apple”

Reduced spoilage/waste, improved quality – USDA approved

Courtesy of Jennifer Armen, Okanagan Specialty Fruits, Canada



Non-browning “Arctic Apple”

Time lapse video

They tasted good for several hours

“Innate” potato approved – reduced browning and acrylamide (↓waste, ↑safety)

Trait #1 - Silenced PPO (Enzyme)

- Non-browning when cut
- Reduced black spot bruise

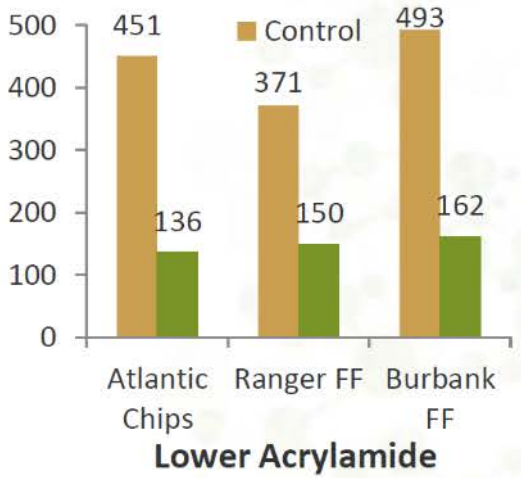
Trait #2 - Reduced Asparagine (Amino Acid)

- Yields a 50-80% reduction in acrylamide when baked or fried
- Meets Prop 65 in California

Four Improved Varieties

- Russet Burbank, Ranger Russet, Atlantic, Snowden
- No effect on taste, texture, or performance
- USDA approval expected in 2014

Non-Browning



Lower Acrylamide

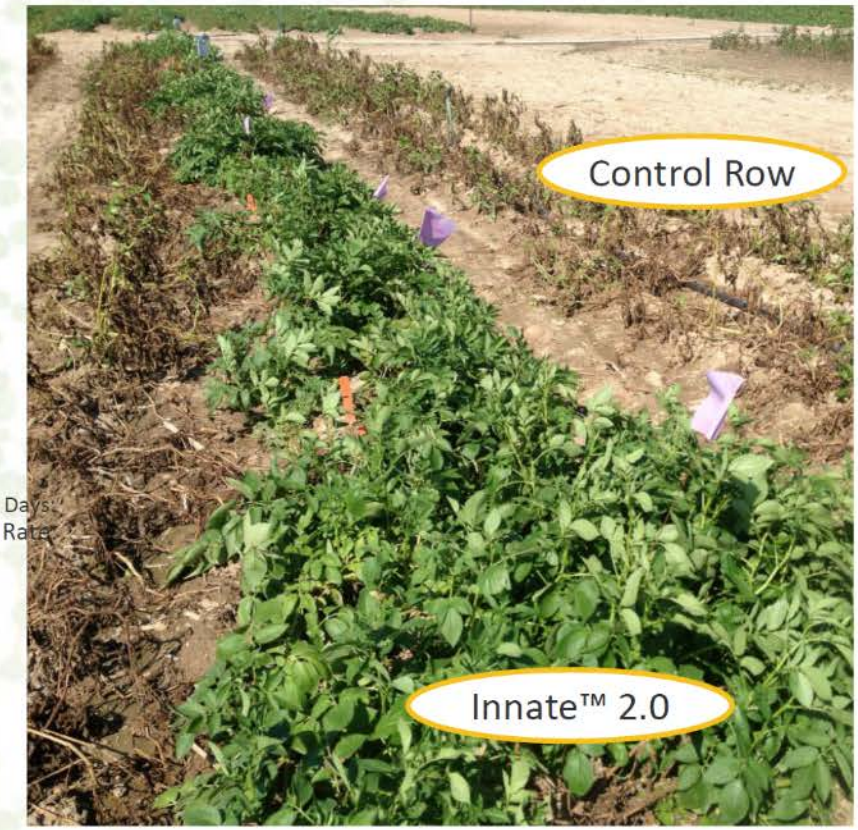
“Innate” potato in my hands for teaching

One hour after cutting – Control vs. Innate

Two days after cutting – Control vs. Innate

“Innate” potato 2.0 – late blight resistant, reduced acrylamide, reduced sprouting and browning (↓ waste, ↑ safety, ↓

Midwest - Sept 4th 2013



Days
Rate

	Control	Innate™ 2.0
Zebra Chip		
Burbank		
Innate™ Burbank		

Potential Innate Potato benefits

- **If all USA potatoes had it's improved traits, each year….**
- Waste reduced by 5 billion pounds
- CO_2 emissions reduced by 734 million pounds
- Water use reduced by 84 billion gallons
- 2.5 million fewer pesticide acre-applications
- Marketable yields increase ~ 20%
- Growers save $240 million in production costs

Am. J. Potato Res.
DOI 10.1007/s12230-015-9485-1

INVITED REVIEW

Biotech Potatoes in the 21st Century: 20 Years Since the First Biotech Potato

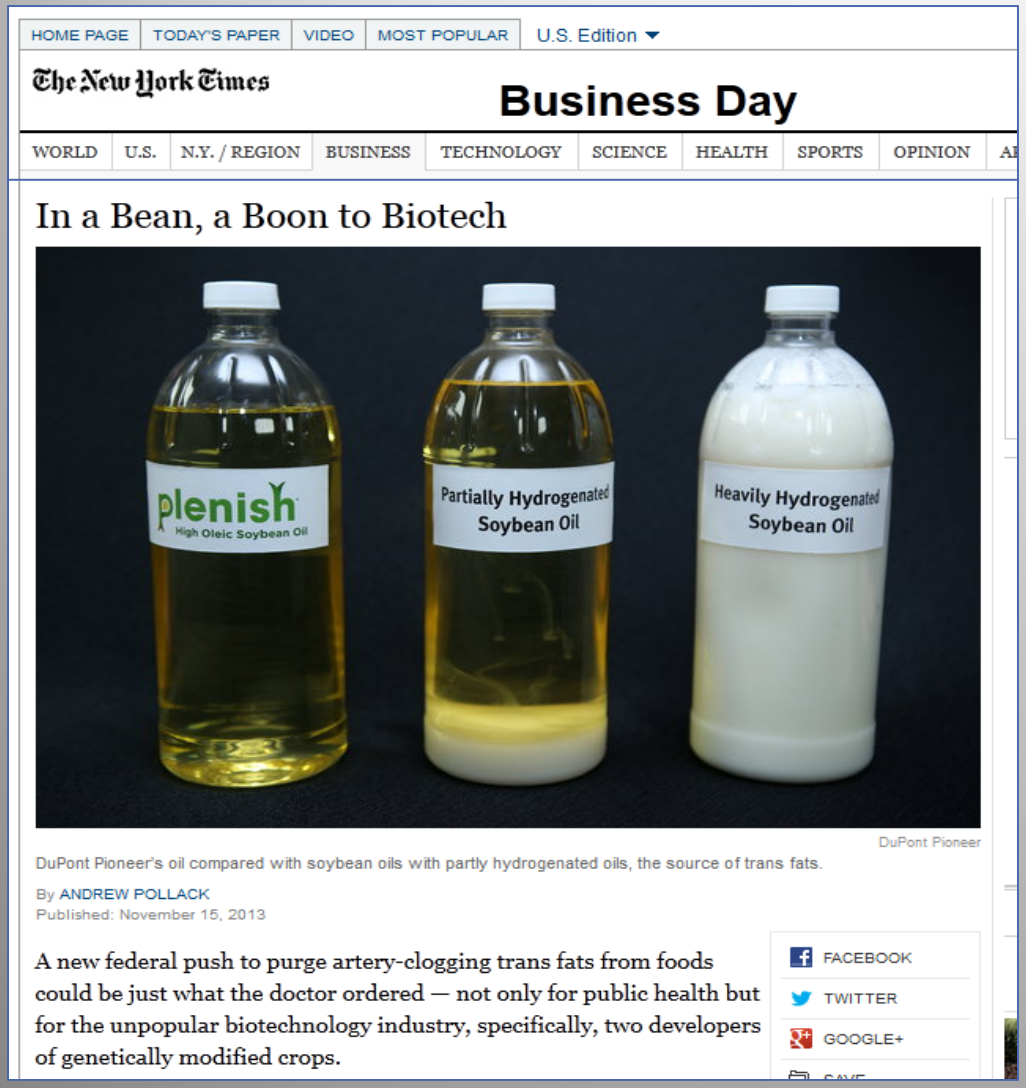
Dennis Halterman[1] · Joe Guenthner[2] · Susan Collinge[3] · Nathaniel Butler[4] · David Douches[4]

Abstract Potato is the world's most important vegetable crop, with nearly 400 million tons produced worldwide every year, lending to stability in food supply and socioeconomic impact. In general, potato is an intensively managed crop, requiring irrigation, fertilization, and frequent pesticide applications in order to obtain the highest yields possible. Important traits are

and the potential effects that biotech potato could have on the industry.

Resumen La papa es el cultivo hortícola más importante en el mundo, con cerca de 400 millones de toneladas producidas a nivel mundial anualmente, acreditando la estabilidad en el

Improved oil



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The New York Times

Business Day

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

In a Bean, a Boon to Biotech

DuPont Pioneer

DuPont Pioneer's oil compared with soybean oils with partly hydrogenated oils, the source of trans fats.

By ANDREW POLLACK
Published: November 15, 2013

A new federal push to purge artery-clogging trans fats from foods could be just what the doctor ordered — not only for public health but for the unpopular biotechnology industry, specifically, two developers of genetically modified crops.

FACEBOOK
TWITTER
GOOGLE+

"The developers, Monsanto and DuPont Pioneer, have manipulated the genes of the soybean to radically alter the composition of its oil to make it longer-lasting, potentially healthier and free of trans fats."

"It almost mirrors olive oil in terms of the composition of fatty acids."

Insect control via RNAi in corn

Host induced gene silencing (HIGS)

LETTERS

nature biotechnology

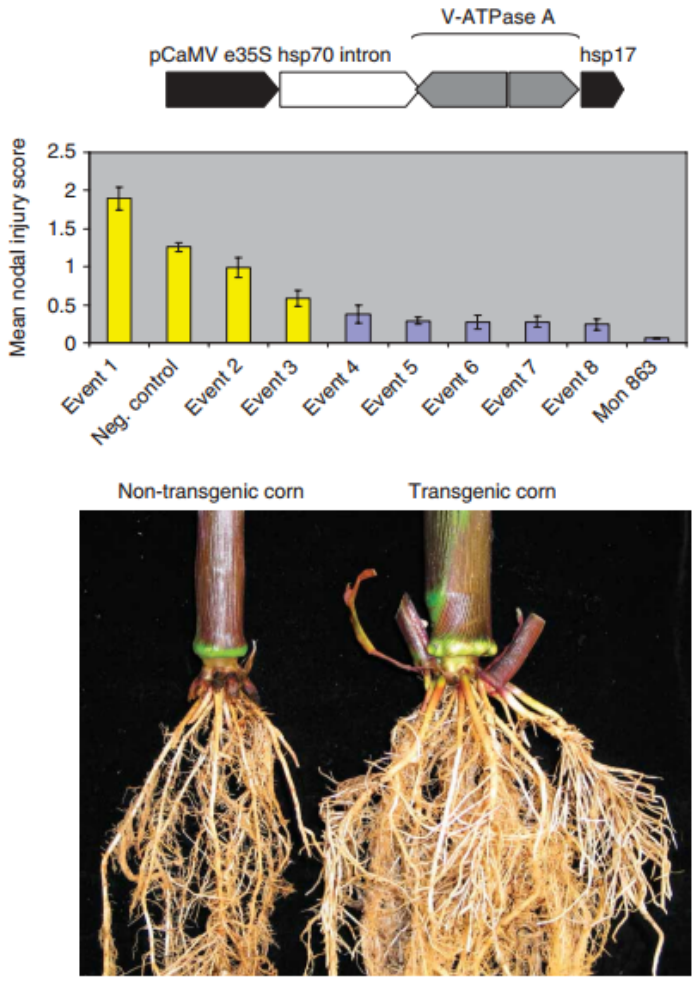
Control of coleopteran insect pests through RNA interference

James A Baum[1], Thierry Bogaert[2], William Clinton[1], Gregory R Heck[1], Pascale Feldmann[2], Oliver Ilagan[1], Scott Johnson[1], Geert Plaetinck[2], Tichafa Munyikwa[1], Michael Pleau[1], Ty Vaughn[1] & James Roberts[1,3]

Commercial biotechnology solutions for controlling lepidopteran and coleopteran insect pests on crops depend on the expression of *Bacillus thuringiensis* insecticidal proteins[1,2], most of which permeabilize the membranes of gut epithelial cells of susceptible insects[3]. However, insect control strategies involving a different mode of action would be valuable for managing the emergence of insect resistance. Toward this end, we demonstrate that ingestion of double-stranded (ds)RNAs supplied in an artificial diet triggers RNA interference in several coleopteran species, most notably the western corn rootworm (WCR) *Diabrotica virgifera virgifera* LeConte. This may result in larval stunting and mortality. Transgenic corn plants engineered to express WCR dsRNAs show a significant reduction in WCR feeding damage in a growth chamber assay, suggesting that the RNAi pathway can be exploited to control insect pests via *in planta* expression of a dsRNA.

initial bioassays, dsRNAs were applied to the surface of the WCR agar diet at concentrations from 520 ng/cm^2 to 780 ng/cm^2. As we anticipated a slower response to dsRNAs than to *B. thuringiensis* insecticidal proteins, the WCR bioassay incubation period was extended from 5 d to 12 d. Indeed, 7 d after infestation, little if any effect was observed. However, numerous dsRNAs exhibited significant activity 12 d after infestation, resulting in both larval stunting and mortality (**Supplementary Table 1** online).

Subsequent feeding assays demonstrated that certain dsRNA samples, including dsRNAs targeting putative genes encoding vacuolar ATPase (V-ATPase) subunit A, D and E, as well as α-tubulin, were active at applied concentrations well below 52 ng/cm^2. We identified additional WCR genes that caused mortality when targeted for suppression using dsRNAs in the WCR feeding assay. A two-tiered screen was implemented in which dsRNAs targeting different genes were tested at 52 and 5.2 ng/cm^2. Of the 290 dsRNAs tested, 125 showed significant ($P < 0.05$) larval mortality and/or stunting at 52 ng/cm^2. Of these, 67 showed significant mortality and/or stunting



ure 2 F1 plants expressing a V-ATPase A dsRNA are protected from WCR ding damage. (**a**) Map of the expression cassette. (**b**) Mean root damage ngs for eight F_1 populations, the parental inbred line (negative control) and the corn rootworm–protected Cry3Bb event MON863; NIS, nodal injury score (Iowa State ranking system). (**c**) The plant on left is a non-transgenic control with average root damage, whereas the plant on the right shows the average root protection seen when the transgene is expressed.

HIGS also effective for fungal resistance

PNAS

Host-induced gene silencing of cytochrome P450 lanosterol C14α-demethylase–encoding genes confers strong resistance to *Fusarium* species

Aline Koch[a], Neelendra Kumar[a], Lennart Weber[b], Harald Keller[c], Jafargholi Imani[a], and Karl-Heinz Kogel[a,1]

[a]Institute for Phytopathology and Applied Zoology and [b]Institute for Microbiology and Molecular Biology, Centre for Bio Systems, Land Use, and Nutrition, Justus Liebig University, D-35392 Giessen, Germany; and [c]Institut Sophia Agrobiotech, Unité Mixte de Recherche 1355 Institut National de la Recherche Agronomique Centre National de la Recherche Scientifique, Université Nice-Sophia Antipolis, 06903 Sophia Antipolis, France

Edited* by Diter von Wettstein, Washington State University, Pullman, WA, and approved October 15, 2013 (received for review April 5, 2013)

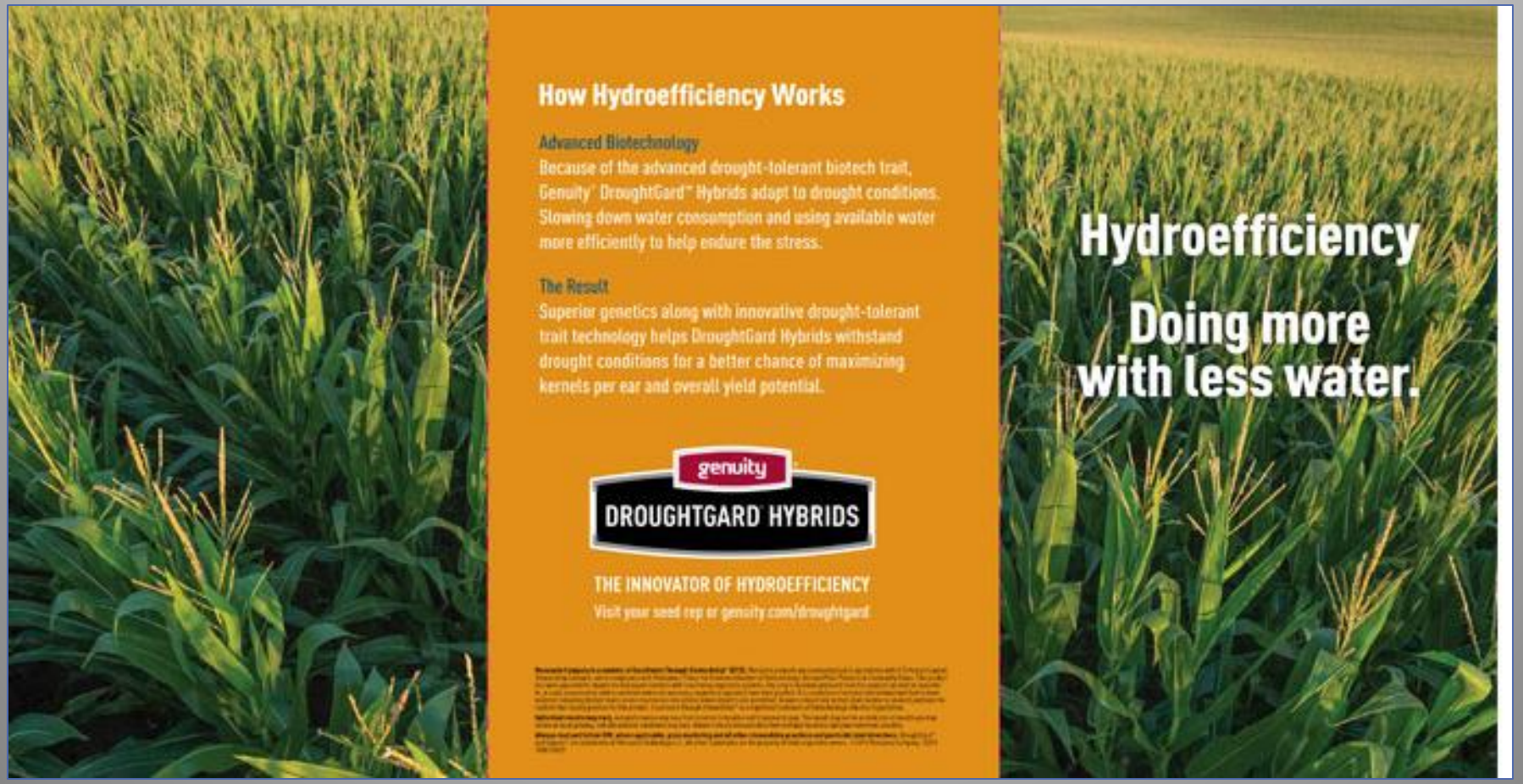
Head blight, which is caused by mycotoxin-producing fungi of the genus *Fusarium*, is an economically important crop disease. We assessed the po… the fungal cytod… genes, which ar… fungal infection. vitro feeding of … plementary to C… inhibition [half-… well as altered f… treatment with … CYP51 enzyme is a target. Expression of the same dsRNA in *Arabidopsis* and barley rendered susceptible plants highly resistant to fungal infection. Microscopic analysis revealed that mycelium formation on *CYP3RNA*-expressing leaves was restricted to the

their discovery in the 1970s. Therefore, it is hardly surprising that reduced sensitivity, or even resistance to DMI fungicides, has …ic fungi (8–14). The …the last few years (15) …control strategies. …as a powerful genetic …plant biotechnology …useful agronomical …gral part of the gene- …tes (16, 17); in plants, …silencing (18). Post-transcriptional gene silencing starts with the initial processing or cleavage of a precursor dsRNA into short 21–25 nucleotide small-interfering RNA (siRNA) or micro RNA (miRNA) duplexes

"…demonstrating that HIGS is a powerful tool, which could revolutionize crop plant protection."

Drought-tolerant maize – Planted on >150,000 acres – Also tested in Africa

Important tool given climate change, water shortages?



Increased gene expression:

Purple GE tomatoes with increased antioxidants and rot resistance

Current Biology 23, 1094–1100, June 17, 2013 ©2013 Elsevier Ltd All rights reserved http://dx.doi.org/10.1016/j.cu

Anthocyanins Double the Shelf Life of Tomatoes by Delaying Overripening and Reducing Susceptibility to Gray Mold

Yang Zhang,[1] Eugenio Butelli,[1] Rosalba De Stefano,[2] Henk-jan Schoonbeek,[1] Andreas Magusin,[1] Chiara Pagliarani,[3] Nikolaus Wellner,[4] Lionel Hill,[1] Diego Orzaez,[5] Antonio Granell,[5] Jonathan D.G. Jones,[6] and Cathie Martin[1,*]
[1]John Innes Centre, Norwich Research Park, Norwich, NR4 7UH, UK

They are produced by plants t
dispersers [9]. Anthocyanin p
induced under stress condition
gens [11]. Besides physiologica
cyanins are associated with pro
[12], cardiovascular diseases [
disorders [13].

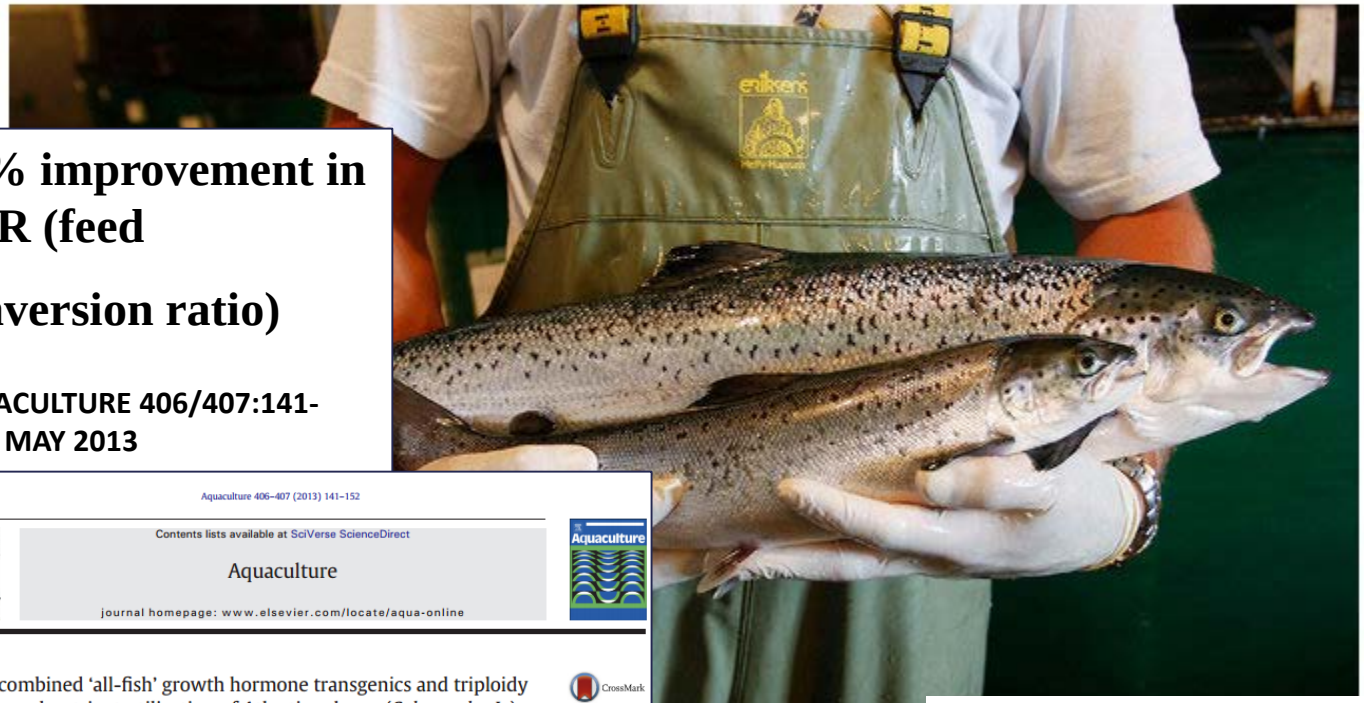
Modified hormone expression

GE salmon approved for contained use last year

BUSINESS DAY

Genetically Engineered Salmon Approved for Consumption

By ANDREW POLLACK NOV. 19, 2015



20% improvement in FCR (feed

conversion ratio)

AQUACULTURE 406/407:141-152 · MAY 2013

Aquaculture 406–407 (2013) 141–152

Contents lists available at SciVerse ScienceDirect

Aquaculture

journal homepage: www.elsevier.com/locate/aqua-online

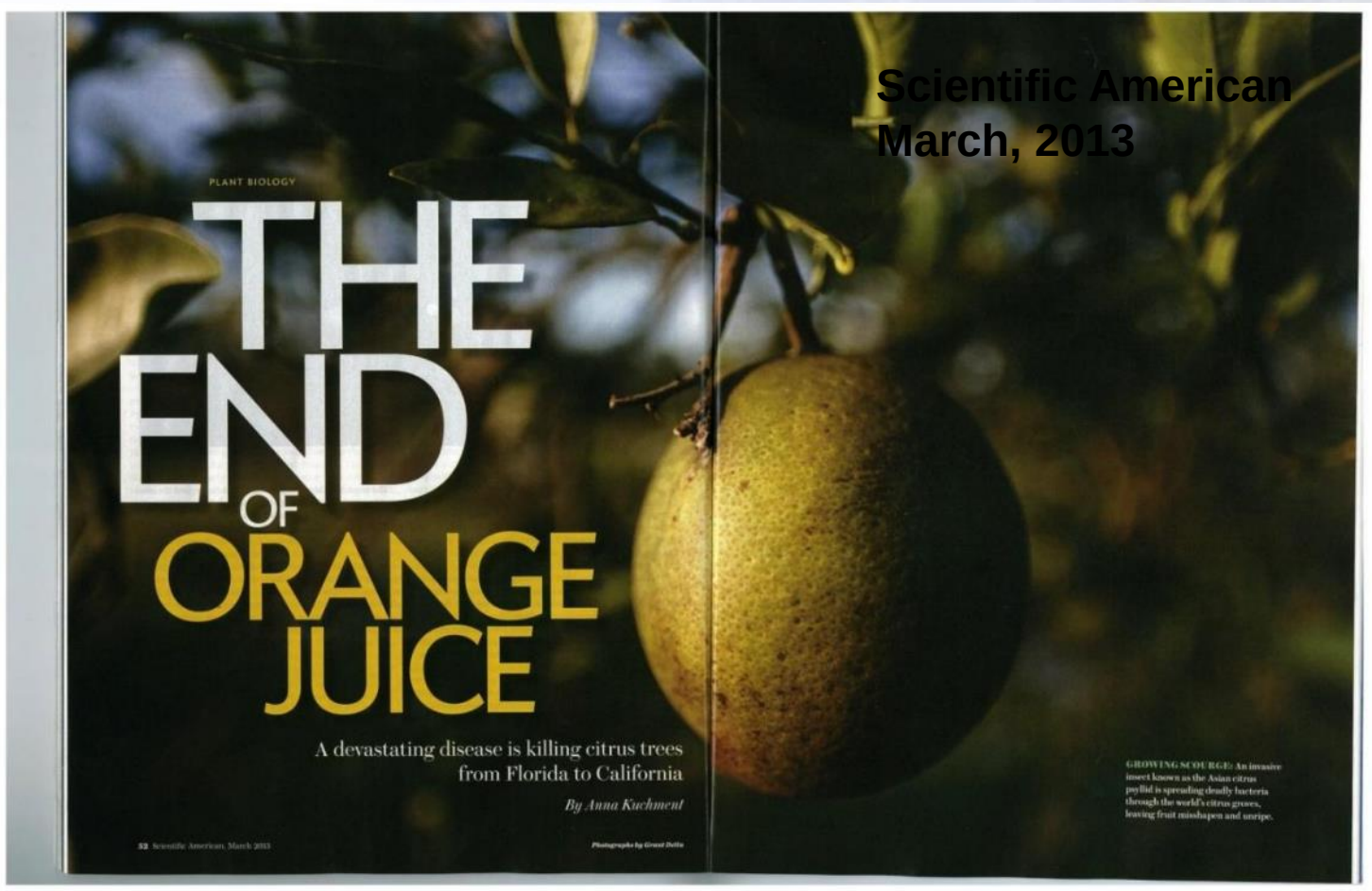
Effects of combined 'all-fish' growth hormone transgenics and triploidy on growth and nutrient utilization of Atlantic salmon (*Salmo salar* L.) fed a practical grower diet of known composition

S.M. Tibbetts [a], C.L. Wall [b], V. Barbosa-Solomieu [c,1], M.D. Bryenton [b], D.A. Plouffe [b], J.T. Buchanan [d], S.P. Lall [a,*]

[a] National Research Council of Canada, Aquatic and Crop Resource Development, 1411 Oxford Street, Halifax, Nova Scotia B3H 3Z1, Canada
[b] Center for Aquaculture Technologies Canada, 0718 Bay Fortune, R.R. No. 4, Souris, Prince Edward Island C0A 2B0, Canada
[c] AquaBounty Canada, 0718 Bay Fortune, R.R. No. 4, Souris, Prince Edward Island C0A 2B0, Canada
[d] Center for Aquaculture Technologies, 8395 Camino Santa Fe Street East, San Diego, CA 92121, United States

The New York Times

Resistance transgenes promising solution/s to devastating ‘citrus greening’



Scientific American
March, 2013

The New York Times

July 27, 2013

A Race to Save the Orange by Altering Its DNA

By AMY HARMON

CLEWISTON, Fla. — The call Ricke Kress and every other citrus grower in Florida dreaded came while he was driving.

Face the “wall of opposition” ?

Defensin-like proteins from spinach for citrus greening disease resistance

Courtesy of Eric Mirkov, Texas A & M

Forest health a major and growing concern

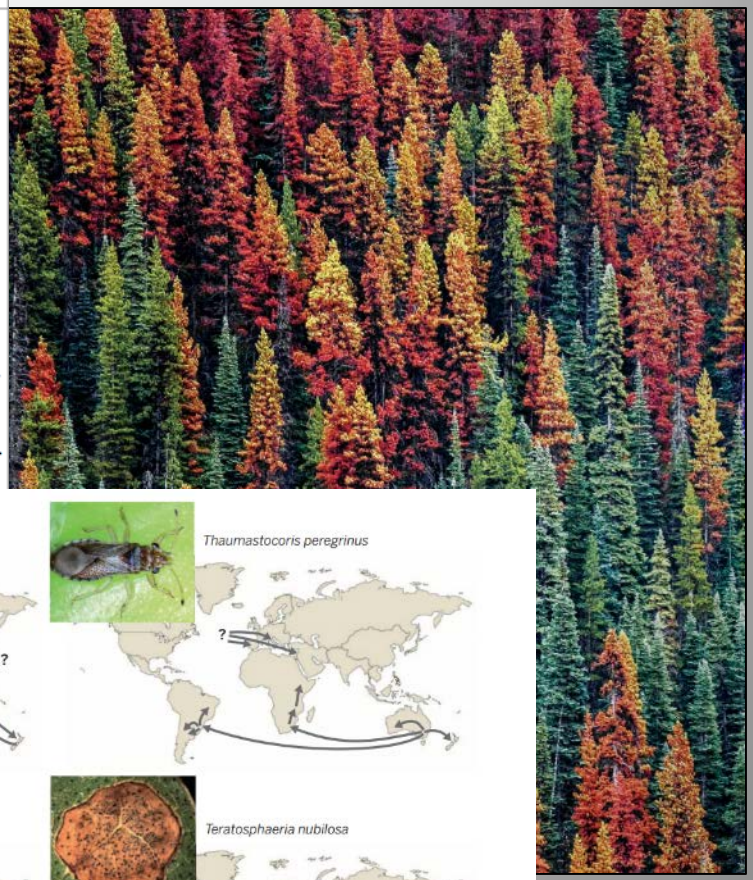
REVIEW

Planted forest health: The need for a global strategy

M. J. Wingfield,[1]* E. G. Brockerhoff,[2] B. D. Wingfield,[1] B. Slippers[1]

Several key tree genera are used in planted forests worldwide, and these represent valuable global resources. Planted forests are increasingly threatened by insects and microbial pathogens, which are introduced accidentally and/or have adapted to new host trees. Globalization has hastened tree pest emergence, despite a growing awareness of the ng of the costs, and an increased focus on the importance of and potential of planted forests, innovative solutions and a ach are needed. Mitigation strategies that are effective only in n invasions elsewhere in the world, ultimately leading to global st problems in the future should mainly focus on integrating lly, rather than single-country strategies. A global strategy to portant and urgently needed.

ems are a huge- ce, easily over- (1–3). Globally, ted to rely on y more depend have been separated from their natural enemies. However, when plantation trees are reunited with their coevolved pests, which may be introduced accidentally, or when they encounter novel pests to which they have no resistance, substantial



n September 8, 2015

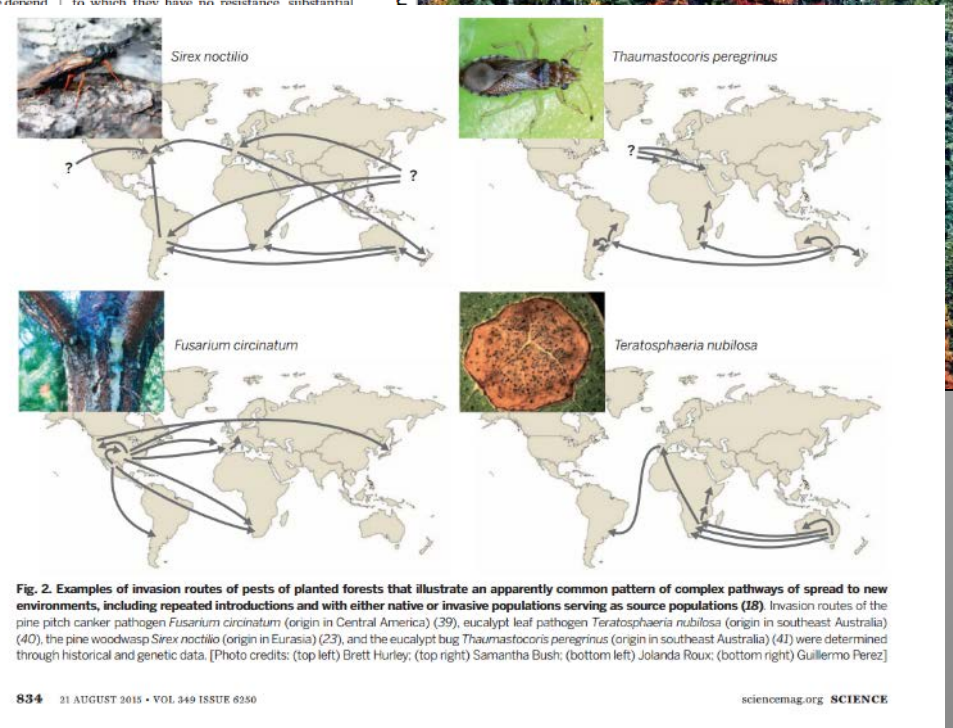
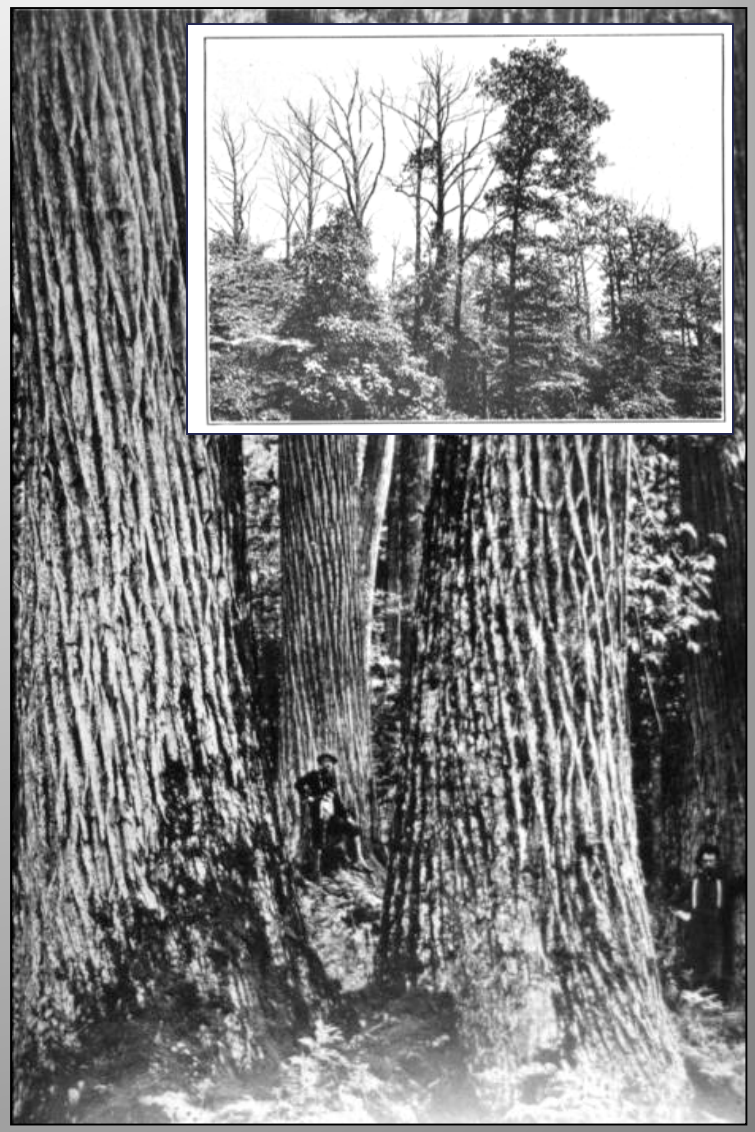


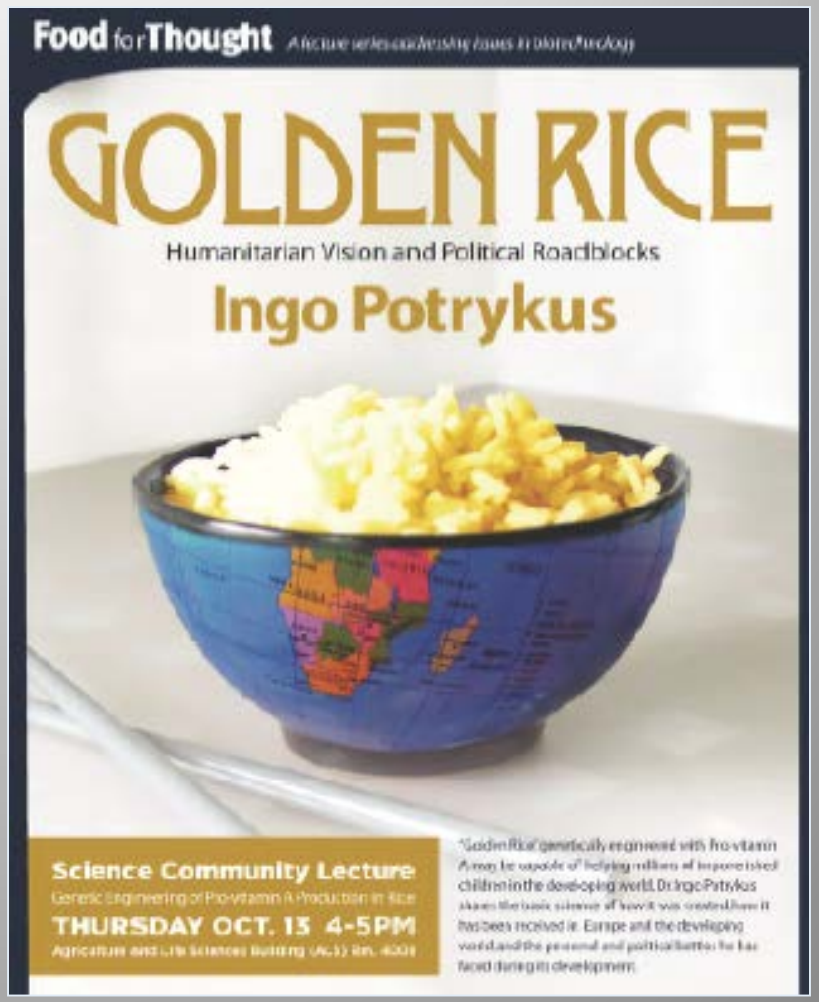
Fig. 2. Examples of invasion routes of pests of planted forests that illustrate an apparently common pattern of complex pathways of spread to new environments, including repeated introductions and with either native or invasive populations serving as source populations (*18*). Invasion routes of the pine pitch canker pathogen *Fusarium circinatum* (origin in Central America) (*39*), eucalypt leaf pathogen *Teratosphaeria nubilosa* (origin in southeast Australia) (*40*), the pine woodwasp *Sirex noctilio* (origin in Eurasia) (*23*), and the eucalypt bug *Thaumastocoris peregrinus* (origin in southeast Australia) (*41*) were determined through historical and genetic data. [Photo credits: (top left) Brett Hurley; (top right) Samantha Bush; (bottom left) Jolanda Roux; (bottom right) Guillermo Perez]

Helping forests: American Chestnut restoration by genetic modification

March 2014 issue - Scientific American



Diverse pipeline of biofortification products = enhancement of critical vitamins or nutrients



Biofortified plants are improving nutrition for many today, and can do more with aid of GE methods

Biofortification breeding well underway, including a provitamin A enriched sweet potato that is **currently** being grown by > half a million families.

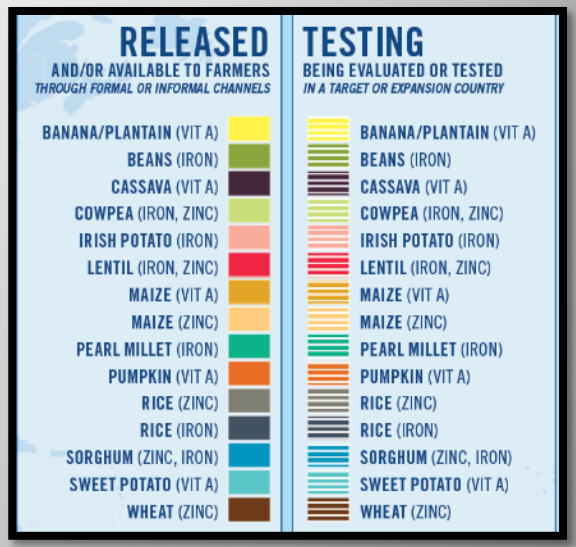
Other projects are underway to increase levels of protein, iron, zinc, antioxidants, and other beneficial components in food.

Gates Foundation a major supporter

Sources: HarvestPlus; CIMMYT

The HarvestPlus program – worldwide impact by traditional breeding

- Nutrient targets start at:
  - 30% of the EAR of iron
  - 40% of the EAR of zinc
  - 50% of the EAR of provitamin A
- Reaches more than 40 countries



Biotech methods useful where breeding is ineffective or slow

- Rice
- Cassava
- Sorghum
- Banana

Rice

Cassava

DuPont reports breakthrough in introducing beta carotene in Sorghum

In Africa, up to half a million children become blind from Vitamin A Deficiency (VAD) with increased risk of cognitive impairment, disease and death from severe infections. Furthermore, nearly 600,000 women die from c..

20 Feb 2014

IOWA, USA: Dupont has achieved a breakthrough in introducing pro-vitamin (beta carotene) into sorghum, a stap food in Africa which is naturally deficient in key nutrients.

This is epxected to help improve nutrition for nearly 300 mn people in Africa dependent on Sorghum. DuPont said that the ability to achieve 100 % of the recommended daily allowance of vitamin A in children from Sorghum has never been achieved before.

In Africa, up to half a million children become blind from Vitamin A Deficiency (VAD) with increased risk of cognitive impairment, disease and death from severe infections. Furthermore, nearly 600,000 women die from childbirth-related causes, many from complications that could be reduced through more vitamin A in their diet.

http://www.commodityonline.com/news/dupont-reports-breakthrough-in-introducing-beta-carotene-in-sorghum-58036-3-58037.html

“Super banana”

Vitamin A Super Banana in human trials

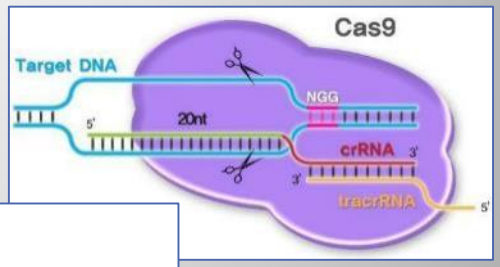
The first human trial to test the efficacy of a genetically modified (GM) nutritionally enhanced banana is starting in the US. Conceived by researchers at the Queensland University of Technology (QUT) in Brisbane, Australia, to provide a good source of beta carotene, the Super Banana has $10 million in backing from the Bill and Melinda Gates Foundation. The genetically enriched, golden-colored banana may help prevent blindness caused by vitamin A deficiency in Ugandan children whose diets are deficient in this nutrient (*Nat. Biotechnol.* **30**, 1017–1019, 2012). But leaders of the banana project are embarking on a historically precarious path. Golden Rice, the previous GM crop developed to alleviate vitamin A deficiency in the poor, met fierce hostility and regulatory hurdles that have plagued its development for 15 years. The rice still hasn't been commercialized in its target country, the Philippines. Whether the banana will meet a similar fate remains to be seen.

Opposition from anti-biotech activists in the media so far has been minimal, and radical activist presence in Uganda and other African countries is generally small. “I don't have the feel-

Erika Fish, QUT

But is it golden? Stephen Buah (left) and James Dale, from Queensland University of Technology, display the Super Banana.

Coming: Gene editing technology for diverse traits



Science magazine names CRISPR 'Breakthrough of the Year'

By Robert Sanders | DECEMBER 18, 2015

In its year-end issue, the journal *Science* chose the CRISPR genome-editing technology invented at UC Berkeley 2015's Breakthrough of the Year.

A runner-up in 2012 and 2013, the technology now revolutionizing genetic research and gene therapy "broke away from the pack, revealing its true power in a series of spectacular achievements," wrote *Science* correspondent John Travis in the Dec. 18 issue. These included "the creation of a long-sought 'gene drive' that

Gene editing with diverse applications – including hornless cattle, non-browning mushrooms

Open Season Is Seen in Gene Editing of Animals

By AMY HARMON NOV. 26, 2015

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t. Jenn Ackerman fo

The New York Times

nature International weekly journal of science

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NATURE | NEWS

Gene-edited CRISPR mushroom escapes US regulation

A fungus engineered with the CRISPR–Cas9 technique can be cultivated and sold without further oversight.

Emily Waltz

14 April 2016

Summary

- GMO is a breeding method not a particular kind of product
- Widespread but uneven use of GMO crops in the world
  - Plateau/decline in area in recent years
- Large benefits for economics and environment, management problems
- Diverse pipeline of new products
  - Many from RNAi / modified native gene expression
  - Abiotic stress tolerance, biofortification
- Gene editing products on the way, regulation unclear