Genetically Engineered Crops: Can Africa Really Benefit??

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

❖Are GE crops being grown in developing countries?

❖What farmers are growing GE crops in developing countries?

❖What kinds of GE crops are they growing?

❖Why are they growing them?

❖What kinds of problems do they raise?

❖Is this a magic bullet for food security in Africa?

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Perspective on agriculture in developing countries…

❖ How much will you spend on your lunch today?

❖ One billion of the world's poorest people live on ≤ $1 per day and depend on their own agriculture for food.

❖ 820 million people go to bed hungry each day

❖ Malnutrition leads to stunted physical/mental development, increased disease suceptibility

❖ No country has achieved a rapid rise from poverty without increasing agricultural productivity

❖ Majority of small farmers are women who often have the fewest resources

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

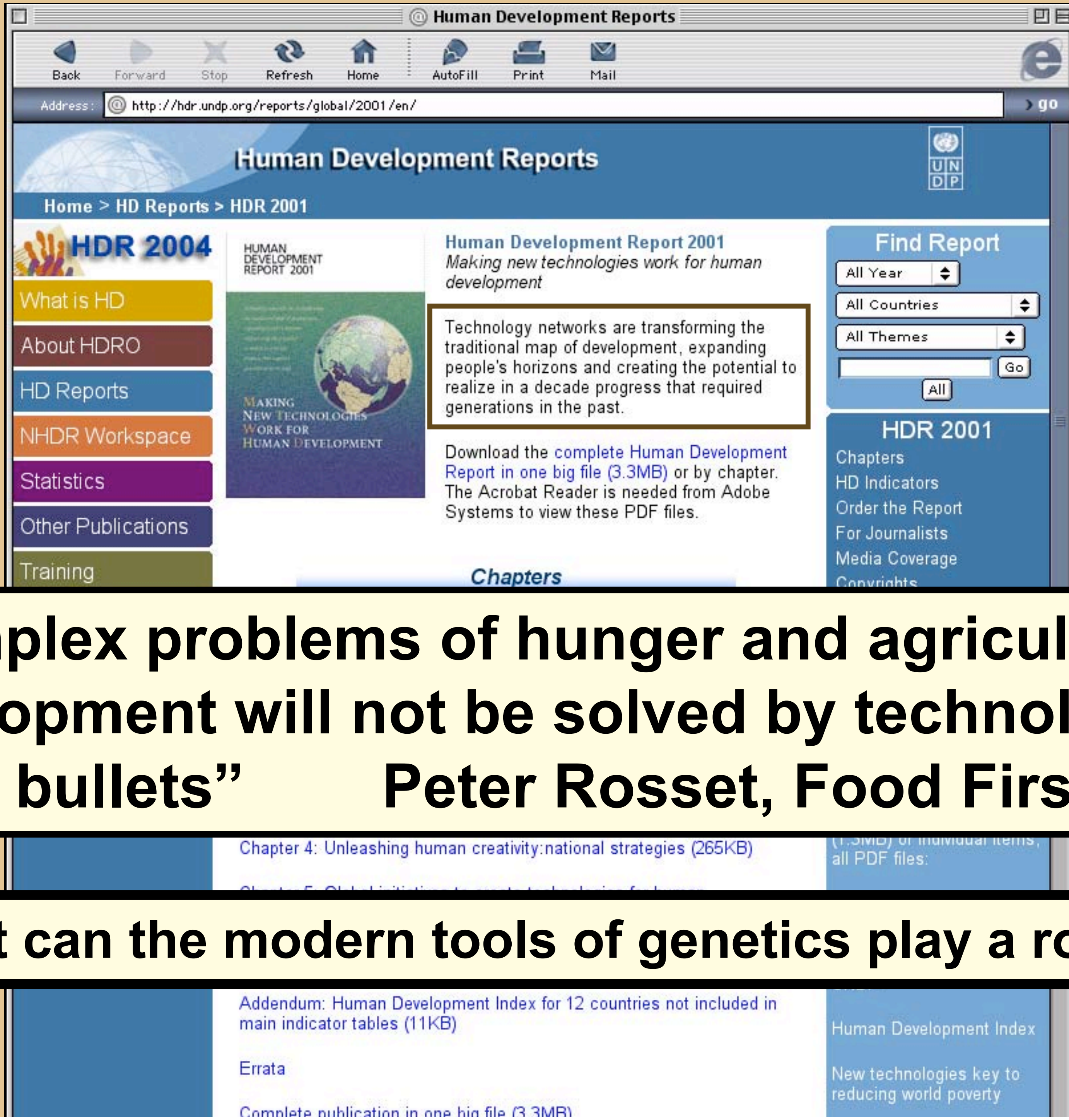
"The farmers usually come on bicycles, sometimes they come on foot. Most people come from far distances, 10 km (six miles) away."

Mrs. Dinnah Kapiza, Agro-dealer, Mponela, Malawi

Mrs. Dinnah Kapiza has transformed her used clothing business into a full-line farming supply store in rural Malawi that is now critical to the success of poor farmers in her region. She opened her store in 2002 with an initial investment of MWK$20,000.00 (Malawian kwacha, equivalent to US$310.00).

http://www.agra-alliance.org/section/people/profiles#kapiza

United Nations Development Programme



"Complex problems of hunger and agricultural development will not be solved by technological silver bullets"   Peter Rosset, Food First

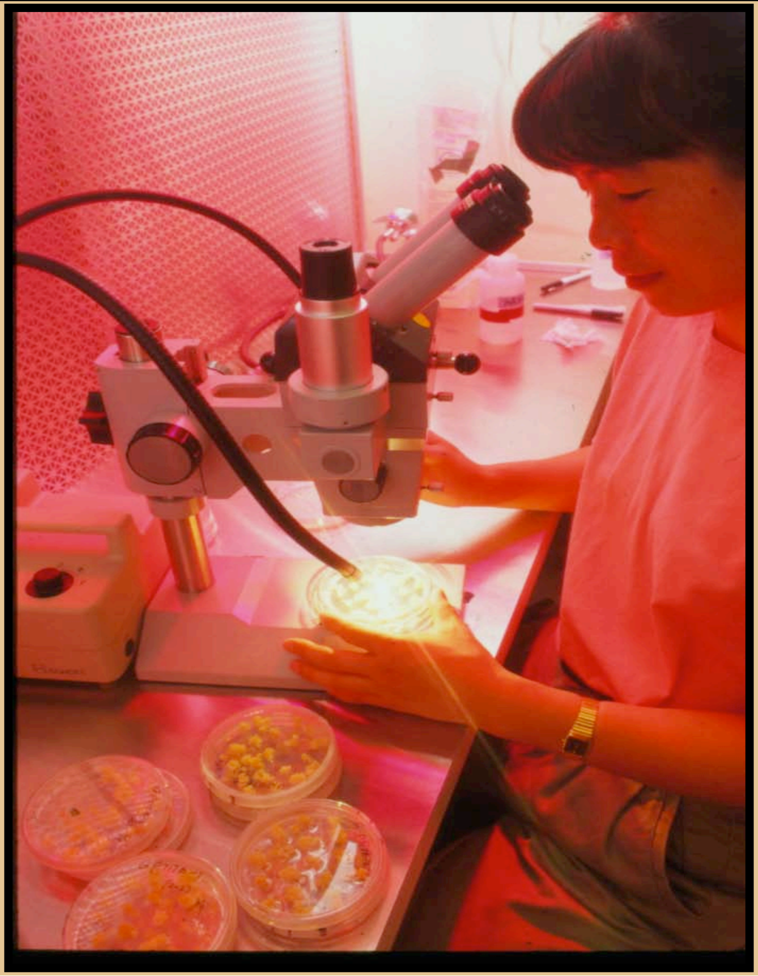
But can the modern tools of genetics play a role?

Agricultural biotechnology is more than just GMOs

Marker-assisted breeding led to new millet hybrid with powdery mildew resistance

PCR for pest disease detection for bananas and papaya

Tissue culture methods of propagation for commercial production of banana, for example, rid the crop of viral disease. Female-managed companies in the Philippines give women a different role in agriculture and provide income



Genetic engineering projects for developing countries: three examples

Private sector: Development of Bt maize

Public sector: Development of Golden Rice

Public-Private sector partnership: Development of SuperSorghum

Private sector:
Development of Bt maize

Is it needed?

"Maize is our staple food, and we have not identified any other source of income from plants to sell, so we continue planting maize."

Her toughest challenges:

- ✓*Affordable transportation to get produce to market*
- ✓*Safe storage from pests*
- ✓*Regular supply of water. (fuel prices make running a pump too expensive)*

Mrs. Bernadette Mwikali Kioko, Farmer, Ukambani, Kenya

http://www.agra-alliance.org/section/people/profiles#kioko

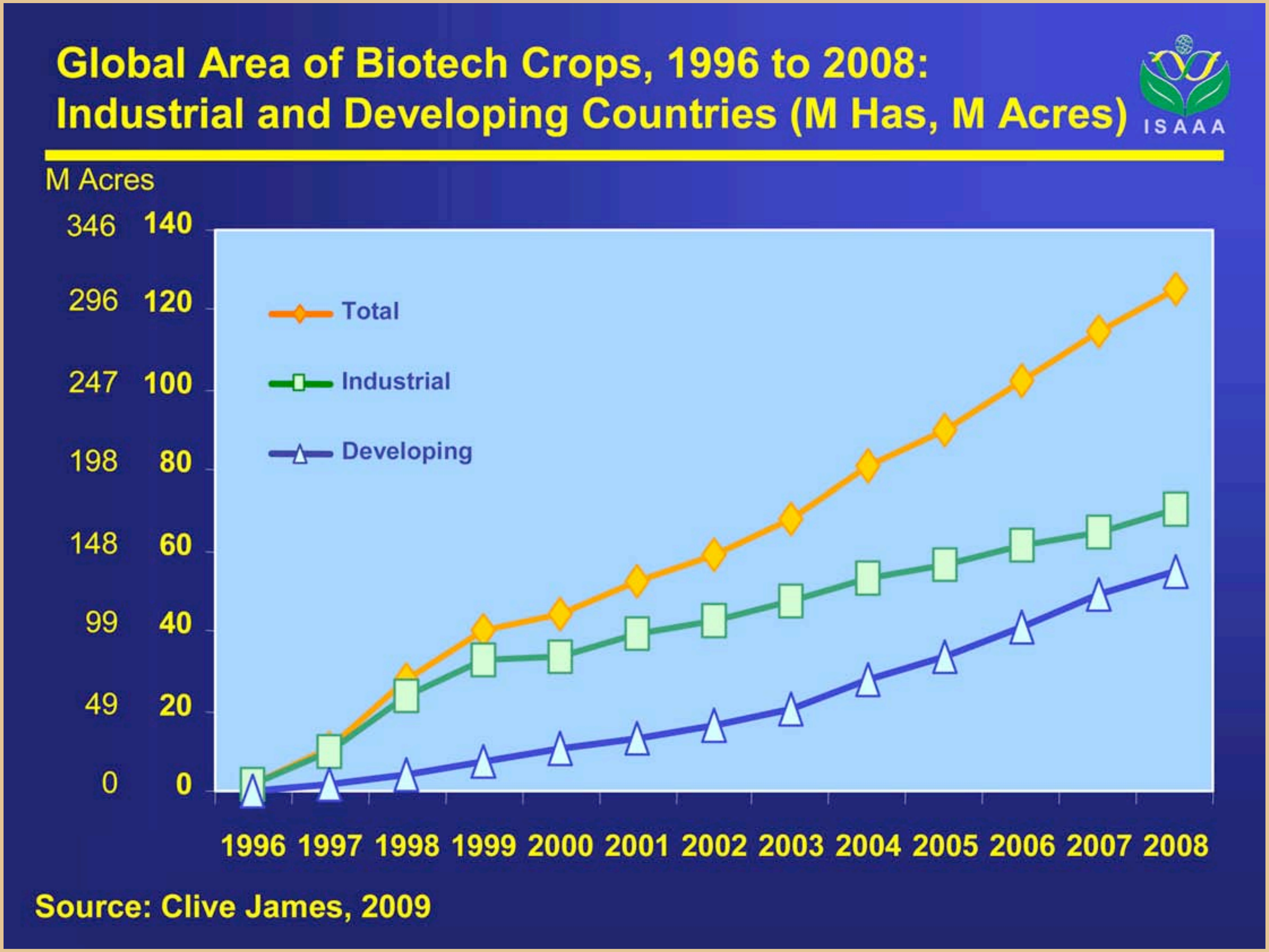
What questions are being asked about these crops?

Are GE crops being grown in developing countries?

Do only large agrochemical companies benefit from crops currently being grown?

Will GE crops address small farmers' needs?

Are GE crops grown in developing countries?

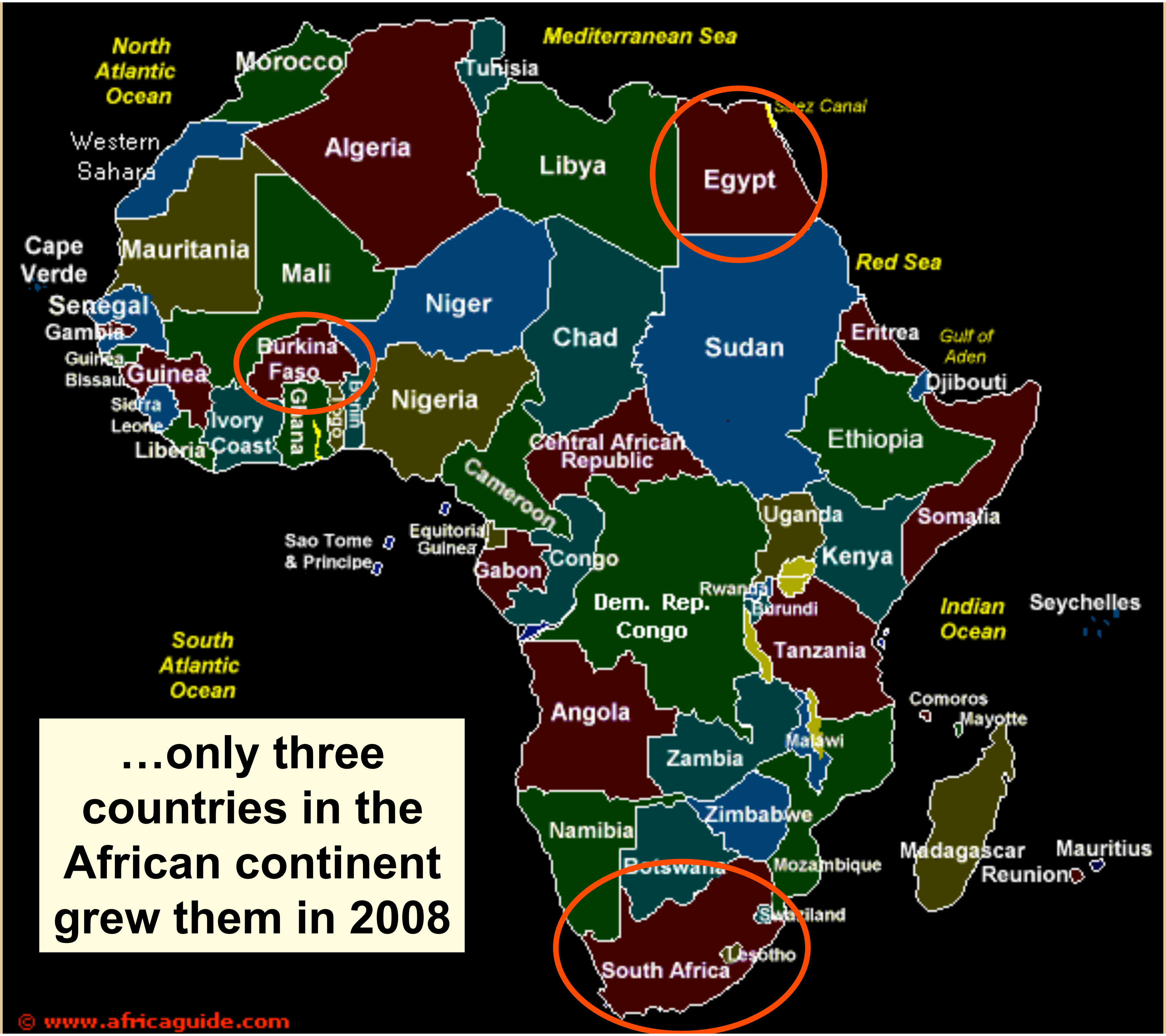


482,812 square miles worldwide in 2008 (equal to combined areas of CA, TX and NY) in 25 industrial and developing countries

But the variety of GE crops is limited and…

25 industrial and developing countries in order of acreage:

United States, Argentina, Brazil, Canada, India, China, Paraguay, South Africa, Uruguay, Bolivia, Philippines, Australia, Mexico, Spain, Chile, Colombia, Honduras, Burkina Faso, Czech Republic, Romania, Portugal, Germany, Poland, Slovakia, Egypt.



…only three countries in the African continent grew them in 2008

Will only large agrochemical companies benefit?

“Economic evidence also does not support that only multinational firms are capturing economic value created by transgenic crops (in developing countries). Benefits are shared by consumers, technology suppliers, adopting farmers.”

(Anderson K and Jackson L 2005. *J African Economies 14: 385-410*)

Will GE crops address small farmers' needs?

"Economic evidence does not support misconception that transgenic crops only benefit large farms; evidence indicates technology might actually be 'pro-poor."

(Ruttan VW 2004. *Intl J Biotechnol 643-54*)

What does "pro-poor" mean?

How can this technology be pro-poor?

Productivity: Evidence for Bt Cotton Gains

Bt cotton in:

- **United States** yield increase 0 – 15%
- **China** yield increase 10%
- **South Africa** yield increase 20%-40%
- **India** yield increase 60 – 80 %

Reason for difference: Small-scale farmers suffer bigger pest-related yield losses due to technical and economic constraints

SOURCE: Qaim M and Zilberman D. 2003. Yield effects of genetically modified crops in developing countries. Science 299:900-902

But Qaim study criticized for taking data from cotton seed provider, Mahyco

Another study, using data collected by researchers on field trials of 9000 farming families in India, found a 45-63% higher yield with Bt vs nonBt crops.

Ref: Bennett *et al*., 2006. " Farm-level Economic Performance of GM Cotton in Maharashtra India" *Rev Agric Econ* 28: 59-71

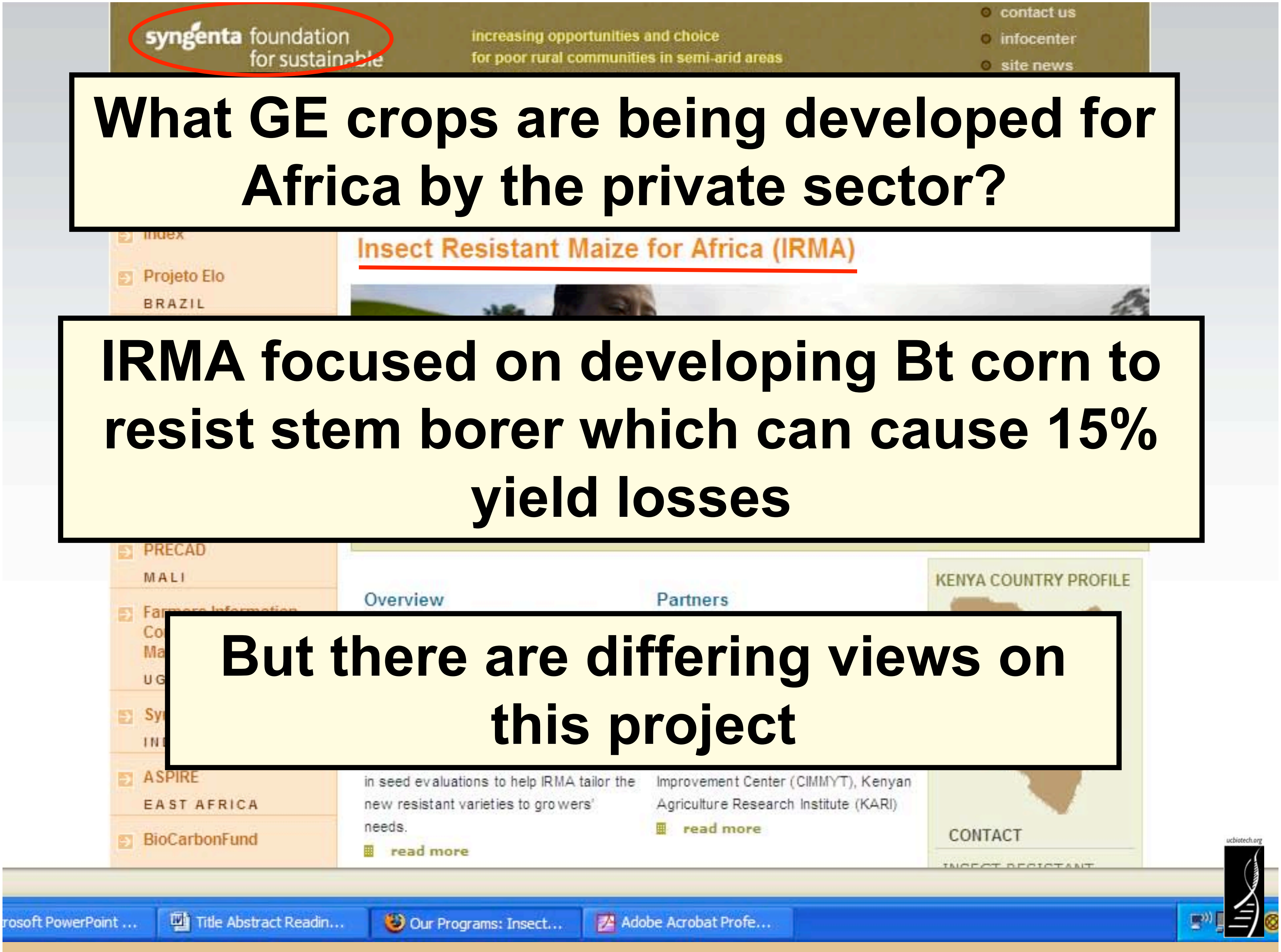
A nonprofit organization, promoting sustainable agriculture and self-reliant economic growth for rural communities, found the opposite results with farmers from a single Indian province: lower yields, more expense, more pesticides with Bt varieties.

Not published; on the organization's website: http://www.i-sis.org.uk/IBTCF.php

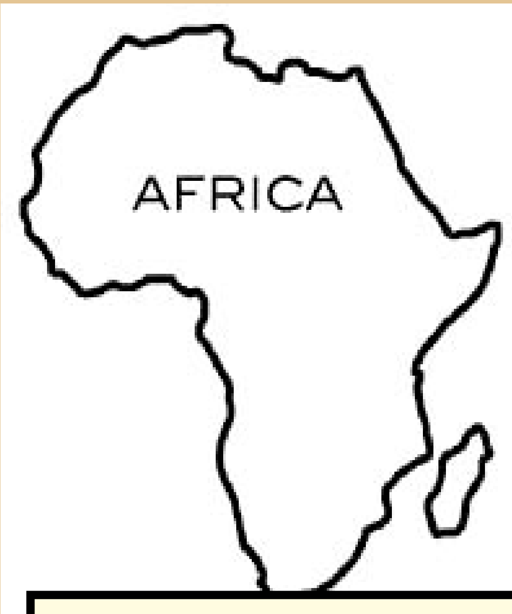
What GE crops are being developed for Africa by the private sector?

IRMA focused on developing Bt corn to resist stem borer which can cause 15% yield losses

But there are differing views on this project



Zimbabwe and Zambia stand united on GMOs



THE HERALD (Harare) Wisdom Mdzungairi
October 11, 2005

International scientists, including those from the United States, have praised Zimbabwe and Zambia for rejecting genetically-modified food donations from the West to feed scores of their rural folk facing drought-induced food shortages.

Some African countries have taken strong stands against, some for GE crops, leaving policymakers and the public confused

policymakers and the public because of lack of reliable information and guidance available to the groups."

Shouldn’t African farmers and consumers make their own decisions on these issues?

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How can this be done effectively?

IRMA started with participatory rural appraisals, involving 900 Kenyan farmers from 43 villages to determine if Bt corn would work on their small-scale farms

Yield indications for first research season for different survey areas.

Site	Variety	Mean yield (kg/kg)	*n*	Yield difference (kg/kg)	*t*-value	% yield difference
Avg. all farmers						
	Own seed	**63**				
	CRN seed	**187**	**175**	**59**	**8.679**	**32%***
	Bt seed	**246**				
Individual Sites:						
Northern Highveld						
	Own seed	32				
	CRN seed	90	33	56	4.490	62%*
	Bt seed	146				
Southern Highveld						
	Own seed	162				
	CRN seed	278	57	57	4.332	21%*
	Bt seed	335				
Hlabisa	Own seed	78				
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	Bt seed	127				

*Yield difference statistically significant at a 95% level.

Following introduction, figures show small-scale farmers are getting increased yields and better quality with Bt maize.

Gouse et al., Three Seasons of Subsistence Insect-Resistant Maize in South Africa: Have Smallholders Benefited? *AgBioForum 9(1)-2*

Bt maize

NO MAGIC BULLET

Is this the only way to address problems for African farmers?

No, problems are different

Different food preferences

Different ecology

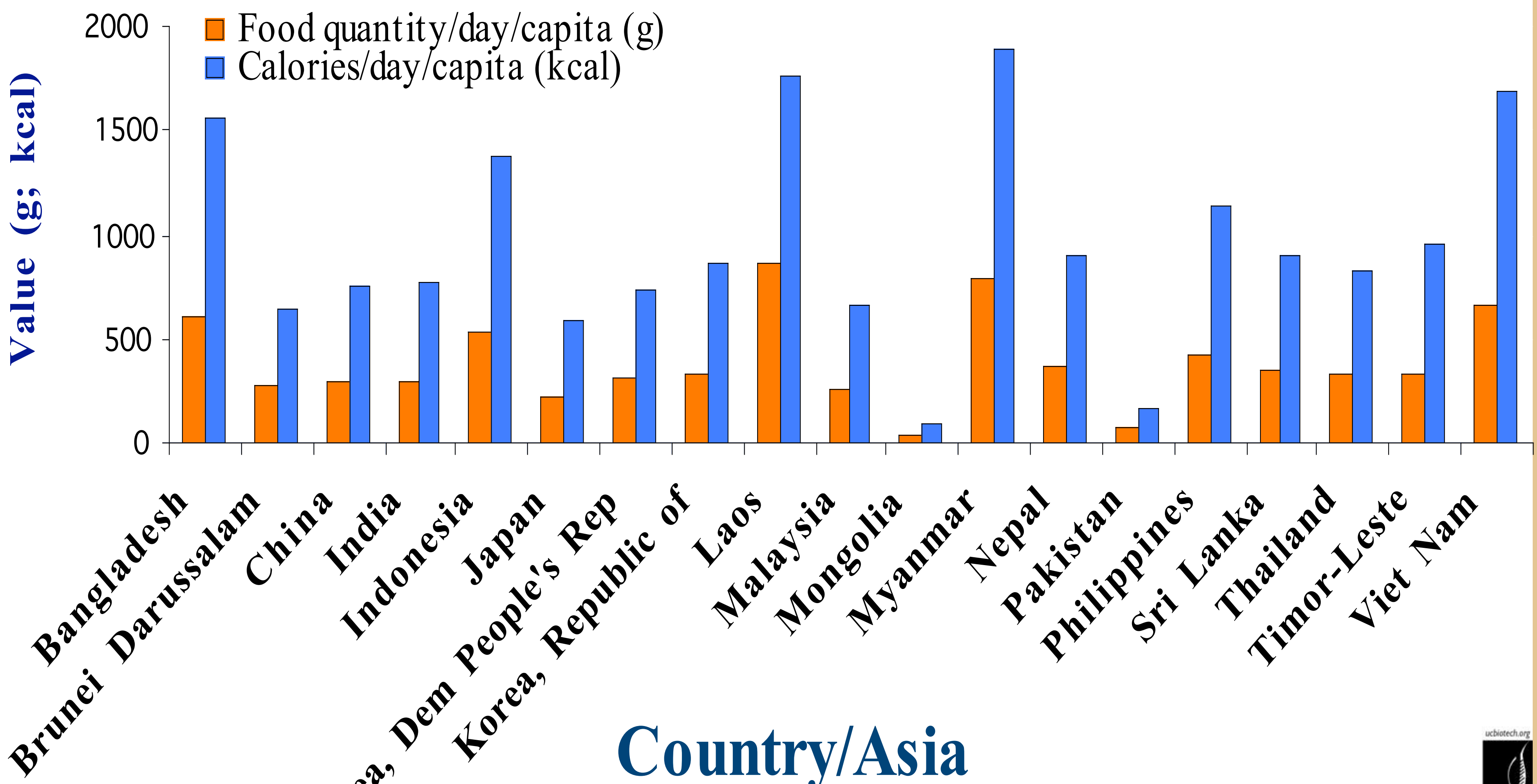
Different health issues

Different agronomic limitations

Public sector: Development of Golden Rice

Rice: Critical Part of Many Diets
2004 (FAOSTAT)*

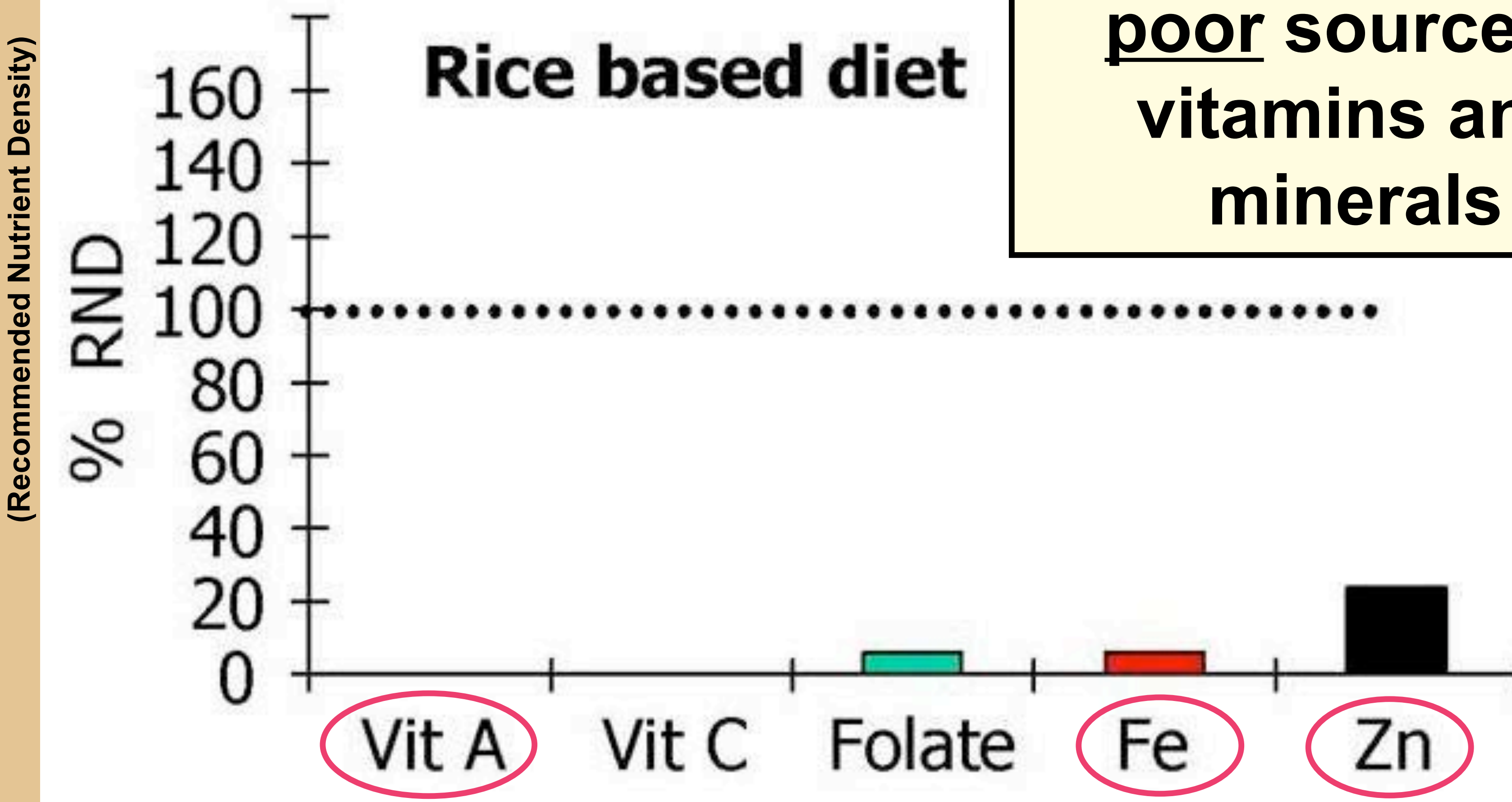
FAO Minimum Dietary Energy Requirement
= 1800 – 2000
(weighted average; kcal/person/day)



Modified from G. Barry, IRRI

* Accessed 02/2007

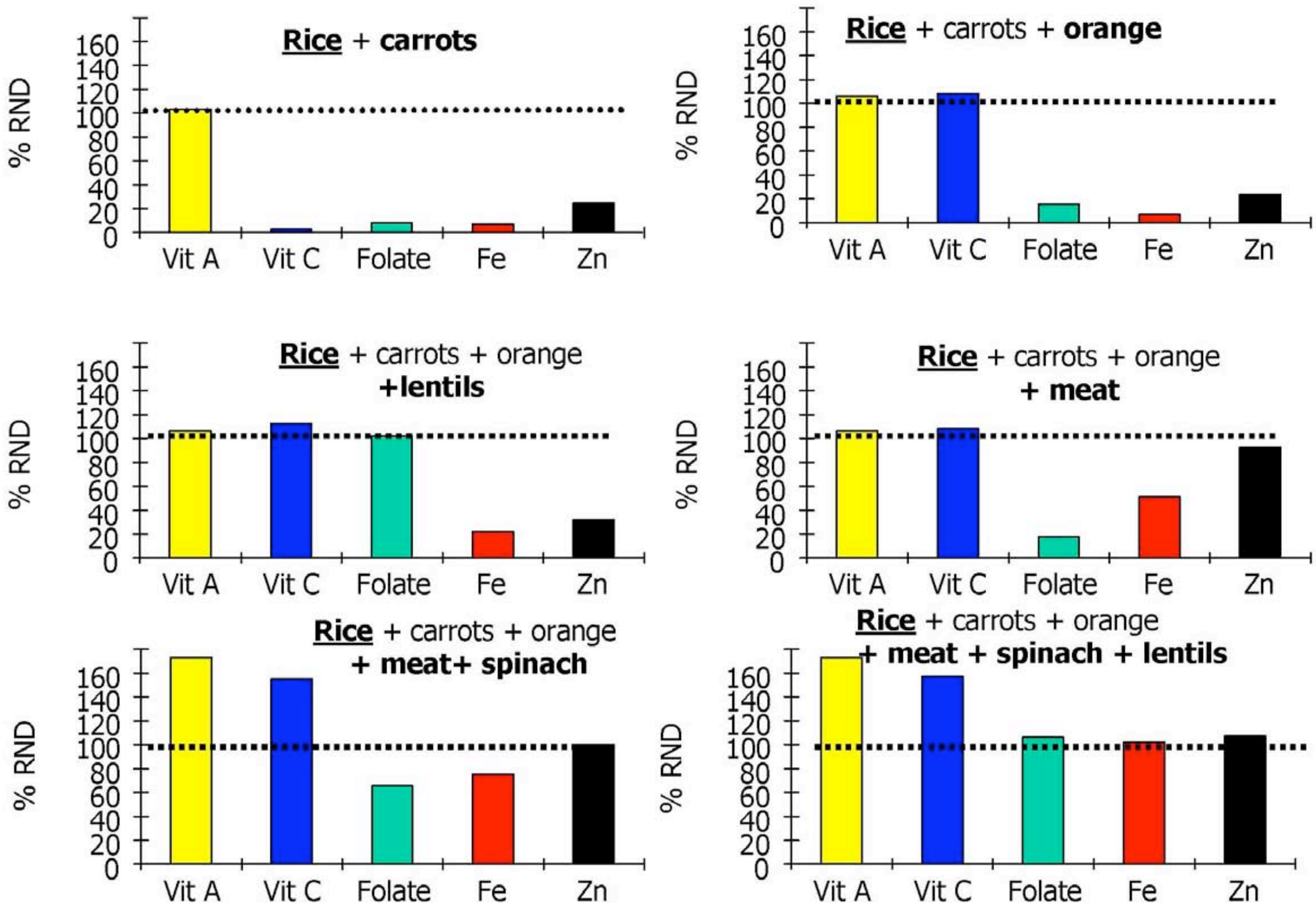
Rice Diet and Micronutrient Nutrition



BUT rice is a very poor source of vitamins and minerals

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

Modified from G. Barry, IRRI



Rice diet can be supplemented with other fruits, vegetables and meat to acquire needed nutrients…but not everyone has that luxury

Modified from G. Barry, IRRI

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

The FACTs in the Philippines are…

2 of 3 infants (6mos.-1yr) have iron-deficiency anemia

1 of 3 Filipinos are at risk of low zinc intake

4 of 10 children are vitamin A deficient

Numbers are increasing since 1990s

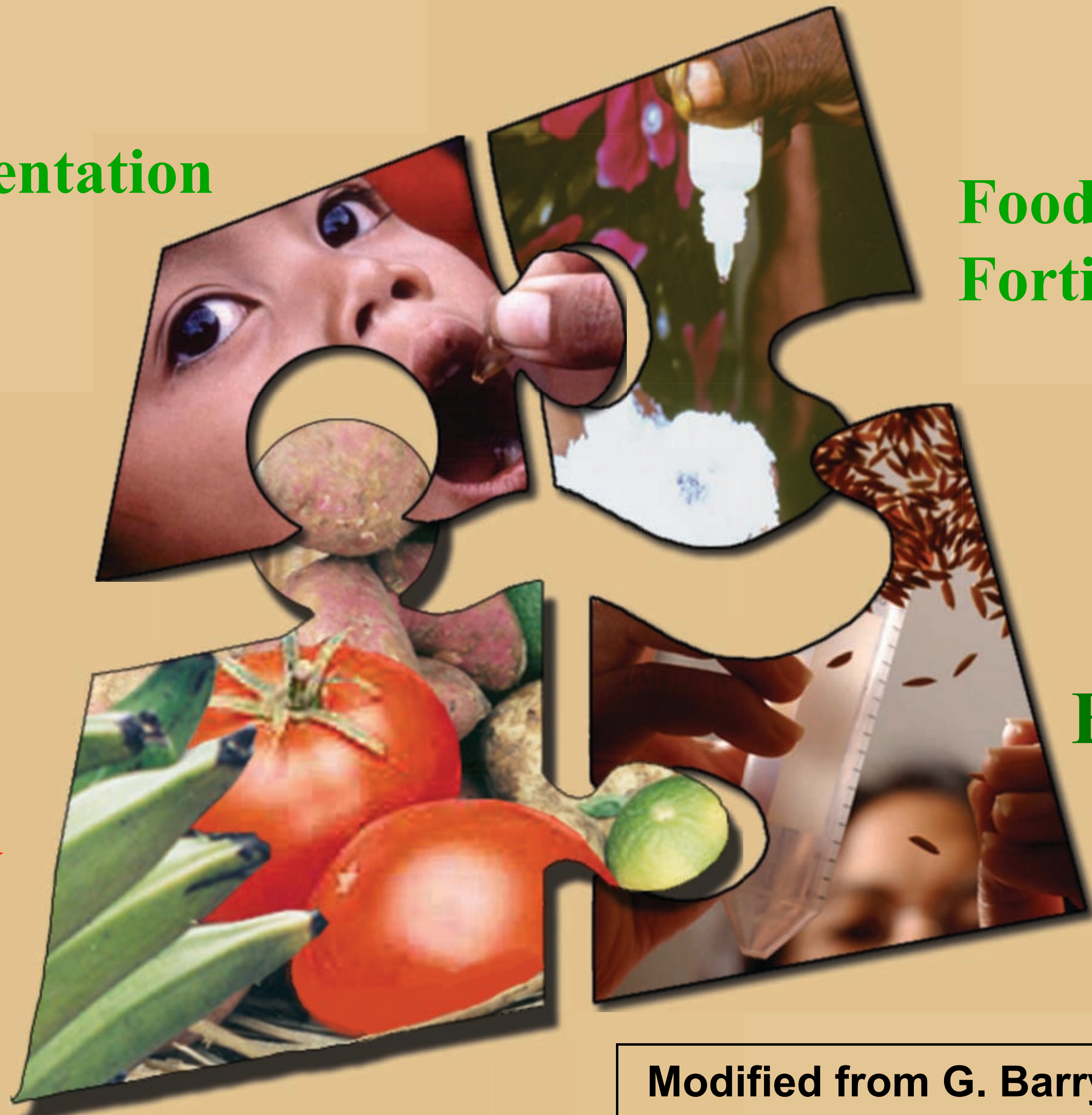
Micronutrient malnutrition is a serious public health problem

From: E. Boncodin, Fedl Budget Secy Manila Philippines

Biofortification can complement current interventions, all of which are needed.

Supplementation

Food Fortification



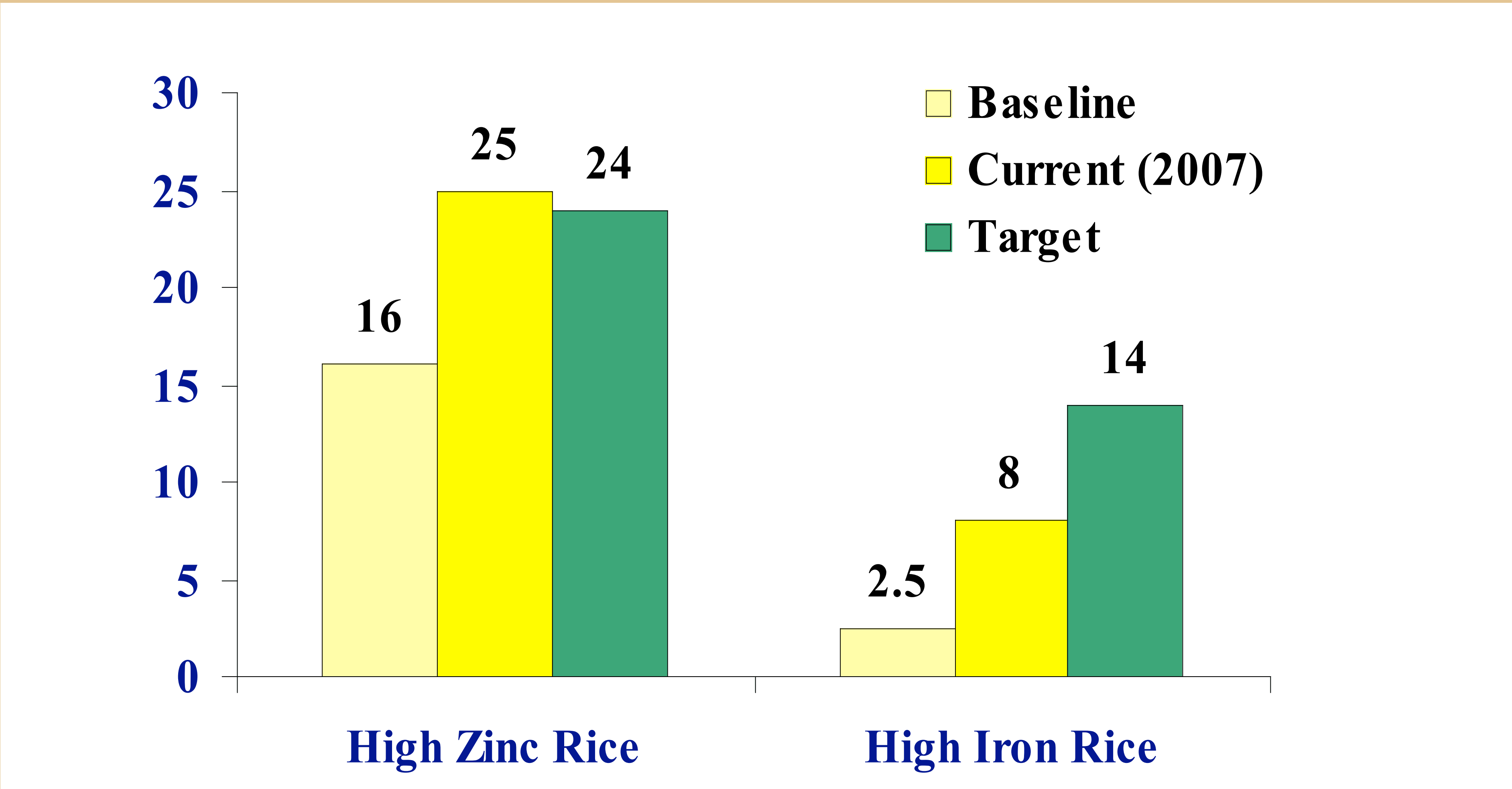
Biofortification

Dietary Diversity

Modified from G. Barry, IRRI

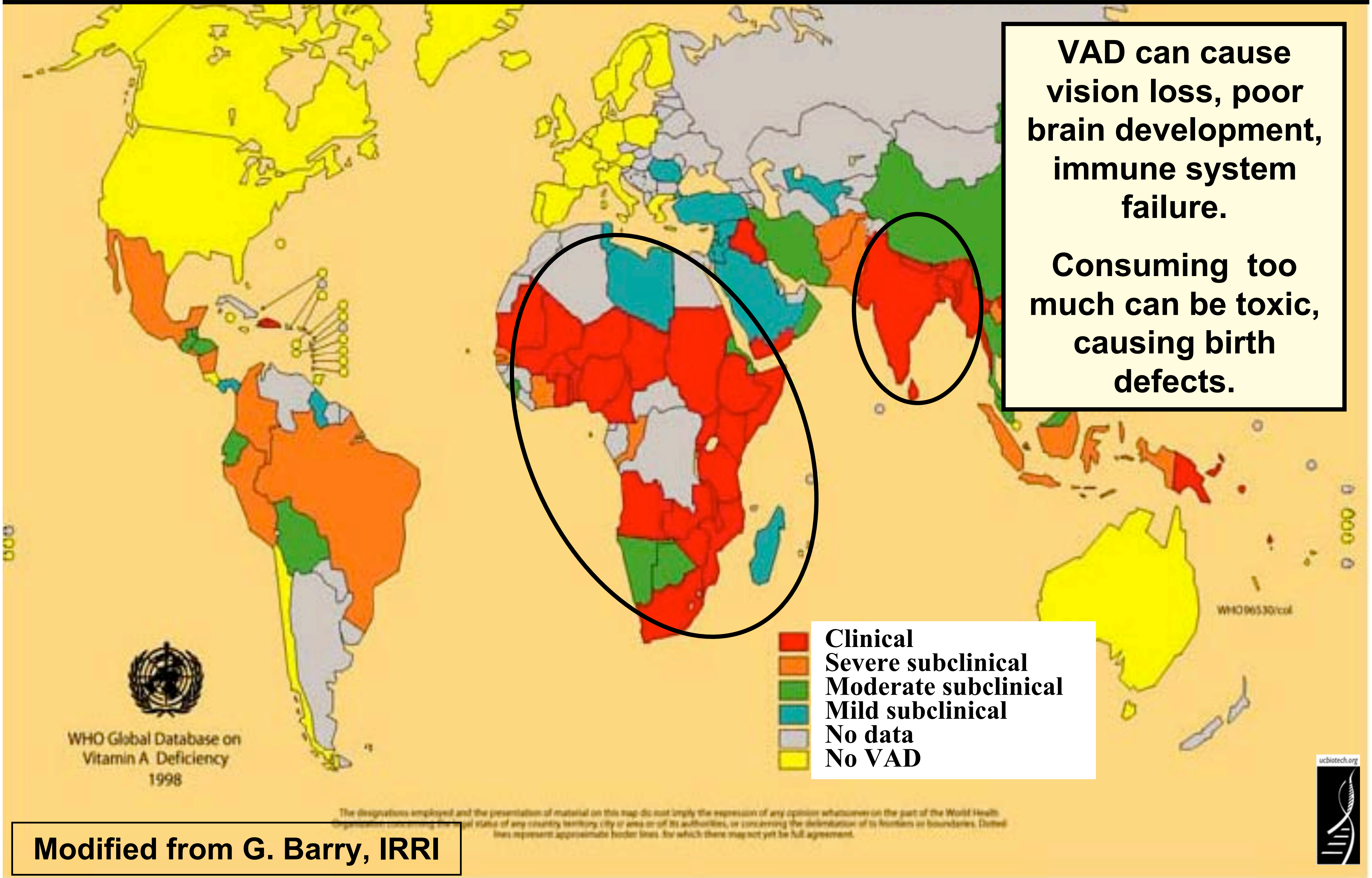
HarvestPlus
Breeding Crops for Better Nutrition

IRRI has made progress on iron and zinc biofortified rice…



From: E. Boncodin, Fedl Budget Secy Manila Philippines

Vitamin A deficiency (VAD): as judged by severity of health impact



VAD can cause vision loss, poor brain development, immune system failure.

Consuming too much can be toxic, causing birth defects.

Modified from G. Barry, IRRI

Golden Rice in 2000

'Golden Rice', developed by Ingo Potrykus and Peter Beyer, was funded by Rockefeller Foundation, Swiss Federal Institute of Technology, European Union, and Swiss Federal Office for Education and Science.

Polished, original version of Golden Rice had measurable levels of β-carotene – to be used as a food-based approach to complement other approaches to reduce problem of Vitamin A Deficiency

Modified from G. Barry, IRRI

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Basic Carotenoid Biosynthetic Pathway

Carotenes

Genes now used in Golden Rice and their source

IPP ⇄ DMAPP

↓

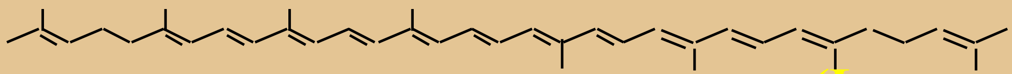
GGPP (C20)

Phytoene synthase → ↓
Daffodil or Maize

Phytoene (C40)

Phytoene desaturase → ↓ desaturation
Bacterial source

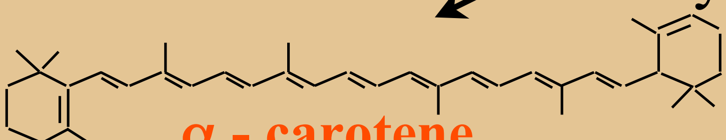
Lycopene (C40)



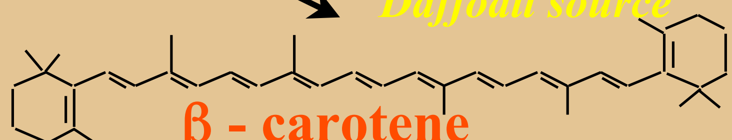
cyclization

(Lycopene cyclase)
Daffodil source

Original gene used



α - carotene



β - carotene

Xanthophylls

α-cryptoxanthin

β-cryptoxanthin

↓

zeaxanthin

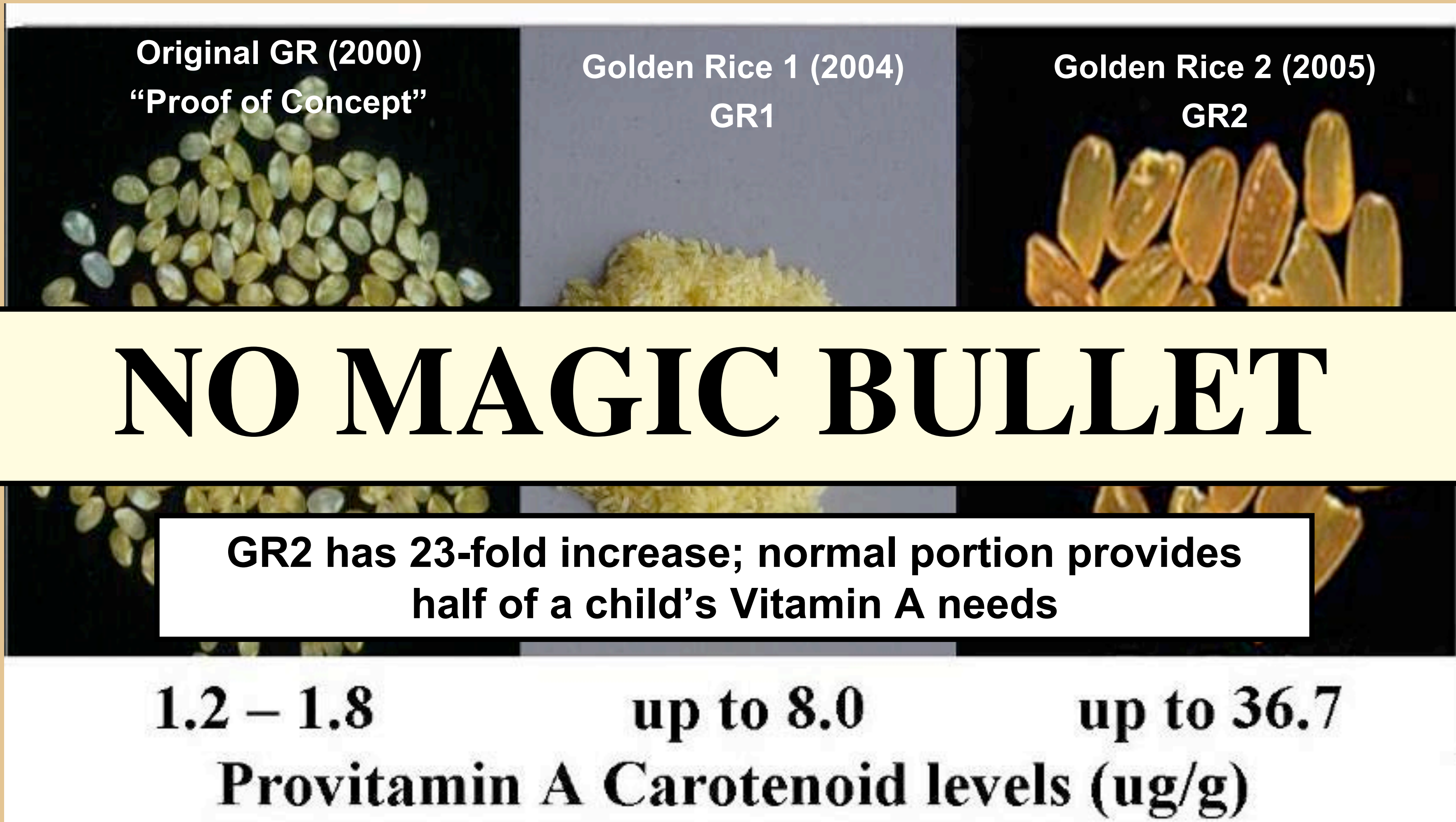
canthaxanthin

Beta-carotene/other provitamin A carotenoids converted to Vitamin A in human body.

Modified from G. Barry, IRRI

Types of Golden Rice

GR1 and GR2 developed by Syngenta, donated to GR Humanitarian Board for use in developing countries by GR Network

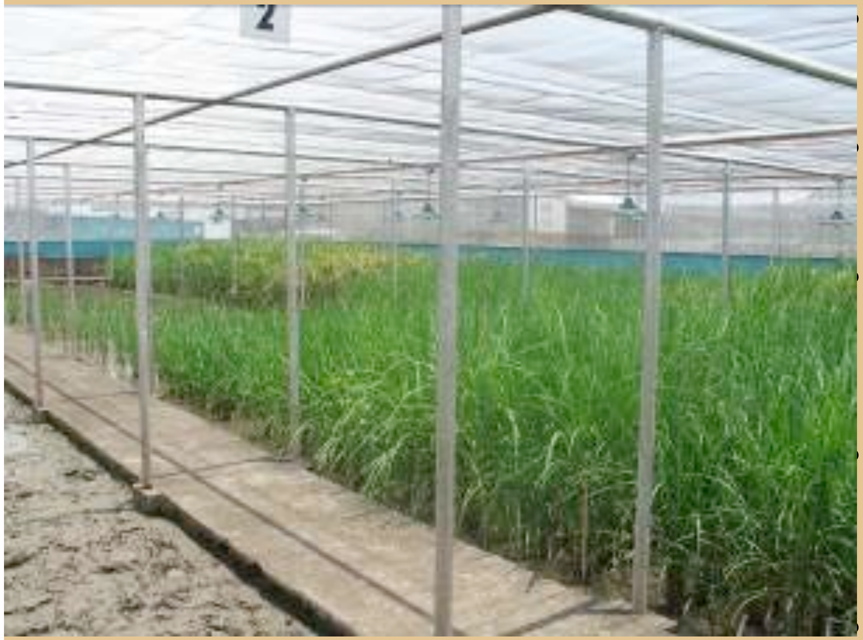


NO MAGIC BULLET

GR2 has 23-fold increase; normal portion provides half of a child's Vitamin A needs

Golden Rice is now a breeding project

Transferring Golden Rice traits into popular rice varieties at IRRI



- IR64 & IR36: Mega-varieties with broad Asian coverage (GR1 & GR2)
- BR29: The most popular and productive *boro* rice variety in **Bangladesh** (GR1 & GR2)
- An IRRI-bred line released as PSB Rc82: the most popular rice variety in the **Philippines** (GR2)
- Only one event will ever be released/go through full regulatory approval; **2011 first release**

Parallel introgression breeding being done by Golden Rice Network partners in **India, Vietnam, and the Philippines**

E. Boncodin, Fedl Budget Secy Manila Philippines

First Outdoor Trial of Golden Rice in Asia

IR64 GR1 event 309; 20 lines

Transplanting at IRRI April 2, 2008

April 10, 2008

May 30, 2008

E. Boncodin, Fedl Budget Secy Manila Philippines

An estimate of the cost effectiveness for GR and VAD relief - India

Table 4. *The annual burden of VAD in India and the cost-effectiveness of GR*

Scenario	Low impact	High impact
Current burden of VAD		
Number of DALYs lost each year (thousands) (DALY = Disability Adjusted Life Years)	2,328	

2 million disability years lost in India to Vitamin A deficiency

71,000 lives lost each year in India to VAD

0.2-1.3 million disability years could be saved with Golden Rice

5,000- 40,000 lives could be saved each year with Golden Rice

And it is cheaper than supplementation by 2- to 6-fold

World Bank cost-effectiveness standard for DALYs saved (U.S.$)	200	
WHO standard for valuing DALYs (U.S.$)	620-1,860	
Cost per DALY saved through supplementation (U.S.$)	134-599	
Cost per DALY saved through industrial fortification (U.S.$)	84-98	

Modified from G. Barry, IRRI

Stein *et al*. 2007 World Development – in press

Mail Online

British scientists condemn using children in GM food trials as unacceptable

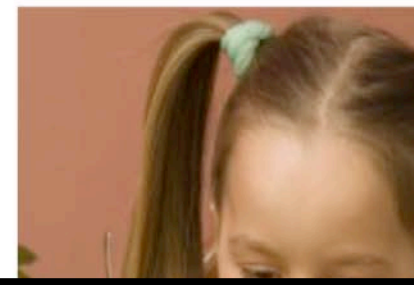
By Sean Poulter
Last updated at 12:46 PM on 17th February 2009

Children have been used as 'lab rats' in GM rice trials that were carried out in breach of ethics rules drawn up in response to the medical crimes of Nazi Germany, it is claimed.

Youngsters aged 6-10 were fed so-called Golden Rice, which has been modified to contain enhanced levels of beta carotene or vitamin A.

The rice is being developed to combat Vitamin A deficiency, which is linked to damage to the sight, poor brain development and immune system failure.

However high consumption can also have harmful toxic effects and cause birth defects.



February 17, 2009

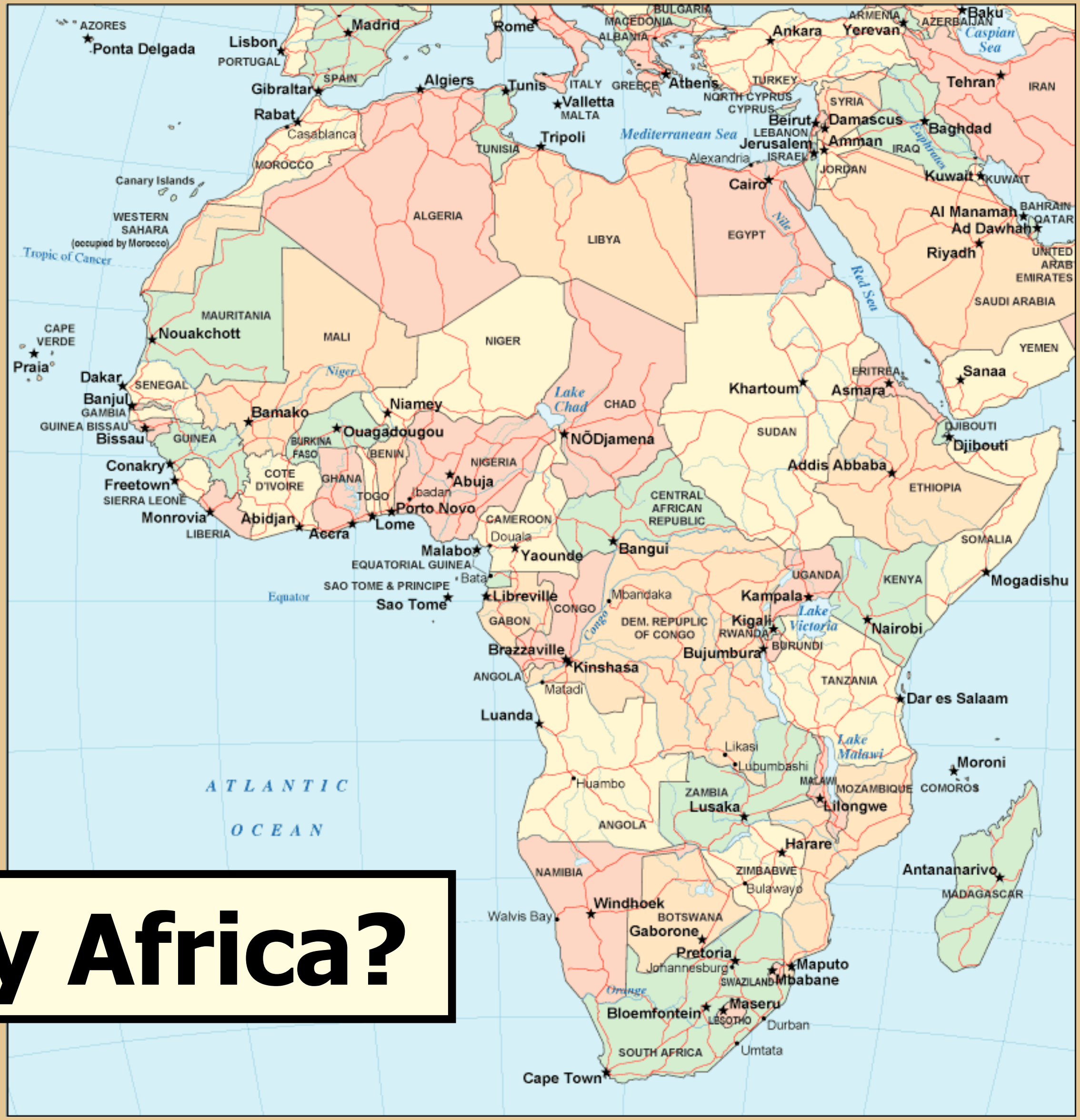
22 scientists signed letter denouncing feeding of Golden Rice to children in the U.S. and China, conducted under NIH and Chinese government guidelines. Claimed it violated Nuremberg code – research ethics principles focused on inhumane Nazi human experimentation during World War II.

In Golden Rice feeding trials scientists claimed humans were being used as guinea pigs, saying there is a large body of evidence showing GM food production can trigger gene mutations which 'can result in health damaging effects when GM food products are fed to animals'.

Do ethics also speak to fact that 1 to 2 million people die from VAD each year?

SOURCE: "British scientists condemn using children in GM food trials as unacceptable", Daily Mail, February 17, 2009.
http://www.dailymail.co.uk/news/worldnews/article-1147635/British-scientists-condemn-using-children-GM-food-trials-unacceptable.html

Public-Private sector partnership: Development of SuperSorghum



Why Africa?

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Homes in rural communities are not spacious, but at least there are small spaces to grow food
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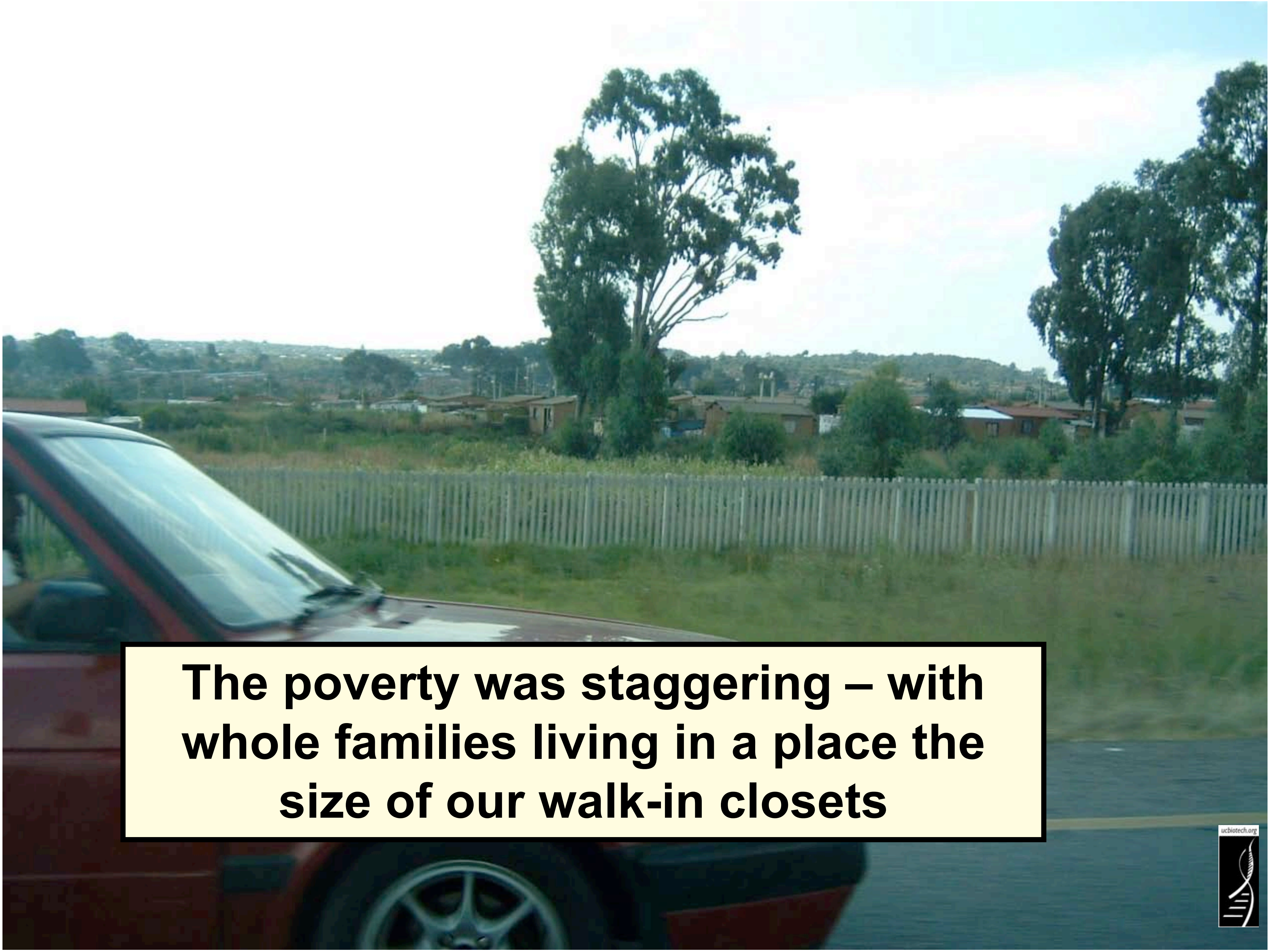
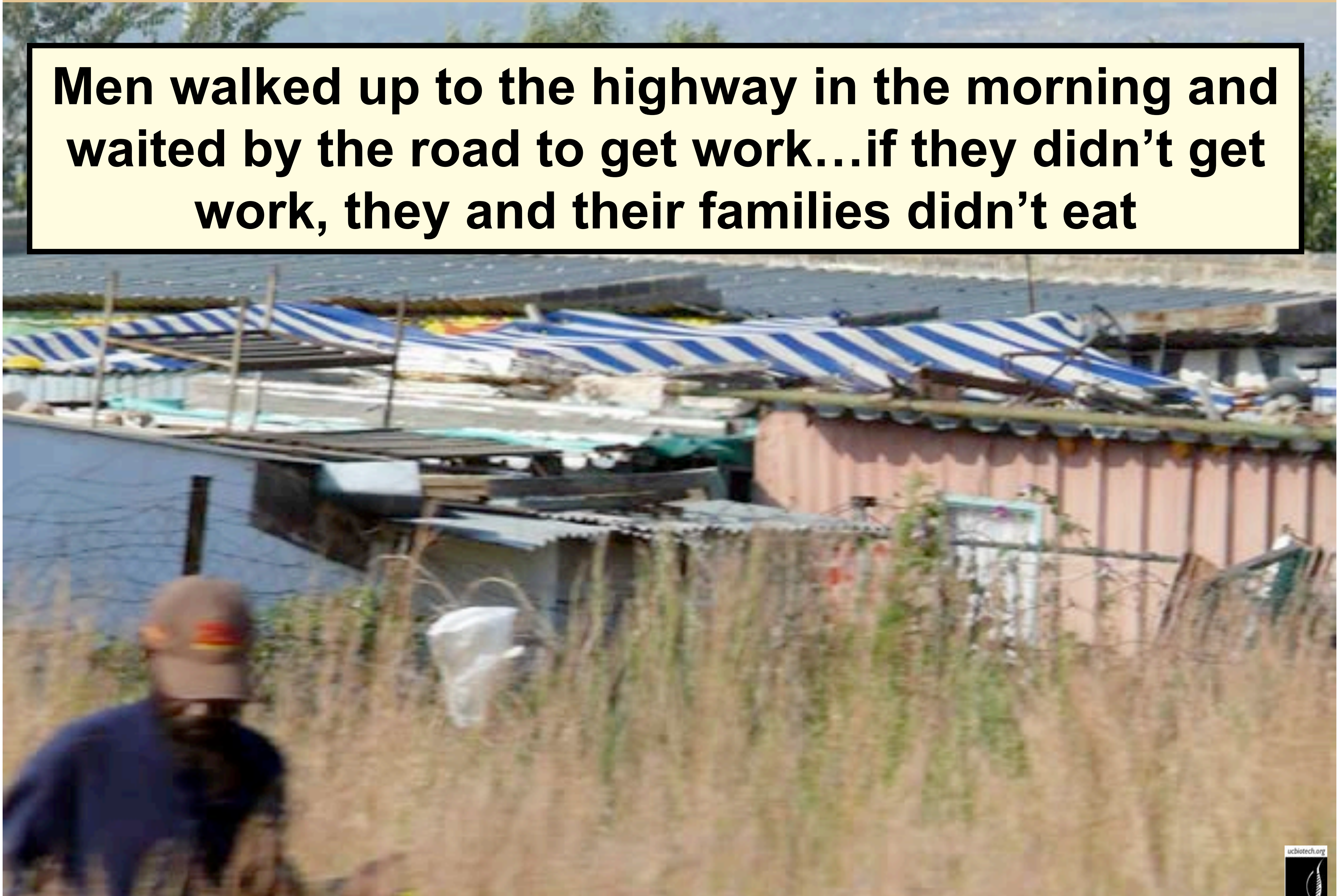
Just outside cities – often juxtaposed next to modern suburbs –as far as the eye could see were tiny huts crammed together with no place to raise crops.


The poverty was staggering – with whole families living in a place the size of our walk-in closets
ucbiotech.org

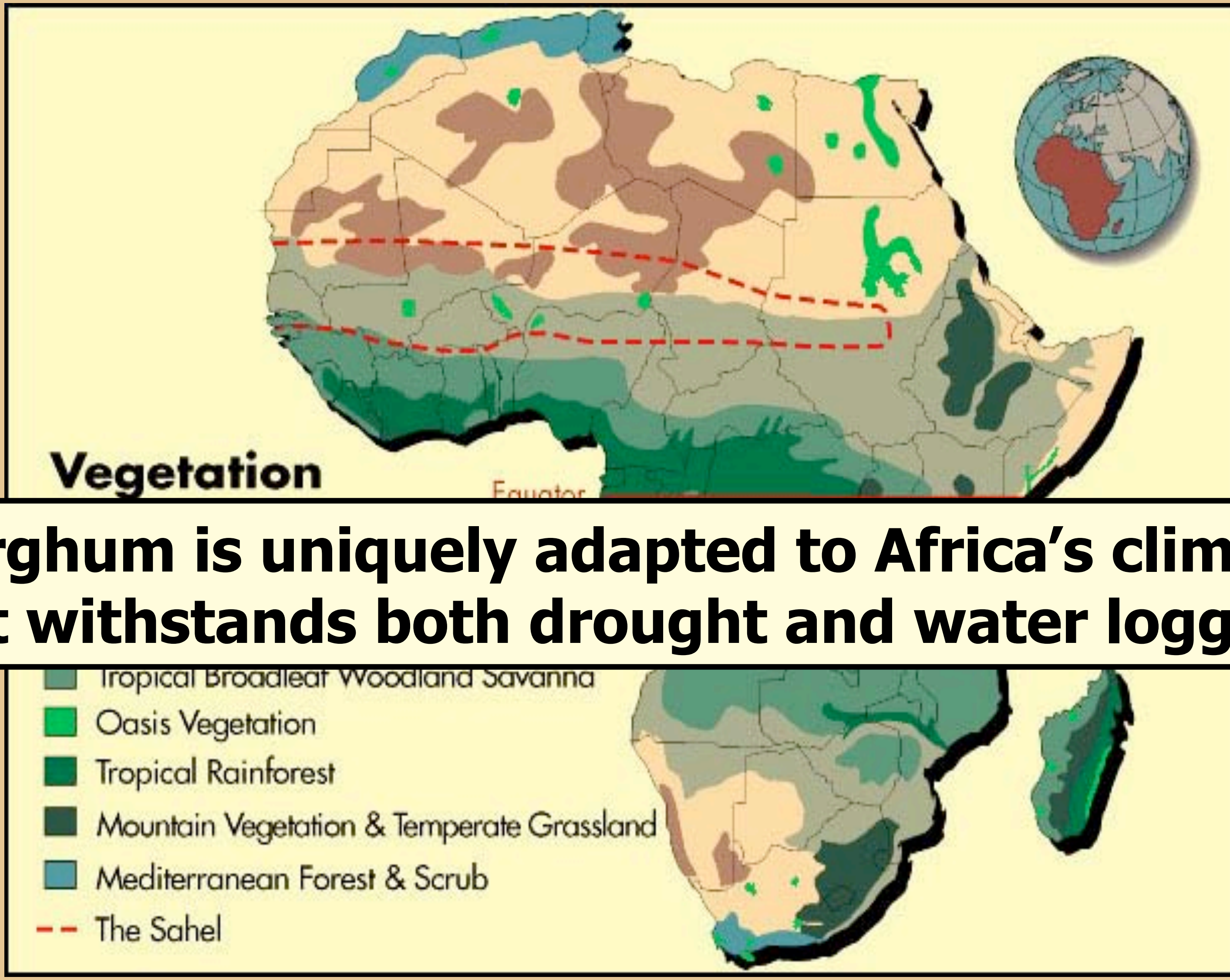
Men walked up to the highway in the morning and waited by the road to get work…if they didn't get work, they and their families didn't eat



Why Is Sorghum the Target?

- Fifth most important food grain
- 90% grown in Africa and Asia in arid and semi-arid regions
- Staple food for 300 million in Africa
- In Africa, 74% of sorghum is consumed at home
- Most as cooked porridge

Sorghum – a staple food for 300 million of the world's poorest – many in parts of Africa



Sorghum is uniquely adapted to Africa's climate – it withstands both drought and water logging

During prolonged drought in South Africa, sorghum thrived while maize struggled!

Maize

Sorghum

Potchestrom, South Africa Feb. 17, 2007

But sorghum is nutritionally deficient in:

Amino acids
Vitamins
Minerals
And is

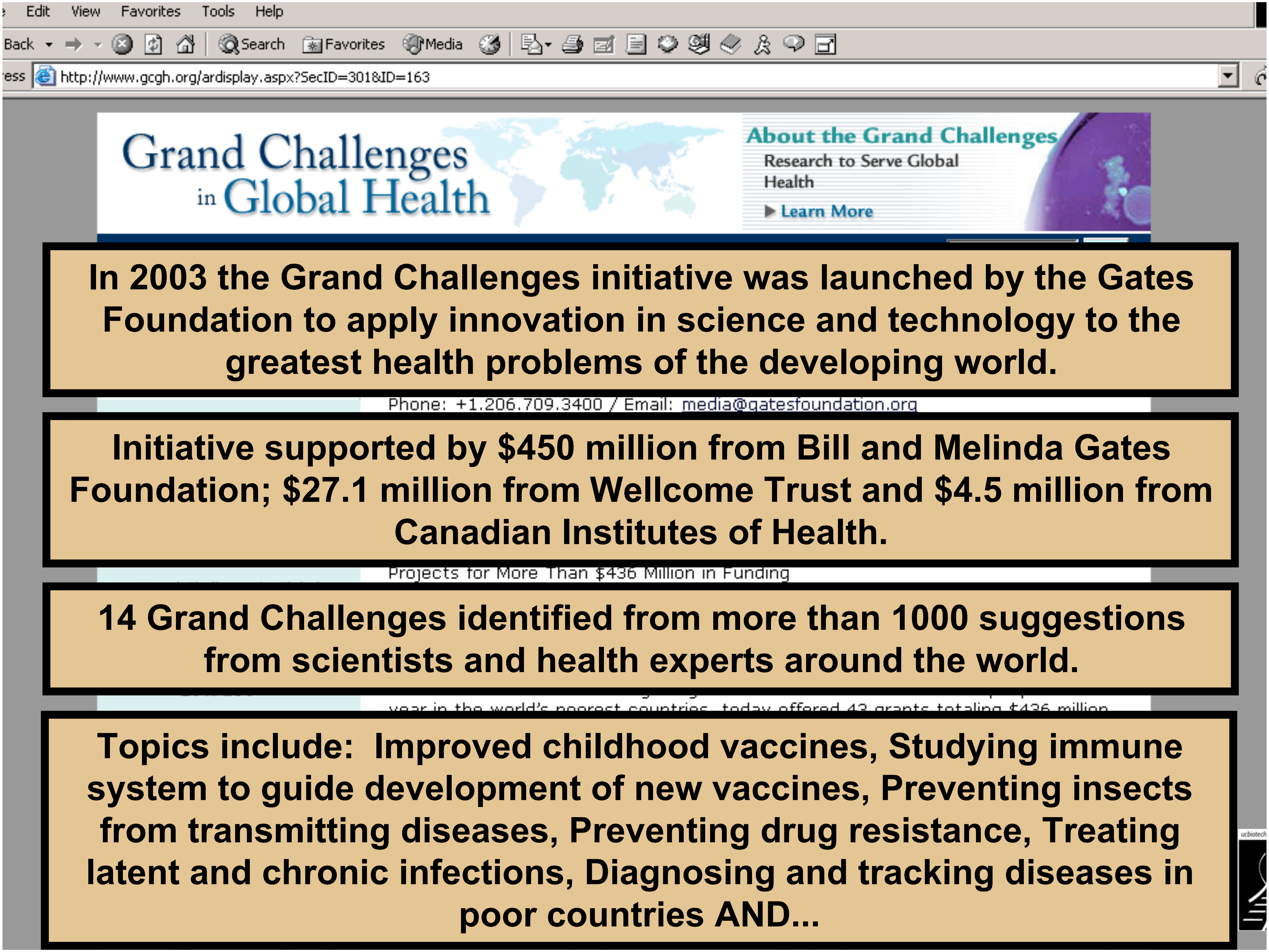
Poorly Digested

Why did I become involved in improving sorghum?

Part of my mandate as public sector scientist and CE specialist

The magnitude of the problem begs for solutions. This was something I wanted to do, but…

How did I become involved?



In 2003 the Grand Challenges initiative was launched by the Gates Foundation to apply innovation in science and technology to the greatest health problems of the developing world.

Initiative supported by $450 million from Bill and Melinda Gates Foundation; $27.1 million from Wellcome Trust and $4.5 million from Canadian Institutes of Health.

14 Grand Challenges identified from more than 1000 suggestions from scientists and health experts around the world.

Topics include: Improved childhood vaccines, Studying immune system to guide development of new vaccines, Preventing insects from transmitting diseases, Preventing drug resistance, Treating latent and chronic infections, Diagnosing and tracking diseases in poor countries AND...

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

Berkeley, California
April 10, 2006

Researchers at the University of California, Berkeley, are joining an ambitious project to improve nutrition for 300 million people in Africa who rely on sorghum as a principal source of food.

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

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

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

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

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

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

Grand Challenge #9: Growing more nutritious staple crops to combat malnutrition

Focuses on 4 crops:

banana, cassava, rice and SORGHUM

Addressing the nutritional challenge

Goal of Super Sorghum Project

Develop more nutritious, easily digestible sorghum, containing higher levels of pro-vitamin A, vitamin E, iron, zinc, and

deficient amino acids, lysine, tryptophan and threonine, for the arid and semi-arid tropical areas of Africa

Super Sorghum nutritional targets are beyond the reach of plant breeding approaches

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Focus of ABS Project: Food Quality

Aims

- ❖Increase levels of Vitamin A and E
- ❖Increase iron and zinc availability
- ❖Improve protein quality
- ❖Improve digestibility upon cooking

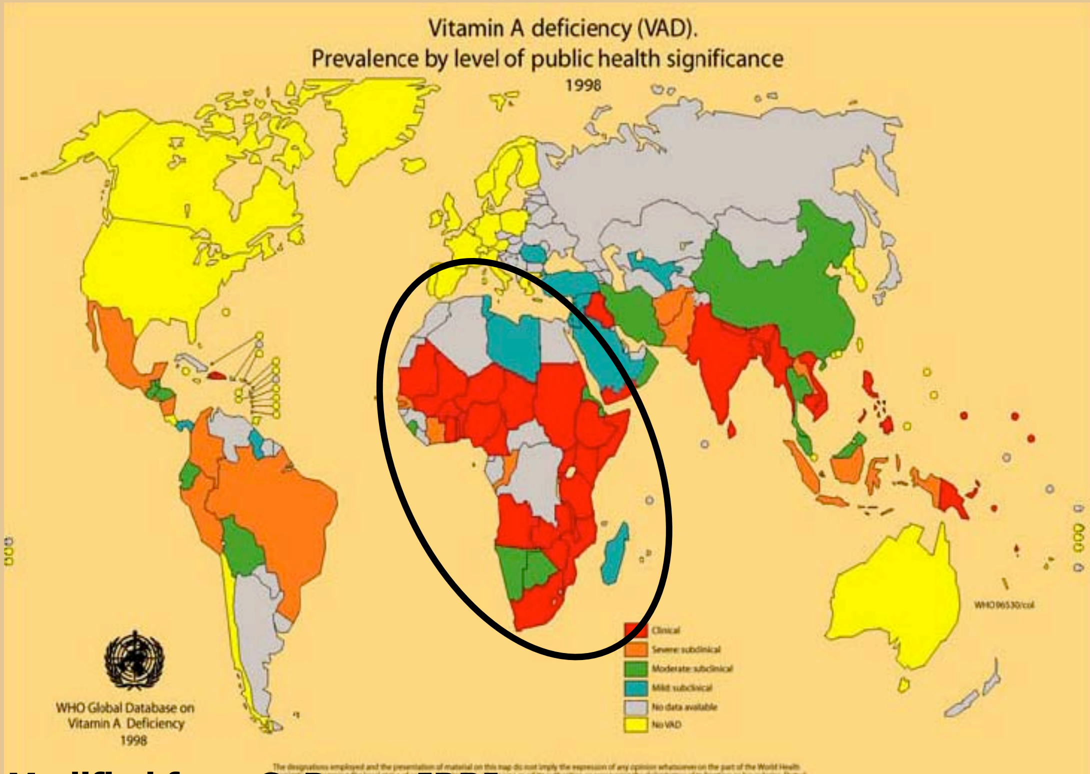
- ❖Earlier breeding efforts to improve some target traits unsuccessful
- ❖GE strategy needed to improve multiple target traits simultaneously
- ❖All genes from crop sources, except one from common microbe
- ❖All approaches validated in corn and other cereals

The Super Sorghum Team in Nairobi Kenya

Consortium Members and Roles

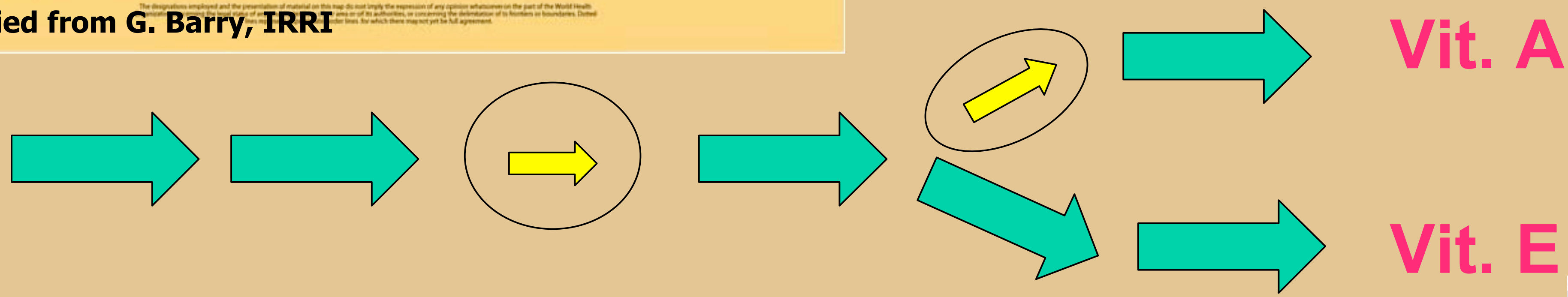
- Africa Harvest - Project coordination & management
- Pioneer Hi-Bred – Sorghum biotechnology
- University of California, Berkeley – Sorghum biochemistry and technology
- CSIR Pretoria - Sorghum biotechnology
- ICRISAT/CGIAR - Germplasm, delivery to target countries
- ARC - Plant breeding, field testing
- University of Pretoria - Nutritional evaluation
- AATF - IP rights brokering, licensing
- FARA – Link to distribution networks

Vitamin A Deficiency:
Severe Health Problem in Africa

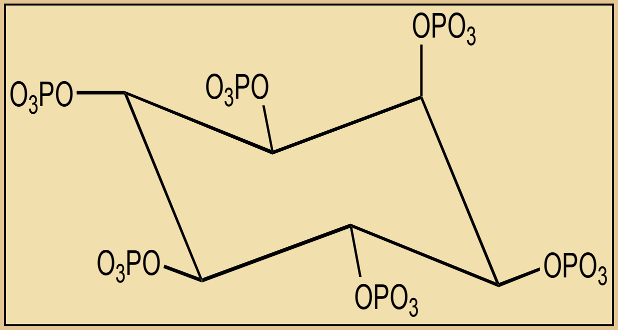


Modified from G. Barry, IRRI

- Sorghum grain - very low levels of Vit A and E
- Vit A critical for eyesight Vit E protects Vit A.
- Increase production by improving rate-limiting steps in biosynthesis



Improving Iron and Zinc Availability by Reducing Phytic Acid in Grain



Phytic Acid

- **Phytic acid in the seed binds iron and zinc**
- **Reduce phytic acid by blocking production**
- **Lower phytic acid frees iron & zinc to be taken up from food**

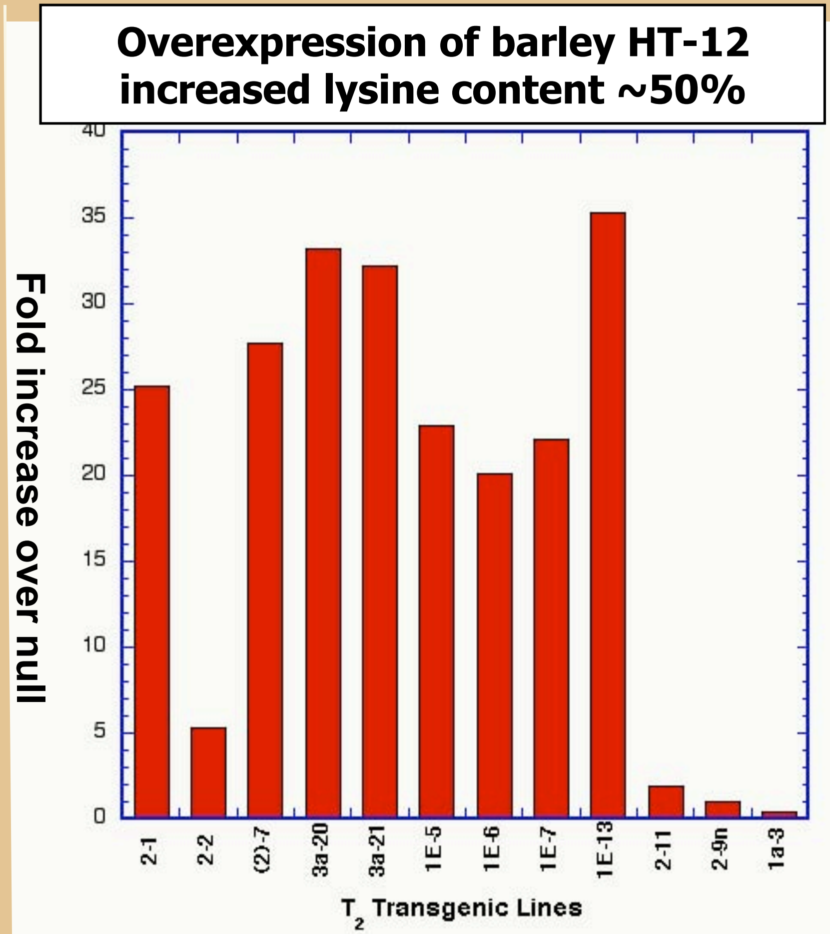
Improving Protein Quality
UCB involvement

- **Improve Protein Quality**
  - Introduce new protein with increased Lys, Trp, Met, Thr
  - Decrease proteins with poor quality
- **Improve Protein Digestibility**
  - Decrease proteins negatively affecting digestibility
  - Alter digestibility of protein

Modifying Amino Acid Content

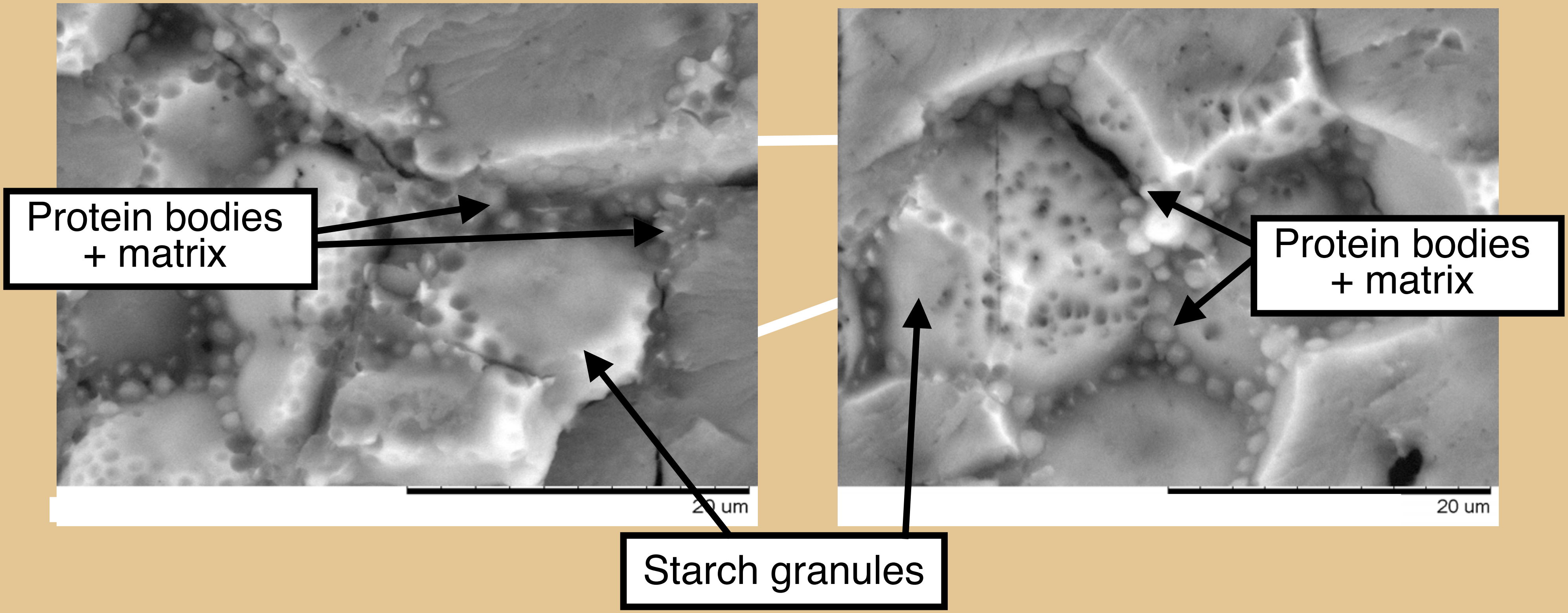
Barley α-hordothionin with 12 lysines increased lysine by ~50%

Another modified barley 67aa protein with 17% Thr, 15% Lys, 6% sulfur aa; 9.5% Trp resulted in ≥100% of target levels of Lys, Met, Thr, Trp in maize



Improving Digestibility

Starch granules embedded in protein matrix

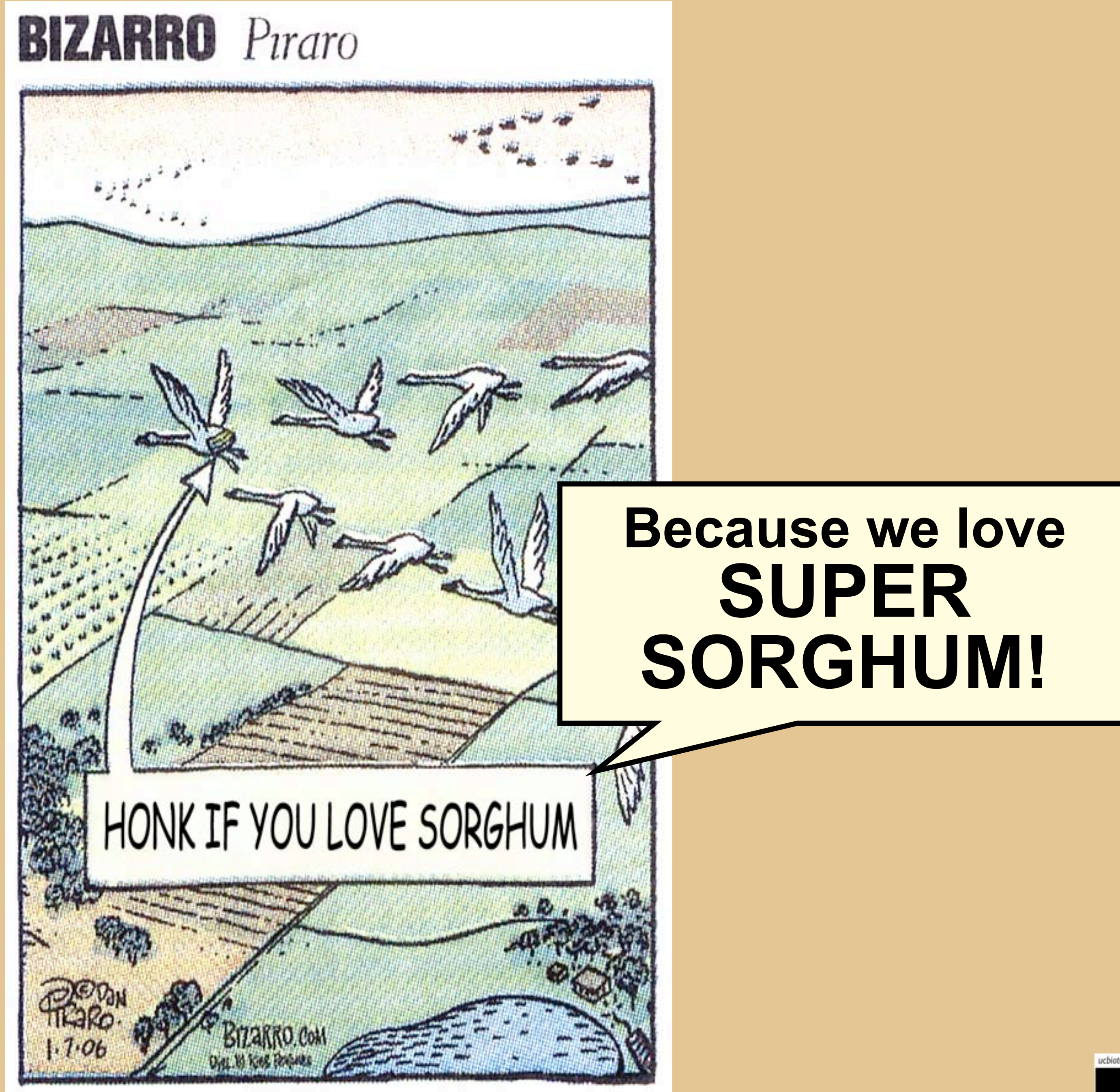


Disulfide bonds within and between kafirins hinder starch and storage protein digestibility upon cooking

Is it just about technology?

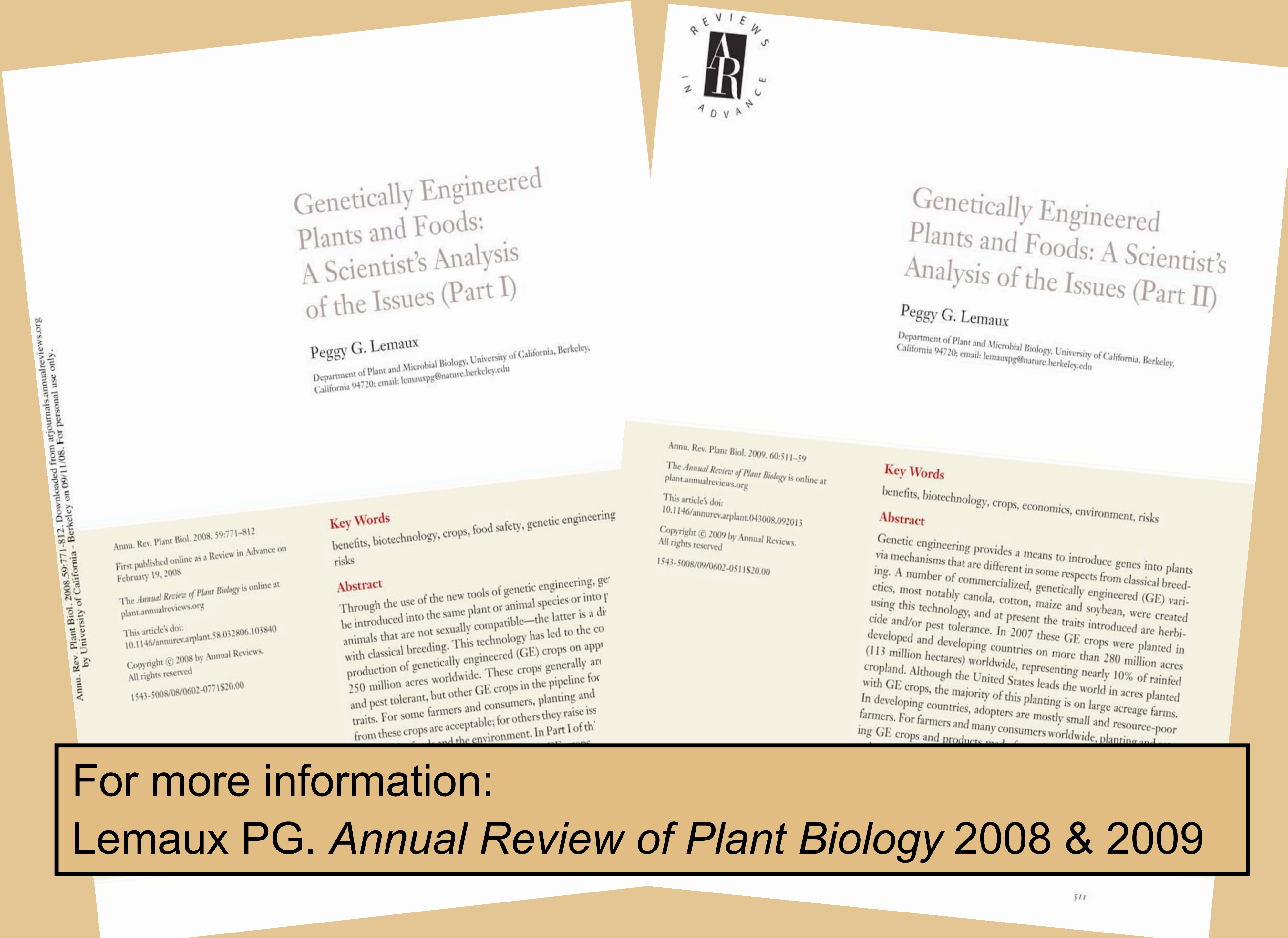
Specific Project Objectives

- Technology transfer from US to Africa
- Human and infrastructure capacity building
- Public/private networking in GM technology by African and US institutions
- Biosafety policy development
- Public acceptance of GM technology increased in Africa



San Francisco Chronicle (modified)

ucbiotech.org



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

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Key Words

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

Abstract

Through the use of the new tools of genetic engineering, ge[…] be introduced into the same plant or animal species or into p[…] animals that are not sexually compatible—the latter is a di[…] with classical breeding. This technology has led to the co[…] production of genetically engineered (GE) crops on appr[…] 250 million acres worldwide. These crops generally ar[…] and pest tolerant, but other GE crops in the pipeline fo[…] traits. For some farmers and consumers, planting and […] from these crops are acceptable; for others they raise iss[…] […] and the environment. In Part I of th[…]

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

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Abstract

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

For more information:

Lemaux PG. *Annual Review of Plant Biology* 2008 & 2009