BIOFORTIFICATION AND AGRICULTURE'S PRIMARY ROLE TO PROVIDE NUTRITIOUS DIETS FOR NATIONAL HEALTH

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HOWARTH BOUIS received his B.A. in economics from Stanford University and his M.A. and Ph.D. from Stanford University's Food Research Institute, a program in agricultural economics. As director of HarvestPlus during 2003-2016, he coordinated an interdisciplinary effort to breed and disseminate micronutrient-rich staple food crops to reduce mineral and vitamin deficiencies among malnourished populations. Since 1993, he has sought to promote biofortification globally.

ABSTRACT

Fundamentally, the prevalence of mineral and vitamin deficiencies is high in developing countries due to fact that agricultural systems do not produce sufficient foods rich in minerals and vitamins. During 1960-2000, the Green Revolution successfully increased cereal production faster than rapidly growing populations, where limited land was available to expand agricultural production. However, there were not the same investments in increasing agricultural productivity for non-staple food groups. Consequently, prices for these food groups – vegetables, fruits, pulses, animal products, which provide dietary quality -- rose rapidly. The prices that consumers pay for iron, zinc, and provitamin A have increased significantly. Looking to the future, many in agricultural community now recognize that agriculture has a fundamental responsibility to produce these minerals and vitamins to secure national health.

Biofortification involves breeding staple food crops to increase their micronutrient content, targeting staple foods widely consumed by low-income families globally. In so doing, biofortification contributes to solving the underlying problem of mineral and vitamin deficiencies by increasing the amount of iron, zinc and provitamin A produced by food systems. Biofortification:

- Taps into the effectiveness and cost-effectiveness of plant breeding as well as of seeds to replicate themselves, where the results of research undertaken in a central location can be replicated in other countries.
- Minimizes the need for behaviour change by: (i) piggybacking on an existing system of agricultural research institutes (international and national) that produces a stream of increasingly productive and climate-adapted crop varieties that are adopted by farmers and eventually account for a high percentage of total food supplies; and (ii) focusing on food staples that the poor already eat in large quantities.
- Provides extra iron, zinc and provitamin A to farmers and consumers at no extra cost by growing and eating biofortified varieties of everyday foods in a one-for-one substitution for non-biofortified varieties and initiates the delivery of these micronutrients in the relatively hard-to-reach rural areas where a majority of the poor reside.

When HarvestPlus first started in 2003, there was much doubt among a range of stakeholders, that biofortification would work. First, we had to prove to the plant science community that higher target levels iron, zinc, and provitamin A could be bred into high-yielding, profitable varieties. Presently, over 100 varieties of twelve biofortified crops have passed the agronomic tests of varietal release committees in 30 developing countries. In 3-5 years, biofortified varieties will be available to farmers and consumers in an additional 30 countries.

The nutrition community initially questioned the efficacy of biofortified crops – would the levels of retained nutrients and absorption be high enough? HarvestPlus has commissioned fifteen efficacy trials, all undertaken in developing countries. While five of these studies are still in process, there is already sufficient positive published evidence for iron and provitamin A, that the World Health Organization is now undertaking a systematic review of the evidence. This review will be completed and findings published by the WHO in 2017.

Can adoption of biofortified crops by farmers be scaled up, and a public health impact demonstrated? For example just four years after release of high-yielding, iron bean varieties in Rwanda, we now have rigorous evidence that 30% of farmers in Rwanda are growing biofortified beans on a regular basis. HarvestPlus estimates that 20 million farmers and consumers presently grow and consume biofortified crops in eight target countries.

The final and major challenge is to mainstream biofortification into the fabric of "business-as-usual" of a range of organizations – public and private agricultural research, institutions that focus on bringing improved agricultural technologies to farmers including multi-lateral lending institutions, private companies, non-governmental organizations, and the policies and programs of national governments, regional organizations, and UN agencies. The vision of HarvestPlus is that by 2030, one billion people will be reached by biofortified crops.

Biofortification and Agriculture's Primary Role to Provide Nutritious Diets for National Health

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Why are Mineral and Vitamin Deficiencies Such A Significant Public Health Problem?

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Consequences Mineral & Vitamin Deficiencies

Vitamin A deficiency
- Supplements reduced child ***mortality*** by 23%
- 375,000 children go blind each year

Iron deficiency
- ***Impaired cognitive abilities*** that cannot be reversed
- 82% of children < 2 years in India are anemic

Zinc deficiency
- increased ***incidence/severity diarrhea/pneumonia; stunting***
- 2 billion people at risk; 450,000 deaths per year

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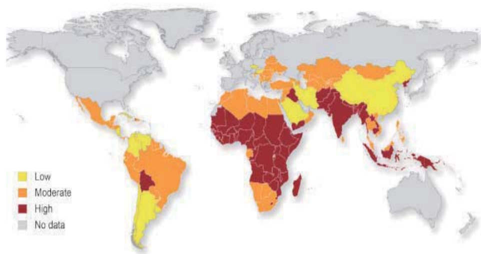
Severity of Micronutrient Deficiencies: Vitamin A, Iron, and Zinc



Source: World Health Organization (WHO) children under 5 prevalence data

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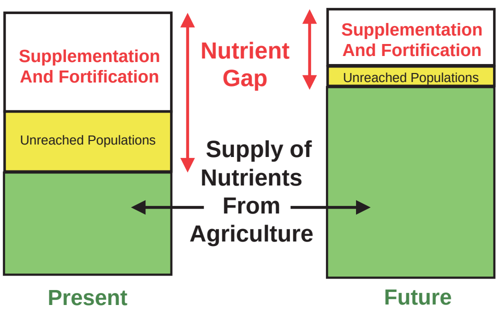
A Primary Role of Agriculture Is To Provide Nutrients for Healthy Populations



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Percent Changes in Cereal and Pulse Production and in Population Between 1965 and 1999

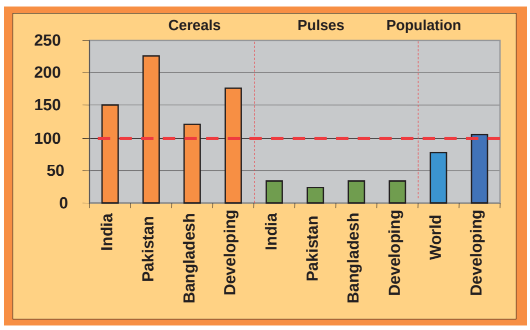

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Figure 2. Price Indices By Food Group for India, 1970-2016, Deflated by Non-Food Price Index

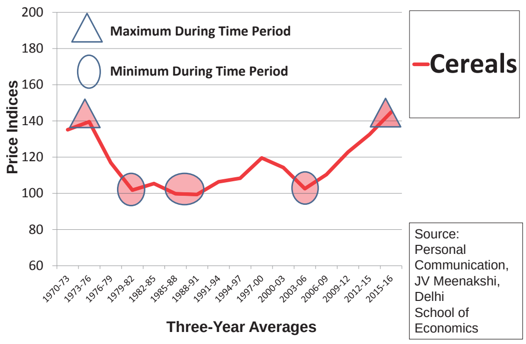

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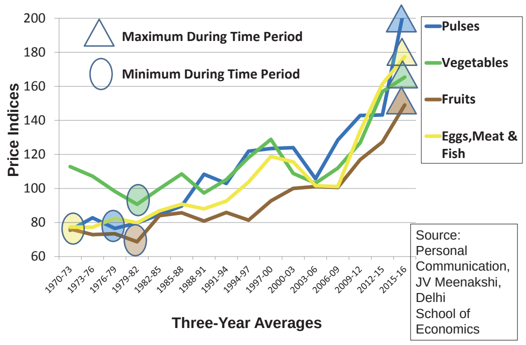
Figure 2. Price Indices By Food Group for India, 1970-2016, Deflated by Non-Food Price Index



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Rice Price Rise in the Philippines, 2006-2016

- The ***non-food*** consumer price index rose by 31%
- The ***food*** consumer price index rose by 63%
- There were the following price rises of individual food groups:
  - Rice 74%
  - Vegetables 82%
  - Fruits 82%
  - Fish 70%
  - Meat 40%
  - Milk, Eggs, Cheese 45%

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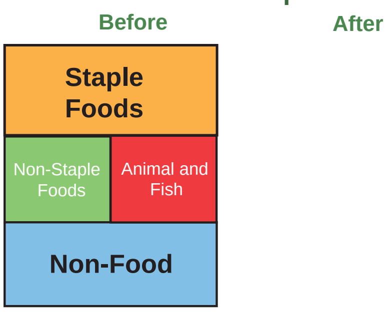
50% Increase in All Food Prices

Share of Total Expenditures



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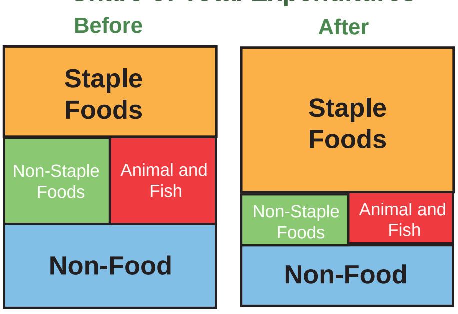

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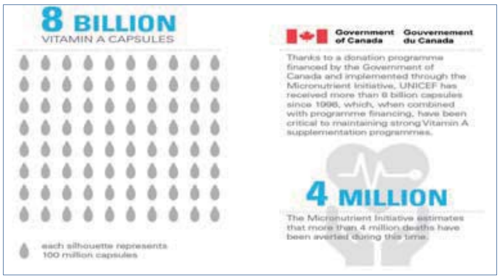
Excerpt From Recent UNICEF Brochure



Cost Per Vitamin A Capsule $US 0.50-1.25 World Bank (2007)

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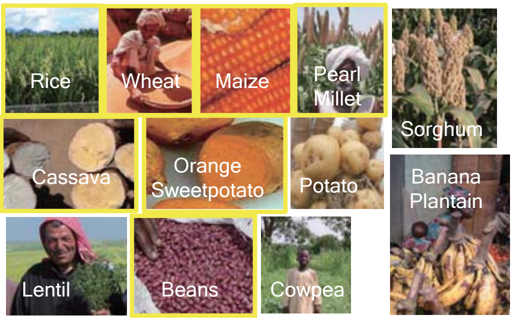
Biofortified crops released in **30 countries**
In-testing in another **25 countries**



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>150 Varieties Released Across 12 crops

Nutritious crops released in 30 countries; in testing in another 25

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Human Nutrition Efficacy Trials

Fourteen Efficacy Trials either completed or in process

- High iron crops ✓+
  - Meta-analysis completed for beans and pearl millet
- High pro-vitamin A crops ✓
  - Multiple efficacy trials completed for sweetpotato, maize, and cassava
- High zinc crops
  - Bioavailability studies positive, efficacy trials in the field

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Functional Outcomes

- Efficacy trials with provitamin A, iron, and zinc biofortified crops have also shown improved functional outcomes:
  - Improved cognitive function (iron)
  - Better work performance (iron)
  - Better sight adaptation to darkness (provitamin A)
  - Reduced morbidity (zinc)

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HarvestPlus Delivery Goals

Globally By 2030

- One billion people will be benefitting from biofortified nutritious foods.

Short-Term Goal By 2020

- 100 million people in farm households will be growing and consuming biofortified nutritious food crops

By the End of 2016

- 20 million people in farm households

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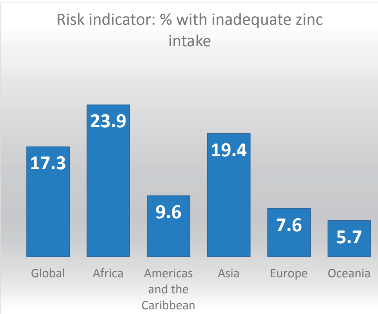
Risk of Zinc Deficiency



Zinc deficiency:

- Susceptibility to infections (diarrhea, malaria, pneumonia)
- 450,000 deaths among preschool children annually
- Stunting?

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Per Capita Energy Intakes Per Day for Jessore By Income Group

	Lower Income	Middle Income	Higher Income
Food Staples	1816	1848	1876
Non-Staple Plant Food	339	427	474
Fish and Animal Foods	47	59	92
All Food Groups	2201	2334	2442

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Per Capita Zinc Intakes (mg/day), Rural Bangladesh 2005, By Income Group

	Lower Income	Middle Income	Higher Income
Food Staples	5.9	6.4	6.9
Non-Staple Plant Food	1.8	2.1	2.4
Fish and Animal Foods	0.6	0.8	1.5
All Food Groups	8.3	9.3	10.8

Estimated Average Requirement ≈ 13 mg Zn/day

15 mg/kg Zn milled rice x 400 gms rice intake/day = 6 mg Zn/day

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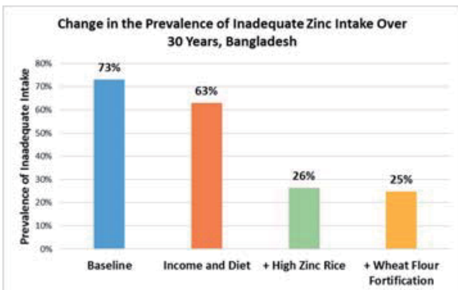
Incremental Changes in the Prevalence of Inadequate Zinc Intake, Bangladesh



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Additional Crop in Cropping Pattern

Before

Aman	Fallow	Boro
Sharna		BRRI dhan28
(155 days)	(70 Days)	(140 days)

Now

Aman		Boro
BRRI dhan62	Mustard/ lentil/ vegetables	BRRI dhan64/ BRRI dhan28
(100 days)	(125-130 days)	(135- 140 days)

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Effect of High Zinc Wheat Intervention on Morbidity Indicators

Indicator	High Zinc Wheat Subjects	Low Zinc Wheat Subjects	Days of Sickness Averted For ~ 1300 Subjects Over 180 Days	Difference Significant at 5% Level of Confidence?
Children 4-6 Years				
Days With Pneumonia	203	244	41	YES
Days With Vomiting	60	99	39	YES
Women 15-49 Years				
Days With Fever	999	1092	93	YES

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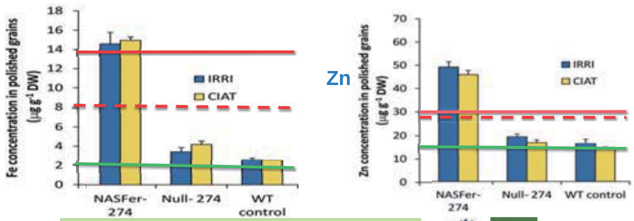
Figure 5. Fe- and Zn-densities in Transgenic Rice

Target density to achieve significant public health impact
Maximum achievable with conventional breeding
Average density in non-biofortified varieties



Proof of concept achieved:
Trijatmiko et al., 2016, www.nature.com/scientificreports

IRRI

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In Conclusion …

"Such intimately related subjects as agriculture, food, nutrition and health have become split up into innumerable rigid and self-contained little units, each in the hands of some group of specialists. The experts, …soon find themselves…learning more and more about less and less…The remedy is to look at the whole field covered by crop production, animal husbandry, food, nutrition, and health as one related subject and…to realize…that the birthright of every crop, every animal, and every human being is health."

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Sir Albert Howard, 1873-1947

"The Soil and Health," 1945

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