Biofortification of Staple Crops: An Emerging Strategy to Combat Hidden Hunger

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Biofortification

- Greek word “bios” means “life”
- Latin word “fortificare” means “make strong”
Biofortification

- Greek word “bios” means “life”
- Latin word “fortificare” means “make strong”

MAKE LIFE STRONG!
A new methodology?

1000 years ago

400 years ago

<400 years ago

<30 years ago

2007!!!
Outline

• Micronutrient Malnutrition in Developing Countries
• Overview of HarvestPlus
• Progress for Selected Crops
  – Nutrition studies in humans
  – Dissemination strategies
% Changes in Cereal & Pulse Production & in Population Between 1965 & 1999

Cereals

Pulses

Population

India

Pakistan

Bangladesh

Developing

India

Pakistan

Bangladesh

Developing

World

Developing
Forecasts for 2007 include a 4% increase in worldwide cereal crop production over 2006 (FAO 2007)
Indices of Inflation-adjusted Prices for Bangladesh

1973-75 = 100
Share of *Energy Intake* For Rural Bangladesh

- **Staples**
- **Non-Staple Plants**
- **Fish and Animal**
Poverty as it relates to hidden hunger

- Poverty
  - Hunger
    - Under-nutrition
      - Nutrient deficiencies
      - Hidden hunger
  - Food insecurity
    - Over-nutrition
      - Obesity

Tanumihardjo et al., JADA, 2007
Vitamin A: Administration of vitamin A capsules in eight carefully conducted studies showed a 23% reduction in child mortality.

Iron: Meta-analysis of 17 trials showed iron supplementation improves mental development scores, especially intelligence tests for children > 7 years old, and in initially iron deficient children.

Zinc: Meta-analysis in prepubertal children showed that supplemental zinc caused a large increase in children’s serum zinc concentrations and positive responses in height and weight.
Extent of Micronutrient Malnutrition

• 2-3.5 billion people are iron deficient; 50% of pregnant women in Asia
• An equal number may suffer from zinc deficiency
• 250 million children are deficient in vitamin A and an unknown number of pregnant women
Consequences of Micronutrient Malnutrition

- higher morbidity
- higher mortality
  - 23% reduction with vitamin A supplementation
- lower cognitive ability
- lower work productivity
- impaired growth
- impaired reproduction
- Estimated 5% annual loss in Gross Domestic Product in South Asia
Niche/Advantages of Biofortification

• **Targets the poor:** eat high levels of food staples

• **Rural-based:** complements fortification and supplementation

• **Cost-effective:** research at a central location can be multiplied across countries and time

• **Sustainable:** investments are front-loaded, low recurrent costs
Level of Investments

• Vitamin A supplements -- $500 million per year
• Iodine fortification of salt -- $200 million per year
• Iron supplements and fortification -- $?? million per year
  ➢ $1 billion per year recurrent costs for fortification plus supplements
  ➢ Annual costs for biofortification currently $25-30 million per year
The case of rice

- Iron fortificant = US$0.02/kg rice
- Rice consumption = 300 g/person/d
- Total: US$2/person/year
The case of rice

- Iron fortificant = US$0.02/kg rice
- Rice consumption = 300 g/person/d
- Total: US$2/person/year

For 500 million people
(half the population of India) = US $1 BILLION
Disability-Adjusted Life Years

• DALYs are a measure of the total number of days that are spent in ill-health each year, accounting for both the severity of the condition and its duration.

• Useful for quantifying potential benefits of a public health intervention.
Benefit/Impact = Improved Functional Outcomes Due to Shift in Distribution (as measured by DALY)

DEFICIENCY

SUFFICIENCY

POPULATION DISTRIBUTION

BIOFORTIFICATION

Cut-off
Sample Calculation of Benefits for India
(Total Burden Due to Iron Deficiency = 4 million DALYs)

0.50 x $500/DALY x 1 million DALYs/year x 20 years = $5 billion in Benefits

Discount over 25 years:
3% = $5,000m/2.16 = $2.3 billion
10% = $5,000m/11.92 = $0.4 billion

DALYS saved = 10 million
HarvestPlus Program Strategy

Develop micronutrient dense staple crops using the best traditional breeding practices and modern biotechnology to achieve provitamin A, iron, and zinc concentrations that can have measurable effects on nutritional status.
CIAT and IFPRI are the co-convening Centers of HarvestPlus
Phase I Crops

- Rice
- Wheat
- Maize
- Cassava
- Sweet Potato
- Beans

Phase II Crops

- Potato
- Barley
- Cowpeas
- Groundnuts
- Lentils
- Millet
- Plantain
- Sorghum
- Pigeon Peas
- Yams
Nutrients Targeted in Crops

- Rice - Zinc and Iron
- Wheat - Zinc and Iron
- Maize - $\beta$-carotene and zinc
- Cassava – $\beta$-Carotene
- Beans - Iron
- Sweetpotato - $\beta$-carotene
- Pearl Millet - Iron and zinc
- Banana and Plantain - $\beta$-carotene
- Lentil - Iron
- Potato - Iron
- Sorghum - Iron
HarvestPlus Management Team

CIAT
1. Breeding
2. Biotechnology
3. End-User Coordinators

Program Director

IFPRI
4. Nutrition
5. Impact and Policy
6. Communications Coordinators

Facilitation
Monitoring
Information Exchange

Wheat
Rice
Beans
Cassava
Maize
Sweet potato
Interdisciplinary Communication and Cooperation is Essential

- Plant Breeders
- Molecular Biologists
- Food Technologists
- Human Nutritionists
- Extensionists
- Experts in Food Product Development/Marketing
- Communications
- Economists
# HarvestPlus: Coordinating a Multidisciplinary Program

<table>
<thead>
<tr>
<th>Function</th>
<th>Rice</th>
<th>Maize</th>
<th>Wheat</th>
<th>Cassava</th>
<th>Sweet potato</th>
<th>Bean</th>
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<tbody>
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<td>1. Breeding</td>
<td>IRRI</td>
<td>CIMMYT</td>
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<td>CIAT</td>
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<td>2. Biotechnology</td>
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<td>3. Food processing</td>
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<td>4. Human nutrition</td>
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<td>5. Reaching end-users</td>
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<td>6. Impact/policy</td>
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<td>7. Communication</td>
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</table>
IMPACT PATHWAY

Identify Target Populations

Setting Targets

Screening for micronutrients and Gene Discovery

Crop improvement

Gene X Environment studies and varietal release

Nutrient Retention processing studies

Bioavailability and Efficacy studies

Seed production and system development

Marketing and Consumer Acceptance

Improved diet for target population
Setting target levels

Crop specific factors

- Per capita consumption levels of the food staple
- Baseline micronutrient content of the crop
- Retention of nutrients in storage, processing, and cooking

Target group specific factors

- Age of target group
- Physiological state, such as growing child, pregnancy or lactation
- Bioavailability of iron or zinc or projected retinol equivalency (provitamin A)
- Nutrient intake from other foods.
# Milestones By Crop – Year 3.5 of 10

<table>
<thead>
<tr>
<th>Step</th>
<th>Sw</th>
<th>Po</th>
<th>Bean</th>
<th>Rice</th>
<th>Wheat</th>
<th>Maize</th>
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</table>
PROGRESS WITH VITAMIN A
Orange Flesheed Sweetpotato
Retention of βCarotene after Cooking & Processing

<table>
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<th>Method</th>
<th>Retention</th>
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<tr>
<td>Boiling</td>
<td>83-92%</td>
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<tr>
<td>Oven drying</td>
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<tr>
<td>6 mm thick slices</td>
<td>47-48%</td>
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<tr>
<td>3 mm thick slices</td>
<td>34-37%</td>
</tr>
<tr>
<td>1x1 cm cubes</td>
<td>31-37%</td>
</tr>
<tr>
<td>Shade drying</td>
<td>18-23%</td>
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<tr>
<td>Sun drying</td>
<td>9-15%</td>
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</table>

South African Trial

Supervised feeding; 125 g x 5 d/wk for 10.5 wk; 1030 μg RAE OFSP vs 0 μg RAE WFSP; 90% compliance; 250% RDA
Change in liver stores of vitamin A

Intervention effect: -0.008 (-0.015, -0.001)

$P = 0.0203$
Sweet potato in Mozambique

- Effectiveness study using an integrated agricultural and nutrition intervention
- 2 year intervention covering 2 agricultural cycles
- 90% of intervention households produced sweet potato
- Intervention children \((n = 498)\) ate more sweet potato and had higher serum retinol than controls \((n = 243)\)

Towards Sustainable Nutrition Improvement in Rural Mozambique

Taste tests are conducted at every adaptive trial harvest to determine preferences of local consumers.
Towards Sustainable Nutrition Improvement in Rural Mozambique

Sweet potato bread maker making his bread at home and selling it in the nearby market of Lualua. Bread is marketed under the name of Golden Bread.
Orange Sweetpotato in Africa – a Success Story

• Active behavior change
• Agronomic ‘equality’ crucial
• Assistance to understanding and overcoming constraints to adoption crucial
  • Farmer participation in breeding and varietal selection
  • Seeds systems development
  • Product and market development
PROGRESS WITH IRON
Target Increase in Iron

Adult woman:

Intake 400 grams dry, milled rice/day

\[ \times \]

+10 mg/kg (parts per million; ppm) Fe

= 

+4 mg Fe/day
Meeting Dietary Iron Requirements at Two Levels of Intake From Rice

7 mg/d intake is sufficient for only 30% of women.

11 mg/d is sufficient for 80% of women.
The Subjects
Religious sisters from 10 convents
High Iron Rice Efficacy Trial

- 9-month feeding trial in the Philippines completed
- Non-anemic, iron-deficient subjects
- Intervention (high iron rice) and control (low iron rice) groups
- +1.5 mg Fe added to diets using under milled rice -- from a base intake of 8.5 mg Fe per day
Total body iron nine months after consuming high-iron or control rice (n=137)

Final body iron (mg/kg)

Body iron at baseline (mg/kg)

From Haas, Beard, Murray-Kolb, del Mundo, Felix and Gregorio, 2005
What increase in body iron stores is “significant,” that is, will result in an observable improvement in function/health?

…. moving most people from a ferritin of <10-12 to a ferritin of >20 ug/L (or adding 80-90 mg of storage Fe) will shift them from "abnormal functioning" to "normal functioning".

Professor John Beard,
Dept. of Nutrition, Pennsylvania State Univ.,
PI high-iron rice study
NO HUMAN STUDY TO DATE WITH A ZINC BIOFORTIFIED CROP
Discover and/or develop micronutrient-rich germplasm

Determine retention
Evaluate efficacy

Adaptive & participatory breeding and varietal selection

CURRENT
HarvestPlus BREEDING, FOOD TECHNOLOGY, AND NUTRITION

1. Diagnostic analyses

TIME IMPACT ANALYSES

Ex ante

PROPOSED END USER ACTIVITIES

Milestones

Ex post

2. Farmer adoption

3. Develop products & markets

4. Create demand

5. Monitor & give feedback

Increased intake & improved micronutrient status

266 HarvestPlus BREEDING, FOOD TECHNOLOGY, AND NUTRITION

1. Diagnostic analyses

2. Farmer adoption

Extension programs Seed systems

3. Develop products & markets

4. Create demand

5. Monitor & give feedback

Increased intake & improved micronutrient status

Milestones

TIME

IMPACT ANALYSES

Ex ante

Ex post

Breeding Crops for Better Nutrition
Reaching End Users

1. Diagnostic analyses

2. Farmer adoption
   - Extension Programs
   - Seed Systems

3. Develop products & markets

4. Create demand

5. Monitor & feedback
Reaching End Users:

Invisible & Visible Nutrients
Orange-fleshed sweetpotato in Africa
• Active behavior change
• Agronomic ‘equality’ crucial
• Assistance to understanding and overcoming constraints to adoption crucial

Farmers are breeding & selecting varieties
Seeds systems development
Product and market development

High Beta Carotene Transgenic Rice in Asia (Golden Rice)
• Active behavior change
• Agronomic ‘equality’ crucial
• Market development

High Mineral Wheat in Asia
• Passive behavior change
• Superior agronomic and quality traits crucial

High Mineral Beans in Africa
• Passive behavior change
• Superior agronomic & quality traits crucial
• Assistance to understanding and overcoming constraints to adoption crucial

Farmers are breeding & selecting varieties
Seeds systems development
Product and market development

INFRASTRUCTURE

VISIBEL TRAIT
Higher Cost

INVISIBLE TRAIT
Lower Cost

Well developed
Lower cost

Under developed
Higher cost
Movement of *Yr9* Virulence

*Centro Internacional de Mejoramiento de Maíz y Trigo*
Pakistan Variety Area Share, 1997

Source: CIMMYT Database
Pakistan, Peshawar

HIGH ZINC

Advanced Line

Inquilab 91
Visible traits

• Nutrition education becomes important
• Focus on children and expectant mothers
• Social marketing
• Convincing local farmers to grow biofortified crops
Time!

600 years