Farming for Nutritious Foods: Agricultural Technologies for Improved Human Health

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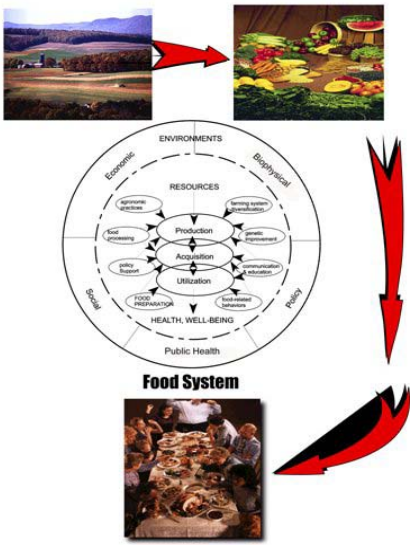
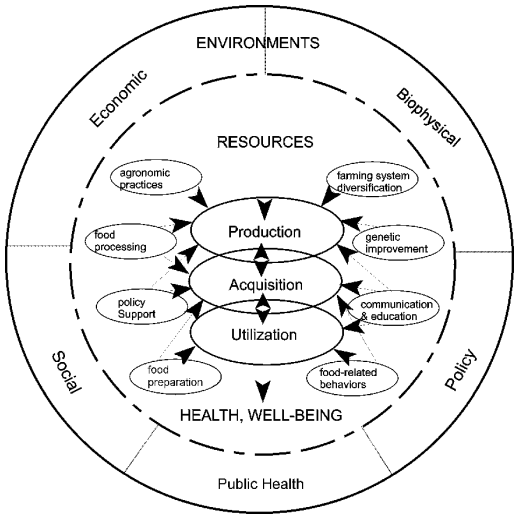
Holistic Food System Perspectives



Holistic Food Systems Model



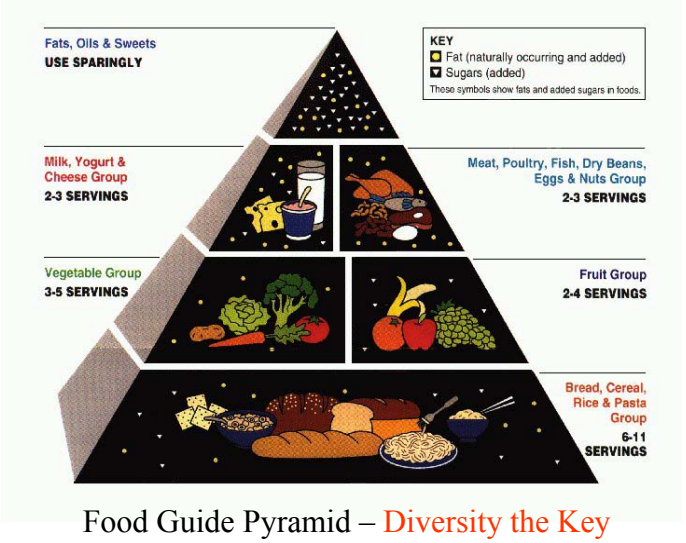
Food Systems, Diet and Disease

- Global food systems are failing to provide adequate quantities of essential nutrients and other factors needed for good health, productivity and well being in many developing nations.
- *Green revolution* cropping systems have resulted in reduced food-crop diversity and decreased availability of micronutrients.
- Nutrition transitions are causing increased rates of chronic diseases (cancer, heart disease, stroke, diabetes, osteoporosis)
- Holistic, sustainable improvements in the entire food system are required to solve the massive problem of malnutrition and increasing chronic disease rates in developed and developing countries.
- How can agriculture & molecular technologies contribute?

Global Food Systems' Problems

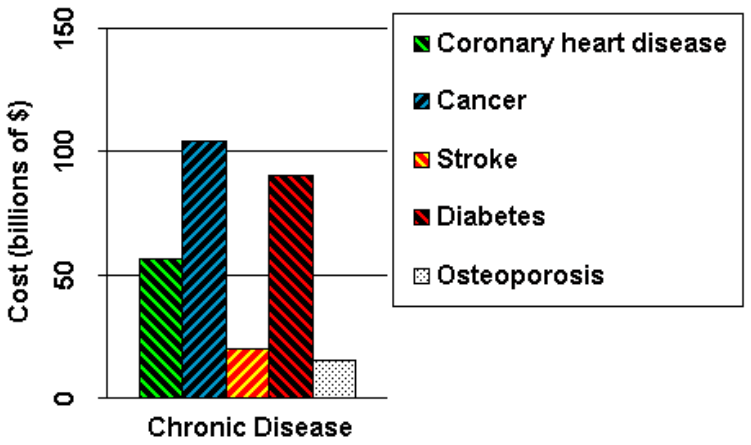
- Agriculture's primary focus is on production alone, with little concern for nutritional or health-promoting qualities.
- Nutritionists tend to emphasize unsustainable medical approaches to solve malnutrition problems
  - supplements
  - food fortificants
- Simplistic views are the norm – looking for "silver bullet" approaches for solutions

Improving nutrient output of agricultural systems to meet human needs



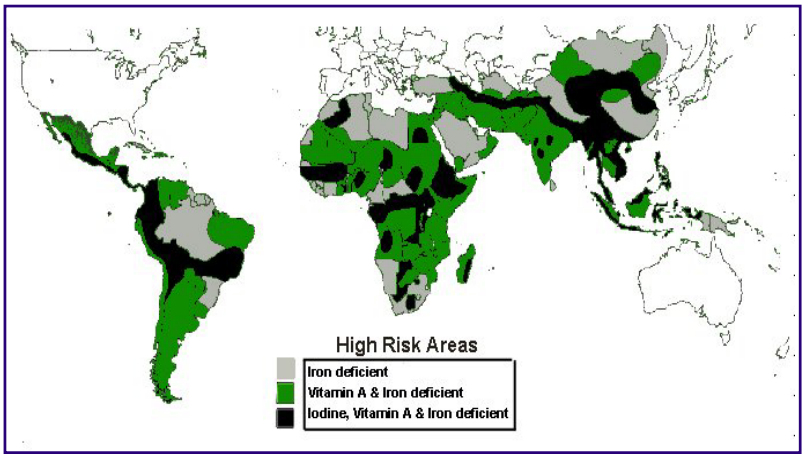
Food Guide Pyramid – Diversity the Key

Cost of Diet-Relaed Disease in USA



Total costs to US Society >$250 billion per year
(data from USDA-ERS, 1995)

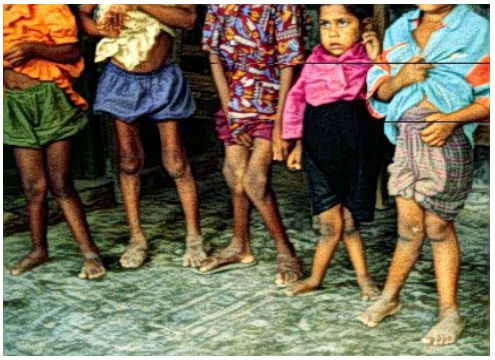
Global Micronutrient Deficiencies



> 3 billion people afflicted

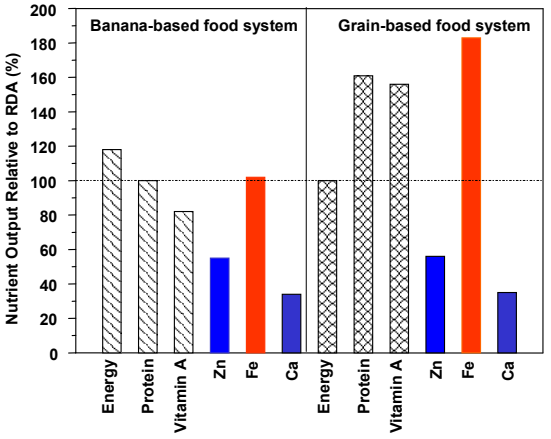
(Map from USAID)

Calcium Deficiency Rickets in Bangladeshi Children



New disease in Bangladesh; also reported in Nigeria

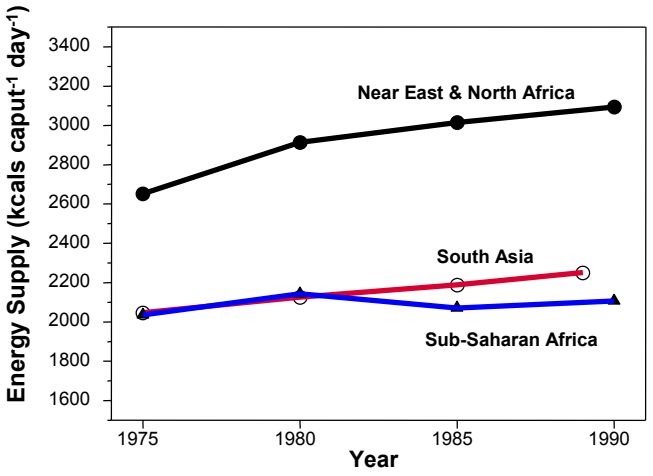
Nutrient Output of Two Ugandan Food Systems



Based on 15 mg Fe per day not 53 mg Fe per day as recommended by FAO/WHO

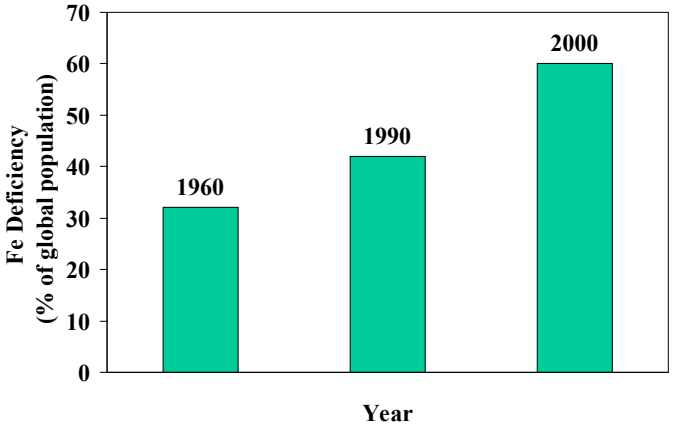
(data from McIntyre et al., 2001)

Dietary Energy Supply

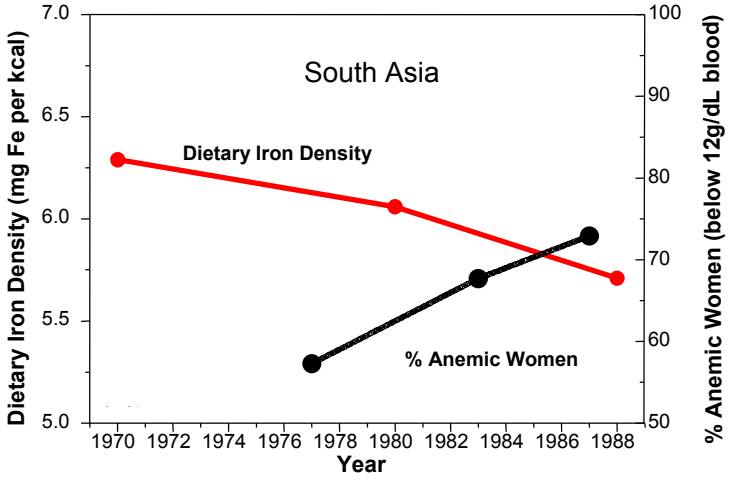


(Data from FAO)

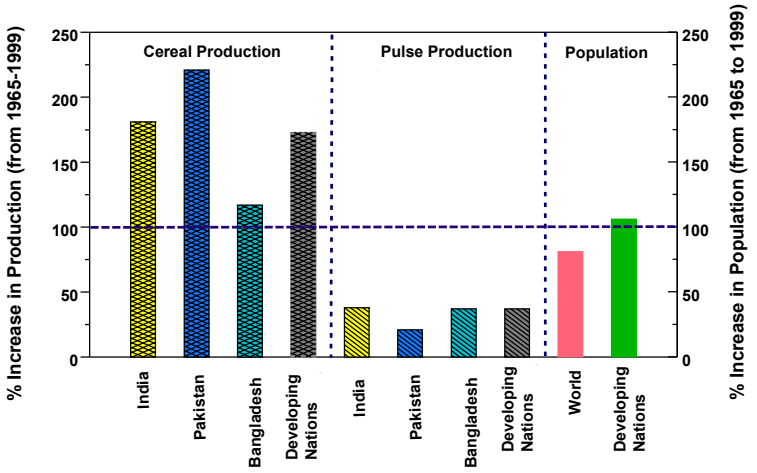
Change in Prevalence of Iron Deficiency Globally



Dietary Iron Density and % Anemic Women in S. Asia



% Changes in Cereal & Pulse Production & in Population Between 1965 & 1999



(FAO data, 1999)

Micronutrients in Whole Cereal Grains and Legume Seeds (Pulses)

	Plant Food	Fe	Zn	Mn	Cu	Mo	Cr	Ni
		($\mu g\ g^{-1}$ dry weight)						
Cereals	Brown rice	20	14	11	2.4	0.78	0.088	-
	Whole soft wheat	39	22	35	4.5	-	0.370	0.31
Legumes	Mung bean	87	41	14	13.0	3.20	0.251	2.04
	Black gram	139	36	19	7.9	0.16	0.530	3.43
	Cowpea	67	45	16	6.3	1.47	0.272	3.44
	Soybean	97	43	26	15.5	-	-	-
	Red kidney bean	64	30	12	6.8	-	-	-

Effects of Polishing and Milling on Rice Grain Micronutrient Concentrations[a]

Micronutrient	Brown Rice	Polished Rice	% Removed
Iron ($mg\ kg^{-1}$)	20	5	75
Copper ($mg\ kg^{-1}$)	3.3	2.9	12
Manganese ($mg\ kg^{-1}$)	17.6	10.9	62
Zinc ($mg\ kg^{-1}$)	18	13	30
Biotin ($\mu g\ kg^{-1}$)	120	50	58
Folic Acid ($\mu g\ kg^{-1}$)	200	160	20
Niacin ($mg\ kg^{-1}$)	47	16	66
Pantothenic Acid ($mg\ kg^{-1}$)	20	10	50
Riboflavin ($mg\ kg^{-1}$)	0.5	0.3	40
Thiamin ($mg\ kg^{-1}$)	3.4	0.7	80
Vitamin B_6 ($mg\ kg^{-1}$)	6.2	0.4	94
Vitamin E ($IU\ kg^{-1}$)[b]	20	10	50

[a]Dry weight basis.
[b]IU = International Unit.

Agricultural Approaches to "Healthier" Plant Foods

- Field Site Selection
- Agronomic Practices
  - macronutrient fertilizers
    - nitrogen, phosphorus, potassium, sulfur, calcium, magnesium
    - effects protein, fats, vitamins, antinutrients, etc.
  - micronutrient & trace element fertilizers
    - Zn, Ni, I, Mo, Se - effective in increasing amount in plant seeds and grains
    - Fe, Cu, Mn, Cr, V, Si - not effective in increasing seed or grain levels
- Cropping systems
  - legume-cereal rotations -effects micronutrient content
  - use micronutrient-dense varieties of food crops
  - increase production of vegetables, fruits, & legumes
- Utilize indigenous plant foods and diversify food systems
- Genetically modify food crops to improve nutrient output of farming systems

Effects of N & K Fertilizers on Vitamin C

(mg/100g fr. wt.)

Vegetable	N_1	N_2	N_3
Swiss chard	67.8	56.1	47.6
Kale, collards	113.0	112.0	66.0
Brussels-sprouts	112.0	101.0	93.0
Vegetable	**K_1**	**K_2**	**K_3**
Swiss chard	49.9	56.1	59.3
Kale, collards	98.0	112.0	118.0
Brussels-sprouts	88.0	101.0	100.0

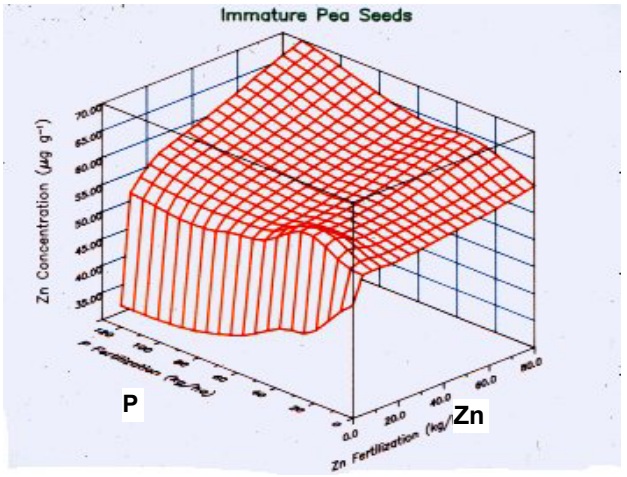
(data from Salunkhe and Deshpande, 1991)

Effects of N and Harvest Date on ß-Carotene Content of Carrots

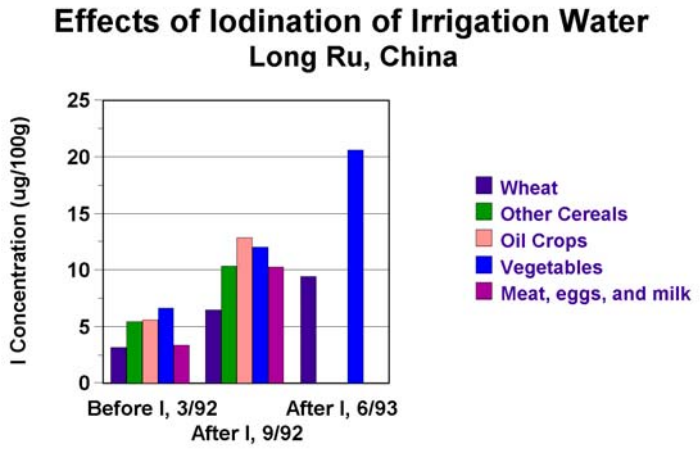
Treatment	Carotene (mg/100g)	Carotene (mg/100g)	Carotene (mg/100g)
(kg N/pot)	1st harvest	2nd harvest	3rd harvest
0.3	113	125	136
0.6	118	128	138
1.2	126	138	147
2.4	126	138	146

from Habben (1972)

P & Zn Fertilizer effects on Zn levels in pea seeds

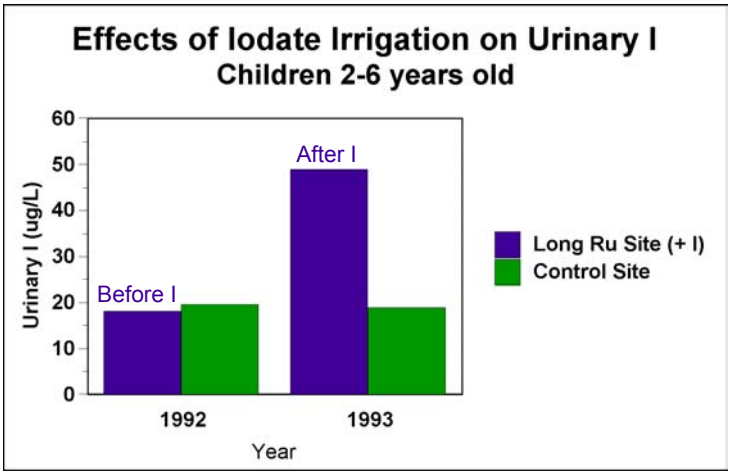


Food Systems Approach to IDD



Cao, et al., 1994

Food Systems Approach to IDD



Cao, et al., 1994

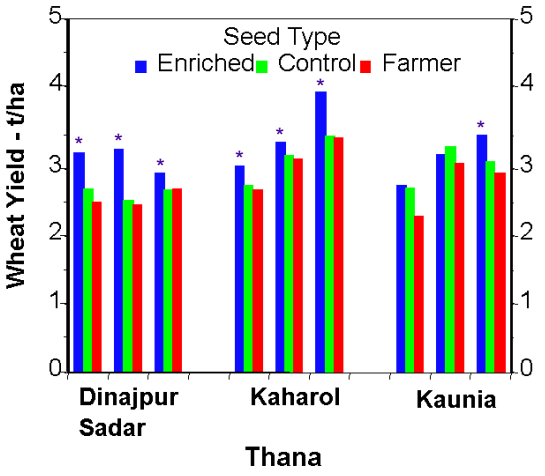
Issues in Breeding for Micronutrient-Dense Food Crops

- Magnitude of change possible and potential impact on health
- Effects on crop yields
- Environment vs. genetic effects on micronutrients
- Consumer acceptance
- Bioavailability - antinutrients, promoters, diet/meal
- Sustainability (soil-mining, farm inputs, environmental concerns)
- Effects of processing & preparation on micronutrients
- Cost / benefit considerations

Agronomic Benefits of Micronutrient Element-Enriched Seeds (e.g. Zn)

- Better seed viability
- Greater seedling vigor
- Denser stands (less soil irrosion)
- Lower seeding rates (lower cost to farmers)
- Larger root absorptive surface (better water & nutrient use efficiency)
- Better resistance to disease
- Better plant survival
- Increased plant & seed yield

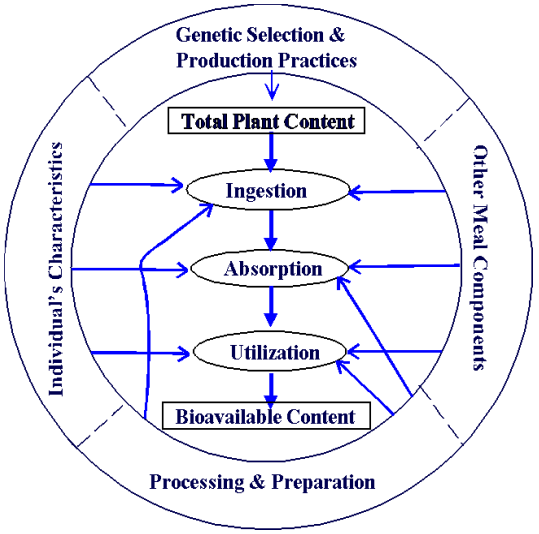
Effects of Micronutrient-Enriched Seed on Wheat (Kanchan) Grain Yields from 9 Farms in Bangladesh



24% > in grain yield (0.69 t/ha) seen on 47 farms over 4 years.

(Data from Duxbury, 2001)

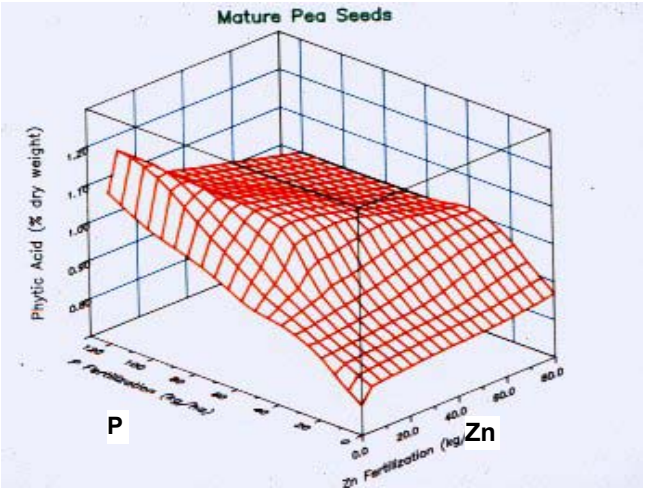
Complexities of Bioavailability



Examples of Antinutrients in Plant Foods Affecting Micronutrient Bioavailability

Antinutrient	Major Dietary Sources
Phytic acid	Whole seeds and grains
Fiber (e.g., cellulose, hemicellulose, lignin, cutin, suberin, etc.)	Whole grain products (e.g., wheat, rice,maize, oat, barley
Tannins, polyphenolics	Tea, coffee, beans, sorghum
Hemagglutinins	Most legumes, wheat
Goitrogens	*Brassicas* and *Alliums*
Heavy metals (e.g., Cd, Hg, Pb)	Plant foods from crops grown on polluted soils (e.g., Cd in rice)

Zn and P fertilizer effects on phytate in pea seeds



Examples of Promoters in Plant Foods

Substance	Nutrient	Major Sources
Certain organic acids (e.g., ascorbate, fumarate, malate, citrate)	Fe/Zn	Fresh fruits & vegetables
Hemoglobin	Fe	Leafy Vegetables
Certain amino acids (e.g., cysteine, histidine)	Fe/Zn	Animal meats
Long-chain fatty acids (e.g., palmitic acid)	Zn	Human breast milk
Fats & lipids	Vitamin A	Animal fats, vegetable oils
Se	I	Sea foods, tropical nuts
Zn, Fe	Vitamin A	Animal meats
β-carotene, provitamin A carotenoids	Fe/Zn	Orange & green vegetables
Non-digestible carbohydrates (e.g., inulin)	Ca, Mg, Fe, Zn	Onion, garlic, wheat grain
Vitamin E	Vitamin A	Vegetable oils, green leafy vegetables
Phytoferritin	Fe	Certain seeds
Lactoferrin	Fe	Human milk

Some Ways to Improve the Health Promoting Quality of Food Crops via Genetic Modifications

- Increase promoter substances (highly desirable)
  - ascorbic acid (vitamin C)
  - sulfur-containing amino acids (cysteine, cystine, methionine)
  - provitamin A carotinoids (vitamin A)
  - meat factor(s?)
  - non-digestible carbohydrates (e.g., inulin)
- Increase or introduce other bioavailable micronutrient-rich compounds (phytoferritin, hemoglobin, human lactoferrin, etc.)
- Decrease antinutrients (do only with caution)
  - phytic acid (*myo*-inositolhexaphosphoric acid)
  - tannins, polyphenolics, fibers, lectin, etc.
- Introduce heat-stable phytases from fungus
- Increase other health promoting factors (e.g., tocopherol, folic acid, biotin, lutein, lycopene, phytosterols, flavonols, *cis* oleic & stearic oils, etc.)

Agriculture's Agenda

- Make human health and well being an explicit goal of agricultural systems in addition to productivity & environmental goals
- Re-diversify cropping systems & design for maximum nutrient output
- Make more use of indigenous micronutrient-dense edible plant species, small livestock, & fish
- Use agricultural practices that increase the bioavailable micronutrient output of farming systems
- Breed for micronutrient-dense staple food crops with micronutrient efficiencies
- Genetically modify plants to increase nutritional & health promoting factors
- Redefine sustainable agriculture to include adequate nutrient output for healthy & productive lives