Harvesting Health: Agricultural Linkages for Improving Human Nutrition

R.M. Welch
USDA-ARS, US Plant, Soil and Nutrition Laboratory, Cornell University, New York, USA

Introduction

Agricultural technologies can be directed at improving the 'healthiness' of foods to meet human needs, but this requires the use of holistic perspectives of food systems to ensure sustainable impact. Global food systems are failing to provide adequate quantities of essential nutrients and other factors needed for good health, productivity, and well-being for vast numbers of people in many developing nations. Cropping systems promoted by the Green Revolution (GR) have resulted in reduced food-crop diversity and a decrease in the availability of micronutrients. Nutrition transitions are causing increased rates of chronic diseases (cancer, heart disease, stroke, diabetes, and osteoporosis) in many developing nations.

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. The question is how can agriculture contribute to sustainable solutions?

Global Food Systems' Problems

Agriculture's primary focus is on production alone, with little concern for nutritional or health-promoting qualities. Nutritionists tend to emphasise unsustainable medical approaches to solve problems of malnutrition by using supplements and fortification of food. Simplistic views are the norm – looking for 'the silver bullet' approaches to solutions. However, there are 50 essential nutrients for sustaining human life (Table 1).

All regions of the world have experienced a worsening of nutritional status during the last decade. High levels of chronic malnutrition exist in food-deficient and food-surplus regions alike. The primary focus has been on protein-energy malnutrition and not on micronutrients, although micronutrient malnutrition is severe. Global micronutrient deficiency is shown in Figure 1.

Over half of the human population is deficient in micronutrients, and a further 15% have inadequate energy supplies, most of these people being in resource-poor countries. The food systems of these people can be said to be dysfunctional since they fail to deliver all the nutrients needed for healthy lives. The problem can be viewed from a food-system perspective, and solutions developed for the food system to ensure that the changes we advocate are agriculturally, environmentally, economically, and socially sound and sustainable. There have been changes in the food production systems of the developing nations in the last 35 years which correspond to the increases in population (Figure 2). There is a drastic decrease in the pulse production compared to the cereal production, but the

Table 1: **The 50 essential nutrients known for sustaining human life** *

Water & Energy (2)	**Protein (amino acids) (9)**	**Lipids/Fat (fatty acids) (2)**	**Macro-minerals (7)**	**Micro-elements (17)**	**Vitamins (13)**
Water Carbohydrates	histidine isoleucine leucine lysine methionine phenylalanine threonine tryptophan valine	linoleic acid linolenic acid	Na K Ca Mg S P Cl	Fe Zn Cu Mn I F B Se Mo Ni Cr V Si As Li Sn Co (in B_{12})	A D E K C (ascorbic acid) B_1 (thiamin) B_2 (riboflavin) B_3 (pantothenic acid) niacin B_6 (pyridoxal) folate biotin B_{12} (cobalamin)

Key: Macro-minerals (as per order in table) – Na = sodium; K = potassium; Ca = calcium; Mg = magnesium; S = sulphur; P = phosphorous; Cl = chlorine
Micro-minerals (as per order in table) V = vanadium; Si = silicon; As = arsenic; Li = lithium; Sn = stannous; Co = cobalt; Fe = iron; Zn = zinc; Cu = copper; Mn = manganese; I = iodine; F = fluorine; B = boron; Se = selenium; Mo = molybdenum; Ni = nickel; Cr = chromium

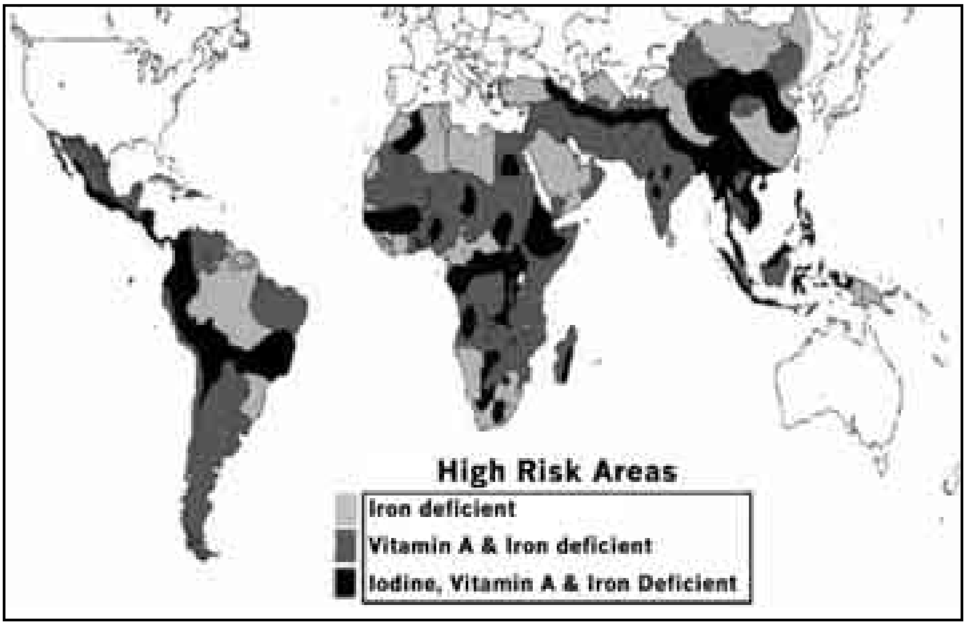

Figure 1: **Global micronutrient deficiencies**
(Source: Map from USAID)

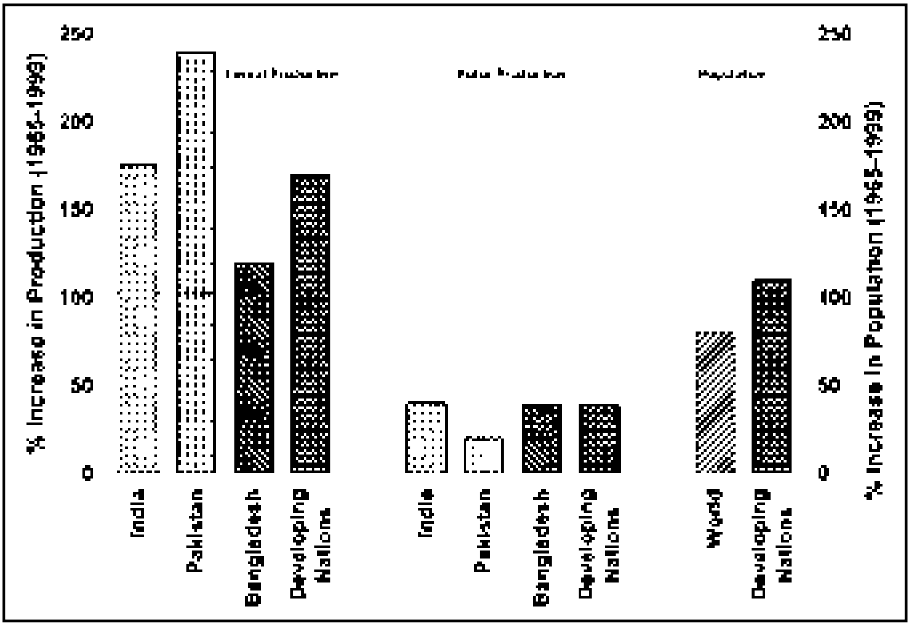

Figure 2: **Percentage changes in cereal and pulse production and in population between 1965 and 1999**

micronutrient content is higher in pulses than in cereals. However, the population increment demanded higher cereal production.

Food systems are generally identified by the main staple or staple food eaten. The rice-based food system in which rice is supplemented with a few vegetables, green leaves, and/or small fish feeds much of China and South and South East Asia. Other major food systems are based on rice-wheat, rice-pulses, maize, bean, maize-bean/cassava, and in Africa, sorghum/millet systems. Polished rice is very low in iron, low in zinc and calcium, and contains almost no pro-vitamin A carotenoids. Deficiencies of these nutrients are common in rice-eating populations. Adding these nutrients back into the food system agriculturally is difficult as the at-risk population in these areas is typically dense and much land must be devoted to rice cultivation to supply caloric needs. Moreover, rice is higher yielding and more tolerant of stresses such as typhoons, disease, pests, and drought than alternative staples that may be more nutritious. Milling of rice has an effect on the micronutrient concentration (Table 2).

Agricultural approaches to 'healthier' plant foods

There are several approaches to producing healthier plants; the simple methods are given below.

- Suitable field site selection and appropriate agronomic practices
- Macronutrient fertiliser applications: nitrogen, phosphorous, potassium, sulphur, calcium, magnesium; affects protein, fats, vitamins, anti-nutrients, etc.
- Micronutrient and trace element fertiliser application

  Zn, Se, Co, Ni, I, Mo, Li, Cl – effective in increasing amounts in plant seeds and grains

  Fe, Cu, Mn, B, Cr, V, Si – not effective in increasing seed or grain levels

Table 2: **Effects of polishing and milling on rice grain micronutrient concentration** [A]			
Micronutrients	**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 (ug kg^{-1})	120	50	58
Folic acid (ug 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			

- Cropping systems' diversification: legume-cereal rotations – affects micronutrient content
- Use micronutrient-dense varieties of food crops
- Increase production of vegetables, fruits, and legumes
- Use indigenous plant foods and diversify food systems
- Genetically modify food crops to improve nutrient output of farming systems

Current supplementation and food fortification programmes are plagued with poor compliance and low long-term efficacy and are sustainable only with long-term external support. Further they do not reach many of the people who are most in need.

Supplying more iron and pro-vitamin A to the diet via the rice crop itself requires breeding of nutrient-dense varieties. Breeding can help to deliver more zinc too, but zinc in rice can also be raised effectively by adding zinc to the system as fertiliser, and this is often done in some areas as rice yield is also sensitive to soils low in zinc. Because of population pressure on the land, it is not easy to add more nutrients to the diet by growing more nutrient-dense secondary staples and viands unless the yield of rice can be increased by fertiliser use. Fertilisation is one method of enrichment of micronutrients in crops. Fertilisation with Zn does have an effect on increasing the yield of wheat grain and Zn concentration in the grain (Table 3).

Table 3: **Effects of zinc fertilisation on yield and zinc concentration of wheat grain**		
Zinc treatment (mg kg^{-1})	**Grain yield (g/plant)**	**Zinc concentration (mg kg^{-1})**
0.00	1.00	9.1
0.05	2.20	9.9
0.20	2.24	14
0.80	2.51	83
3.20	1.70	145

Genetic potential to improve the micronutrient efficiency of crops

Historically, plant breeders did not select for micronutrient efficient traits in food crops. Generally they used more fertile soils in selection processes, and this resulted in high-yielding varieties that require high inputs to maximise yield. Within wild relatives and land races of crop plants, a wide variation exists to improve micronutrient efficiencies in crop plants. The ability to screen genotypes for micronutrient efficiency traits is a limitation to breeders. The CGIAR-Harvest Plus programme has launched some projects on this line of breeding for micronutrient-dense staple plant foods. The following organisations are involved in breeding for micronutrients.

Consultative Group on International Agricultural Research (CGIAR) cooperators
International Food Policy Research Institute (IFPRI) – coordination of project
International Rice Research Institute (IRRI) – rice breeding
International Centre for Tropical Agriculture (CIAT) – beans and cassava breeding
International Maize and Wheat Improvement Centre (CIMMYT) – wheat and maize breeding
International Institute of Tropical Agriculture (IITA) – maize and sweet potato breeding International Potato Center (CIP) – sweet potato
International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) – phase 2 crops
International Centre for Agricultural Research in the Dry Areas (ICARDA) – phase 2 crops
University of Adelaide, Waite Campus
United States Department of Agriculture, Agricultural Research Service (USDA-ARS) – US Plant, Soil & Nutrition Laboratory, Cornell University, Ithaca, New York (NY); Children's Nutrition Research Center at Baylor College, Houston, Texas; Grand Forks Human Nutrition Research Center, Grand Forks, USA
Other international centres
Other universities in developed and developing countries
National agricultural research services
Non-government organisations

Issues in bio-fortifying staple food crops

There are several issues that could challenge the bio-fortification of crops. They include the magnitude of change possible and potential impact on health; effects on crop yields; farmer acceptance; environment vs. genetic effects on micronutrients; consumer acceptance and safety; bio-availability – anti-nutrients, promoters, diet/meal sustainability (soil-mining, farm inputs, environmental concerns); effects of processing and preparation on micronutrients; and cost and benefit considerations. But there are agronomic benefits from enrichment of micronutrients in seeds, as for example, zinc enrichment that could increase seed viability and seedling vigour and lead to denser stands (less soil erosion), lower seeding rates (lower cost to farmers), larger absorptive surface of roots (better efficiency of water and nutrient use), better resistance to disease, better plant survival, and increased plant and seed yield.

The importance of bio-availability

One important issue is that of bio-availability. Bioavailability is the amount of a nutrient in a food that can be absorbed from a typical diet and used in the body. Bioavailable amount of a micronutrient in a meal, not the total amount, is the critical factor for human health. Most staple plant foods (cereal grains and legume seeds) eaten alone contain very low levels of bioavailable Fe and Zn (e.g., about 5%) because of the anti-nutrients they contain (like phytate and polyphenols). Increasing the bioavailability of micronutrients from 5 to 30% would have the same effect as increasing their total amounts in staples 6-fold. The complexity of the factors that effect bioavailability are shown in Figure 3. The anti-nutrients in food plants affect the bioavailability of micronutrients. Examples of some antinutrients are given in Table 4.

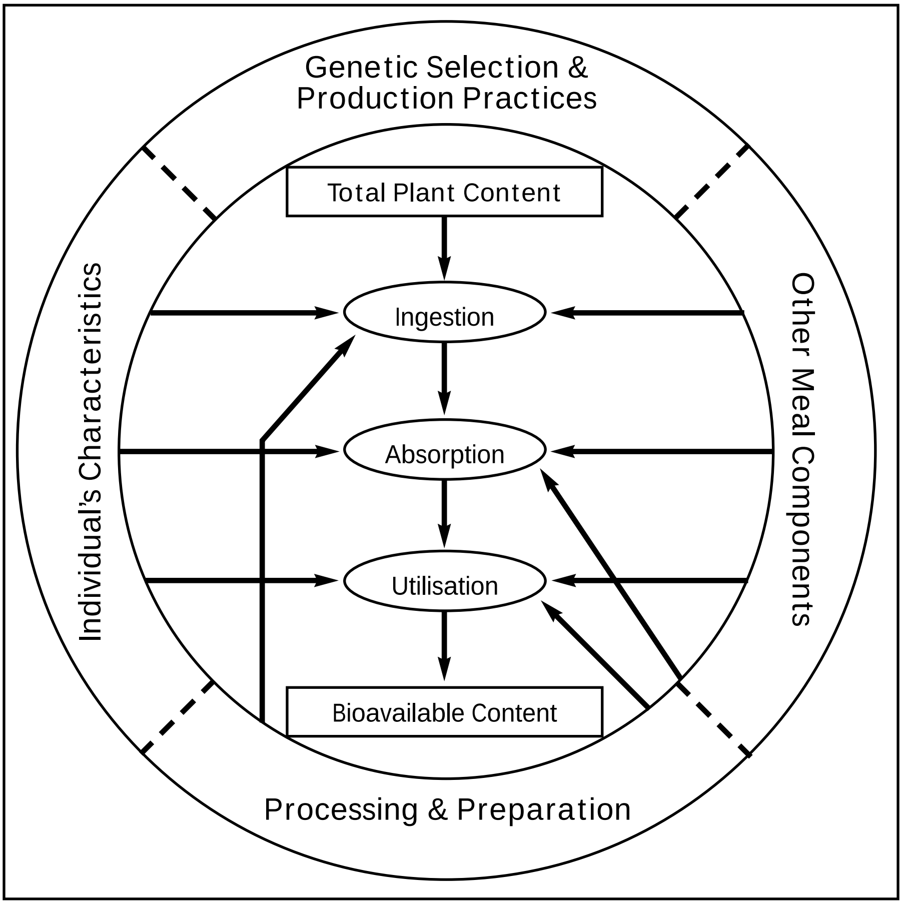

Figure 3: **Complexities of bioavailability**

Agronomic concerns in changing anti-nutrients in food crops

Anti-nutrients are major plant metabolites. They perform beneficial functions in plant growth and development (e.g., disease and insect resistance, nutrient stores). For example, phytate plays a role in inhibiting fungal infection of seeds and the production of aflatoxin B1, a potent carcinogen. Phytic acid is a major storage site of P and other mineral elements (e.g., Fe, Zn, Cu, Mn, K, Mg, Ca). High levels of anti-nutrients may affect seed vigour and viability. Crop production could be negatively affected when crops are sown in nutrient-poor soils.

Human health concerns in lowering phytic acid in food crops

If phytic acid is lowered in the food of humans it appears to decrease the risk of cancer (human cells tested: colon adenocarcinoma, erythoroleukaemia, mammary

Table 4: **Examples of antinutrients in plant food affecting bioavailability of micronutrients**	
Antinutrient	**Major dietary sources**
Phytic acid	Whole seeds and grain
Certain types of fibre (e.g., cellulose, hemicellulose, lignin, cutin, suberin)	Whole grain products (e.g., wheat, rice, maize, oats, barley
Tannins, polyphenolics	Tea, coffee, beans, sorghum
Hemaglutinins	Most legumes, wheat
Goitrogens	*Brassicas* and *Alliums*
Heavy metals (e.g., Cd, Hg, Pb)	Plant foods from crops grown on polluted soi ls (e.g., Cd in rice)
Key: Cd = cadmium; Hg = mercury; Pb = lead	

adenocarcinoma, and prostate adenocarcinoma); up-regulates tumour suppressor genes p53 and p21 (WAF1CIP1) in HT-29 human colon carcinoma cells; appears to be involved in signal transduction pathways, cell cycle regulatory genes, differentiation genes, oncogenes and tumor suppressor genes; inhibits the production of carcinogenic aflatoxins in cereal grain; possibly plays a role in preventing heart disease; lowers serum cholesterol and triglycerides; may prevent renal calculi (kidney stones); and greatly decreases heavy metal bioavailability (e.g., Cd). Dietary phytate can accumulate in the brain and in plasma (Grases et al. 2002). There are also interactions between micronutrients themselves that affect bioavailability (Figure 4).

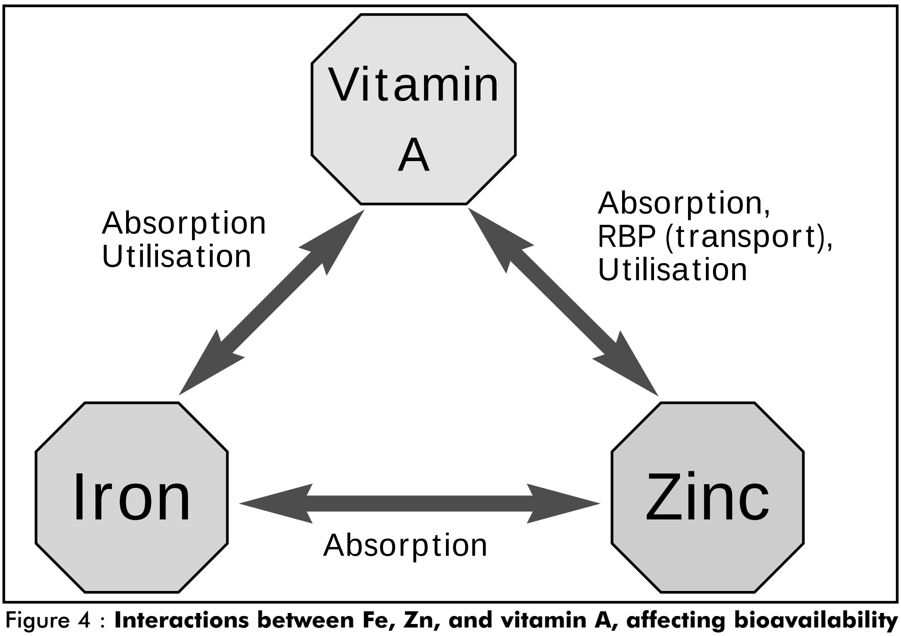

Figure 4 : **Interactions between Fe, Zn, and vitamin A, affecting bioavailability**

Agricultural agenda for better health

One major agricultural agenda for better human health includes making human health and well-being an explicit goal of agricultural systems in addition to productivity and environmental goals, re-diversifying cropping systems, and designing for maximum nutrient output. It is important to make more use of indigenous edible plant species that have a dense micronutrient content, in addition to small livestock and fish. Other strategies might be: use of agricultural practices (e.g., fertilisers) that increase the bioavailable micronutrient output of farming systems; breeding and selection for bioavailable micronutrient-dense staple food crops with micronutrient efficiencies; and genetically modifying plants to increase nutritional and health-promoting factors. Redefining sustainable agriculture to include adequate nutrient output for healthy and productive lives is a sine qua non for improving human health .

References

Grases, F; Garcia, R.; Redondo, E. (2000) *A pilot clinical trial to evaluate the safety and efficacy of a saponin (escin) as inhibitor of the indinavir (IDV) crystallization in urine of HIV infected patients,* Balcar Collaborative Group for the Study of Nephrolithiasis. Paper presented at the 40th Interscience Conference on Antimicrobial Agents and Chemotherapy, September 2000, Toronto, Canada