LEVERAGING AGRICULTURE FOR IMPROVING NUTRITION & HEALTH

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BIOFORTIFICATION: LEVERAGING AGRICULTURE TO REDUCE HIDDEN HUNGER

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Micronutrient Malnutrition: A Hidden Hunger

Experts estimate that 2 billion people, mostly in poorer countries, suffer from micronutrient malnutrition, also known as hidden hunger.[1] This is caused by a lack of critical micronutrients such as vitamin A, zinc, and iron in the diet. Hidden hunger impairs the mental and physical development of children and adolescents and can result in lower IQ, stunting, and blindness; women and children are especially vulnerable. Hidden hunger also reduces the productivity of adult men and women due to increased risk of illness and reduced work capacity.

In 2008, *The Lancet* published a landmark series of articles on maternal and child undernutrition highlighting the extent of hidden hunger. One study cited in the *Lancet* series found that men who had received nutrition supplements (that included micronutrients) from ages 0–36 months earned a higher hourly wage than men who had not received the supplements. The group that received nutrition supplements from ages 0–24 months earned 46 percent over average wages.[2] Hidden hunger's enormous consequences, not only to individuals but also to society through reduced economic productivity, have brought more attention to the issue recently. Also in 2008, a panel of noted economists that included five Nobel Laureates, ranked efforts to reduce hidden hunger among the most cost-effective solutions to global challenges. One of these efforts, biofortification, was ranked fifth.[3]

Leveraging Agriculture to Improve Nutrition through Biofortification

Agriculture is the primary source of nutrients necessary for a healthy life, but agricultural policies and technologies have focused on improving profitability at the farm and agroindustry levels, not on improving nutrition.[4] Given the prevalence of hidden hunger, there is growing interest in the role agriculture should play in improving nutrition, in particular by paying more attention to the nutritional quality of food.

Biofortfication is a scientific method for improving the nutritional value of foods already consumed by those suffering from hidden hunger. Scientists first breed crops whose edible portions (seed, tuber, or roots, for example) have improved nutritional value. Malnourished communities receive these biofortified crops to grow and eat. When consumed regularly, biofortified foods can contribute to body stores of micronutrients throughout the life cycle. This strategy should contribute to the overall reduction of micronutrient deficiencies in a population, but it is not expected to *treat* micronutrient deficiencies or eliminate them in all population groups.

The Biofortification Process

Biofortication requires experts from different fields to work together. Plant breeders explore the full spectrum of crop genetic diversity, especially seed banks, to first identify nutrient-rich germplasm, or lines, of food crops that can be used to breed more nutritious varieties. These lines are then crossed with established high-yielding lines to breed new crop varieties that not only have higher amounts of a desired nutrient, but also are high yielding and competitive with other nonbiofortified varieties. Plant breeders can use both conventional plant breeding and transgenic methods to reach their breeding targets. (For a complementary approach to biofortification, see Box 1.)

Nutritionists must determine the additional amount of a nutrient a food crop must provide to measurably improve nutrition when that crop is harvested, processed or cooked, and eaten. To do so, nutritionists must account for

1. nutrient losses after the crop is harvested (nutrients can degrade substantially during storage, processing, or cooking),
2. the amount of the nutrient that the body actually absorbs from the food (bioavailability), and
3. the amount of the staple food actually consumed on a daily basis by age and gender.

These data are then used to set breeding targets for specific nutrients.

Once these new crop lines have been bred, they are field-tested by a national agricultural system in multiple locations in target regions where the crop will be grown. This ensures the crops perform well and maintain their nutritional profile, which can be affected by the growing environment. The most promising lines are selected for further testing and eventual release as new varieties through public channels, the private sector, or both.

Nutritionists also test promising new lines and varieties prior to release, to ensure they have a measurable positive impact on the micronutrient status of target communities. This is done through controlled human feeding trials called efficacy studies.

Box 1 — More Than One Way to Biofortify

Another agricultural approach, referred to as agronomic biofortification, seeks to improve the mineral content of food crops through fertilizer applications. For example, adding zinc-enriched fertilizer to the soil results in increased uptake of zinc, by crops such as wheat, and increases the bioavailable zinc concentration in the edible portion of the plant. The HarvestZinc Fertilizer Project(www.harvestzinc.org) is exploring and testing fertilizer use to improve cereal crops' zinc concentration.

Source: Ismail Cakmak, "Enrichment of Cereal Grains with Zinc: Agronomic or Genetic Biofortification?" *Plant Soil* 302 (2008):1–17

Together with nutritionists, economists conduct field experiments to evaluate the impact of production and consumption of biofortified varieties of crops on various livelihoods and health outcomes. Behavioral-change experts help identify what drives consumption patterns and how biofortified crops and foods can be better promoted. Ultimately, a range of skills in farm extension, seed replication and distribution systems, and product marketing and management are also needed to ensure the final product is successfully taken up in target communities.

Special consideration should be given to crops whose color or taste is changed by improved nutrient content. To date, this has been the case when crops such as sweet potato, cassava, and maize have been enhanced with vitamin A. These crops turn from a typical white or pale yellow to a deeper yellow or orange in color due to the higher levels of beta-carotene (a precursor to vitamin A) they now contain. This orange color can be an asset in helping consumers identify more nutritious varieties.

HarvestPlus, a Challenge Program of the Consultative Group on International Agricultural Research (CGIAR), leads a global effort to develop and deliver biofortfied staple food crops with one or more of three nutrients most limiting in the diets of the poor: vitamin A, zinc, and iron.[5] HarvestPlus is an interdisciplinary program that works with experts in more than 40 countries. A release schedule for HarvestPlus crops is shown in Table 1. Other global, regional, and country biofortification programs are working around the world.

Advantages of Biofortification

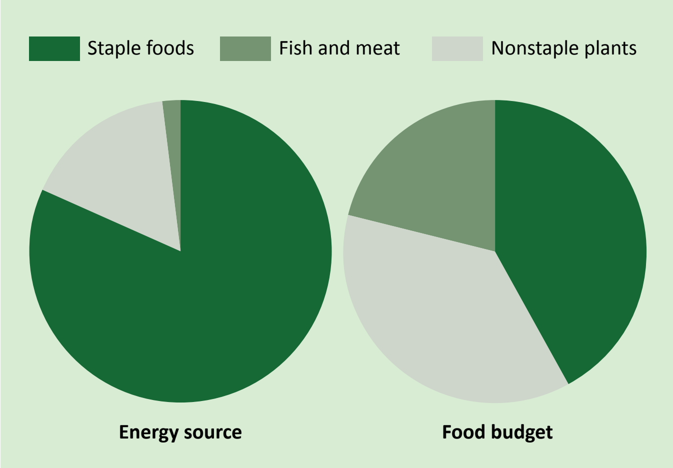
Dietary diversity is the ultimate long-term solution to minimizing hidden hunger. This will require substantial increases in income for the poor so they are able to afford more nutritious nonstaple foods such as vegetables, fruits, and animal products. Biofortification can be effective in reducing hidden hunger as part of a strategy that includes dietary diversification and other interventions such as supplementation and commercial fortification.

Table 1 — HarvestPlus target crops and countries

Crop	Nutrient	Target country	Traits	Release year
Bean	Iron (Zinc)	DR Congo, Rwanda	virus resistance, heat, & drought tolerance	2012
Cassava	Vitamin A	DR Congo, Nigeria	virus resistance	2011
Maize	Vitamin A	Zambia	disease resistance, drought tolerance	2012
Pearl millet	Iron (Zinc)	India	mildew resistance, drought tolerance	2012
Rice	Zinc (Iron)	Bangladesh, India	disease & pest resistance	2013
Sweet potato	Vitamin A	Uganda, Mozambique	virus resistance, drought tolerance	2007
Wheat	Zinc (Iron)	India, Pakistan	disease resistance	2013

Note: HarvestPlus also supports biofortification of the following crops: Banana/Plantain (vitamin A), Lentil (iron, zinc) Potato (iron, zinc), Sorghum (zinc, iron).
Source: Harvest Plus, "Crops," http://www.harvestplus.org/content/crops, accessed January 25, 2011.

Figure 1 — Share of energy source and food budget in rural Bangladesh



Source: HarvestPlus, "Food Crisis," http://www.harvestplus.org/content/food-crisis, accessed January 25, 2011.

Biofortification has four main advantages when applied in the context of the poor in developing countries. First, it targets the poor who eat large amounts of food staples daily. Second, biofortification targets rural areas where it is estimated that 75 percent of the poor live mostly as subsistence or smallholder farmers, or landless laborers. These populations rely largely on cheaper and more widely available staple foods such as rice or maize for sustenance. Despite urbanization and income growth associated with globalization, diets of the rural poor will continue to be heavily based on staple foods like cereals and tuber crops in many regions.[6] Expected increases in food prices, exacerbated by climate change, are likely to increase this reliance on staple foods (see Box 2).

For example, Figure 1 shows the relative share of calories from different types of foods people consume in rural Bangladesh. Staple foods, mostly rice, account for more than 80 percent of the caloric energy intake. Nonstaple plant foods and meat products account for less than 20 percent of energy intake, yet rural Bangladeshis spend almost 60 percent of their food budgets on these more expensive, and more nutritious, foods.

Supplements or fortified food products are often not widely available in rural areas; in fact, coverage of fortified foods in rural areas may be less than one-third.[7] Therefore, locally produced, more nutritious staple food crops could significantly improve nutrition for the rural poor who eat these foods on a daily basis.

Third, biofortification is cost-effective. After an initial investment in developing biofortified crops, those crops can be adapted to various regions at a low additional cost and are available in the food system, year after year. *Ex ante* research that examined the cost-effectiveness of a variety of staple crops biofortified with provitamin A, iron, and

Box 2 — The Challenge of Rising Food Prices and Climate Change

Future population and income growth will result in increased demand for food that will outstrip productivity, resulting in higher food prices. Climate change, which adds stress to agricultural systems, has a multiplier effect resulting in even higher food prices. Rising food prices will negatively affect the nutrition of the poor who cope by protecting consumption of staple foods (whose cost has risen) to keep from going hungry. In doing so, they reduce consumption of more expensive nonstaple foods. However, nonstaple foods have higher micronutrient content, so further reducing the already low amounts of these foods that the poor consume will increase micronutrient malnutrition. In those societies where preference is given to males in the intrahousehold distribution of nonstaple foods, women and children are likely to be most negatively affected. Biofortification can help make up for the expected micronutrient shortfall, especially among poor consumers.

Climate change may also have an impact on the nutritional quality of the crop itself. While rising CO_2 levels may accelerate plant growth initially, some studies suggests that the nutrient content of crops is likely to decline, especially as plants adapt to higher atmospheric CO_2 levels. One review found a decline in micronutrient content. Overall, the evidence on effects of climate change on nutritional quality is mixed. Further research is needed as there is variability in how plants will respond to the different effects of climate change. Biofortification could offer a solution in those instances where crop nutritional quality will decline.

Sources: Fábio M. DaMatta, Adriana Grandis , Bruna C. Arenque , Marcos S. Buckeridge. "Impacts of Climate Changes on Crop Physiology and Food Quality," *Food Research International* 43, no. 7 (2010): 1814–1823; I. Loladze, "Rising Atmospheric CO2 and Human Nutrition: Toward Globally Imbalanced Plant Stoichiometry?" *Trends in Ecology & Evolution* 17 (2002): 457–461; Gerald C. Nelson, Mark W. Rosegrant, Amanda Palazzo, Ian Gray, Christina Ingersoll, Richard Robertson, Simla Tokgoz, Tingju Zhu, Timothy B. Sulser, Claudia Ringler, Siwa Msangi, and Liangzhi You, *Food security, farming, and climate change to 2050* (Washington, DC: IFPRI, 2010).

zinc in 12 countries in Africa, Asia, and Latin America found that biofortification could be highly cost-effective, especially in Asia and Africa.[8] Fourth, because this strategy relies on foods people already eat habitually, it is sustainable. Seeds, roots, and tubers can usually be saved by farmers and shared with others in their communities. Once the high-nutrition trait is bred into the crops, it is fixed, and the biofortified crops can be grown to deliver better nutrition year after year—without recurring costs.

Biofortification: Limitations and Challenges

Promising as it is, biofortification faces limitations and challenges. First, biofortification requires a paradigm shift. Agricultural scientists need to add nutrition objectives to their breeding programs, in addition to standard goals such as productivity and disease resistance. Plant breeders must then work closely with nutritionists to develop breeding targets for nutrients. Nutritionists and health professionals also need to accommodate agriculture-based approaches in their toolbox along with clinical interventions. Agricultural science and nutrition are compartmentalized disciplines that must integrate for biofortification to succeed.

Second, biofortification will be widely adopted only when proponents show these new foods improve nutrition. Most biofortified crops are still in the development pipeline. However, one biofortified staple food crop that has been successfully released is the orange (or orange-fleshed) sweet potato (OSP; see Box 3). As other crops follow, nutritionists will be able to build a body of evidence that biofortification is a viable agriculture-based intervention to improve nutrition.

Third, the amounts of nutrients that can be bred into these crops are generally much lower than can be provided through fortification and supplementation. However, by providing 30–50 percent of the daily nutrient requirement, biofortified crops can significantly improve public health in countries where hidden hunger is widespread (poor consumers in most cases will already be consuming 50 percent of requirements). Transgenic approaches can be used to improve the nutrient content of crops where natural variation in germplasm is limited. However, transgenic crops also face more regulatory hurdles compared to their conventionally bred counterparts. Whether conventionally or transgenically bred, biofortified crops should shift significant numbers of people that are receiving a little less than their estimated nutrient requirement, into a state of nutritional adequacy, for that nutrient.

Fourth, nutritionists now focus on the -9-to-24-month age group, when micronutrients are crucial for healthy development. Infants consume relatively low amounts of staple foods and yet have relatively higher micronutrient requirements, making biofortification's contribution to micronutrient adequacy in this group limited. There are exceptions; due to the particularly high vitamin A content of many OSP varieties, regular consumption of these by the mother could contribute substantially to vitamin A intakes of breastfed children 6–23 months of age. In Mozambique and Uganda, a HarvestPlus project also showed substantially improved vitamin A intakes from OSP in children aged 6–35 months (see Box 3).

However, researchers need to better understand biofortfication's potential impact on the -9-to-24-month age group through the mother's micronutrient status *going into* pregnancy, when her micronutrient requirements substantially increase. This micronutrient status could be better for mothers who have consumed biofortified crops from adolescence, or even earlier.

Institutionalizing Biofortification as a Sustainable Strategy to Address Hidden Hunger

While substantial progress has been made to date in breeding and testing biofortified food crops, agricultural donors have been the primary investors in biofortification research. Health and nutrition donors and decisionmakers must also be convinced that biofortification is worthy of investment. To this end, researchers must provide more scientific evidence of biofortfied foods' effectiveness in improving micronutrient status as measured under controlled conditions and through pilot dissemination efforts. Building this evidence base for product effectiveness will be crucial in convincing nutrition and public health policymakers and practitioners that biofortification is a viable strategy to improve nutrition.

Box 3 — Orange Sweet Potato: An Emerging Success Story

Varieties of orange sweet potato (OSP) with very high levels of vitamin A have been conventionally bred to combat vitamin A deficiency in regions of Africa where sweet potato is a staple food. Studies have shown OSP improves the vitamin A status in young African children. Beginning in 2007, pilot programs successfully disseminated OSP to more than 24,000 households in Uganda and Mozambique. The programs cultivated areas devoted to OSP production, and vitamin A intakes for young children, older children, and women increased significantly as a result of the project intervention.

Sources: HarvestPlus, *Disseminating Orange-Fleshed Sweet Potato: Findings from a HarvestPlus Project in Mozambique and Uganda* (Washington, DC: HarvestPlus, 2010); J. W. Low, M. Arimond, N. Osman, B. Cunguara, F. Zano, and D. Tschirley, "A Food-Based Approach Introducing Orange-Fleshed Sweet Potatoes Increased Vitamin A Intake and Serum Retinol Concentrations in Young Children in Rural Mozambique," *Journal of Nutrition*, 137, no.5 (2007): 1320–1327.

Concurrently, increasing the efficiency of breeding biofortified crop varieties will be important in bringing agricultural decisionmakers on board. This requires a better understanding of the key plant genes that (1) drive translocation of minerals from soils through the plant to seeds, and (2) are responsible for synthesis of vitamins in seeds. Moreover, research strategies that can leverage larger impacts should be supported. For example, most biofortification breeding efforts are directed at increasing the levels of selected minerals and vitamins. There is promising evidence, however, that breeding for prebiotics (nondigestible food ingredients that have health benefits) could greatly improve absorption and use of micronutrients.[9]

Biofortification has distinct advantages that can complement other traditional approaches to improve nutrition. As more evidence emerges that nutritionally enhanced staple foods can alleviate crucial micronutrient deficiencies cost-effectively, biofortification will emerge as an agriculture-based strategy that helps to meet the nutritional needs of malnourished communities throughout the world.

NOTES

1. World Health Organization and Food and Agriculture Organization of the United Nations, *Guidelines on Food Fortification with Micronutrients*, ed. L. Allen, B. de Benoist, O. Dary, and R. Hurrell (Geneva: World Health Organization, 2006).
2. John Hoddinott, John A. Maluccio, Jere R. Behrman, Rafael Flores, and Reynaldo Martorell, "Effect of a Nutrition Intervention during Early Childhood on Economic Productivity in Guatemalan Adults," *Lancet* 371 (2008): 411–16.
3. See Copenhagen Consensus 2008: Results, http://www.copenhagenconsensus.com/Home.aspx and Copenhagen Consensus, "Micronutrient Fortification and Biofortification," http://www.copenhagenconsensus.com/Default.aspx?ID=1456.
4. Howarth E. Bouis and Ross M. Welch, "Biofortification—a Sustainable Agricultural Strategy for Reducing Micronutrient Malnutrition in the Global South." *Crop Science* 50, no.2 (2010): S-1–S-13.
5. K. H. Brown, "The Importance of Dietary Quality versus Quantity for Weanlings in Less Developed Countries: A Framework of Discussion," *Food and Nutrition Bulletin* 13 (1991): 86–92.
6. Siwa Msangi, Timothy B. Sulser, Andrew Bouis, Daniel Hawes, and Miroslav Batka, *Integrated Economic Modeling of Global and Regional Micronutrient Security*, HarvestPlus Working Paper 5 (Washington, DC: HarvestPlus, 2010).
7. See Copenhagen Consensus 2008: Results, http://www.copenhagenconsensus.com/Home.aspx and Copenhagen Consensus, "Micronutrient Fortification and Biofortification," http://www.copenhagenconsensus.com/Default.aspx?ID=1456.
8. J.V. Meenakshi, Nancy L. Johnson, Victor M. Manyong, Hugo DeGroote, Josyline Javelosa, David R. Yanggen, Firdousi Naher, Carolina Gonzalez, James García, and Erika Meng, "How Cost-Effective is Biofortification in Combating Micronutrient Malnutrition? An *Ex Ante* Assessment," *World Development* 38, no. 1 (2010): 64–75.
9. Howarth E. Bouis and Ross M. Welch.,"Biofortification—a Sustainable Agricultural Strategy for Reducing Micronutrient Malnutrition in the Global South," *Crop Science* 50, no. 2 (2010): S-1–S-13.

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