Biofortification

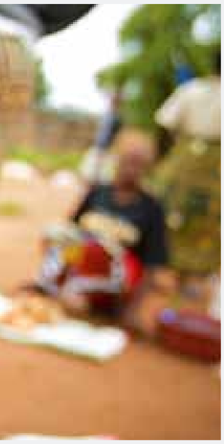
Lasting solutions to micronutrient malnutrition and world hunger

by John Morgan

Left: Sweet potato biofortified with vitamin A. *Photo by Y. Islam (HarvestPlus).* Above: Child eating an orange-fleshed sweet potato. *Photo courtesy of the Gates Foundation.*

In a modern world where the West is afflicted by the diseases of excess nutrition, much of the rest of the globe suffers at the hands of hunger. It ranks as the world's top health risk, taking the lives of more people annually than the combined effects of AIDs, malaria, and tuberculosis. One in seven is affected by hunger, and it kills five million children a year, particularly in Asia, Africa, and the Pacific region where half of the world's population lives.

A troubling component of hunger is micronutrient deficiency. Called "hidden hunger," it stems from the lack of essential dietary vitamins and minerals such as iron, zinc, iodine, and vitamin A, causing a variety of diseases and other maladies such as blindness, brain damage, and death.



But the problem isn't immune to solutions. Over the past 20 years, an ingenious approach has sought to affect micronutrient malnutrition at its root cause, with the crop plants themselves. In 1993, a small group of researchers concerned about hunger wondered if they could breed plants selectively such that they would provide more of these critical micronutrients.

The answer, after 20 years of hard work, is yes. In fact, it is possible to increase nutrition *and* yields through selective breeding. Called *biofortification*, this program is thriving as a part of the puzzle that seeks to have a real impact on the world's number one killer.

"I tell everybody, 'this isn't Einsteinian thought. This is absolutely common sense! If you want nutrients, and your primary supplier of nutrients is agriculture, well, let's get agriculture to do it. And let's have support systems in place to see that it gets done,'" says ASA, CSSA, and SSSA member Ross Welch, an expert in plant physiology with the USDA-ARS's Robert Holley Research Center for Agriculture and Health at Cornell University. Recently retired, Welch is an original member of the group that established biofortification as a viable tool for counteracting malnutrition.

Welch stresses that the key to biofortification is both quality *and* quantity versus the traditional focus of breeding for higher yields or pest resistance. He adds that while the Green Revolution provided some relief to world hunger by feeding people rice, wheat, and maize, the shortcoming with this effort is that these foods are traditionally very low in nutritional value. As such, people in need are certainly getting calories but not much more in terms of essential nutrients; thus, the hidden hunger.

"As eaten, [rice, wheat, and maize] provided two of the 42 nutrients we require. They provided carbohydrates for calories and some protein and very little other nutrients. And they displaced nutrient rich cropping systems," Welch explains. "[The Green Revolution] saved literally millions, if not billions, of people from starva-

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From top to bottom: Biofortified sweet potato at CIAT's headquarters in Colombia (*photo by Neil Palmer/CIAT*), women prepare fufu with yellow cassava in Nigeria (*photo by Y. Islam/HarvestPlus*), and yellow cassava and gari (cassava flour) (*photo by Peter Kulakow/IITA*).

tion, but it had these unforeseen consequences, like a huge increase in micronutrient malnutrition, especially in south Asia and other developing nations."

Biofortification is a departure from the Green Revolution. Welch and his colleagues sought to selectively breed crop plants that would be significantly higher in micronutrients than their predecessors, while also increasing yields. Today this means focusing on high-iron pearl millet and beans; high-zinc rice and wheat; and high–vitamin A maize, cassava, and sweet potato. In all cases, these crops have not only been successful, but there are new strains in the pipeline that may double the micronutrient levels already achieved. As such, biofortification is making it possible for a child in Africa to get her daily value of vitamin A via orange sweet potato—a concept that was unimaginable 20 years ago.

Orange maize in Zambia. *Photo courtesy of CIMMYT.*

Persistence Pays when Shifting Paradigms

But today's successes must be understood in the context of how hard it was to get to this point. While the concept of biofortification seems like it would receive instant support, getting buy-in from potential partners and sponsors was very tough. People certainly care about world hunger, and those in developed countries give significant amounts of money to nourishment efforts. But a paradigm for understanding malnourishment and working to mitigate it was well established, and the idea of biofortification simply didn't fit the mold initially.

The issue was that biofortification represented a new way of looking at hunger. Traditionally, nutritionists looked at it as a nutrition problem, and the agriculture community perceived it as a yield problem. Biofortification was asking both communities—and their related benefactors—to look at the problem holistically, or as a "systems problem," Welch says—one that takes into account the related issues of how plants take up nutrients, how it is possible to select for those desirable nutrients, and how humans ingest and process those plants and nutrients while being mindful of the many issues involved when introducing new crops to farming families that are accustomed to what's been done traditionally.

In the late 1990s, the group took the story on the road, giving presentations about the concept around the world. Very active in this tour was another early partner in the project, plant scientist Robin Graham of the University of Adelaide. The idea they pitched included early research showing that improving the zinc content of wheat seeds was not only useful for delivering zinc to humans, but also improved yields because nearly 50% of the earth's cultivated soils are zinc deficient. It turned out that wheat enjoys having more zinc for growth as much as the humans who consume it.

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Welch, Graham, and their plant-breeding cooperators proceeded with preliminary research into germplasm screening, which demonstrated that through conventional breeding, it was possible to produce crops that were simultaneously both high in nutrients and high yielding. The group had also progressed into early crosses with beans, cassava, maize, rice, and wheat, and the results of this foundational work were published in 2001. Eventually, the fledgling group received funding from the Danish International Development Agency (DANIDA), and things started moving.

"It was a hard sell. I think one of the reasons it was a hard sell was because you're trying to bring two different sectors together that aren't used to working together," recalls Howarth Bouis, an agricultural economist and another founding member of the initial biofortification team.

The present-day incarnation of that small team is HarvestPlus, directed by Bouis. A Herculean effort with more than 200 research and implementation partners from more than 40 countries, HarvestPlus has an annual budget in the tens of millions of dollars with major funding from the Bill and Melinda Gates Foundation, UKAID, and CIDA (the Canadian International Development Agency); with further contributions from the World Bank, USAID, and others. Indeed, HarvestPlus and biofortification are nearly synonymous; in fact, the term "biofortification" was coined at a 2001 meeting by Steve Beebe, head of the HarvestPlus bean program. (Editor's note: a superb summary article of biofortification by Bouis and Welch appeared in the March–April 2010 issue of *Crop Science*).

HarvestPlus is part of the Consultative Group on International Agricultural Research (CGIAR) Program on Agriculture for Nutrition and Health and is coordinated by the International Center for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI). After 20 years since beginning the biofortification program, HarvestPlus is now entering Phase III of the project: getting seeds to farmers and, more importantly, improving the health of people who eat the resulting plant foods.

"By the end of 2013, approximately one million target farming household members in target countries will have access to [and/or] consume biofortified crops," says Wolfgang Pfeiffer, deputy director of operations for HarvestPlus.

Biofortification: A Marriage of Nutrition and Agriculture

But while funding was certainly essential for this new way of

From top to bottom: A maize field at a research station in Mozambique (*photo by Yassir Islam/HarvestPlus*), biofortified maize (*photo by choconancy1/Flickr*), tortillas made with biofortified maize (*photo by CIMMYT*), and girl enjoying yellow cassava (*photo by CIAT*).

thinking about curtailing hunger, another early hurdle was to define and navigate what would essentially become a new branch of science—a branch stemming from the "grafting" of agriculture and nutrition. All of this started with basic research into better understanding how nutrients are metabolized by plants and, in turn, how humans process those plants after consuming them.

One of the many threads of research included the work of ASA and CSSA member Mike Grusak, a USDA-ARS plant physiologist and professor of pediatrics at the Baylor College of Medicine. Grusak also serves as the technical editor of CSSA's Biomedical, Health-Beneficial, and Nutritionally Enhanced Plants division (C9) and is a representative to the CSSA board of directors. He initiated some of the basic science studies looking at how transport proteins move iron or zinc through plants in order to better understand the movement of these metals from roots into the leaves and from the leaves into the seeds.

"What we were trying to do at the time was to identify some of the genes involved with these processes so that we could then identify molecular markers the breeders could use for conventional breeding," Grusak explains.

This research illustrates the complicated yet coordinated nature of the efforts contributing to the success of biofortification. Grusak stresses that while he was uncovering the many facets of the process of identifying genetic markers, breeder colleagues were working hard to put that knowledge to work.

Impact on the Ground: Delivering Biofortified Crops to Farmers Field

Today the work has shifted decidedly from breeding to getting the seeds in the hands of farmers. Bouis explains that the process for selectively breeding for a biofortified crop takes multiple years, which includes significant participation by scientists in target regions. The process includes a rigorous independent approval process that, in turn, takes a couple more years before a crop is finally released into the seed pipeline of a given country. Then come the complicated issues involved with introducing a brand new seed

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strain to farmers whose livelihoods depend on the small tracts of soil around their homes. Indeed, during a recent visit to Africa, Mike Grusak found himself face to face with the harsh realities of these farmers.

“I’d been to Africa before, but with this opportunity, I really got out into the small villages and farmers’ fields and had a chance to see the situation with the farmers and the production problems they’re having and soil fertility problems they’re having,” Grusak recounts. “It’s potentially a life or death situation. They don’t have the luxury of just saying, ‘O.K., I’ve got an empty field over there, so let me try it.’ They don’t have empty fields. Every square meter was planted with something. And they’re still barely scraping out an existence.”

The soils, Grusak explains, are so significantly less fertile in these regions that a one-acre bean plot planted in Rwanda yields 90% less compared with an identical plot planted in Wisconsin, for example. Indeed, he recalls the pivotal point earlier in his career at which he contemplated the potential impacts that the basic science in his lab could have on lives thousands of miles away.

“I realized I could publish this work, and we can come up with this good science, but if I don’t get a breeder to use and translate this information in a way that brings out a new cultivar that gets to the farmer and people are eating it, then what have I done? All I’ve done is just generated the knowledge,” he recounts. “Not that that’s a bad thing. But it wasn’t as fulfilling for me as starting to work with breeders.”

The efforts have paid off. Early effectiveness trials indicate that biofortified crops are making a significant difference. Bouis reports that a recent HarvestPlus pilot project of 24,000 households in Mozambique and Uganda showed a 70–100% increase in vitamin A in preschool children and mothers as a result of consuming biofortified orange sweet potato.

“One of the things that I really like is that we’re able to link this upstream research to finally having impact on the ground,” Bouis says.

Thus, the story of biofortification is a wonderful example of research happening in the laboratories of the developed world that is making tangible differences in the developing world. As Ross Welch stresses, world hunger is a complex systems problem that requires research into how plants metabolize nutrients, how humans process those nutrients, how to breed selectively for improved nutrition, and how to actually affect change in struggling communities worldwide—all areas with more questions to be asked and answers to be found. And in the end, the success of countering world hunger will depend, in part, on holistic solutions such as biofortification.

“I think we will be successful,” Bouis concludes. “We’ve made a tremendous amount of progress, but I’d say it’s another 10 years from now before you say, ‘O.K., it really was a big success. It really worked.’ ”

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