Biofortified crops

Dr. Brian Hilton

Dr. Brian Hilton researched and promoted biofortified crops for over 20 years. Brian worked as part of a team testing the first orange sweet potato varieties in Mozambique in 2002. He has 25 years of experience working with farmers in Indonesia, Chad and Mozambique. Brian now works with World Vision Australia, coordinating World Vision's biofortification networks with CGIAR institutions that are breeding biofortified crops and with HarvestPlus whose mandate is to reach 1 billion people with biofortified foods by 2030.

Introduction: Micronutrient Deficiencies

An estimated two billion or more people suffer from 'hidden hunger', the deprivation of micronutrients necessary for growth and good health. In young children, micronutrient deficiency causes malnutrition that results in permanent cognitive damage. Malnourished children never catch up with their better-nourished peers resulting in a lifetime of poorer health and lower productivity. That's a big worry.

The most common micronutrient deficiency is iron. More than 30% of the world's population—about two billion people—are anaemic (a condition symptomatic of iron deficiency). Anaemia contributes to 20% of maternal deaths (WHO 2017a). Another common micronutrient deficiency is vitamin A deficiency, a common cause of preventable blindness and a risk factor for increased severity of infectious disease and mortality. An estimated 250 million children are deficient in vitamin A and each year, an estimated 250,000 to 500,000 children go blind because of it. More than half of these children die within one year after losing their sight (WHO 2017b). Zinc deficiency is another concern; more than 116,000 children die each year because of it, and an estimated 17% of the global population is at risk of inadequate zinc intake (HarvestPlus 2017).

Scientists and governments have addressed micronutrient deficiencies with vitamin and mineral supplementation programs, and with food fortification programs where millers and processors put vitamins and minerals into food. These programs have been cheap and effective, but there can be coverage gaps. Food fortification programs have decent coverage in urban areas where people purchase processed fortified food, but they are less effective in rural areas where families don't purchase much food.

Diet diversity is the ideal mechanism for addressing micronutrient deficiencies, but is very difficult to achieve in the countries we work in because of poverty, long dry seasons, or tiny land areas. For example, haem iron (derived from animal sources) is easier to absorb than non-haem iron (plant based). This is problematic, because the poorer the population, the less meat is eaten and the less diverse the diet. For all these reasons, most favour a combined approach of vitamin supplementation, fortification, diet diversity and biofortification, rather than using a single approach to address micronutrient deficiency.

Biofortification

Figure 1. Zambian farmer showing provitamin A hybrid maize on left vs conventional hybrid on right. *Source: Brian Hilton*

Biofortification is the process of breeding crops for increased nutritional content or increased nutrient density. In economic crisis, poor people tend to cut down on purchases of expensive non-staples, such as meat, fruit and vegetables (Bouis 2011). This makes staples like wheat, rice, maize, beans, and cassava good targets of biofortification programs, because we know the poorest and most malnourished will be eating these foods even in hard times.

Conventional breeders have used two pathways to biofortify crops: 1) finding varieties of plants that exhibit β carotene pigments and 2) finding strong roots that are more efficient in taking up iron and zinc. When seeking to address vitamin A deficiencies, breeders cross with varieties expressing orange plant pigments (β carotene) such as those found in Indian corn or in orange sweet potatoes. In selecting for stronger roots, plant breeders can screen varieties for high iron and zinc content and then cross those varieties with plants having high yield characteristics. When breeders investigate why the former crops accumulate more iron and zinc, they usually find that the roots are better able to extract minerals from the soil. Plants improve their ability to extract nutrients by pumping organic acids into the rhizophere to dissolve and increase the uptake of iron and zinc by plant roots. Because of the similarity between cations Fe^{2+} and Zn^{2+}, crops that are biofortified for zinc are often also biofortified for iron (though to a lesser degree) and vice versa. High iron beans being promoted in Burundi are 70% higher in iron, but also 40% higher in zinc than normal beans. The high zinc wheat in Pakistan is also higher in iron.

That brings me to standards. When looking at micronutrient content in a crop, one can often see a large range that is further widened by different soil types, locations and climates. HarvestPlus (http://www.harvestplus.org/node/553) is an international organization in the CGIAR system that sets the target standards for biofortified crops (that is, the increase in concentration of a particular nutrient must be above a certain threshold to meet the target standards). For example, the baseline iron content of beans is 50 ppm, with a target of 94 ppm for biofortified beans. A couple of years ago I was enthusiastic about supporting a project to promote a new higher-iron bean in one African country, when members of HarvestPlus gently reminded me that the bean variety in my proposal had only 63 ppm iron and did not meet their targets for biofortification. It was a good point. To really make a difference in nutrition, biofortified crops need to be much higher in micronutrients—usually over 70% higher.

Crop breeding is a difficult job. Breeders select for many different traits, including high yield, pest resistance, drought tolerance, grain size and taste. These scientists are often under intense pressure, especially to increase drought tolerance of crops. Adding an additional parameter like nutrition increases their work load exponentially, so you can imagine that not every breeder is excited by this new challenge. In my experience, the women scientists that I have worked with are much more supportive of biofortification than are the men, because women better understand the importance of nutrition. By contrast, some breeders, when presented with the catalogue of advanced lines from the CGIAR centres, simply pick the highest yielders or biggest seeds without any thought to the nutrition. HarvestPlus is trying to change this by winning the hearts and minds of plant breeders in this great debate, through workshops, conferences and support for national breeding programs testing biofortified crops.

Biofortification can increase nutrient levels enough to improve human nutrition without reducing yield. I work mostly in very poor countries such as Burundi, Mozambique, Bangladesh, and East Timor, where there haven't been many new varieties released in recent times. In Burundi, new high iron beans are yielding 30% more than conventional beans because there have been so few previous releases. New orange sweet potato varieties are going to be released in Burundi in 2017; the last white sweet potato variety was released in 1988, so there is a good chance the new orange sweet potato varieties (that have been bred for characteristics that include higher yield) will yield much better than local white sweet potato. With hybrid orange provitamin A maize (high in β-carotene, the precursor of vitamin A) in southern Africa, yields are still lower compared to other hybrid maize, but the yield difference is decreasing over time as new provitamin A varieties come out.

Figure 2. Seven high iron bean types in Burundi, including both bush beans and pole beans. Different colours are preferred in different regions. *Source: Brian Hilton*

Biofortified Crops

Many biofortified crops have been released. I will go over a few of the really exciting ones (also see Table 1). The orange sweet potato, yellow cassava, and orange banana provide provitamin A. High zinc wheat and high zinc rice improve access to that important mineral and are promoted where zinc deficiency is high. High iron millet, high iron beans, and high iron lentils help prevent anaemia from iron deficiency. These crops have come out sporadically across Africa, South America, and Asia, as crop breeders and governments have become interested.

Seed from the varieties listed in Table 1 should be available from the respective national department of agriculture or from seed companies within that country. Many of these varieties are available, but not well-promoted. Note that several of these (banana, cassava and sweet potato) can be propagated vegetatively, resulting in clones that retain the high-nutrient status of the original plants.

For a more extensive list of biofortified staple crops, visit http://www.harvestplus.org/sites/default/files/publications/HarvestPlus_BiofortifiedCropMap_2016.pdf (http://www.harvestplus.org/sites/default/files/publications/HarvestPlus_BiofortifiedCropMap_2016.pdf)

Table 1. Biofortified crops that have been or soon will be released. (The crops listed here are all conventionally bred).

Crop	Countries released	Countries testing and close to release	Propagation strategy	Can farmers save their own seed
Provitamin A maize	Zambia, DRC, Zimbabwe	Many	Seed	No, best to buy new seed yearly
Orange sweet potato	Many		Vegetative (cuttings)	Yes (cuttings)
High zinc rice	India, Bangladesh	At early stages in many Asian countries	Seed	Yes
High zinc wheat	Pakistan	Bangladesh, Afghanistan	Seed	Yes
Yellow cassava	Nigeria, DRC	Ghana, Sierra Leone	Vegetative (cuttings)	Yes (cuttings)
High iron beans	Uganda, Rwanda, Burundi, Mexico	Many countries in East and Southern Africa	Seed	Yes
High iron lentils	Nepal, Bangladesh		Seed	Yes
High iron pearl millet	India	Pakistan, West Africa	Seed	Yes

Most row crops seem to be self-pollinated or only partly cross-pollinated, making it easier for farmers to maintain their varieties through seed-saving. Farmers in our programs are saving wheat, rice, peanuts, beans, sorghum, cowpea, pigeon pea, soybean etc. Wheat is mostly self-pollinated before the flowers open; some could be cross pollinated by wind, but the pollen is so heavy it usually doesn't travel far. Sorghum is only about 5% out-crossed, so that seed maintains its purity for a number of years. Still, for the seed-propagated crops in Table 1, the best way to maintain the high-nutrient trait in each variety is to regularly purchase seed from local suppliers. The investment is usually offset by the higher returns of using quality seed. Even if a variety is known to be self-pollinated, farmers should probably purchase new seed every four or five years. This reduces risks of contamination by seed-transmitted viruses and pollen from non-biofortified varieties; cross-pollinated crops are more susceptible to contamination than self-pollinating crops, but outcrossing (often through insect activity) occurs even in self-pollinated crops. Provitamin A maize is a hybrid and only available from seed companies; it is best to buy hybrid maize seed every year, because cross pollination and breakdown of the variety occurs in subsequent plantings.

Biofortified crops can have visible or invisible traits. Provitamin A maize is visibly orange, so farmers can identify what they have. The colour of the maize nsima (porridge) is also a light orange; it is a pleasing color, but most cultures will take a while to get used to it. Some sort of behaviour change may be needed. In Mozambique, I could easily follow the spread of orange sweet potatoes into new villages because the traits were visible.

Crops higher in minerals have invisible traits—it is not obvious that these crops are more nutritious. These crops with invisible traits can scale up very fast, but farmers growing them are often not aware that they are more nutritious. Farmers may instead grow them for higher yield. I call this 'nutrition by stealth.' I personally like to see biofortified crop scale-ups accompanied by nutrition projects where mothers and fathers can gain knowledge about nutrition. Nutritional knowledge is truly empowering.

Measuring Impact

The Biofortification Priority Index (BPI) assesses impacts for seven biofortified crops across 127 countries. The impacts are estimated by the number of people growing and consuming the crop in each country, along with the severity of micronutrient deficiency that the crop is addressing (Asare-Marfo *et al.* 2013).

The 2016 Global Nutrition Report (p. 18) notes that returns on investment in nutritional interventions are 16 times what was invested, because the impacts on mothers and young children are multiplied over their lifetimes. I have been doing agriculture projects for 30 years and have yet to find projects with more impact per dollar than the scale up of biofortified crops. Consider the new high zinc (and high iron) wheat in Pakistan called Zincol 2016 (Figure 3). 200 million bread-eaters live in Pakistan; you can imagine the impact that this crop could have on a population deficient in iron and zinc. This high zinc wheat would rank high on the BPI.

Figure 3. Zincol 2016 wheat in Pakistan. Brian Hilton with HarvestPlus Wheat Breeder Yacub Mujadin. *Source: Brian Hilton*

Genetic Engineering

As genetic engineering becomes more widely accepted, more and better biofortified crops will become available. Genetic engineering involves a process of inserting DNA into a plant. Conventional breeding (crossing of two varieties) requires many generations of crossing. Even if the desired gene has been identified in a wild variety of a crop plant within the same species, there is no guarantee that a breeder will be able to bring it over to the domesticated crop by crossing. Genetic engineering offers a faster and more direct approach for bringing that gene across. Genetic modification among plants of the same species is called cisgenisis. Breeders can also introduce new genes in plants by transferring genes from other species; this is called transgenesis.

An example of a transgenic crop is Golden Rice (http://www.goldenrice.org/Content2-How/how1_sci.php) coming out in Bangladesh and the Philippines. Two genes, one from a daffodil and the other from a soil bacterium, have been introduced to enable the rice to synthesize β-carotene in the grain. This is exciting for nutritionists; micronutrient deficiencies are life-threatening in the Philippines, and genetic modification (GM) both increases the range of crops that can be biofortified and reduces the time needed for national breeding programs to release these crops. GM also offers scientists more pathways to biofortify crops. The inserted genes in golden rice activate the mechanism for β-carotene synthesis in the grain. The inserted genes in (forthcoming) high iron rice turn off the plant's mechanism for iron satiation, so that the rice plant is always trying to take up more iron.

After golden rice, high iron rice and high iron wheat will be the next generation of GM biofortified crops; in fact, these crops are at advanced stages in the pipeline. What will delay them in most parts of the world are national government policies regulating the use of GM crops. Transgenesis is a concern for some, who worry about unintended food safety issues and natural crossing of genetically modified crops into conventional crops and wild relatives. Concern about safety of transgenic crops, however, needs to be balanced against the good that those crops could produce in the extremely poor target populations. Herein lies another great debate, about which everyone seems to have a strong opinion. One opinion not generally heard in the debates is that of the malnourished poor who would benefit most from these crops.

[Editors: In keeping with our areas of strength, ECHO seed resources are focused on non-GMO OPVs, primarily of underutilized food plants.]

Conclusion

The list of available biofortified crops is steadily increasing. If you are promoting crops such as beans or lentils, the new high iron biofortified varieties could be available in your country. I use biofortified crops as a focal point to get donors to invest in integrated agriculture and nutrition projects.

Figure 4. Orange sweet potatoes have been introduced into children's diets in Mozambique. *Source: Brian Hilton*

In my early career I was interested in helping farmers in Chad and Mozambique obtain high yields, increase income and get out of poverty. These farmers were mostly entrepreneurial and mostly men. To be sure, those farmers started out very poor and a lot of progress was made. However, now I go deeper into the community and seek families with malnourished children, the types of farmers that do not often show up at community meetings. I work with others to improve their nutritional knowledge and to help mothers increase their skill in child care and feeding practices. In many respects this has been difficult, but as the Global Nutrition Report states, reaching these farmers and helping their children recover from malnutrition can have huge and long-lasting impacts. Promoting biofortified crops can be an important part of improving nutrition.

References

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