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# CHAPTER 17

## THE WAY FORWARD

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**ABSTRACT**

Biofortification has made more rapid progress in Africa than in Asia or Latin America. Thus, Africa provides an important first view into learning how to implement biofortification successfully, and its potential to improve nutrition and public health. The preceding articles have summarized the evidence available for biofortification, particularly in the African context. Over the last 15 years, biofortification research demonstrated broadly that:

- Conventional breeding can add extra nutrients in the crops without reducing yields.
- When consumed, the increase in nutrient levels can make a measurable and significant impact on human nutrition.
- Farmers are willing to grow biofortified crops and consumers to eat them.

While there remains more to be learned, the biofortification intervention should now be scaled up. To reach full potential, a global effort, with many partners – governments, researchers, private sector actors, civil society organizations, and farmers – is now required to bring more crops to more farmers, changing more lives.

**Key words:** Biofortification, Micronutrient Deficiency, Agriculture, Nutrition, Micronutrient Targets, HarvestPlus

## GLOBAL PROGRESS ON BIOFORTIFICATION

Biofortification has made more rapid progress in Africa than in Asia or Latin America. Thus, Africa provides an important first view into learning how to implement biofortification successfully, and its potential to improve nutrition and public health. Breeding progress has been more rapid with provitamin A crops (sweet potato, cassava, maize) than for iron and zinc crops. Thus far, provitamin A crops predominate in Africa, despite the fact that systematic breeding for iron beans (which are released in Africa) was initiated before the start of HarvestPlus – at CIAT under a precursor program, the CGIAR Micronutrient Project. Stakeholder interest in linking agriculture and nutrition, including importantly national governments, community development agencies, and donors, has been particularly keen in Africa.

HarvestPlus's delivery science work has focused on the eight target countries (Bangladesh, DR Congo, India, Nigeria, Pakistan, Rwanda, Uganda, and Zambia) where HarvestPlus and national partners are taking the lead. Target countries represent a variety of market environments for biofortified crops, from a primarily commercial private sector approach (India, Zambia), to various mixed public-private delivery systems (Bangladesh, Nigeria, Rwanda, Uganda), to primarily public or informal market systems (DR Congo). HarvestPlus also works closely with government-sponsored biofortification programs in Brazil, China, and India. Through the HarvestPlus Latin American and Caribbean (LAC) program, led by EMBRAPA, HarvestPlus provides technical assistance and support to government-driven biofortification programs in Bolivia, Colombia, Guatemala, Haiti, Nicaragua, and Panama and is exploring efforts in several additional countries. Increasingly, HarvestPlus is seeking partners to take the lead in scaling up biofortification in partnership countries, a growing list that includes Ghana, Kenya, Malawi, Tanzania, and Zimbabwe, and is expected to include several additional countries, such as Cambodia, Indonesia, Myanmar, Nepal, Sri Lanka, and Vietnam. Under the auspices of the Sweetpotato for Profit and Health Initiative, International Potato Center (CIP) and its partners are promoting orange sweet potato (OSP) in 19 sub-Saharan countries, emphasizing the use of an integrated agriculture-nutrition education approach. The wide variety of market environments in which biofortification is being implemented offer a rich platform for learning and ultimately for accelerating momentum towards scale.

Additionally, significant progress has already been made in integrating biofortification into regional and national policies. At the Second International Conference on Nutrition (ICN2) held in Rome in 2014, high-level government representatives from Bangladesh, Malawi, Nigeria, Pakistan, and Uganda highlighted the role of biofortification in their national strategies to end malnutrition by 2025. Panama and Colombia were among the first countries to include biofortification in their national food security plans. Biofortification has been included in national nutrition strategies in Nigeria, Rwanda, Ethiopia and Zambia. HarvestPlus is engaged with regional and global processes, like the African Union and NEPAD's Comprehensive Africa Agriculture Development Programme (CAADP) and the Scaling Up Nutrition (SUN) Movement, to ensure an enabling environment for biofortification. Inclusion of biofortification as an objective in CAADP and African Union (AU) policy documents will help to mainstream the technology in efforts to increase the food supply and improve agriculture research and technology dissemination and adoption. Indicators to track the production of biofortified crops ensure that progress can be monitored over time.

Efforts are underway to include biofortification in global standards and guidelines for food products and labeling, such as the Codex Alimentarius, the food standards-setting agency administered jointly by the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO), and recognized by the Sanitary and Phytosanitary Agreement (SPS) of the World Trade Organization (WTO) as its reference organization. These efforts are important to ensure the development and enforcement of biofortification standards, particularly as momentum builds and more players enter the field.

## LEARNING FROM THE GROWING EVIDENCE BASE

The preceding articles have summarized the evidence available for biofortification, focusing on the African context. Over the last 15 years, biofortification research has demonstrated broadly that:

- Conventional breeding can add extra nutrients in the crops without reducing yields.
- When the biofortified foods are consumed at current dietary levels, the increase in nutrient intake can make a measurable and significant impact on nutrition status.
- Farmers are willing to grow biofortified crops and consumers to eat them.

This evidence was developed as researchers carried out a series of activities along the impact pathway, classified into three phases of discovery, development, and delivery, described in detail in previous publications. As usual, as more evidence accumulates, more areas for further exploration emerge. This chapter summarizes the state of evidence along the impact pathway, indicating areas where further research and innovation is needed. We conclude with a vision of how to scale up biofortification over the next fifteen years, including the role of the HarvestPlus program as partners increasingly take on the work of delivering biofortified crops to the farmer, and how biofortification fits as a complement to other strategies to reduce micronutrient deficiency.

### Nutrition Groundwork, Bioavailability, and Efficacy for Impact

The early days of the biofortification program focused on preparing the groundwork for the introduction of biofortified crops. Nutritionists worked with plant breeders to establish nutritional breeding targets, based on food consumption patterns of target populations, estimated nutrient losses during storage and processing, and nutrient bioavailability, as discussed in chapter 1. These assumptions and the potential for given nutrient levels to affect nutrient intake and nutrition status have been validated through extensive research and reported in chapters 2-4.

As chapter 4 discusses, vitamin and mineral retention has been found largely within the bounds of the original assumptions. However, retention of vitamin A is much more

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complex to assess than retention of iron or zinc. Mineral retention is largely a function of processing, while vitamin A oxidizes and degrades over time. Research continues to assess best practices for processing and storing vitamin A food products applicable to the local context, particularly for puree made from orange sweet potato, gari made from vitamin A cassava, and maize meal made from vitamin A maize. Nutritionists are also collaborating with plant scientists to explore breeding for increased beta-cryptoxanthin (a component of provitamin A) in maize, which is thought to be more stable than beta-carotene.

Bioavailability and efficacy studies have tested the effects of biofortified crops when consumed. Vitamin A nutrition research found efficient conversions from provitamin A to retinol, and in most cases, more efficient than originally estimated. Efficacy studies have demonstrated that increasing provitamin A intake through consuming vitamin A-biofortified crops results in increased circulating beta-carotene, and has a moderate effect on vitamin A status, as measured by serum retinol. Consumption of orange maize specifically has been demonstrated to improve total body vitamin A stores as effectively as supplementation. It is now commonly accepted that vitamin A biofortified crops have the potential to improve vitamin A status in deficient populations, but additional research is needed, using other, more sensitive biochemical indicators, as well as functional indicators, to fully understand the health impact of consuming provitamin A biofortified foods.

Iron nutrition research demonstrated the efficacy of biofortified iron bean and iron pearl millet in improving the nutritional status of target populations. Iron studies also suggest that reducing absorption inhibitors, such as polyphenols and phytic acid, may further improve the efficacy of iron beans, in particular, and research in this area continues. Zinc studies have demonstrated that biofortified zinc wheat is bioavailable, and initial results of zinc wheat efficacy studies are promising. Because plasma zinc concentration, the biomarker widely used to estimate zinc status, has limitations in measuring changes in dietary zinc, foundational research to identify and test more sensitive biomarkers is underway. These biomarkers will be tested in the zinc rice efficacy trial.

As biofortification is adopted on a larger scale, there is a greater need to understand how multiple biofortified crops, consumed together, will affect nutrient intake, nutrition, and health. Multi-crop efficacy studies are underway, as is additional research to identify food matrices that optimize the biological impact of consuming biofortified foods. Although the expense would be high and logistics difficult, it will be important to measure the effects of long-term consumption of biofortified foods by women from adolescence, and on the micronutrient status of their infants during the first 1,000 days period, when the greatest impact is expected. Food-to-food fortification (combining foods to reduce anti-nutrients and improve bioavailability) is another area for further investigation, with preliminary work in this area being completed in Nigeria.

Based on this evidence, some nutrient targets have been revised, as discussed in chapter 1. For vitamin A and iron, targets have remained the same. For zinc crops, targets have been slightly increased from the original targets set. This change resulted from an expert consultation, convened by HarvestPlus in 2012, which concluded that the reference value

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for adult women used to set the original zinc breeding targets (1.86 mg Zn/day) should be revised upward (using a new reference intake of 2.5-2.9 mg Zn/day) to conform to current evidence.

**Crop Development: Challenges and Opportunities**

Simultaneously with nutrition research, plant breeders first screened existing crop varieties and accessions in global germplasm banks to identify genetic variation for particular micronutrient traits. Based on the genetic variation identified, a more narrow set of crop and micronutrient combinations emerged as most promising, forming the basis for crops discussed in this special issue. Limited variation for iron in wheat, maize, and rice means that the iron target level for these crops cannot be achieved through conventional breeding. Therefore, transgenic approaches are being explored through upstream research.

The crop development work has focused on conventionally breeding crops with the desired nutrient levels, in collaboration with international research institutes and national research partners in target countries, to submit the best-performing varieties to national governments for release. Crop development research demonstrated that increased nutrient levels could be bred into crops without compromising yield or other farmer-desired traits. Biofortification research has greatly expanded the field of knowledge on vitamin and mineral heritability and mechanisms of mineral loading in rice and wheat grain, in particular. Advances in genomic research, such as the identification of the alleles for lycopene epsilon cyclase (lycE) and beta-carotene hydroxylase 1 (crtRB1), which substantially increase the accumulation of beta-carotene in grain, have allowed plant breeders to use marker-assisted selection to more efficiently breed for the nutrient traits. Coupled with breakthroughs in high-throughput screening technologies, these advances reduce the time to market for current and future biofortified varieties. Breeding pipelines at CGIAR centers and national agricultural research systems (NARS) are filled, with next wave varieties to be released in the near future and even better varieties in development.

Despite these great successes, many challenges remain. The key challenge for biofortification is to move beyond a biofortification-focused breeding program, with funding specifically for biofortified crops, to mainstream the nutrient traits into all relevant crop pipelines and the best crop backgrounds being developed by CGIAR centers and NARS. While the CGIAR made a verbal, public commitment to do this, this commitment has not yet been fully realized, with the exception of sweet potato at CIP. The mainstreaming of biofortified traits in plant breeding programs is a necessary but not sufficient step in securing the sustainability of the biofortification strategy and for realizing its full potential as a cost-effective intervention. As discussed in chapter 14, biofortification is already considered a cost-effective solution to reducing micronutrient deficiency, but we expect the cost-effectiveness to further improve once biofortified traits are part of "business as usual" for plant breeders, and are considered non-negotiable traits, just like drought tolerance, productivity, and disease resistance.

Other challenges include integrating consideration of nutritional traits into national variety release policies, limited harmonization of seed systems in many regions which prevents varietal release from transcending borders, and breeding for nutrient content in

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combination with other, newly identified goals, such as increased dry matter content for tuber crops, and reduced carotenoid degradation in vitamin A crops. Funding, of course, is always a limiting factor, particularly for the secondary staples (like lentil, banana/plantain, sorghum, and Irish potato) that are not as well supported by international or national research systems as primary staple crops.

## DELIVERY, VALUE CHAIN INTEGRATION, AND SCALING UP

Delivery and scaling up – from seed multiplication, to extension to farmers, to creating demand and linking supply and demand through markets – has been an area of great learning. Orange sweet potato, the first biofortified crop to be grown at scale, has laid the foundation for success and supplied initial lessons to inform the delivery of other biofortified crops.

Throughout the 1990s, researchers were experimenting with the use of orange sweet potato to improve community nutrition. As early as 2004, the efficacy of consuming OSP to improve health had been demonstrated. From 2007 to 2009, HarvestPlus, the International Potato Center, and partners distributed orange sweet potato to farmers in Uganda and Mozambique, with the goal of understanding whether farmers would grow and eat OSP in real world conditions. The results of this study demonstrated unequivocally that biofortification could work – important evidence at a time when the lengthy processes of breeding and nutrition-testing for several other crops were ongoing. The early and continuing success of OSP has helped sustain the long-term interest of donors and other stakeholders. The OSP is the most successful example of biofortification – one that continues to yield groundbreaking findings, such as the effects of consuming OSP on reducing diarrhea incidence and duration in children under five. Because OSP is vegetatively propagated, scaling up has been more gradual than for seed propagated crops, but the process has also offered insight into how varieties diffuse through informal seed systems, creating small-scale business opportunities along the value chain.

HarvestPlus and its partners believe that biofortified crops can and must be delivered through the same seed system through which farmers typically obtain seed. This helps ensure long-term sustainability. As chapters 7-10 discuss, each country and seed system presents its own challenges for integrating biofortified crops. Many lessons, however, apply across the spectrum of seed and market systems, which in many African countries are weak regardless of whether the variety is biofortified or not. These include: multiplication of a sufficient amount of planting material is a crucial first step; integrating biofortified crops into sustainable value chains, as well as creating knowledge and demand, are essential to scaling; and partnerships are the future.

Without planting material, whether seed, vines, or stem cuttings, there are no biofortified crops, and biofortification cannot succeed. In these early years of implementation, HarvestPlus and its partners have focused on strengthening capacity and reducing risk to ensure that planting material is available for farmers. In most countries, HarvestPlus has worked closely with NARS to ensure that sufficient breeder and foundation seed is available for the production of certified seed by cooperatives or the private sector. In countries with robust private seed systems that reach smallholder farmers, private seed companies are a natural partner, which is particularly advantageous in crops where hybrid seeds predominate (for example Seed Co. in Zambia) and where seed companies operate regionally. In some cases, HarvestPlus has brokered agreements between seed companies and interested non-governmental organizations (NGOs) or government entities to ensure that there will be a market for the seed produced by the private sector, reducing the risk associated with that private sector investment. The government of Zambia now includes orange maize in its seed subsidy program for farmers, further increasing demand and reducing risk for private sector investment in seed production.

Demonstrations and trials have been key demand drivers at the farm level. Seed delivery, in most cases, has led with small promotional seed packs, which allow interested farmers to try the new product without taking on a great deal of risk in cultivating a crop for which the market has not yet been tested.

Particularly for vitamin A crops, which differ in color from their non-biofortified counterparts, farmers need to see and taste the yellow or orange product to believe. To improve acceptability of the color of vitamin A crops, HarvestPlus and its partners have used community opinion leaders and tasting fairs to pique interest. Nutrition messaging aimed at both men and women has also been key, and in general, involving women farmers has been key to increasing demand for biofortified crops. While many biofortified crops are acceptable to farmers and consumers without further information about their nutrition traits, nutrition information helps ensure that the biofortified foods are integrated into child diets.

Once planting material is available and farmers are interested, creating multi-stakeholder platforms – integrating private and public sector actors and interests – has been essential to scaling. In target countries, there has been rapid acceptance of biofortification by government entities, and national governments have proactively integrated it into their agriculture and nutrition policies. As African Union Commissioner Rhoda Peace Tumusiime stated at the Global Fortification Summit in Arusha in 2015, "…as Africans like to eat natural fresh foods, we may need more biofortification than fortification." Still, bureaucratic divisions between agriculture and health continue to present a challenge to the implementation of biofortification programs. If biofortification is embedded within agricultural programs, nutrition messaging may get short shrift. If it is marketed as a health program, however, farmers may not have access to the extension information or support they require to grow biofortified crops.

In countries where value chains are weak or informal, capacity building for actors along the value chain is needed, and, in some cases, also marketing tools and market analysis. While these activities are largely beyond the scope of HarvestPlus, partners in countries do this important strengthening work. In the medium term, a challenge remains targeting biofortified crops and foods to those most vulnerable to micronutrient deficiency. In the long-term, however, if biofortified crops gain a sufficiently high market share, targeting will not be necessary.

Looking ahead, there remains much to be learned about improving the cost-effectiveness of disseminating planting materials, combining biofortified crops with other complementary approaches to addressing micronutrient deficiency, and developing a wider range of food products. HarvestPlus will focus on these questions, among others, in the next five years.

**The Future Lies in Partnerships**

Looking further ahead, however, HarvestPlus believes that the future of biofortification lies in expanding and strengthening existing partnerships. Current examples begin to suggest the potential of this approach. As discussed in chapter 12, the HarvestPlus partnership with World Vision is a great example of what can be done to grow biofortification, and how, in a few short years, the integration of biofortified crops into programs can scale up far beyond initial expectations.

The World Food Programme's (WFP) Purchase for Progress program is very interested in local purchasing of biofortified crops, and partnerships are being developed in several countries. In Rwanda, local bean production is purchased and stored in WFP warehouses for later emergencies. As more partners begin to integrate biofortified crops into their own programming, HarvestPlus will continue to serve in a convening role, supporting partners through technical assistance, impact assessment, and the development of new tools, including adding a costing tool to the existing biofortification priority index.

The World Bank is now implementing a number of projects supporting biofortification, including the Global Agriculture and Food Security Project-awarded Multi-sectoral Food Security and Nutrition Project in Uganda, which is accelerating the scale-up of orange sweet potato and iron beans. As a convener of development partners, the Bank plays an important role in encouraging nutrition-sensitive agricultural approaches, including biofortification, in arena like the Global Donor Platform for Rural Development.

The strong commitment of key donors, such as the Bill & Melinda Gates Foundation, UKAid, Canada, and USAID, has not only enabled biofortification to reach its current level but has facilitated bringing new partners on board as these organizations encourage cross-sectoral partnerships and linkages between research and dissemination institutions. Their continued support will be critical to meet desired targets.

Training partners is critical to ensure that partners do not have to re-invent the wheel. The Sweetpotato for Profit and Health Initiative's efforts in developing comprehensive training materials and investment guides, coupled with technically focused working groups, is an example of how to strengthen a given community of practice.

It is important to explore partnerships appropriate for each country context and market system, focusing on long-term sustainability and market development. Scaling will require building new and expanding existing partnerships, maintaining engagement, and increasing partner capacity. Earlier phases of HarvestPlus focused on building an evidence base for biofortified crops, working with research partners to initiate studies on agronomic characteristics, nutritional efficacy, and consumer acceptance, investing specifically in upgrading equipment and training technical staff.

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As HarvestPlus shifted into delivery, it launched delivery partnerships with private seed companies, local and international NGOs, government extension programs, and school feeding programs. In its first years of delivery activities, HarvestPlus has developed in more than 100 delivery partners, trained thousands of extension staff on agronomic practices and nutrition messages for biofortification, and developed technical packages for partners to use in delivery programming.

Going forward, new and diverse partners will join the biofortification effort, including food processing companies and retailers, United Nations (UN) agencies, regional organizations, and innovative financing mechanisms and development banks. A focus is building capacity for evidence sharing and policymaking at national and regional levels, including through the SUN platform and CAADP nutrition initiatives. Downstream partners include private sector seed and food companies, from small start-up companies to large multinationals, who may also themselves undertake some upstream research in product development. Involving private sector seed companies to develop and test biofortified varieties shortens the time to market and lays the groundwork for the proof-of-concept stage. Food companies test biofortified crops for use in processed foods, evaluating mineral and vitamin retention for different types of processing.

**The Way Forward**

To reach its full potential, biofortification must be integrated as a core activity within a range of global institutions. This will require three critical elements.

- *Demand*: Both rural and urban consumers come to see the value of, and demand high mineral and vitamin content in their staple foods.
- *Policy*: A wide range of national and international public officials come to recognize the significant impact of biofortification for improving and sustaining public health, as well as the high economic return to investments in biofortification and the legitimacy conferred by international recognition (especially by standards bodies).
- *Supply*: Agricultural research entities, both public and private, come to recognize high mineral and vitamin content as core plant breeding objectives; varietal release committees make minimum levels of minerals and vitamins a requirement for approval for release (in addition to the standard agronomic traits, such as high yield).

Over the next five years, HarvestPlus and its partners will focus on expanding knowledge in key areas and developing lessons learned. Even as evidence to biofortification grows, more research is needed to support scaling out and learning about delivery of biofortified crops through a systematic approach, especially to assess effectiveness and delivery at scale through markets, and to mainstream biofortification into crop improvement research, nutrition and agriculture policy, and partner activities.

This research will be supported by the monitoring efforts and impact assessments HarvestPlus has already undertaken. For each country where HarvestPlus and its partners

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are delivering biofortified crops, a monitoring system is in place that collects information on a priority list of process, output, and outcome indicators. Country-specific Theories of Change are linked to a global Theory of Change, and indicators are regularly used to verify assumptions and guide delivery strategies. Impact is measured through effectiveness studies and impact assessments. The effectiveness study for OSP has been completed, one iron bean effectiveness study is underway, and a zinc wheat effectiveness study is planned. These studies are complemented by impact assessment studies for a wider range of countries, which measure adoption, diffusion, and dis-adoption rates; improve our understanding of factors and delivery strategies that facilitate adoption and consumption; and measure the micronutrient intake differential that can be attributed to biofortified crops (by comparing adopters and non-adopters). The combined results of the impact assessment, effectiveness, and efficacy studies, can help estimate nutrition impact of biofortification in terms of reduction in micronutrient deficiency. Evaluation of the impact assessment and effectiveness evidence will help inform scaling up of high impact and low cost delivery strategies.

Key to the sustainability of biofortification will be the role of CGIAR centers to develop additional waves of high-yielding, biofortified germplasm with higher nutrient content. These new lines will be distributed globally to NARS for further crossing, testing for adaptation to local conditions, and eventual release or direct commercialization. The CGIAR Centers and national breeding programs must eventually include biofortified traits within regular breeding programs.

As discussed above, partnerships will be essential to building momentum and success, and partnerships must be developed at all levels: community, national, regional, and global. Strategic advocacy, particularly at the national and regional level in Africa, will augment these efforts.

**Biofortification is About Changing Lives**

It can be easy to forget that behind the scientific evidence and the statistics of households and market share reached, there are real families and people whose lives are changing due to biofortified crops. Some of these lives, with their stories of healthier pregnancies and healthier children, are movingly chronicled in Roger Thurow's recent book, *The First 1,000 Days*. Mothers discuss the bright future of their babies raised on biofortified orange sweet potato and iron beans. They remark upon how quickly these babies have reached developmental milestones compared to their other, older children. Most of all, they ask for more crops, saying "if there are other crop varieties you are hiding, please bring them here." The evidence provided in this issue brings to light such stories, like the farmers who produce sweet potato vines in Uganda and have improved their livelihoods, farmers whose lives have changed due to the higher yielding iron beans, and children whose diarrheal episodes and duration reduced as a result of eating orange sweet potato. Beyond the tangible short-term effects, the long-term benefits from improved nutrition for the children cannot be overlooked, including the expected reduction in health burden as a result on the improvements in nutrition and health for beneficiary communities and nations. These real stories point to a social return on investment beyond what is currently recognized.

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As this special issue has demonstrated, the evidence for biofortification is significant and robust. A global effort, with many partners – governments, researchers, private sector actors, civil society organizations, and farmers – is now required to bring more crops to more farmers, changing more lives. Perhaps 25 years from now, a child will be surprised to learn that there was such a thing as white maize, and ask her grandmother if this is true. “Did you eat white maize as a little girl? Did it taste different than the orange maize that everyone grows now?,” she might ask. To make this vision a reality, we must recognize that we have come a great distance – and that more important work lies ahead.