

Scaling Up Delivery of Biofortified Staple Food Crops Globally: Paths to Nourishing Millions

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Abstract

Background: Micronutrient deficiencies affect over one quarter of the world's population. Biofortification is an evidence-based nutrition strategy that addresses some of the most common and preventable global micronutrient gaps and can help improve the health of millions of people. Since 2013, HarvestPlus and a consortium of collaborators have made impressive progress in the enrichment of staple crops with essential micronutrients through conventional plant breeding.

Objective: To review and highlight lessons learned from multiple large-scale delivery strategies used by HarvestPlus to scale up biofortification across different country and crop contexts.

Results: India has strong public and private sector pearl millet breeding programs and a robust commercial seed sector. To scale-up pearl millet, HarvestPlus established partnerships with public and private seed companies, which facilitated the rapid commercialization of products and engagement of farmers in delivery activities. In Nigeria, HarvestPlus stimulated the initial acceptance and popularization of vitamin A cassava using a host of creative approaches, including “crowding in” delivery partners, innovative promotional programs, and development of intermediate raw material for industry and novel food products. In Uganda, orange sweet potato (OSP) is a traditional subsistence crop. Due to this, and the lack of formal seed systems and markets, HarvestPlus established a network of partnerships with community-based nongovernmental organizations and vine multipliers to popularize and scale-up delivery of OSP.

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Conclusions: Impact of biofortification ultimately depends on the development of sustainable markets for biofortified seeds and products. Results illustrate the need for context-specific, innovative solutions to promote widespread adoption.

Keywords

biofortification, iron, India, vitamin A, Nigeria, Uganda

Introduction

More than 2 billion people worldwide do not get enough essential micronutrients in their diets to properly sustain health.¹ Micronutrient deficiencies lead to negative nutritional and health outcomes, including increased susceptibility to infectious diseases, poor physical growth, and diminished cognitive development. They also result in significant losses due to decreased productivity and economic potential later in life.² HarvestPlus and its partners lead the development and delivery of biofortified crops to improve micronutrient intake and the health status of millions of people living in low-income smallholder farm households globally.³

Biofortification

Biofortification is the process of increasing the amount of micronutrients in food crops during plant growth through conventional plant breeding or agronomic practices, such as fertilizer application.⁴ It is an agricultural-nutrition strategy that addresses the most common and preventable global micronutrient gaps between physiological needs and intake in populations that depend on staple food crops for nourishment and have limited or no access to alternative sources of micronutrients, including fortified foods, supplements, or more diverse diets.

Following an initial investment in crop breeding and the development of a streamlined breeding pipeline, the nutritional traits fixed in released biofortified varieties remain stable within the genetic pool for each crop. Breeders ensure that agronomic and other end-user quality and marketing traits are either maintained or improved. Additional costs to adapt the crops to new agroecological zones are minimal. These factors help

make biofortification a highly cost-effective investment for health⁵⁻⁷; for every US\$1 invested in biofortification, as much as US\$17 in health and livelihood benefits can be gained.⁸

HarvestPlus, a part of the CGIAR Research Program on Agriculture for Nutrition and Health, has led a global effort to improve nutrition through biofortification, in partnership with multiple CGIAR centers. The main focus of this effort is on the conventional (selective) breeding of varieties of staple crops that are an important source of energy and nutrients for smallholder farming families including beans, cassava, maize, sweet potato, pearl millet, rice, and wheat. By the end of 2019, over 242 conventionally bred biofortified crop varieties had been released in 30 countries.^{7,9,10}

Over 15 years of peer-reviewed efficacy and effectiveness research has shown that biofortified foods measurably improve micronutrient intake, nutritional status, and health outcomes causally associated with vitamin A, iron, and zinc when eaten as a main portion of the diet.¹¹⁻¹⁸ For example, consumption of provitamin A-biofortified maize significantly improved pupillary responsiveness and provitamin A-orange sweet potato (OSP) reduced the prevalence and duration of diarrhea episodes^{16,18}; iron-biofortified beans and pearl millet significantly improved cognitive function^{15,19}; and zinc-biofortified wheat significantly reduced reported maternal and child morbidity.²⁰ Through daily consumption of biofortified foods, 25% to 100% of the Estimated Average Requirements (EAR) of vitamin A, iron, or zinc can be met for young children (1-6 years) old and nonpregnant, nonlactating women of reproductive age (WRA; 15-49 years old).

Farmers are willing to grow biofortified crops because they are high yielding and have several agronomic benefits in addition to improved nutrition. Studies also show that consumers prefer

biofortified crops over comparable nonbiofortified varieties (based on appearance, smell, taste, and texture) and consumer acceptance (as measured by willingness to pay) increases when consumers receive information on the nutritional benefits.^{8,21-26} In the context of climate change, the projected decline in available dietary micronutrients²⁷ will make strategies like biofortification even more vital for vulnerable populations to maintain good health.

Strategic Delivery and Impact: Introducing, Scaling, and Anchoring

The sustainability and impact of biofortification will ultimately depend on the development of sustainable markets for biofortified seeds and products. HarvestPlus envisions that by 2030, one billion people will benefit from biofortified foods globally.⁷ To achieve this ambitious target and get biofortified foods to those who need them most requires evidence-based, context-specific delivery strategies that are cost-effective, replicable, and rapidly scalable, taking into account complex regional, national, and local policy and market environments, food systems, and other sociocultural factors. This article presents 3 country- and crop-specific case studies from India, Nigeria, and Uganda to illustrate some of the adaptive and tailored approaches that can be used to introduce, scale up, and anchor biofortification into a food system.

HarvestPlus follows a 3-stage pathway to discover, develop, and deliver biofortified crops and foods.⁹ The third stage, delivery, aims to sequentially introduce biofortified crops to farmers, scale-up operations to reach a sizable market share, and finally, anchor biofortification in local food systems to ensure long-term sustainability.²⁸ To illustrate the delivery pathway for released biofortified crop varieties, activities for each case study are grouped into the following segments of the value chain for biofortified crops (Figure 1):

- Seed/cutting multiplication
 - Released varieties are licensed to seed companies or multipliers.
 - Planting material (seeds or vine/stem cuttings) are multiplied.
 - Planting material are packaged and delivered to distribution points (eg,

subnational depots, agro-dealers, retailers, or development partner warehouses).

- Transfer of seed to farmers
 - Farmers acquire seeds or vine/stem cuttings for planting through either direct purchase, as demonstration packs on a noncash payment, or by diffusion (ie, from fellow farmers).
 - Farmers recycle or retain part of their own harvest to plant in next season.
- Crop production and postharvest handling
 - Farmers grow biofortified crops.
 - Farming households harvest and allocate biofortified crops to various uses.
- Utilization of biofortified crops
 - Biofortified crops allocated for home consumption are prepared and consumed by people in farm households.
 - Sold biofortified crops are processed by micro, small, or medium enterprises (MSMEs) and large commercial processors into various products for sale to farm and nonfarm consumers.

Also discussed are 4 crosscutting themes that must be fully integrated across the value chain for successful delivery and scaling up of biofortified crops:

Awareness raising and demand creation: Producing (a) messages on the production, nutrition, and health benefits of biofortified crops, (b) promotional materials, and (c) a strategy for dissemination of key messages.

Enabling environment: Taking a multisectoral approach by working with public and private sector partners across the value chain, including researchers, policy-makers, businesses, farmers, and civil society organizations. HarvestPlus inputs into and advocates for policy reviews and facilitates the development of standards and guidelines for biofortified crops at global, regional, and national levels.

Capacity strengthening of value chain actors: Developing training materials

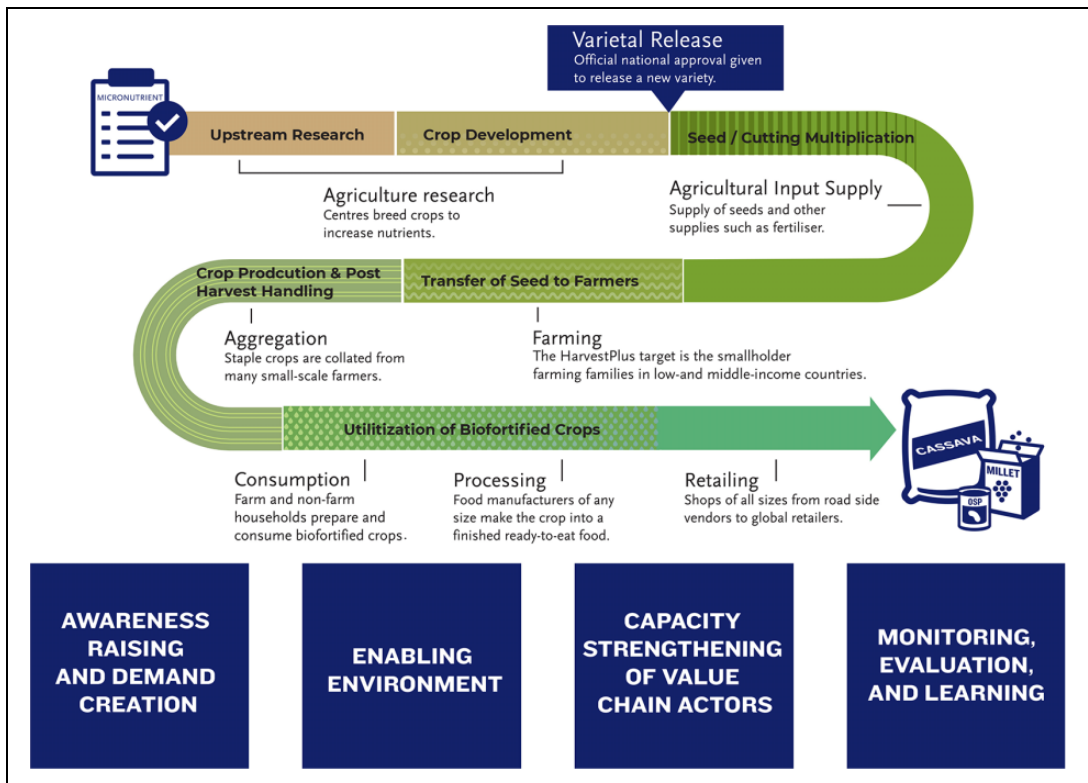


Figure 1. Value chain for biofortified crops.

and providing financial and practical support for value chain actors (eg, partner staff, seed multipliers, farmers, and processors).

Monitoring, evaluation, and learning: Establishing a monitoring, evaluation, and learning (MEL) system to track and assess delivery progress, utilization of seed, adoption of varieties, and consumption of biofortified foods, as well as gather feedback from farmers and consumers about biofortified crops and foods. A comprehensive MEL system generates evidence and lessons learned on the adoption and utilization of biofortified crops. Monitoring, evaluation, and learning system data are also used to assess the cost-effectiveness of various delivery models and strategies and provides much-needed feedback to delivery teams to recalibrate delivery strategies.

Results: Case Studies

This article provides specific examples of how biofortification has been implemented in different countries using a food systems approach to improve the quality of diets. The following 3 cases from India, Nigeria, and Uganda illustrate factors that enable sustainable scaling up. They reveal lessons learned from delivery across 3 countries to provide guidance and illustrate that any strategy for scaling up biofortification needs to be evidence-based, entrepreneurial by design, and context-specific.

India: Iron Pearl Millet

Background

India has made significant economic progress in recent decades, but undernutrition and micronutrient deficiencies remain high. Approximately half of all children <5 years old and nonpregnant,

nonlactating WRA are anemic.²⁹ This public health problem is driven in large part by inadequate dietary intakes of iron typical of vegetarian diets, and limited access to food supplements and commercially fortified foods.³⁰

Pearl millet is an important food in arid and semiarid regions of India. It is grown on more than 10 million hectares, producing over 9 million tons annually for human and livestock food and for other uses.³¹ Rajasthan, Maharashtra, Gujarat, and Uttar Pradesh are the major pearl millet producing states of India, and among those most affected by iron deficiency.³²

In 2012, the first open pollinated variety (OPV) of iron pearl millet (IPM) (ICTP-8203 Fe) was developed by the ICRISAT and commercialized by Nirmal Seeds as truthfully labeled in Maharashtra. In 2014, HarvestPlus collaborated with ICRISAT and Mahatma Phule Krishi Vidyaapeeth (MPKV) Rahuri university to release and notify this variety as Dhanashakti.

Subsequent breeding efforts shifted to the development of IPM hybrids for commercial cultivation due to farmer preference for their higher yield, better disease tolerance, and higher potential market demand. By the end of 2019, 9 hybrid varieties and 1 OPV variety of IPM had been developed and released in collaboration with ICRISAT and state agricultural universities (Chaudhary Charan Singh Haryana Agricultural University, MPKV, Vasantrao Naik Marathwada Krishi Vidyapeeth, and Swami Keshwanand Rajasthan Agricultural University) under the All India Coordinated Research project on pearl millet.

Iron pearl millet can provide up to 80% of the EAR for iron for young children (1-6 years) old and nonpregnant, nonlactating WRA when it is consumed daily as a staple food. An efficacy study evaluating the effect of IPM (86.3 mg Fe/kg) compared to conventional pearl millet (21.8-52.1 mg Fe/kg) on nutrition and health outcomes of Indian adolescent children showed that eating IPM daily significantly improved iron status (serum ferritin and total body iron) after 4 months, as well as cognitive function after 6 months^{12,13,15}; children who were iron deficient at baseline and ate IPM were 64% more likely to resolve their deficiency by 6 months.¹²

By 2018, nearly 500 000 people from farming households in India were consuming IPM.³³ Other biofortified staple crops have also been released or are under testing in India, including zinc wheat and zinc rice, with the collective aim of lessening widespread multiple micronutrient gaps. This case study focuses on the delivery and scaling up of IPM as the first biofortified crop released in India.

Seed Multiplication

India is known for its commercial seed sector. Conventional pearl millet breeding programs are well established in both the private and public sectors. Public sector seed companies play a pivotal role in government seed subsidy programs for new varieties. HarvestPlus supported ICRISAT to lead the production of early generation IPM seed and partnered with 2 public sector seed companies, Maharashtra State Seed Company and Karnataka State Seed Company, to produce and market Dhanashakti. An average of 370MT of the variety is now produced annually.

Transfer of Seed to Farmers

In India, IPM seed is distributed by seed companies through market channels (consisting of company distributors and agro dealers or retail networks), where farmers purchase seed directly. HarvestPlus supports seeds companies to market IPM by codeveloping promotion and nutrition messages, providing branded packaging labeling and seeds for product demonstrations, and delivering training to sales, marketing, and retail partners. Training focuses on the relative advantages of IPM including superior yield, maturation, and market demand³⁴ and outlines the equal costs of cultivation and farm management for hybrid IPM and conventional pearl millet.

Crop Production and Postharvest Handling

Iron pearl millet is grown under large commercial and small-scale subsistence production systems. To strengthen farmer capacity to produce IPM, HarvestPlus and seed companies provide partners (eg, extension workers and seed company sales

agents) with production and nutrition messages for dissemination to farmers, including how to visibly distinguish IPM varieties from other conventional varieties during the vegetative growing stage. HarvestPlus has observed that farmers initially grow IPM on a trial basis and then procure more seed to expand the area under cultivation in subsequent years. A 2018 study in 3 districts of Maharashtra state found 89% of interviewed households had grown IPM OPV only, suggesting a high rate of replacement over non-IPM varieties.³⁵ As of 2019, approximately 240 000 farmers were growing IPM in India and an estimated 0.7% of total pearl millet area was allocated to IPM.¹⁰

Utilization of Biofortified Crops

Across rural, urban, and peri-urban areas IPM is sold in fresh produce markets as grain and in retail shops as flour. It is consumed mainly as chapatti and is popular for its great taste when compared with conventional pearl millet chapatti. To create awareness and encourage consumption of IPM products, HarvestPlus carries out promotional activities and shares messages on the nutrition and health benefits of iron, including via labels on IPM flour bags.

Awareness Raising and Demand Creation

Since iron is not a visible trait that can be used to distinguish IPM from other varieties, seed and food companies are required to label IPM seed and flour sold in retail outlets to differentiate it and build consumer trust. As a prerequisite for the uptake of IPM grains and IPM value-added products, large food companies must demonstrate rigorous quality control and assurance systems and their ability to accurately label and market IPM. Food companies are also provided with technical assistance on the processing of biofortified foods to ensure adequate nutrient retention and shelf life.

In 2012, Nirmal Seeds led a large-scale demand-creation campaign for IPM which included farmer training and the establishment of multilocation demonstration plots to showcase the superior agronomic traits and nutritional benefits of Dhanashakti. Other seed companies have since used this strategy to promote other IPM

varieties that have been subsequently released. In the last 5 years, thousands of farmers and technical staff have attended these demonstrations, providing useful farmer feedback on agronomic and nutritional traits, such as IPM grain quality, color, yield, and the taste of IPM products.

Monitoring, Evaluation, and Learning

HarvestPlus leads a robust MEL system that covers the entire IPM value chain, from varietal development to the utilization of IPM products. Farmer and consumer input are considered in the development of IPM varieties. Once varieties are released and licensed to commercial seed companies, the MEL approach is designed to suit commercial delivery strategies. HarvestPlus identifies information needs and develops tools and methods for collecting and reporting data on IPM seed production, distribution, and growing and utilization of IPM grain. Through signed data sharing agreements with seed companies, HarvestPlus gathers quarterly data on seed production and distribution. HarvestPlus also conducts monitoring surveys to assess several variables including varietal penetration, household-level production, and utilization of harvested IPM grain.

Enabling Environment

Partnership cultivation and policy integration have advanced through the collaboration of key stakeholders and partners. HarvestPlus supports this collaboration through participation in numerous national agriculture and nutrition activities. For example, contributions to the National Coalition of Food and Nutrition Security led to the incorporation of biofortification in the 2016 Sustainable Nutrition Revolution policy. HarvestPlus also established a biofortification platform that convenes over 20 private and public sector partners on pearl millet to test and evaluate early generation material and advance pipeline products.

The Indian government is a committed advocate for IPM. It declared 2018 the “Year of Millets,” incentivizing farmers to grow “nutri-cereals” deemed important for improving food and nutrition security.³⁶ The Food and Agriculture Organization of the United Nations (FAO)

will observe 2023 as the “International Year of Millets,” upon the request of the Indian government.³⁷ The government has also recommended the inclusion of millets in the wide-reaching public food distribution system—previously limited to rice and wheat.³⁸ Alongside these declarations, in 2018, the Indian Council of Agricultural Research established minimum levels of iron (42 ppm) and zinc (32 ppm) for all released pearl millet varieties.³⁹ These policy positions in favor of biofortification will greatly increase the breeding, release, production, and consumption of IPM in India.

Capacity Strengthening of Value Chain

Actors

For long-term sustainability, HarvestPlus encourages seed companies to initiate IPM breeding and establish their own high-iron product lines. Seed companies are established as partners in evaluating how germplasm and candidate varieties perform under different agroecological conditions. They are encouraged to use high-iron lines developed at ICRISAT to develop their own high-iron hybrids for commercialization. Through mainstreaming, it is now estimated that the high-iron trait is in approximately 50% of ICRISAT’s pearl millet germplasm.

Technical knowledge on the production and nutritional benefits of IPM are shared with academia, food industry, Food Safety Standards Authority of India, and other value chain partners. The shift in focus toward supply chain development is expected to catalyze greater reach of nutrient-rich products. HarvestPlus also continues to engage the FAO/World Health Organization Food Standards Program and Codex Alimentarius to develop global standards for biofortified crops. Today, IPM is emerging as an innovative, value-added health food product.

Scaling for Sustainability

By 2030, HarvestPlus aims to reach a substantial market share with IPM in India. Factors known to drive farmer adoption of IPM are improved nutrition and productivity. Biofortified varieties have a yield advantage of 6% to 38% over

conventional varieties, providing higher economic return per unit area.³³ Surveys of areas growing IPM show nearly a third of farmers purchase biofortified seed for its nutrition and a large proportion of those who plant it do so instead of conventional varieties (in Maharashtra in 2018, 22% of farming households surveyed planted IPM; of these, 93% replaced a nonbiofortified variety).^{40,41}

Strategic priority areas required to sustainably anchor IPM in the Indian food system are:

- Piloting the inclusion of IPM in existing public institutional programs that feed vulnerable populations, namely the Public Distribution System, the Mid-Day Meal program that provides lunch to 100 million school-aged children, and the Integrated Child Development Services program that provides supplementary nutrition to over 34 million young children and 7 million pregnant and lactating mothers.
- Continuing to develop portable rapid testing to validate grain mineral values, facilitating differentiation of IPM from conventional varieties to establish a segmented higher nutrient supply chain for IPM in the newly established Public Distribution System for millets.
- Exploring partnerships with food companies to increase the shelf life and reach of pearl millet flour in the wider food system, while incentivizing farmers to produce IPM.
- Supporting stakeholders to screen germplasm and advance product pipelines for breeding pearl millet varieties at the established minimum levels of iron and zinc.

Nigeria: Vitamin A Cassava

Background

In Nigeria, nearly one-third of preschool children are vitamin A deficient and 13% of WRA are at risk of vitamin A deficiency (VAD).^{29,42} Reducing and preventing VAD remains a challenge. Most people are unable to diversify their diets, nearly half of preschool children do not receive the recommended biannual vitamin A

supplements, foods fortified with vitamin A are often inaccessible to rural families, and regulation and standard control for fortified foods is poor.⁴³

Nigeria is the world's largest producer of cassava, the vast majority of which is produced by smallholder farmers.⁴⁴ Over 90% of cassava produced is for human consumption, and thus cassava represents a major staple, eaten daily by more than 100 million Nigerians.⁴⁵ White cassava can provide most of the body's daily energy requirements but lacks essential micronutrients required for good health, including vitamin A.

Biofortified cassava, by contrast, is yellow in color due to its high β -carotene (provitamin A) content. HarvestPlus has led the conventional breeding of vitamin A cassava (VAC) and provides technical and financial support to the National Root Crops Research Institute and the IITA to breed and release VAC varieties. The first VAC variety was released in 2011 and promotional efforts to disseminate VAC varieties began in 2014. To date, 6 varieties of VAC have been released and are being produced across the country.

At current consumption levels, VAC varieties can provide up to 100% of the EAR for vitamin A for young children (1–6 years) old and nonpregnant, nonlactating WRA. Evidence shows that regular intake of biofortified vitamin A crop varieties significantly improves the vitamin A status and health of young children.^{16,18,46–49} In Eastern Kenya, children (5–13 years) old who consumed boiled and mashed VAC daily experienced significant improvements in serum retinol and β -carotene concentrations compared to those who consumed white cassava after 4.5 months.⁴⁹

By 2019, an estimated 1 697 000 Nigerians were growing VAC varieties in more than 26 states.¹⁰ Although HarvestPlus and its partners are also promoting vitamin A-biofortified OSP and maize, this case study focuses on the scaling up and anchoring of VAC in the Nigerian food system.

Seed/Cutting Multiplication

To develop and deliver VAC varieties to millions of cassava farmers in Nigeria first required a

mapping of the cassava value chain. Unlike maize which is fully commercialized, VAC required both public and private commercial partners to multiply planting material, develop a strong value proposition, stimulate demand, and reach rural farming households through commercial and noncommercial delivery channels.

Unlike other staple crops, cassava stems have low multiplication rates, short shelf life, and are bulky—leading to high transportation costs. Therefore, to attract potential investors and reduce transportation costs, HarvestPlus used a decentralized stem multiplication approach. Partners in 4 pilot states (Oyo, Imo, Benue, and Akwa Ibom) provided an initial commercial base for VAC stems while fields established at IITA served as backup. Efforts were intensified to popularize VAC among various stakeholders at the national, state, and local communities and create value for both VAC stems and tubers. HarvestPlus gradually created a network of commercial VAC stems multipliers, while simultaneously growing other aspects of the value chain. Since 2011, HarvestPlus has developed the VAC seed system consisting of smallholder and large-scale commercial stem multipliers and has grown the land area under cultivation for VAC from 65 to 50 000 hectares by the end of 2018.³³

Transfer of Seed to Farmers

Two delivery channels were predominantly used for initial VAC stem dissemination: (a) a social delivery channel (direct stem delivery to targeted poor farming households by HarvestPlus); or (b) a farmer-to-farmer channel (cassava stems are shared freely among farmers in Nigeria). Farmers who received stems on a noncash basis shared them with other farmers during the following planting season.

A commercial delivery channel, however, is better equipped to enable larger scale farmers to sell stems. Thus, in 2015, HarvestPlus launched a commercial stem popularization and awareness campaign to connect small- and large-scale farmers with stem multipliers, reducing the quantity of stems distributed as promotional packs. This gradual shift from a social to a commercial stem multiplication and marketing

system helped build a self-sustaining VAC market; by 2018, approximately 8% of VAC stems were purchased by farmers.⁵⁰ Progress is underway, with support from the Gates Foundation through IITA's BASICS project, to further improve the emerging cassava commercial seed system, including development of guidelines and quality standards.

Crop Production and Postharvest Handling

Vitamin A cassava production in Nigeria is dominated by subsistence smallholder farmers who produce it mainly for household consumption and by smallholder farmers who produce it mainly for profit. These farmers either allocate part of their harvest to on-farm household consumption or sell excess tubers directly to commercial food processors, local marketers, or aggregators. By 2018, VAC became the third most preferred cassava variety in Nigeria; it was grown in more than 26 states⁵¹ and covered approximately 8.2% of national cassava area.

Utilization of Biofortified Crops

In Nigeria, more than 80% of VAC tubers are processed and consumed as primary traditional Nigerian food products (eg, gari and fufu). The rest are processed as secondary products (eg, abacha, lafun, snacks, and confectionaries). For family consumption, farmers process VAC fresh tubers into gari or fufu in their homes or use local cassava processing centers.

To encourage investment in VAC and increase supply, HarvestPlus actively links farmers to aggregators, and in some circumstances, farmers directly to processors. HarvestPlus also stimulates demand by developing innovative food products and intermediate raw material for industry. HarvestPlus helped establish point of sale locations, including online markets, Biofort restaurants, and roadside points to increase access to VAC products.

HarvestPlus also identified, trained, and provided start-up support to MSME food processors on best practices for producing high-quality food products and reducing nutrient losses during processing and storage. For quality control and

uniformity of VAC food products, HarvestPlus developed innovative tools, including a moisture meter and extruder. Processed VAC products are packed and labeled with messages on the nutrition and health benefits and sold in retail shops in rural, urban, and peri-urban areas. Large-scale processors are also involved in the processing of VAC into gari, fufu, high-quality flour, and other products. By 2018, 300 private selling points had been established across 10 states.⁵²

Awareness Raising and Demand Creation

Acceptability and adoption of VAC is influenced by its yellow color and its value-added food products, which are easily differentiated from conventional white varieties. Behavior change communication and effective promotional efforts were pivotal to achieve initial acceptance by farmers, consumers, policy-makers, and other stakeholders. Social and print media, radio, and television were all used extensively to communicate the nutritional value and agronomic traits of VAC to consumers in local languages. Other creative approaches, including "crowding in" delivery partners helped make VAC products the preferred choice over their white counterparts. In a survey carried out in 2018, 73% of respondents indicated knowledge of VAC, demonstrating the effectiveness of the promotional strategy.⁵⁰

Finally, the establishment of a Nutritious Food Fair, an annual national event to showcase and share information on nutrition and biofortification, was highly instrumental in building linkages among farmers, processors, marketers, and consumers. Attendance grew to over 5000 people by 2019. Attendees include prominent government officials, Nollywood celebrities, international visitors, secondary school children, implementers of livelihood programs in agriculture and nutrition, and investors in the nutritious food sector, including farmers, processors, food manufacturers, and food distribution companies.

Capacity Strengthening of Value Chain Actors

There is a notion in Nigeria that yellow and orange colors are associated with quality.⁵³

HarvestPlus, together with its partners, thus developed a brand for yellow VAC and established a team of master trainers at the national and state levels. Master trainers produce, process, and distribute VAC and its value-added products. Over 7650 processors, 300 MSMEs, and 100 bulking agents have subsequently been trained in VAC product development and processing.

Monitoring, Evaluation, and Learning

To gather data and lessons learned on the delivery and utilization of VAC stems and food, HarvestPlus developed a MEL system. There are 2 pathways through which implementation progress data are gathered: first, delivery partners are trained to use standard tools and methods to collect data and report on delivery progress quarterly. A data quality assurance strategy is implemented to ensure high data quality from partners. Second, HarvestPlus developed data sharing agreements with private commercial partners along the VAC value chain; they share agreed data on stem/tuber production, processed products, and HarvestPlus uses these data for quarterly reporting. HarvestPlus also conducts periodic surveys and evaluations to assess the evolution of outcome-level results on the utilization of stems, harvested tubers, and processed products. This body of evidence is used to inform breeding objectives and delivery strategies, as well as design advocacy and communication messages.

Enabling Environment

Successful progress toward scaling up has been bolstered by political and financial support from governmental agencies. Biofortification has been integrated into national agriculture and health programs, including the Micronutrient Deficiency Control Program (2013-2019), the National Strategic Plan of Action for Nutrition (2014-2019), the National Policy on Food and Nutrition (2016), and the Agricultural Sector Food Security and Nutrition Strategy (2016-2025). Investment by the Ministry of Agriculture through the Federal College of Agriculture, Akure, has supported infrastructure development

and training of 5000 youth and investors on production, processing, and marketing of biofortified foods.

HarvestPlus Nigeria advocacy efforts were the main stimulus for attaining these significant policy shifts. Through ongoing engagement with relevant authorities and public officers and appointed biofortification champions, biofortification has been advocated for at the highest policy-making platforms, including national legislative committees, the National Nutrition Committee, and the planning committee for National Nutrition Week. In Nigeria, HarvestPlus works with nearly 120 multisectorial partners, including government, nongovernmental organizations (NGOs), private sector, academia, and the media.

Scaling for Sustainability

HarvestPlus Nigeria plans to significantly increase the number of farmers growing VAC by 2030. The average yield for VAC varieties is significantly higher than non-VAC varieties (20.5 MT/ha vs 10.2MT/ha).⁵⁰ From a farmer perspective, this yield advantage makes investment in VAC profitable: in Oyo State, every NGN 1.00 spent on VAC production yielded NGN 2.09 in return.⁵⁴ However, although farmers perceive VAC to be superior on numerous agronomic and consumption traits,⁵⁴ its market availability and perceived market potential remain low; stimulus is needed to drive this demand.⁵⁰

Thus, HarvestPlus will continue advocating to food processing companies to take up investments in biofortification, while incentivizing and celebrating successful models for scaling up. The Nutritious Food Fair will continue to be a platform to enable stakeholder interaction and foster business and social relationships related to biofortification. Emphasis will also be placed on institutionalizing a digital information monitoring, intelligence, and sharing system called BiofortSTAT. The platform will encourage participation in the biofortification value chain for investors.

By working with private and nonprivate sector partners, HarvestPlus will raise consumer awareness of biofortification and improve the ease by which quality products can be determined—

encouraging consumers to make informed decisions about which foods to buy and eat, anchoring VAC in the Nigerian food system. This will be achieved by:

- Using traditional and social media channels to disseminate nutrition messaging;
- Developing and providing tools for the rapid determination of good quality products; and
- Providing technical assistance for processors to register with the quality regulation body, the National Agency for Food Drug Administration and Control.

Uganda: OSP

Background

In Uganda, an estimated 11 million people experience acute food insecurity and multiple micronutrient deficiencies coexist.⁵⁵ Nearly 30% of preschool aged children are affected by VAD and 1 of 2 children <5 years old are anemic.⁵⁶ Supplementation and fortification coverage are limited. Fortified maize and wheat flour coverage is less than 50%, and vitamin A fortified oil is only marginally higher.⁵⁷ Only 62% of children <5 years old are reached with 6-monthly vitamin A supplementation, and 23% of pregnant women are reached with routine iron supplementation.^{56,58}

Sweet potato is a traditional food crop in Uganda, grown by approximately 2.7 million farmers and consumed by more than half of all households.⁵⁹ Sweet potato varieties in Africa are predominately white or yellow in color and provide no or little vitamin A. Since 2007, HarvestPlus has worked with the National Agricultural Research Organization (NARO), the International Potato Centre (CIP), and the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) in Uganda to develop, release, deliver, and promote biofortified vitamin A OSP varieties.

Orange sweet potato varieties released in Uganda provide up to 100% of the EAR of vitamin A for young children (1-6 years) old and nonpregnant, nonlactating WRA, they mature

up to one month earlier, and they can be up to 60% higher yielding than existing nonbiofortified varieties. Efficacy and quasi-experimental studies evaluating nutrition outcomes show that regular consumption of OSP significantly improves vitamin A intake and status.^{46,47} Effectiveness studies in Uganda and Mozambique demonstrated OSP consumption significantly increased vitamin A intake among children and women and reduced the prevalence and duration of diarrhea in children <5 years old by 39% and more than 10%, respectively.^{16,45}

By the end of 2018, an estimated 9% of the total sweet potato area under cultivation in Uganda was allocated to 6 varieties of OSP in 40 districts. Although HarvestPlus and other partners also breed, develop, deliver, and promote high-iron beans in Uganda, this case study describes the delivery pathway of biofortified OSP varieties led by HarvestPlus.

Seed/Cutting Multiplication

Once new OSP varieties are released, virus/disease free (“clean”) early generation OSP vines are multiplied by private and public laboratories in Uganda, including Biocrops, Senai, Makerere University laboratories, and the National Crops Resources Research Institute. These laboratories produce clean vines using tissue culture techniques under controlled, sterile environments. Vines are then transferred to community-based secondary multipliers to further multiply them under screen houses. The final stage of vine multiplication is done in open-field nurseries for large-scale multiplication, after which the vines are delivered to farmers for root production.

HarvestPlus works with the government extension system to enable community-based vine multiplication by identifying and training farmers, which has led to the development of a decentralized vine multiplication system consisting of 39 primary and 150 tertiary multipliers across operational districts. A decentralized multiplication system reduces the distance over which vines are transported and thus minimizes loss. HarvestPlus provides initial material support to establish vine screen houses and nurseries and works with government, universities, and other partners to

develop vine inspection protocols and tools that are used and enforced by vine inspectorates.

Transfer of Vines to Farmers

There are 3 pathways through which OSP vines reach farmers. First, HarvestPlus contracts NGOs that have established working relationships in intervention areas and a credible track record of delivering agricultural or nutrition/health inputs in rural areas. These NGOs identify and train farmers on OSP vine production and supervise vine distribution. Recipients of vines enter into a contractual agreement to payback the vines once they have planted enough to cut and share back with HarvestPlus. Second, farmers and other institutions can purchase vines on a cash basis, directly from vine multipliers. Third, OSP growers share vines with fellow farmers. Using these 3 delivery pathways, the number of households reached annually increased from 60 000 in 2014 to 217 000 in 2018, and an estimated 5% of total sweet potato area under cultivation in Uganda was allocated to OSP.¹⁰

Crop Production and Postharvest Handling

Farmers who receive vines through HarvestPlus and its partners are trained on OSP good agricultural practices, while farmers who acquire them through other pathways are trained by government extension staff and vine multipliers. The expectation is that farmers who receive vines for the first time will test grow and evaluate the variety and subsequently expand their area under cultivation. Surveys show the total root yield for most OSP varieties is significantly higher than farmers' preferred local non-OSP varieties; the economic advantage of higher production per unit area is a driving factor for farmer adoption.⁶⁰

As of 2018, OSP growers were allocating nearly 30% of their sweet potato area to OSP varieties.⁵¹ The OSP grown is consumed by the farming household, sold, or shared as gifts.⁶¹ HarvestPlus helps identify and train farmer producer groups and links them to fresh produce markets directly or through aggregators. In addition, farmer producer groups close to highways are

supplied with branded tents to sell OSP roots, mainly to travelers.

Utilization of Biofortified Crops

In farm households, OSP roots are consumed boiled, steamed, fried, or roasted. To increase the shelf life, farmers also dry or process the roots into chips or flour. Farmers sell OSP fresh roots to fellow farmers in rural areas and to retailers in urban and peri-urban fresh market outlets, while flour is sold to small-scale bakeries.

HarvestPlus identifies and trains community-based MSME processors and links them to OSP farmer groups. Examples of community-based MSMEs in Uganda include Divine Investments Ltd in Northern Uganda, who produces 40MT of OSP flour a day, and SOSPA in Eastern Uganda, which produces an estimated 20MT per month. These MSMEs have increased demand for OSP roots, and thus increased production at the farm level. Micro, small, or medium enterprises process most of the OSP roots into chips and flour. OSP flour is an essential ingredient for a wide range of food products that are mainly consumed by urban and peri-urban consumers.

Enabling Environment

HarvestPlus Uganda has continuously advocated for biofortification at all levels of government and with the private sector and civic society. These advocacy efforts have led to the inclusion of biofortification in the National Anemia Prevention Action Plan, Uganda's Nutrition Action Plan, and the National Nutrition policy. OSP and high-iron beans are now promoted under a government-led World Bank-funded Food and Nutrition Security Project and a National Biofortification Technical Working Group, launched to help coordinate all biofortification activities in Uganda. The NARO has mainstreamed breeding for higher β -carotene and other related traits in their breeding programs.

Awareness Raising and Demand Creation

To raise awareness about OSP, HarvestPlus has developed evidence-based advocacy and

promotional materials for different audiences ranging from grandmothers in rural areas to national policy-makers. HarvestPlus also uses field days, drama, exhibitions, radio talk shows, advocacy “champions,” the lead mother concept,⁶² and sales promotions to stimulate demand for OSP vines, roots, and their processed products.

Monitoring, Evaluation, and Learning

HarvestPlus has developed a MEL system to track delivery progress and assess the impact of OSP in Uganda. Partners are trained to use standard tools and methods to collect data and report quarterly on delivery progress. To ensure high-quality data from partners, HarvestPlus has put into place a rigorous data quality checking system, which includes conducting periodic critical reviews, surveys, and evaluations to assess the evolution of results on the utilization of vines, harvested roots, and processed products. This body of evidence is used to inform breeding objectives and delivery strategies, and to design advocacy and communication messages. Using this system, HarvestPlus has been able to establish estimates for the national capacity for OSP vine production, vine delivery, and the utilization of the harvested roots.⁶³

Capacity Strengthening of Value Chain Actors

By the end of 2018, HarvestPlus had developed a critical mass of capable value chain actors by facilitating the activities of 3 breeders, 31 vine multipliers, 7 seed inspectors, 48 extension staff, 5 processors, and 511 000 OSP farmers.⁵¹ In collaboration with CIP, MAAIF, the Ministry of Health, and Makerere University, HarvestPlus also developed training material on (a) good agricultural practices, (b) nutrition and utilization, (c) marketing and value addition, and (d) MEL. To ensure effective learning, HarvestPlus uses demonstration plots and farmer field schools, exchange visits, role-plays, and community cooking demonstrations. The Ugandan government and other partners have adopted many of the

training materials produced by HarvestPlus and its partners.

Scaling for Sustainability

To sustainably anchor OSP in Uganda’s food system requires that OSP traits are mainstreamed into the sweet potato breeding pipeline, and the number of and capacity of OSP value chain actors (from vine multipliers, to farmers, to marketers, and food processors) is increased. Specifically, there is need to:

- Develop and release more OSP varieties that are uniquely suitable for different purposes, such as fresh root consumption and industrial processing.
- Improve the OSP vine system by strengthening the capacity of existing vine multipliers and identifying new ones to ensure increased access to vines by farmers.
- Support the establishment of resilient vine nurseries in the drier northern parts of Uganda to improve access to, and timely availability of, high-quality vines.
- Integrate OSP into public seed and food distribution programs to stimulate production and increase marketing and consumption of OSP roots and food products.
- Support commercialization of OSP along the value chain (eg, processing/value addition to stimulate production) and produce a wider range of products (eg, properly packed OSP flour and puree-based products) to increase off-season availability of OSP and reach more nonfarm consumers.

Discussion

Each crop country context requires a unique approach to sustainably scale-up and anchor biofortification in the food system. These case studies illustrate several common elements that can support the strategic introduction, delivery, and impact of this intervention.

First, biofortified seeds and cuttings must be introduced into farming systems. This requires a proven pipeline of nutrient-enriched varieties that meet the agronomic, taste, and nutrition

expectation of farmers. The CGIAR has pledged to “mainstream” nutrition traits into all germ-plasm.²⁸ Nonvisible trait crops, like IPM in India, will benefit more from this approach than visible trait crops, such as OSP in Uganda and VAC in Nigeria, which require market segmentation based on color. India—where minimum standards for iron and zinc have been set for pearl millet breeding—is leading the way. Moving forward, the establishment of systems for quality assurance will be necessary, particularly for private sector partners.

Next, a self-sustaining and demand-driven seed multiplication system for biofortified crop varieties is required. Adequate and timely supply of biofortified seeds and planting material requires the strengthening of seed systems and strategic placement of multipliers of planting material across production zones. Demand for biofortified varieties by farmers is dependent upon their demonstrable agronomic, nutrition, and economic advantages. For example, in Uganda and India, OSP and IPM, respectively, provide a significant yield advantage over conventional varieties; in Nigeria, VAC provides farmers with a 2:1 return on their investment.

Concurrently, effective multisectoral advocacy fosters an enabling environment to integrate biofortification across food systems, policies, and programs; nutrition is often a shared priority of public, civic, and private sector decision-makers. In India and Uganda, for example, participation in multisectoral platforms resulted in the inclusion of biofortification in federal ag-nutrition and health programs and policies. The endorsement of biofortification by trustworthy influencers, such as traditional leaders in Nigeria, builds consumer confidence and promotes farming household adoption.

Demand creation activities, such as linking farmers to markets and manufacturing biofortified food products, incentivize farmers and food processors toward a long-term commitment to biofortification. The latter also creates opportunities for nonfarm consumers to buy and eat biofortified food products. There is no one-size fits all approach to marketing biofortification; as seen in all 3 case studies, multiple tactics and behavior change communication strategies can

successfully promote biofortified crops, such as farmer-to-farmer diffusion, public expos, and media campaigns.

Finally, the successful scaling and anchoring of biofortified crops hinders on collaborative private and public partnerships. This is clear across all 3 case studies: in India, where the private sector dominates millet seed production and delivery, companies are primarily taking IPM to market; in Nigeria, while public partnerships stimulated the supply chain, the long-term success of VAC lies in private commercial collaboration; and in Uganda, progress has been achieved largely through NGO partners.

Conclusion

Biofortification is a novel approach to improve nutrition in vulnerable populations. Scaling it up and anchoring it in food systems requires concerted efforts at the global, regional, national, and local levels. Case studies illustrate some of the elements that catalyze these efforts. In all contexts, the prerequisites to scaling up are a pipeline of nutrient-enriched crops varieties, evidence that biofortification is efficacious, willingness by farmers and consumers to grow and eat biofortified foods, and coordination among government, civil society, and commercial partners.

Over a decade of research, delivery, and monitoring and evaluation have revealed that conventional breeding increases nutrient levels without reducing yields, the extra nutrients in biofortified crops significantly improve micronutrient status and health, farmers are growing biofortified crops, consumers are avidly eating them, and biofortification is cost-effective. As policy-makers and publics alike connect innovation in agriculture with improved nutrition for societal growth and development, the pathways to scale-up biofortified foods will widen, improving people’s health worldwide.

Authors’ Note

J.K.F, K.D.M., and B.M. wrote the manuscript. E.B. had primary responsibility for final content. All authors read and approved the manuscript. J.K.F. and K.D.M.

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