Biofortification: the Evidence

HarvestPlus leads a global effort to develop and deploy micronutrient-rich staple food crops. The process used is known as biofortification, and it targets foods widely consumed by low-income families in Africa, Asia, and Latin America, which are often starchy staple food crops with little nutritional value. The focus is on providing sufficient levels of vitamin A, iron and/or zinc (three of four micronutrients identified by WHO as most essential) through these crops, based on normal diet patterns, to reduce malnutrition-related health problems. Over the last 15 years, HarvestPlus and its partners have demonstrated that:

- Breeding can increase nutrient levels enough to improve human nutrition without reducing yield.
- Extra nutrients in the crops can improve micronutrient status.
- Farmers are willing to grow biofortified crops and consumers to eat them.
- Biofortification is cost-effective.

The evidence, thus far, is well documented (Bouis et al. 2011; Saltzman et al. 2013; Johnson et al. 2015) and the Second Global Conference on Biofortification (Kigali 2014) concluded that there is sufficient proof that biofortification works. This document summarizes key evidence to support scaling biofortification to improve nutrition globally. It also highlights additional research that is underway, including robust new trials that test the efficacy of biofortified crops to enhance nutritional status in the first 1,000 days, as women and young children are a target group for biofortification. Other research will test the efficacy of consuming several different biofortified crops, each providing different vitamins and/or minerals to the food basket.

As delivery progresses, HarvestPlus and its partners will measure adoption and consumption impact of new biofortified crops among target groups. The studies will assess the impact of biofortified crops on outcomes for women and girls, including both nutritional status and adoption effects, such as time allocation, income, and market participation. Related research will evaluate the effectiveness of various delivery methods, including both public and private sector systems, and develop lessons learned to inform large-scale implementation.

Breeding can increase nutrient levels enough to improve human nutrition without reducing yield

Plant breeders screen thousands of different types of crop seed stored in global seed banks to discover varieties with naturally higher amounts of micronutrients. These are used to breed new high-yielding biofortified crop varieties that are also disease and pest resistant, and climate smart. Working with both international research institutes and national agricultural research systems, researchers have been able to develop, test, and release varieties suited to local conditions and consumer preferences. To date, biofortified crops, including vitamin A-rich orange sweet potato (OSP), iron bean, vitamin A cassava, vitamin A maize, zinc rice, and zinc wheat are being grown in 30 countries. Crop improvement research continues, producing varieties with higher levels of vitamins and minerals and ensuring that the best germplasm for climate-adaptive traits continues to be used in breeding biofortified crops.

Biofortified crops are designed to meet the specific dietary needs and consumption patterns of women and children. HarvestPlus breeding targets for biofortified crops are set such that, for preschool children 4-6 years old and for non-pregnant, non-lactating women of reproductive age: the amount of iron in iron beans and iron pearl millet will provide approximately 50% of the Estimated Average Requirement (EAR); zinc in zinc wheat and zinc rice will provide 60%

of the EAR; and, provitamin A in vitamin A cassava and vitamin A maize will provide 50% of the EAR, and up to 100% in the case of orange sweet potato.

Seeds for nutrient-rich crops are being made available as public goods to national governments, which officially release new crop varieties. Where they are sold by the private sector, they are competitively priced so that subsistence and smallholder farmers can afford them. In the long run, the cost difference for these seeds should be negligible.

Extra nutrients in the crops can improve micronutrient status

Nutritionists measure retention of micronutrients in crops under typical processing, storage, and cooking practices to be sure that sufficient levels of vitamins and minerals will remain in foods that target populations typically eat (for summary results, see De Moura et al. 2015). They also study the degree to which nutrients bred into crops are absorbed, first by using models, then, with the most promising varieties, by direct study in humans in controlled experiments. Absorption is a prerequisite to demonstrating that biofortified crops can improve micronutrient status, but the change in status with long-term intake of biofortified foods must be measured directly. Therefore, randomized controlled efficacy trials are used to demonstrate the impact of biofortified crops on micronutrient status and functional indicators of micronutrient status (i.e. visual adaptation to darkness for vitamin A crops, physical activity for iron crops, etc.). These studies provide evidence that biofortified crops are efficacious; highlights are discussed below, and further detail is summarized in De Moura et al. (2014). Finally, effectiveness research provides evidence that biofortified crops can improve the nutritional status of populations in typical, real world non-experimental conditions. Thus far, effectiveness evidence is available only for orange sweet potato.

Orange Sweet Potato

Consumption of orange sweet potato (OSP) can result in a significant increase in vitamin A body stores across age groups (Haskell et. al 2004; Low et al. 2007; van Jaarsveld et al. 2005).

The primary evidence for the effectiveness of biofortification comes from OSP, assessed through a randomized controlled trial. The OSP intervention reached 24,000 households in Uganda and Mozambique from 2006–2009 with adoption rates of OSP greater than 60% above control communities (Hotz et al. 2012a). The introduction and promotion of OSP assessed in Mozambique over four growing seasons demonstrated that serum retinol increased significantly at endline for children in the OSP intervention group (Hotz et al. 2012b). Introduction of OSP in rural Uganda resulted in increased vitamin A intakes among children and women, and improved vitamin A status among children by decreasing the prevalence of low serum retinol by 9 percentage points. Women who got more vitamin A from OSP also had a lower likelihood of having marginal vitamin A deficiency (Hotz et al. 2012a). Recent research on the health benefits of biofortified OSP in Mozambique showed that biofortification can improve child health; consumption of biofortified orange sweet potato reduced the prevalence and duration of diarrhea in children under five (Jones & De Brauw 2015).

Vitamin A Cassava

To date, only a small efficacy study has been completed in Eastern Kenya with 5–13-year-old children. This trial demonstrated small but significant improvements in vitamin A status, measured both by serum retinol and *beta*-carotene, in the yellow cassava versus the control group (Talsma et al. 2015). A larger-scale efficacy trial is underway.

Vitamin A Maize

An efficacy study conducted in Zambia with 5–7-year-old children showed that, after three months, the total body stores of vitamin A in the children who were in the orange maize group increased significantly compared with those in the control group. The beta-carotene in maize is an efficacious source of vitamin A when consumed as a staple crop (Gannon et al. 2014).

Iron Bean

Biofortified beans have been demonstrated as efficacious in two different populations. Mexican primary school children were observed to have improved transferrin receptor levels after consuming biofortified black beans for 3.5

months (Haas 2014). In Rwanda, iron-depleted university women showed a significant increase in hemoglobin and total body iron after consuming biofortified beans for 4.5 months (Haas et al. 2016).

Iron Pearl Millet

The efficacy of iron pearl millet was evaluated in secondary school children from Maharashtra, India. A significant improvement in serum ferritin and total body iron was observed in iron-deficient adolescent boys and girls after consuming pearl millet flat bread twice daily for four months. The prevalence of iron deficiency was reduced significantly in the high-iron group. Those children who were iron deficient at baseline were significantly (64%) more likely to resolve their deficiency by six months. This study demonstrated that iron pearl millet is efficacious in improving iron status in children (Finkelstein et al. 2015).

Zinc Rice

A 2010 zinc bioavailability pilot trial, designed to estimate the amount of zinc absorbed from zinc rice and compare that with absorption from conventional rice using the triple stable isotope tracer ratio technique, did not produce detectable differences in absorbed zinc (Islam et al. 2013). The study was redesigned and a new absorption trial is planned, followed by an efficacy trial.

Zinc Wheat

An absorption study among women in Mexico showed that total absorbed zinc was significantly greater from the biofortified variety of wheat as compared with non-biofortified wheat (Rosado et al. 2009). Two efficacy trials using zinc wheat are underway, one among school children and another among preschoolers and their mothers.

Farmers are willing to grow biofortified crops and consumers to eat them

Economists are leading studies to inform delivery and marketing strategies to maximize adoption and consumption of biofortified crops. Research on consumer acceptance—both sensory evaluation (e.g. appearance, taste, texture) and willingness to pay—has found that for some crops (vitamin A maize, vitamin A cassava, iron pearl millet) consumers like biofortified varieties as much as, or more than, conventional ones, even in the absence of information about nutritional benefits of biofortified varieties. In all crop studies, consumers preferred sensory attributes of and valued biofortified varieties more than non-biofortified ones when given nutrition information. Highlights of the consumer acceptance research are discussed below and further detailed in Birol et al. (2015).

Orange Sweet Potato

Sensory evaluation studies conducted in Uganda, Tanzania, Mozambique, and South Africa showed that consumers liked the sensory attributes of OSP, as well as those of various products (e.g., bread, chips, and doughnuts) made with OSP. Studies conducted in rural areas of Uganda revealed that when nutrition information on the benefits of OSP was provided, consumers valued orange varieties more than white ones. Another study conducted in Mozambique found that consumers valued OSP and that the value was influenced by information on nutritional benefits. These studies highlight the importance of information campaigns in driving demand for OSP (Chowdhury et al. 2011).

Vitamin A Cassava

A consumer acceptance study conducted in Imo and Oyo states of Nigeria tested yellow cassava *gari* (a popular fermented food) against local *gari*. The local *gari* tested was white in Oyo but yellow (mixed with red palm oil) in Imo, in accordance with regional preferences (Oparinde et al. 2014). In Imo state, tests revealed that in the absence of nutrition information, local *gari* was preferred to the *gari* made with either light- or deeper-colored yellow cassava varieties. Once consumers were told about the nutritional benefits of yellow cassava, however, *gari* made with the deeper-colored yellow cassava was preferred. Nutrition campaigns are very important in this state.

In Oyo state, tests revealed that consumers preferred the *gari* made with light yellow cassava even in the absence of nutrition information. Once consumers received information about the nutritional benefits of yellow cassava varieties, light-colored yellow cassava remained as the most popular variety, but *gari* made with deeper-colored yellow cassava was preferred over the local variety. In Oyo, the light-colored yellow cassava could become a popular variety even without nutrition campaigns.

Vitamin A Maize

In a consumer acceptance study in rural Zambia, consumers valued more highly *nshima* made with orange maize compared with *nshima* from white and yellow maize varieties, even in the absence of nutrition information (Meenakshi et al. 2012). Nutrition information, however, translated into value for orange maize. Two media channels (simulated radio messaging and community leaders) were used to convey the nutrition message. The study found consumers showed similar values regardless of the media source, implying that radio messaging, which is significantly less costly than face-to-face message delivery, can be used to convey nutrition information.

Iron Bean

Consumer acceptance studies conducted in rural Rwanda showed that even in the absence of nutrition information, consumers in Western province liked the sensory attributes of one of the iron bean varieties tested more than the local or other iron bean variety (Oparinde et al. 2016). Information on the nutritional benefits of iron bean varieties did not have a clear effect on consumers' preference. In urban wholesale and retail markets, consumers preferred one of the iron bean varieties more than the local and other iron bean variety tested. With information on nutritional benefits of iron bean varieties, however, consumers preferred both iron bean varieties to the local one.

Iron Pearl Millet

A consumer acceptance study was conducted in rural Maharashtra, India, where *bakhri* made with iron pearl millet and market-purchased pearl millet were evaluated (Banerji et al. 2013). Results reveal that even in the absence of information about the nutritional benefits of iron pearl millet, consumers liked the sensory attributes of the grain and *bakhri* of the iron pearl millet variety as much as (if not more than) those of the conventional variety.

Biofortification is cost-effective

Ex-post cost-effectiveness data is currently available for orange sweet potato in Uganda, where biofortification was demonstrated to cost US$15-$20 per Disability Adjusted Life Year (DALY) saved, which the World Bank considers highly cost effective (World Bank 1993; HarvestPlus 2010). For other countries where large-scale delivery efforts have recently started or are about to begin, HarvestPlus has calculated the ex-ante cost per DALY saved for each of the country-crop-micronutrient combinations HarvestPlus is currently targeting. The preliminary results showed that for each of the country-crop-micronutrient combinations considered, biofortification is a cost-effective intervention per World Bank standards. Compared to other interventions, such as supplementation and fortification, biofortification was found to be significantly more cost effective in most countries analyzed (Birol et al. 2014).

Using a different approach, the Copenhagen Consensus ranked interventions for reducing micronutrient deficiencies, including biofortification, among the highest value-for-money investments for economic development. For every dollar invested in biofortification, as much as US$17 of benefits may be gained (Hoddinott, Rosegrant, and Torero 2012).

Research findings have shown that biofortification is a cost-effective and feasible means of reaching malnourished rural populations who may have limited access to diverse diets, supplements, and commercially fortified foods. While biofortification is one solution among many that are needed to solve the complex problem of micronutrient deficiency, scaling up the use of biofortified crops will benefit millions of people.

References

Banerji, A., S. Chowdhury, H. De Groote, J.V. Meenakshi. 2013. Using Elicitation Mechanisms to Estimate the Demand for Nutritious Maize: Evidence from Experiments in Rural Ghana. HarvestPlus Working Paper 10. Washington, DC: HarvestPlus.

Birol, E., D. Asare-Marfo, J. Fiedler, B. Ha, K. Lividini, M. Moursi, M. Zeller, J.V. Meenakshi, and A. Stein. 2014. "Cost-effectiveness of biofortification." *Biofortification Progress Briefs.* Washington, DC: HarvestPlus.

Birol, E., J.V. Meenakshi, A. Oparinde, S. Perez, and K. Tomlins. 2015. "Developing country consumers' acceptance of biofortified foods: A synthesis." *Food Security* 7(3): 555.-568.

Bouis, H. E., C. Hotz, B. McClafferty, J. V. Meenakshi, and W. H. Pfeiffer. 2011. "Biofortification: A new tool to reduce micronutrient malnutrition." *Food and Nutrition Bulletin* 32 (Supplement 1): 31S-40S.

Chowdhury, S., J. V. Meenakshi, K. Tomlins, and C. Owori. 2011. "Are consumers in developing countries willing to pay more for micronutrient-dense biofortified foods? Evidence from a field experiment in Uganda." *American Journal of Agricultural Economics* 93 (1): 83–97.

De Moura, F., A. Miloff, and E. Boy. 2015. "Retention of provitamin A carotenoids in staple crops targeted for biofortification in Africa: Cassava, maize, and sweet potato." *Critical Reviews in Food Science and Nutrition* 55(9): 1246-69.

De Moura, F., A. Palmer, J. Finkelstein, J. Haas, L. Murray-Kolb, M. Wenger., E. Birol, E.Boy. and J. P. Pena-Rosas. 2014. "Are biofortified staple food crops improving vitamin A and iron status in women and children? New evidence from efficacy trials." *Advances in Nutrition* (5): 568-570.

Finkelstein, J., S. Mehta, S. Udipi, P. Ghugre, S. Luna, M. Wenger, L. Murray-Kolb, E. Przybyszewski, and J. Haas. 2015. "A Randomized Trial of Iron-Biofortified Pearl Millet in School Children in India." *Journal of Nutrition.* DOI: 10.3945/jn.114.208009

Gannon, B., C. Kaliwile, S. Arscott, S. Schmaelzle, J. Chileshe, N. Kalungwana, M. Mosanda, K. Pixley, C. Masi, and S. Tanumihardjo. 2014. "Biofortified orange maize is as efficacious as a vitamin A supplement in Zambian children even the presence of high liver reserves of vitamin A: A community-based, randomized placebo-controlled trial." *American Journal of Clinical Nutrition* December.

Haas, J. 2014. "Efficacy and other nutrition evidence for iron crops." *Biofortification Progress Briefs.* Washington, DC: HarvestPlus.

Haas, J., S.V. Luna, M.G. Lung'aho, F. Ngabo, M. Wenger, L. Murray-Kolb, S. Beebe, J. Gahutu, and I. Egli. 2016. "Consuming iron biofortified beans significantly improved iron status in Rwandan women after 18 weeks." *Journal of Nutrition,* forthcoming.

Haskell, M. J., K. M. Jamil, F. Hassan, J. M. Peerson, M. I. Hossain, G. J. Fuchs, and K. H. Brown. 2004. "Daily consumption of Indian spinach (basella alba) or sweet potatoes has a positive effect on total-body vitamin a stores in Bangladeshi men." *American Journal of Clinical Nutrition* 80: 705-14.

Hoddinott, J., M. Rosegrant, and M. Torero. 2012. "Investments to Reduce Hunger and Undernutrition," Copenhagen Consensus Challenge Paper. http://www.copenhagenconsensus.com/sites/default/files/Hunger+and+Malnutrition.pdf

Hotz, C., C. Loechl, A. de Brauw, P. Eozenou, D. Gilligan, M. Moursi, B. Munhaua, et al. 2012a. "A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women." *British Journal of Nutrition* 108: 163-176.

Hotz., C., C. Loechl, A. Lubowa, J. Tumwine, G. Ndeezi, A. Masawi, R. Baingana, et al. 2012b. "Introduction of B-carotene-rich orange sweet potato in rural Uganda results in increased vitamin A intakes among children and women and improved vitamin A status among children." *Journal of Nutrition* 142: 1871-1880.

Islam, M., L. Woodhouse, M. Hossain, T. Ahmed, M. Huda, T. J. Peerson, C. Hotz, K. Brown. 2013. "Total zinc absorption from a diet containing either conventional rice or higher-zinc rice does not differ among Bangladeshi preschool children." *Journal of Nutrition* 143: 519–525.

Johnson, N., H. Guedenet, A. Saltzman. 2015. "What Will It Take for Biofortification to Have Impact on the Ground? Theories of Change for Three Crop-country Combinations." International Food Policy Research Institute Discussion Paper 01427.

Jones, K., and A. de Brauw. 2015. "Using agriculture to improve child health: Promoting orange sweet potatoes reduces diarrhea." *World Development* 74: 15-24.

Low J. W., M. Arimond, N. Osman, B. Cunguara, F. Zano, and D. Tschirley. 2007. "A food-based approach introducing orange fleshed sweet potato increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique." *Journal of Nutrition* 137: 1320-7.

Meenakshi, J. V., A. Banerji, V. Manyong, K. Tomlins, N. Mittal and P. Hamukwala. 2012. "Using a Discrete Choice Experiment to Elicit the Demand for a Nutritious Food: Willingness-to-Pay for Orange Maize in Rural Zambia," *Journal of Health Economics* 31: 62-71.

Meenakshi, J. V., N. Johnson, V. Manyong, H. DeGroote, J. Javelosa, D. Yanggen, F. Naher, et al. 2010. "How cost-effective is biofortification in combating micronutrient malnutrition? An ex ante assessment." *World Development* 38 (1): 64–75.

Oparinde, A., A. Banerji, E. Birol, and P. Ilona. 2014. "Information and Consumer Willingness to Pay for Biofortified Yellow Cassava: Evidence from Experimental Auctions in Nigeria." HarvestPlus Working Paper 13. Washington, DC: HarvestPlus.

Oparinde, A., E. Birol, A. Murekezi, L. Katsvairo, M. Diressie, J.D. Nkundiamana, and L. Butare. 2016. "Radio messaging frequency, information framing and consumer willingness to pay for biofortified iron beans: Evidence from revealed preference elicitation in rural Rwanda." *Canadian Journal of Agricultural Economics,* forthcoming.

Rosado, J., K.M. Hambidge, L. Miller, O. Garcia, J. Westcott, K. Gonzalez, J. Conde, C. Hotz, W. Pfeiffer, I. Ortiz-Monasterio, and N. Krebs. 2009. "The quantity of zinc absorbed from wheat in adult women is enhanced by biofortification." *Journal of Nutrition* 139: 1920–1925.

Saltzman, A., E. Birol, H. Bouis, E. Boy, F. De Moura, Y. Islam, and W. Pfeiffer. 2013. "Biofortification: Progress toward a more nourishing future." *Global Food Security* 2 (1): 9–17.

Talsma, E., I. Brouwer, H. Verhoef, G. Mbera, A. Mwangi, A. Demir, B. Maziya-Dixon, E. Boy, M. Zimmermann, and A. Melse-Boonstra. 2015. "Biofortified yellow cassava and vitamin A status of Kenyan children: a randomized controlled trial." *American Journal of Clinical Nutrition.*

van Jaarsveld, P. J., M. Faber, S. A. Tanumihardjo, P. Nestel, C. J. Lombard, and A. J. Spinnler Benadé. 2005. "ß-carotene rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test." *American Journal of Clinical Nutrition* 81: 1080-1087.

World Bank. 1993. *World Development Report.* Washington, D.C.