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Biofortification: The Evidence

A summary of research that supports the scaling up biofortification to improve nutrition globally

HarvestPlus leads a global effort to develop and scale up micronutrient-rich staple food crops. The process used is known as biofortification: a cost-effective, sustainable solution that uses conventional plant breeding to increase the density of vitamins and minerals in staple crops consumed widely as part of everyday diets in Africa, Asia, and Latin America and the Caribbean. Micronutrients, although only required by the body in very small amounts, are essential to good health, cognition, and productivity.

Biofortification helps minimize the widespread gap between micronutrient requirements and intake by increasing the proportion of dietary vitamin A, iron, and zinc—three micronutrients of public health significance globally. Biofortified crops are particularly useful for delivering added nutrients to rural communities, where the majority of lower-income, small-holder farming families reside and where commercial fortification and/or supplementation is often inaccessible. Women and young children are the primary targets of biofortification because they have high nutrient needs that often go unmet; yet, since staple foods are consumed widely by all household members, biofortification can provide profound health benefits to the whole family.

According to preliminary monitoring data estimates, by the end of 2017 approximately 30 million people were benefitting from biofortified crops in HarvestPlus' 14 target countries across Africa, Asia, and Latin America and the Caribbean. By 2020, HarvestPlus aims to reach 20 million farming households with biofortified planting material, benefiting at least 100 million people, and, by 2030, one billion people are expected to consume biofortified foods globally.

HarvestPlus and its partners measure the impact of biofortified crop consumption on women and children's nutritional status and functional outcomes, such as mental and physical performance. Delivery progress and the impacts of adoption on livelihoods are captured through HarvestPlus' rigorous monitoring and evaluation system. Assessments of the effectiveness, cost-effectiveness, and impact of various delivery and promotion strategies are tested along value chains to share lessons learned and catalyze scale-up.

Over the last 15 years, research conducted by HarvestPlus and its partners has demonstrated that:

- Conventional crop breeding can increase nutrient levels without compromising yield
- Extra nutrients in crops measurably improve micronutrient status, health, and cognitive abilities
- Farmers are willing to grow biofortified crops and consumers are willing to eat them
- Biofortification is cost-effective

The evidence that biofortification works is robust and well documented [1-4]. *The African Journal of Food, Agriculture, Nutrition, and Development* and the *Annals of the New York Academy of Sciences* recently devoted special issues to biofortification, which summarize the evidence landscape and suggest the way forward for this agricultural-nutrition intervention [5, 6].

Conventional crop breeding can increase nutrient levels without compromising yield

Plant breeders screen thousands of crop varieties stored in global seed banks to discover varieties with naturally higher amounts of essential micronutrients. Then, through collaborations with various breeding centers of the Consortium of International Agricultural Research (CGIAR), and national agricultural research systems, these nutrient-rich varieties are used to breed biofortified varieties that are also high-yielding, disease and pest resistant, and climate smart in local agro-ecological conditions.

Planting material for biofortified crops are made available as public goods to national governments, who test and officially release the enriched varieties for planting in their country. Where they are sold by the private sector, they are competitively priced so smallholder farmers can afford them.

Biofortified crops are bred to fulfill a significant portion of the dietary requirement of iron, zinc, or vitamin A among women and children, based on their usual eating patterns, in populations where these crops are consumed as staples. It is estimated that for children 4- to 6-years-old and for non-pregnant, non-lactating women of reproductive age, biofortification provides an additional 35% of the Estimated Average Requirement (EAR) of iron in beans and 40% in pearl millet; the additional zinc in wheat and rice provides up to 25% and 40% of the EAR, respectively; and, provitamin A in yellow cassava, orange maize, and OSP provides > 50% of the EAR.

More than 180 varieties of eleven biofortified crops, including vitamin A orange sweet potato (OSP), vitamin A yellow cassava, vitamin A orange maize, iron beans, iron pearl millet, zinc rice, and zinc wheat, have been officially released in over 30 countries and are being tested and grown in over 30 more. As crop development research advances, the nutrient density of crops is further increased, and biofortified varieties are better adapted to the changing climate and consumer preferences. Most recently, zinc maize was released in Honduras and will be released in additional Latin American countries in 2018.

Extra nutrients in crops improve health, micronutrient status, and cognitive abilities

Nutritionists measure the loss and retention of micronutrients in crops under traditional processing, storage, and cooking conditions to be sure that sufficient levels of vitamins and minerals remain in foods that target populations typically eat [7-12]. Nutritionists also study the degree to which nutrients bred into crops are absorbed in the body, a prerequisite to improving micronutrient status [13]. Randomized controlled efficacy trials are used to demonstrate the impact of biofortified crops on nutritional status and functional indicators of micronutrient status (e.g. visual adaptation to darkness for vitamin A crops; and memory, attention, and physical activity for iron crops). Finally, randomized controlled effectiveness studies provide evidence that biofortified crops can improve the nutritional status of populations under typical (non-clinical) conditions.

As the case for biofortification builds, rigorous external reviews of the evidence are also taking place. For example, a recent systematic review of three randomized efficacy trials on iron-biofortified crops reinforced the conclusion that iron-biofortified interventions significantly improve iron status—particularly among women and children in low-income communities who need it most [14]. In addition, a World Health Organization (WHO) Cochrane review committee was assembled in 2016 to review the scientific evidence and country experiences of scaling up biofortification. Eight papers were published in the *Annals of the New York Academy of Science* as part of the consultation and a WHO recommendation on biofortification is expected in 2019.

Vitamin A Orange Sweet Potato

Consumption of OSP can result in a significant increase in vitamin A body stores across age groups [15-17]. The primary evidence for the effectiveness of biofortification comes from OSP, assessed through a randomized controlled effectiveness trial. The study reached 24,000 households in Uganda and Mozambique from 2006 to 2009, with adoption rates of OSP reaching over 60% among the beneficiaries. In Uganda, the introduction and promotion of OSP over four growing seasons resulted in significantly increased serum retinol at endline for children under five in the OSP intervention group who had low vitamin A status at the beginning of the study [18]. In Mozambique, consumption of OSP by children under five significantly reduced the burden of diarrhea, the second leading cause of death in this age group globally; the likelihood of experiencing diarrhea was reduced by 39% and duration of diarrhea episodes was reduced by more than 10% [19].

Vitamin A Yellow Cassava

An efficacy study in Eastern Kenya with 5- to 13-year-old rural school children demonstrated modest but significant improvement in serum concentrations of retinol and beta-carotene in the vitamin A yellow cassava versus the control group [20]. A recently completed efficacy trial with children under five in rural Nigeria aims to demonstrate the protective effect of yellow cassava on vitamin A status.

Vitamin A Orange Maize

Beta-carotene in orange maize is an efficacious source of vitamin A when consumed as a staple crop. An efficacy study in rural Zambia with 5- to 6-year-old children showed that after three months, total body stores of vitamin A in children eating orange maize increased significantly compared to control group [21]. A larger trial with over 1,000 marginally malnourished 4- to 8-year-old children in another farming district of Zambia demonstrated that vitamin A orange maize consumption increased serum beta-carotene concentrations but did not improve serum retinol [22]. In this same trial, visual adaptation to darkness was assessed: among children who were vitamin A deficient at baseline, those who consumed orange maize had greater improvement in pupillary responsiveness than those in the control group, improving their ability to see in dim light [23]. Another study in the same region showed no increase in mean breast milk retinol concentration among women who consumed vitamin A orange maize; however, the plausible downward trend in the risk of low milk retinol warrants further investigation [24].

Iron Beans

Biofortified iron beans have been demonstrated to be efficacious in two different populations. In Mexico, after consuming biofortified black beans for 3.5 months, the iron status of primary school children improved [25]. In Rwanda, iron-deficient university women showed a significant increase in hemoglobin, ferritin, and total body iron after consuming biofortified beans for 4.5 months [26]. The latter study also found that iron beans had a profound effect on cognition: iron deficient women who ate biofortified beans experienced improved memory and ability to pay attention [27], key skills for optimal performance at school and work. The study also measured physical performance and preliminary results suggest improvements in iron status were accompanied by a reduction in time spent in sedentary activity [28].

Iron Pearl Millet

Iron pearl millet was demonstrated to be an efficacious approach to improve iron status in adolescent children through a six-month study conducted in rural Maharashtra, India. After only four months, iron deficiency was significantly reduced and serum ferritin and total body iron were significantly improved in secondary school children who consumed iron pearl millet flat bread twice daily. Children who were iron deficient at baseline were 64% more likely to resolve their deficiency by six months [29]. Forthcoming results from the same trial indicate that iron biofortified pearl millet consumption also improved cognitive performance [30].

Zinc Rice

A 2010 zinc bioavailability pilot trial, designed to estimate the amount of absorbed zinc from zinc rice compared to conventional rice, did not produce detectable differences [31]. The study was redesigned adjusting for zinc losses during rice processing and a new absorption trial is planned with a higher zinc rice variety, followed by an efficacy trial. Another study compared the absorption of zinc from a biofortified rice variety and commercially fortified rice in 16 healthy adults. Their findings indicate that biofortification of rice is likely as good as postharvest zinc fortification at tackling zinc deficiency [32].

Zinc Wheat

An absorption study among women in Mexico showed that total absorbed zinc was significantly greater from biofortified wheat than from non-biofortified wheat [33]. These findings were corroborated when the absorption of zinc in whole and refined flour from postharvest fortified wheat and agronomically biofortified wheat were tested prior to a randomized controlled efficacy trial in India [34]. Two efficacy trials using wheat biofortified by foliar spraying with zinc fertilizer were completed in 2015: one with 250 school children in Bangalore and the other with 3,000 pairs of women and children under two in New Delhi. Final reports are expected by the end of 2018.

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

Economists are leading studies to inform delivery and marketing strategies that will maximize adoption and consumption of biofortified crops. Farmers' willingness to grow biofortified crops is investigated through farmer field day evaluations, adoption studies, as well as impact evaluation studies. These studies showed that farmers liked the various agronomic and consumption attributes of biofortified crops, and—in all cases studied—the rates of adoption and diffusion of biofortified varieties were significant and sustained [35]. Sensory evaluations (e.g. of appearance, taste, and texture) and willingness to pay studies of vitamin A maize, vitamin A cassava, and iron pearl millet found that consumers liked biofortified varieties as least as much as conventional ones, even in the absence of information about the nutritional benefits. For all crops studied, consumers valued the biofortified varieties and preferred the sensory attributes over non-biofortified varieties when given nutrition information. Highlights from a detailed review of these consumer acceptance findings [36] are discussed below.

Vitamin A Orange Sweet Potato

The randomized effectiveness controlled trial in Mozambique and Uganda (2006-2009) evaluated the impact of two delivery models (one providing more intensive training on nutrition and best agronomics practices than the other) on OSP adoption, vitamin A intake, and vitamin A status of beneficiary households. The study found that 61% and 68% of beneficiary households adopted OSP in Uganda and Mozambique, respectively, and no significant differences in the adoption, vitamin A intake, and vitamin A status outcomes resulting from the two delivery models [37]. In 2011, a follow-up study in Uganda found that adoption rates remained high in two of the three study areas and that nutrition information was well retained. The area with the lower adoption rates became a major supplier, but not consumer, of OSP [38]. These impact evaluations provided a crucial evidence-base for donors and helped inform the scaling up of biofortification in Uganda [39].

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 made with OSP such as bread [36]. Studies in rural Uganda revealed that when nutrition information on the benefits of OSP was provided, consumers valued the vitamin A rich orange varieties more than white ones [40]. Another study conducted in Mozambique also found that consumers valued OSP and that the value was influenced by information on

nutritional benefits [41]. Collectively, these studies highlight the importance of information campaigns in driving demand for OSP.

Vitamin A Yellow Cassava

A consumer acceptance study in two states within Nigeria tested vitamin A yellow cassava *gari* against local *gari.* In the state of Oyo, the local *gari* tested was made with white cassava, and in the state of Imo it was yellow (white cassava mixed with red palm oil), in accordance with regional preferences. In Oyo, consumers preferred *gari* made with light yellow cassava even in the absence of nutrition information. Once consumers received information about the nutritional benefits of vitamin A yellow cassava varieties, light-colored yellow cassava remained the most popular, but *gari* made with deeper-colored yellow cassava was preferred over the local variety [42].

In Imo, in the absence of nutrition information, local *gari* was preferred to the *gari* made with either light- or deeper-colored yellow cassava varieties. However, once consumers were told about the nutritional benefits of yellow cassava, *gari* made with the deeper-colored yellow cassava was preferred, highlighting the importance of information campaigns in this area.

Vitamin A Orange Maize

In Zambia, farmer field day surveys in 2012 and an adoption study in 2016 confirmed a strong preference by farmers for both the production and consumption attributes of vitamin A orange maize varieties compared with conventional white maize varieties. Farmers appreciated the yield, cob size, and cob-filling characteristics of the new varieties, as well as the taste and aroma of orange maize preparations. Nearly all farmers (97%) said they would grow orange maize in the next season and that they were planning to plant four times more seed than they did in the previous (2014-2015) season [43].

In another consumer acceptance study in rural Zambia, consumers valued *nshima* made with vitamin A orange maize more highly than *nshima* from white and yellow maize varieties, even in the absence of nutrition information [44]. When nutrition information was delivered by radio or community leaders, it translated into even greater acceptance of orange maize. The increases in acceptance were similar regardless of the media source, implying that radio—which is significantly less costly than face-to-face messaging—can be used to effectively convey nutrition information. Another study, conducted in rural Ghana, found that consumers valued *kenkey* made with orange maize less than *kenkey* made with either white or yellow maize, but the provision of nutrition information reversed this preference. An information campaign will be key to driving consumer acceptance of orange maize in Ghana [45].

Iron Beans

A study conducted in Rwanda in 2015 assessed the adoption and diffusion rates of iron bean varieties after eight seasons of intensive delivery efforts. Data from this nationally representative study revealed that 28% of rural bean-producing households—about half a million households—had planted at least one iron bean variety in at least one of the past eight seasons. Also, in the first bean-growing season of 2015, an estimated 20% of all bean growers in Rwanda (more than 300,000 rural households) grew iron beans. Further analysis revealed several encouraging findings: awareness of iron beans is high among bean growers in Rwanda, with over two-thirds having heard of iron varieties; diffusion levels are high, with four out of 10 farmers receiving planting material from a farmer in their social network; and, the proportion of land farmers are allocating to iron beans is increasing (from 48% in season one to 70% in season six). Additionally, in the season this study was conducted (Season B, 2015) iron bean varieties made up almost 12% of the national bean production, and within households, 80% of iron beans produced were saved for household consumption [46].

Consumer acceptance studies conducted in rural Rwanda showed that even in the absence of nutrition information, consumers in the Northern Province liked the sensory attributes of a biofortified red iron bean variety more than a white iron bean or local bean variety [47]. Nutrition information had a positive effect on the premium consumers in urban wholesale, and retail markets were willing to pay for iron beans: when provided, both iron bean varieties were preferred to the local variety. When compared across regions, consumers in the rural Western Province and urban wholesale market also had similar preferences for one of the iron bean varieties tested, suggesting potential for linking demand and supply [48]. Another analysis of multiple sensory attributes revealed several opportunities for marketing iron beans in both rural and urban markets [49]. Consumer acceptance of iron beans was also evaluated in Northwest Guatemala, and it was found that irrespective of information on nutritional benefits, consumers had equal preference for iron beans and the popular conventional bean in that region [50].

Iron Pearl Millet

A consumer acceptance study of *bhakri* made with iron pearl millet conducted in rural Maharashtra, India, revealed that even in the absence of information about the nutritional benefits, consumers liked the sensory attributes of iron pearl millet grain and the *bhakri* made from it as much as, if not more than, conventional pearl millet grain and *bhakri*. When nutrition information was provided, consumer acceptance and willingness to pay was even greater [51].

Biofortification is cost-effective

Cost-effectiveness data on OSP from Uganda demonstrated that biofortification costs $15-$20 USD per Disability Adjusted Life Year (DALY) saved, which the World Bank considers highly cost-effective [52, 53]. For other countries where large-scale delivery efforts have recently started or are about to begin, HarvestPlus has calculated the expected cost per DALY saved for each context. Preliminary results show that for every country-crop-micronutrient combination, biofortification is cost-effective per the 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 [54]. Even in countries where relatively few DALYs are lost due to micronutrient deficiency, biofortification is expected to have an advantageous benefit-cost ratio [55].

The Copenhagen Consensus ranked interventions that reduce micronutrient deficiencies, including biofortification, among the highest value-for-money investments for economic development. For every dollar invested in biofortification, as much as $17 USD of benefits may be gained [56].

Agricultural systems provide the most sustainable means to add essential vitamins and minerals into the diet; biofortification is a cost-effective, feasible agricultural-nutrition intervention that can reach malnourished rural populations who may have limited access to diverse diets, supplements and/or commercially fortified foods [57].

References

1. Bouis HE, Hotz C, McClafferty B, Meenakshi JV, Pfeiffer WH. Biofortification: a new tool to reduce micronutrient malnutrition. Food and Nutrition Bulletin. 2011 Mar;32(1):S31-40.

2. Saltzman A, Birol E, Bouis HE, Boy E, De Moura FF, Islam Y, Pfeiffer WH. Biofortification: Progress toward a more nourishing future. Global Food Security. 2013 Mar 31;2(1):9-17.

3. Johnson, N, Guedenet H, Saltzman A. 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. Washington, DC: International Food Policy Research Institute. 2015.

4. Bouis HE, Saltzman A. Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. Global Food Security. 2017 Mar 31;12:49-58.

5. Bouis H, Saltzman A, Low J, Ball A, Covic N. An overview of the landscape and approach for biofortification in Africa. African Journal of Food, Agriculture, Nutrition and Development. 2017b;17(2):11848-64.

6. Garcia-Casal MN, Peña-Rosas JP, Giyose B. Staple crops biofortified with increased vitamins and minerals: considerations for a public health strategy. Annals of the New York Academy of Sciences. 2017 Feb 1;1390(1):3-13

7. Boy E, Miloff A. Provitamin A carotenoid retention in orange sweet potato: A review of the literature. Sight and Life Magazine. Basel, Switzerland: Sight and Life Foundation. 2009 Mar; 3:27-33.

8. Carvalho LM, Corrêa MM, Pereira EJ, Nutti MR, Carvalho JL, Ribeiro EM, Freitas SC. Iron and zinc retention in common beans (Phaseolus vulgaris L.) after home cooking. Food & Nutrition Research. 2012 Feb 29;56.

9. De Moura FF, Palmer AC, Finkelstein JL, Haas JD, Murray-Kolb LE, Wenger MJ, Birol E, Boy E, Peña-Rosas JP. Are biofortified staple food crops improving vitamin A and iron status in women and children? New evidence from efficacy trials. Advances in Nutrition: An International Review Journal. 2014 Sep 1;5(5):568-70.

10. De Moura FF, Miloff A, Boy E. 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. 2015 Jul 29;55(9):1246-69.

11. Mugode L, Ha B, Kaunda A, Sikombe T, Phiri S, Mutale R, Davis C, Tanumihardjo S, De Moura FF. Carotenoid retention of biofortified provitamin A maize (Zea mays L.) after Zambian traditional methods of milling, cooking and storage. J Agric Food Chem. 2014 Jul 9;62(27):6317-25

12. Taleon V, Mugode L, Cabrera-Soto L, Palacios-Rojas N. Carotenoid retention in biofortified maize using different post-harvest storage and packaging methods. Food Chemistry. 2017 Oct 1;232:60-6.

13. La Frano MR, de Moura FF, Boy E, Lönnerdal B, Burri BJ. Bioavailability of iron, zinc, and provitamin A carotenoids in biofortified staple crops. Nutrition Reviews. 2014 May 1;72(5):289-307.

14. Finkelstein JL, Haas JD, Mehta S. Iron-biofortified staple food crops for improving iron status: A review of the current evidence. Current Opinion in Biotechnology. 2017 Apr 30;44:138-45.

15. Haskell MJ, Jamil KM, Hassan F, Peerson JM, Hossain MI, Fuchs GJ, Brown KH. Daily consumption of Indian spinach (Basella alba) or sweet potatoes has a positive effect on total-body vitamin A stores in Bangladeshi men. The American Journal of Clinical Nutrition. 2004 Sep 1;80(3):705-14.

16. van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Benadé AJ. β-Carotene-rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. The American Journal of Clinical Nutrition. 2005 May 1;81(5):1080-7.

17. Low JW, Arimond M, Osman N, Cunguara B, Zano F, Tschirley D. A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. The Journal of Nutrition. 2007 May 1;137(5):1320-7.

18. Hotz C, Loechl C, Lubowa A, Tumwine JK, Ndeezi G, Masawi AN, Baingana R, Carriquiry A, de Brauw A, Meenakshi JV, Gilligan DO. Introduction of β-carotene–rich orange sweet potato in rural Uganda resulted in increased vitamin A intakes among children and women and improved vitamin A status among children. The Journal of Nutrition. 2012 Oct 1;142(10):1871-80.

19. Jones KM, de Brauw A. Using agriculture to improve child health: Promoting orange sweet potatoes reduces diarrhea. World Development. 2015 Oct 31;74:15-24.

20. Talsma EF, Brouwer ID, Verhoef H, Mbera GN, Mwangi AM, Demir AY, Maziya-Dixon B, Boy E, Zimmermann MB, Melse-Boonstra A. Biofortified yellow cassava and vitamin A status of Kenyan children: A randomized controlled trial. The American Journal of Clinical Nutrition. 2016 Jan 1;103(1):258-67.

21. Gannon B, Kaliwile C, Arscott SA, Schmaelzle S, Chileshe J, Kalungwana N, Mosonda M, Pixley K, Masi C, Tanumihardjo SA. Biofortified orange maize is as efficacious as a vitamin A supplement in Zambian children even in the presence of high liver reserves of vitamin A: A community-based, randomized placebo-controlled trial. The American Journal of Clinical Nutrition. 2014 Dec 1;100(6):1541-50.

22. Palmer AC, Siamusantu W, Chileshe J, Schulze KJ, Barffour M, Craft NE, Molobeka N, Arguello MA, Mitra M, Caswell B, Klemm RD. Provitamin A–biofortified maize increases serum β-carotene, but not retinol, in marginally nourished children: A cluster-randomized trial in rural Zambia. The American Journal of Clinical Nutrition. 2016a Jul 1;104(1):181-90.

23. Palmer AC, Healy K, Barffour MA, Siamusantu W, Chileshe J, Schulze KJ, West KP, Labrique AB. Provitamin A carotenoid–biofortified maize consumption increases pupillary responsiveness among Zambian children in a randomized controlled trial. The Journal of Nutrition. 2016b Dec 1;146(12):2551-8.

24. Palmer AC, Chileshe J, Hall AG, Barffour MA, Molobeka N, West KP, Haskell MJ. Short-term daily consumption of provitamin A carotenoid–biofortified maize has limited impact on breast milk retinol concentrations in Zambian women enrolled in a randomized controlled feeding trial. The Journal of Nutrition. 2016c Sep 1;146(9):1783-92.

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

26. Haas JD, Luna SV, Lung'aho MG, Wenger MJ, Murray-Kolb LE, Beebe S, Gahutu JB, Egli IM. Consuming iron biofortified beans increases iron status in Rwandan women after 128 days in a randomized controlled feeding trial. The Journal of Nutrition. 2016 Aug 1;146(8):1586-92.

27. Murray-Kolb LE, Wenger MJ, Scott SP, Rhoten SE, Lung'aho MG, Haas JD. Consumption of Iron-Biofortified Beans Positively Affects Cognitive Performance in 18-to 27-Year-Old Rwandan Female College Students in an 18-Week Randomized Controlled Efficacy Trial. The Journal of Nutrition. 2017 Nov 1;147(11):2109-17.

28. Luna SV, Lung'aho M, Gahutu JB, Haas J. Effects of an iron-biofortification feeding trial on physical performance of Rwandan women. European Journal of Nutrition & Food Safety. 2015 Aug 14;5(5):1189.

29. Finkelstein JL, Mehta S, Udipi SA, Ghugre PS, Luna SV, Wenger MJ, Murray-Kolb LE, Przybyszewski EM, Haas JD. A randomized trial of iron-biofortified pearl millet in school children in India. The Journal of Nutrition. 2015 Jul 1;145(7):1576-81.

30. Scott S, Murray-Kolb L, Wenger M, Udipi S, Ghugre P, Haas J. Iron-biofortified pearl millet improves attentional function in Indian adolescents, a 6-month randomized controlled trial. The FASEB Journal. 2014; 28(1); Supplement 619.2.

31. Islam MM, Woodhouse LR, Hossain MB, Ahmed T, Huda MN, Ahmed T, Peerson JM, Hotz C, Brown KH. Total zinc absorption from a diet containing either conventional rice or higher-zinc rice does not differ among Bangladeshi preschool children. The Journal of Nutrition. 2013 Apr 1;143(4):519-25.

32. Brnić M, Wegmüller R, Melse-Boonstra A, Stomph T, Zeder C, Tay FM, Hurrell RF. Zinc absorption by adults is similar from intrinsically labeled zinc-biofortified rice and from rice fortified with labeled zinc sulfate. The Journal of Nutrition. 2016 Jan 1;146(1):76-80.

33. Rosado JL, Hambidge KM, Miller LV, Garcia OP, Westcott J, Gonzalez K, Conde J, Hotz C, Pfeiffer W, Ortiz-Monasterio I, Krebs NF. The quantity of zinc absorbed from wheat in adult women is enhanced by biofortification. The Journal of Nutrition. 2009 Oct 1;139(10):1920-5.

34. Signorell C, Moretti D, Zeder C, Tay F, Boy E, Khetarpaul N, Cakmak I, Zimmerman M. Evaluation of Zinc Bioavailability in Humans from Foliar Zinc Biofortified Wheat and from Intrinsic vs. Extrinsic Zn Labels in Biofortified Wheat. European Journal of Nutrition and Food Safety. Conference Abstract. 2015 August 14; 5(5): 863-864

35. Saltzman A, Birol E, Oparinde A, Andersson MS, Asare-Marfo D, Diressie MT, Gonzalez C, Lividini K, Moursi M, Zeller M. Availability, production, and consumption of crops biofortified by plant breeding: current evidence and future potential. Annals of The New York Academy of Sciences. 2017 Feb 1; 1390:104-114.

36. Birol E, Meenakshi JV, Oparinde A, Perez S, Tomlins K. Developing country consumers' acceptance of biofortified foods: a synthesis. Food Security. 2015 Jun 1;7(3):555-68.

37. Arimond M, Ball AM, Bechoff A, Bosch D, Bouis H, de Brauw A, Coote C, Dove R, Eozenou P, Gilligan D, Hotz C, Kumar N, Labarta R, Loechl C, Low J, Magezi S, Massingue J, Meenakshi JC, Moursi M, Musoke C, Namanda S, Nsubuga H, Okwadi J, Tomlins K, Wamaniala M, Westby A. Reaching and Engaging End Users (REU): Orange Fleshed Sweet Potato in East and Southern Africa. Washington, DC: HarvestPlus. 2010.

38. McNiven S, Gilligan D, Hotz C. Sustainability of Impact: Dimensions of decline and persistence in adopting a biofortified crop in Uganda, 3ie Impact Evaluation Report 35. New Delhi: International Initiative for Impact Evaluation (3ie). 2016.

39. Menon, R. Using evidence to inform the scale-up and adoption of bio-fortified orange sweet potato in Uganda, 3ie Evidence Use Brief Series. New Delhi: International Initiative for Impact evaluation (3ie); 2017.

40. Chowdhury S, Meenakshi JV, Tomlins KI, Owori C. 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. 2011 Jan 10: 93(1):83-97.

41. Naico AT, Lusk JL. The value of a nutritionally enhanced staple crop: results from a choice experiment conducted with orange-fleshed sweet potatoes in Mozambique. Journal of African Economies. 2010 Mar 30;19(4):536-58.

42. Oparinde A, Banerji A, Birol E, Ilona P. Information and consumer willingness to pay for biofortified yellow cassava: evidence from experimental auctions in Nigeria. Agricultural Economics. 2016a; 47:215-233.

43. Tedla Diressie M, Zulu E, Smale M, Simpungwe E, Birol E. An assessment of the vitamin A maize seed delivery efforts to date: Agro-dealer sales and farmer production in Zambia. SUNFUND Project Report. Washington, DC: International Food Policy Research Institute. 2016.

44. Meenakshi JV, Banerji A, Manyong V, Tomlins K, Mittal N, Hamukwala P. 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. 2012 Jan 31;31(1):62-71.

45. Banerji A, Chowdhury S, De Groote H, Meenakshi JV, Tomlins K, Haleegoah J, Ewool M. Using elicitation mechanisms to estimate the demand for nutritious maize: Evidence from experiments in rural Ghana. Working Paper 10. Washington, DC: International Food Policy Research Institute. 2013.

46. Asare-Marfo D, Herrington C, Birachi E, Birol E, Cook K, Diressie MT, Dusenge L, Funes J, Katsvairo L, Katungi E, Labarta R, LaRochelle C, Lividini K, Moursi M, Mulambu J, Murekezi A, Musoni A, Nkundimana JA, Vaiknoras K, Zeller M. Assessing the adoption of high iron bean varieties and their impact on iron intakes and other livelihood outcomes in Rwanda: Main survey report. Washington, DC: HarvestPlus. 2016.

47. Oparinde A, Birol E, Murekezi A, Katsvairo L, Diressie MT, Butare L. 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/Revue Canadienne D'Agroeconomie. 2016b Dec 1;64(4):613-52.

48. Oparinde A, Murekezi A, Birol E and Katsvairo L. Demand-Pull Creation, Public Officer's Endorsement, and Consumer Willingness to-Pay for Nutritious Iron Beans in Rural and Urban Rwanda. HarvestPlus Working Paper No. 26, International Food Policy Research Institute, Washington DC. 2017.

49. Murekezi A, Oparinde A, Birol E. Consumer market segments for biofortified iron beans in Rwanda: Evidence from a hedonic testing study. Food Policy. 2017 Jan 31;66:35-49.

50. Pérez S, Buriticab A, Oparinde A, Birol E, Gonzalez C, Zeller M. Identifying Socioeconomic Characteristics Defining Consumers' Acceptance for Main Organoleptic Attributes of an Iron-biofortified Bean Variety in Guatemala. International Journal on Food System Dynamics. 2017 Jul 10;8(3):222-35.

51. Banerji A, Birol E, Karandikar B, Rampal J. Information, branding, certification, and consumer willingness to pay for high-iron pearl millet: Evidence from experimental auctions in Maharashtra, India. Food Policy. 2016 Jul 31;62:133-41.

52. World Bank. World Development Report 1993: Investing in Health. Washington, DC: World Bank. 1993.

53. Meenakshi JV, Johnson NL, Manyong VM, DeGroote H, Javelosa J, Yanggen DR, Naher F, Gonzalez C, García J, Meng E. How cost-effective is biofortification in combating micronutrient malnutrition? An ex ante assessment. World Development. 2010 Jan 31;38(1):64-75.

54. Birol E, Asare-Marfo D, Fiedler J, Ha B, Lividini K, Moursi M, Zeller M, Meenakshi JV, Stein A. Cost-effectiveness of biofortification. The 2nd Global Conference on Biofortification: Conference Brief #17. Washington, DC: HarvestPlus. 2014.

55. Lividini K, Fiedler JL, De Moura FF, Moursi M, Zeller M. Biofortification: A review of ex-ante models. Global Food Security. 2017 Nov 23.

56. Hoddinott J, Rosegrant M, Torero M. Investments to reduce hunger and undernutrition: Copenhagen Consensus Challenge Paper. 2012.

57. Bouis, HE. The role of agriculture and biofortification in the UN Decade of Action on Nutrition. UNSCN News 42: A Spotlight on the Nutrition Decade. 2017 p 33-41.