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Reducing Mineral and Vitamin Deficiencies through Biofortification: Progress under HarvestPlus

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When HarvestPlus first started in 2003, there was much doubt among a range of stakeholders, that biofortification would work. Over the last 15 years, biofortification research has demonstrated broadly that (Saltzman *et al.,* 2013):

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

The final task is to mainstream biofortification as central activities of a number of organizations.

Crop Development and Release

First, we had to prove to the plant science community that higher target levels iron, zinc, and provitamin A could be bred into high-yielding, profitable varieties. The crop development work focused on breeding crops with the desired nutrient levels, in collaboration with international research institutes and national research partners in target countries, to submit the best-performing varieties to national governments for release. Crop development research demonstrated that increased nutrient levels could be bred into crops without compromising yield, or other farmer-desired traits.

Biofortification research has greatly expanded the field of knowledge with regard to vitamin and mineral heritability and mechanisms of mineral loading in rice and wheat grain, in particular. Advances in genomic research, such as the identification of the alleles for lycopene epsilon cyclase (lycE) and beta-carotene hydroxylase 1 (crtRB1), which substantially affect the accumulation of beta-carotene in grain, have allowed plant breeders to use marker-assisted selection to more efficiently breed for the nutrient traits (Hares *et al.,* 2008). Coupled with breakthroughs in high throughput screening technologies, like XRF and NIRS, these advances reduce the time to market for current and future biofortified varieties. Breeding pipelines at CGIAR centers and NARS are filled, with next wave varieties to be released in the near future and even better varieties in development.

Presently, over 150 varieties across twelve biofortified crops have passed the agronomic tests of varietal release committees in 30 developing countries. They are in multi-location testing in an additional 25 countries.

Human Nutrition

Second, the nutrition community questioned the efficacy of biofortified crops – would the levels of retained nutrients and absorption be high enough? HarvestPlus has commissioned fourteen efficacy trials, all undertaken in developing countries. While four of these studies are still in process, there is already sufficient positive published evidence for iron and provitamin A, that the World Health Organization is now undertaking a systematic review of the evidence. This review will be completed and findings published by the WHO in 2017.

Bioavailability and efficacy studies have tested the effects of biofortified crops when consumed. Vitamin A nutrition research found efficient conversions from provitamin A to retinol, in most cases, more efficient than originally estimated. Efficacy studies have demonstrated that increasing provitamin A intake through consuming vitamin A-biofortified crops results in increased circulating beta-carotene, and has a moderate effect on vitamin A status, as measured by serum retinol. Consumption of orange maize specifically has been demonstrated to improve total body vitamin A stores as effectively as supplementation (Gannon *et al.,* 2012). Nutritionists agree that vitamin A biofortified crops have the potential to improve vitamin A status in deficient populations, but additional research is needed, using

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other, more sensitive biochemical indicators, as well as functional indicators, to fully understand the health impact of consuming biofortified foods.

Iron nutrition research demonstrated the efficacy of biofortified iron bean and iron pearl millet in improving the nutritional status of target populations (Finkelstein *et al.,* 2015). Iron studies also suggest that reducing absorption inhibitors, such as polyphenols and phytic acid, may further improve the efficacy of iron beans, in particular, and research in this area continues. Zinc studies have demonstrated that biofortified zinc wheat is bioavailable, and initial results of zinc wheat efficacy studies are promising. Because plasma zinc concentration, the biomarker widely used to estimate zinc status, has limitations in measuring changes in dietary zinc, foundational research to identify and test more sensitive biomarkers is underway. These biomarkers will be tested in the zinc rice efficacy trial scheduled for late 2016.

Scaling Up

Third, could the adoption of biofortified crops by farmers be scaled up, and a public health impact demonstrated? We are not there yet on the measurement of a public health impact at a national scale, but for example, introduction of orange sweetpototo in Mozambique showed substantial reductions in diarrhea among children (Jones *et al* 2015). Just four years after release of high-yielding, iron bean varieties in Rwanda, we now have rigorous evidence that 30% of farmers in Rwanda are growing biofortified beans on a regular basis. We estimate that 20 million farmers and consumers presently grow and consume biofortified crops.

HarvestPlus and its partners believe that biofortified crops can and must be delivered through the same seed system through which farmers typically obtain seed. Each country and seed system presents its own challenges for integrating biofortified crops. Many lessons, however, apply across the spectrum of seed and market systems. These include: multiplication of a sufficient amount of planting material is a crucial first step; integrating biofortified crops into sustainable value chains, as well as creating knowledge and demand, are essential to scaling; and partnerships are the future.

Without planting material, whether seed, vines, or stem cuttings, there are no biofortified crops. In these early years of implementation, HarvestPlus and its partners have focused on strengthening capacity and reducing risk to ensure that planting material is available for farmers. In most countries, HarvestPlus has worked closely with NARS to ensure that sufficient breeder and foundation seed is available for the production of certified seed by cooperatives or the private sector. In countries with robust private seed systems that reach smallholder farmers, private seed companies are a natural partner, which is particularly advantageous in crops where hybrid seeds predominate (e.g. Seed Co. in Zambia (hybrid maize) and Nirmal Seeds in India (hybrid pearl millet) and where seed companies operate regionally).

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

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

Mainstreaming

In short, we have proven that biofortification works.

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

Demand: Both rural and urban consumers come to see the value of, and demand, high mineral and vitamin content in their staple foods.

Policy: A wide range of national and international public officials come to recognise the significant impact of biofortification for improving and sustaining public health, as well as the high economic return to investments in biofortification and the legitimacy conferred by international recognition (especially by standards bodies).

Supply: Agricultural research entities, both public and private, come to recognise high mineral and vitamin content as core plant breeding objectives; varietal release committees make minimum levels of minerals and vitamins a requirement for approval for release (in addition to the standard agronomic traits, such as high yield).

Vision

Our vision is that the quality of food staples globally will be continuously improved as a matter of routine, not just with iron, zinc, and provitamin A, but eventually with additional minerals, vitamins, and compounds as well. Not only do crop yields need to be increased to feed a growing population under serious land and water constraints in the context of climate change, but to nourish these populations properly, the density of minerals, vitamins, and other compounds in crops needs to be increased. The science is there to accomplish all this quite cost-effectively, if the investments are made now.

HarvestPlus has set an ambitious target of having one billion people benefit from biofortied crops by the year 2030. HarvestPlus intends to provide leadership in this effort over the next decade in one of the largest nutrition interventions ever undertaken.

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