HarvestPlus: Developing and delivering micronutrient-dense crops

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Abstract

Plant breeding for micronutrient density (biofortification) gained legitimacy when micronutrient deficiencies were recognized as global public health challenge of the 21st century. In response, HarvestPlus was established to add food nutritional quality to agricultural production research paradigms and reduce micronutrient malnutrition among poor at-risk populations by capitalizing on agricultural research as tool for public health interventions. HarvestPlus' applied and strategic research is driven by an impact/product pathway that integrates crop development, nutrition, socio-economic disciplines and country specific crop delivery plans. As for novel traits, biofortified product concepts must consider factors associated with probability of success in achieving: i) *technological goals* with trait discovery and expression in adapted genotypes, ii) *crop improvement goals* to generate a biofortified germplasm product without compromising agronomic performance, nutrition, or end-use quality; and iii) *commercial goals* to guide the design and delivery of the technology. HarvestPlus has three project phases: i) discovery (2004-2008), ii) development (2009-2013), and iii) delivery (2014-2018). An enhanced knowledge base allowed shifting from an emergent to a deliberate strategy with prioritizing 10 country/micronutrient crop profiles for six crops and projecting release dates in phase II. State-of-art and knowledge base is presented and multidisciplinary themes are explained with an emphasis on product development.

Key Words

HarvestPlus, biofortification, agriculture, plant breeding, micronutrients.

Introduction

HarvestPlus seeks to develop and distribute varieties of food staples (rice, wheat, maize, cassava, pearl millet, beans, and sweetpotato) which are high in iron, zinc, and provitamin A through an interdisciplinary, global alliance of scientific institutions and implementing agencies in developing and developed countries. Biofortified crops offer a rural-based intervention that, by design, initially reaches these more remote populations, which comprise a majority of the undernourished in many countries, and then penetrates to urban populations as production surpluses are marketed. In this way, biofortification complements other nutrition intervention programs such as fortification and supplementation.

A multidisciplinary approach

In broad terms, for biofortification to be successful first, breeding must be successful – high nutrient density must be combined with high yields and high profitability. Second, nutritional efficacy must be demonstrated – the micronutrient status of human subjects must be shown to improve when consuming the biofortified varieties as normally eaten. This includes evaluating that sufficient nutrients are retained during processing and cooking and that these nutrients are sufficiently bioavailable. Third, the biofortified crops must be adopted by farmers and consumed by those suffering from micronutrient malnutrition in significant numbers (Bouis *et al.* 2009).

Figure 1 reveals the incorporation of these key research issues in the impact pathway. The interdisciplinary nature of biofortification research necessitates collaboration between plant breeding and a range of disciplines including:

a) Socioeconomics: to accurately identify target populations that both consume the target crops and hold the largest share of the micronutrient burden (Figure 1, step 1) and, to measure the effectiveness of biofortified crops to improve human health as a cost-effective public health intervention (Figure 1, step 10).
b) Human nutrition: to determine micronutrient target levels that will have a measurable impact on human health (Figure 1, step 2); to estimated amount of the crop consumed by the target population; to evaluate the retention of the added micronutrient after storage, processing, and cooking (Figure 1, step 6) ; to test the bioconversion/ bioavailability of nutrients ingested from biofortified crops (Figure 1, step 7); and, to ultimately measure the biological impact of biofortified crops on human nutritional status (Figure 1, step 7).
c) Marketing Specialist: effectively delivering seed and generating demand for biofortified crops to farmers and dissemination partners.

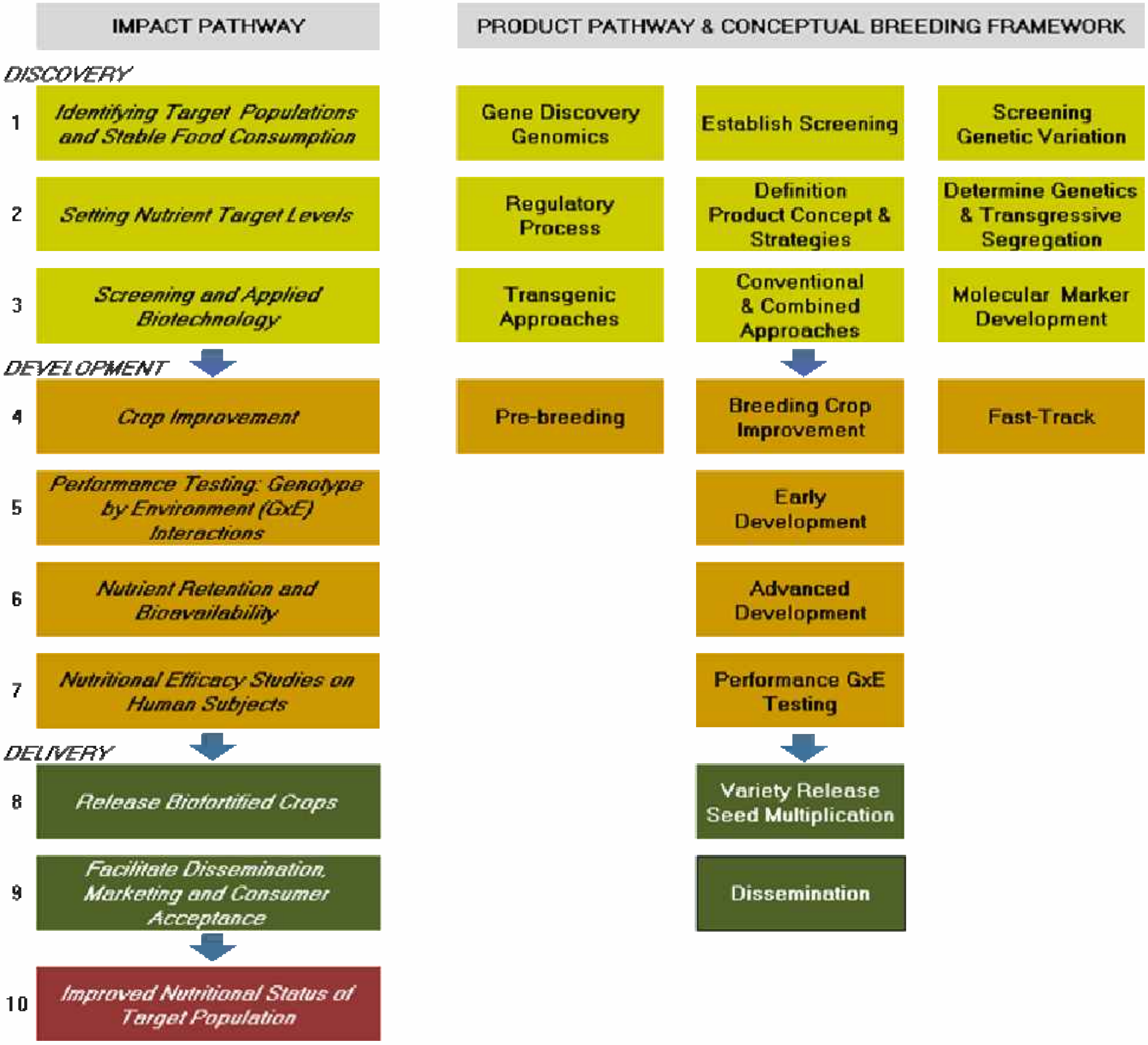

Figure 1. HarvestPlus Impact (left) and Product (right) Pathway.

Crop development elaborated

Figure 1 outlines the key biofortified germplasm development activities and product pathway (Pfeiffer and McClafferty 2007). Different research categories reflect sequentially arranged stages and milestones, and are superimposed upon a decision tree that allows monitoring progress and making strategic and go/no-go decisions when goals and targets cannot be achieved. Crop improvement activities under HarvestPlus focus, first, on exploring the available genetic diversity for iron, zinc, and provitamin A carotenoids. In parallel, agronomic and end-use features are characterized. In project phase I, establishing screening posed a major challenge as sampling/analytical protocols, high-throughput screening methods and in-house screening capabilities had to be developed, standardized and implemented, and environments characterized for their suitability for breeding and testing for micronutrients. Exploring the genetic diversity allowed identifying: (1) parental genotypes for use in crosses, genetic studies, molecular marker development, and parent-building, and (2) existing varieties, pre-varieties in the release pipeline, or finished germplasm products for "fast-tracking". Fast-tracking refers to releasing, commercializing, or introducing genotypes that combine the target micronutrient density with the required agronomic and end-use traits so they can be quickly delivered to producers and have an immediate impact on micronutrient-deficient populations. The micronutrient trait source is essential for the next breeding steps. If variation is present in unadapted trait sources, pre-breeding is necessary prior to using the trait in final product development; if variation is present in the tactical gene pool, the materials can be used directly to develop competitive varieties. The next breeding steps involve developing and testing micronutrient-dense germplasm, conducting genetic studies, and developing molecular markers to facilitate breeding. Then, genotype x environment interaction (GxE) – the influence of the growing environment on agronomic traits and micronutrient expression – needs to be determined in experiment stations and in farmers' fields in the target countries. Parallel to GxE trials, agronomy trials are conducted which include macro and micro fertilizer treatments to develop crop management recommendations for biofortified crops.

Beyond meeting *technological goals* of trait discovery and expression in adapted genotypes, and *crop improvement goals* that generate an agronomically and nutritionally superior biofortified germplasm product (both elaborated above), plant breeders must also address *commercial goals* that guide the design and delivery of this agricultural technology for public health. The commercial goal stage of HarvestPlus crop development invests in establishing productive research networks that link national research programs in target regions of the developing world with advanced agriculture and nutrition research institutes around the globe to help build sustainable research capacity in biofortification where it is most needed. Commercial goals insist breeders are keenly aware of consumer (not just farmer) acceptance and marketability of nutrient rich crops should those factors influence the breeding product concept. If organoleptic properties or grain color changes as a result of biofortification, can plant breeding mitigate these outcomes? The ultimate acceptance, and subsequent impact, of biofortified crops on producers and consumers will hinge on plant breeders not only developing attractive trait packages that do not compromise agronomic characteristics but also understand the value farmers and consumers place on the traits that will determine crop adoption and may require adjustments to the crop development strategy.

Results and conclusions

To date, HarvestPlus research has proven that added micronutrients have a measurable impact on human micronutrient status (Haas *et al.* 2005; van Jaarsveld *et al.* 2005; Low *et al.* 2007) but much work remains. The product development and release schedule given in Figure 2 reflects progress accomplished in developing micronutrient dense, competitive crops.

	DISCOVERY SCREENING	CROP IMPROVEMENT EARLY	CROP IMPROVEMENT LATE	GxE TESTING	RELEASE	TARGET COUNTRY
% TARGET						
SWEET POTATO	>100				2007	UGANDA MOZAMBIQUE
MAIZE	100	75	50		2011	ZAMBIA *OPVS Hybrids*
CASSAVA	100	>75	75	50	2012	NIGERIA DR CONGO
BEAN	>100	75-90	50		2010	RWANDA DR CONGO
PEARL MILLET	>100	100	75-100	50-75	2011	INDIA *OPVS Hybrids*
RICE *polished*	>100	100	75-100		2012	BANGLADESH INDIA
WHEAT	>100	75			2013	INDIA PAKISTAN

🟧 VITA A
⬛ IRON
🟩 ZINC

Figure 2. Product development and release schedule 2009 (iron, zinc, provitamin A expressed as percent of breeding target in lines at indicated stage of breeding).

As the program enters its second phase of full-scale crop development, planning is underway for effective delivery of these novel crops and the networks of expertise that makes up the multidisciplinary tapestry of biofortification continues to expand. Communication and marketing specialists are now becoming engaged with crop development and nutrition scientists to ensure adoption and sustainability or this agricultural innovation for public health.

References

Bouis HE, Hotz C, McClafferty B, Meenakshi JV, Pfeiffer WH (2009). Biofortification: A new tool to reduce micronutrient malnutrition. In '19th International Congress of Nutrition. Bangkok, Thailand, October 4-9, 2009'.

Haas JD, Beard JL, Murray-Kolb LE, del Mundo AM, Felix A, Gregorio GB (2005). Iron-biofortified rice improves the iron stores of non-anemic Filipino women. *Journal of Nutrition* **135**, 2823-2830.

Low JW, Arimond M, Osman N, Cunguara B, Zano F, Tschirley D (2007). A food-based approach introducing orange-fleshed sweet potatoes increased vitamin A intake and serum retinol concentrations in young children in rural Mozambique. *Journal of Nutrition* **137**, 1320-1327.

Pfeiffer WH, McClafferty B (2007). Biofortification: breeding micronutrient-dense crops. Chapter 3. In 'Breeding major food staples for the 21st century'. (Eds MS Kang, PM Priyadarshan) pp. 61-91. (Blackwell Scientific: Oxford).

Stein AJ, Meenakshi JV, Qaim M, Nestel P, Sachdev HPS, Bhutta ZA (2005). Analyzing the health benefits of biofortified staple crops by means of the Disability-Adjusted Life Years Approach: A handbook focusing on iron, zinc and vitamin A. *HarvestPlus Technical Monograph Series #4* (International Food Policy Research Institute (IFPRI): Washington D.C.).

van Jaarsveld PJ, Faber M, Tanumihardjo SA, Nestel P, Lombard CJ, Benadé Spinnler AJ (2005). β-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.