Study on HarvestPlus' Contribution to the Development of National Biofortification Breeding Programs

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Views expressed in this report belong to the evaluator and do not necessarily reflect official opinions of A4NH or HarvestPlus, the programs commissioning and participating in the evaluation.

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Acronyms and abbreviations

A4NH	Agriculture for Nutrition and Health
AICRP-PM	All India Coordinated Research Project on Pearl Millet
AICPMIP	All India Coordinated Pearl Millet Improvement Project
BINA	Bangladesh Institute of Nuclear Agriculture
BMGF	Bill & Melinda Gates Foundation
BRRI	Bangladesh Rice Research Institute
BSMRAU	Bangabandhu Sheikh Mujibur Rahman Agricultural University
CAADP	Comprehensive Africa Agriculture Development Programme
CCAFS	Climate Change, Agriculture, and Food Security
CIAT	International Center for Tropical Agriculture
CIMMYT	International Maize and Wheat Improvement Center
CIP	International Potato Center
CRP	CGIAR Research Program
EGS	Early generation seed
FPO	Farmer production organizations
GAIN	Global Alliance for Improved Nutrition
GxE	genotype x environmental interaction
ICAR	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFPRI	International Food Policy Research Institute
IPM	Iron pearl millet
IRRI	International Rice Research Institute
MSSC	Maharashtra State Seeds Corporation
NARES	National Agricultural Research and Extension Systems
OPV	Open pollinated variety
OTE	Outcome trajectory evaluation
PABRA	Pan-Africa Bean Research Alliance
PMHPRC	Pearl Millet Hybrid Parents Research Consortium
ppm	Parts per million
R&D	Research and development
RAB	Rwanda Agriculture and Animal Resources Development Board
RTB	Roots, Tubers and Bananas
SAUs	State agricultural universities
ToC	Theory of change
USAID	United States Agency for International Development
XRF	X-ray fluorescent

Executive summary

Rationale, purpose and scope

This evaluative review is one of a series of end-of-program studies being carried out by the CGIAR Research Program (CRP) on Agriculture for Nutrition and Health (A4NH) to document lessons from its achievements to inform future research and development (R&D) efforts. This study looks at lessons learned from HarvestPlus' work with National Agricultural Research and Extension Systems (NARES) to develop and implement sustainable biofortification breeding programs. HarvestPlus is part of A4NH.

Starting in the late 1990s, CGIAR began looking at the potential for breeding to increase the micronutrient concentration in staple crops (aka biofortification) in an effort to contribute to a reduction in micronutrient malnutrition. Most of this work has taken place under HarvestPlus, which began a 'proof of concept' phase in 2003. The review focuses on HarvestPlus' second and third phases in which biofortification breeding programs were established in several countries. The scope of the study is set by the country x biofortified crop combinations chosen – zinc rice in Bangladesh, iron beans in Rwanda and iron pearl millet (IPM) in India. The scope is also set by the evaluation questions agreed at the start:

EQ 1: How and to what extent did HarvestPlus contribute to the establishment and implementation of sustainable biofortification breeding programs in Bangladesh, India and Rwanda?

EQ 2: How and to what extent can the respective biofortification breeding programs be scaled and made more sustainable?

EQ 3: What are the implications of this evaluative review for how CGIAR researchers work with NARES on breeding programs for biofortified crops?

Review method. This study takes a theory-driven evaluation approach, specifically Outcome Trajectory Evaluation (OTE; Douthwaite et al., forthcoming) developed as part of policy outcome evaluation carried out by the CRP on Roots, Tubers and Bananas (RTB) with support from A4NH on biofortification in Africa (Douthwaite, 2020).

Findings relevant to Evaluation Question 1.

The question "how and to what extent did HarvestPlus contribute to the establishment and implementation of sustainable biofortification breeding programs in Bangladesh, India and Rwanda?" was answered by developing and validating a theory of change (ToC). The ToC showed that HarvestPlus' contribution came about by employing strategies to achieve three immediate outcomes that in turn together contributed to the establishment and implementation of sustainable biofortification breeding programs. The following findings relate to the strategies used to achieve the three immediate outcomes.

<u>Findings relevant to immediate outcome: Strengthened support base</u>

Strategy: *Funding support/Funding biofortification breeding in national programs*
<u>Finding 1</u>: HarvestPlus funded national partners to undertake biofortification breeding starting in 2009 in the three respective countries. Without this funding, it is highly unlikely that the biofortification breeding programs would have ever been set up.

Strategy: Funding support/Subsidizing the price of seed to allow greater farmer access
<u>Finding 2</u>: Once the biofortified varieties were approved for release, HarvestPlus subsidized the price of biofortified seed to allow greater farmer access in Rwanda and Bangladesh. While initially very

successful in Rwanda, this led to a gap in the market when the indirect HarvestPlus subsidy was removed, and criticism that HarvestPlus should have worked to support value chain actors rather than become one itself. However, if HarvestPlus had been less interventionist, it may not have achieved such high adoption levels in a such a short period of time.

Strategy: Building enabling institutions/Working with or independently of existing consortia/multi-stakeholder platforms sharing a similar objective

Finding 3: HarvestPlus took different approaches to engaging with other trajectory actors in India compared to Rwanda, depending on the size and governance structure of the country. In India, to reach the states growing pearl millet, HarvestPlus worked through the umbrella of the Indian Council on Agricultural Research's (ICAR's) All India Coordinated Research Program on Pearl Millet (AICRP-PM), a consortium of 12 State Agricultural Universities (SAUs) involved in breeding pearl millet. HarvestPlus also worked through the International Crops Research Institute for the Semi-Arid Tropic (ICRISAT)-led Pearl Millet Hybrid Parents Research Consortium (PMHPRC) that included 30 seed companies. In Rwanda, HarvestPlus could have worked through the long-established International Center for Tropical Agriculture (CIAT)-led Pan-Africa Bean Research Alliance (PABRA) network, but chose instead to work directly with the Rwanda Agriculture and Animal Resources Development Board (RAB), taking a more interventionist approach to ensure rapid iron bean seed distribution and uptake in Rwanda.

Strategy: Building enabling institutions/Support to biofortification seed systems

Finding 4: In Rwanda, HarvestPlus supported the development of a specification for iron beans to be used as part of iron bean seed certification. In India, the program was party to the decision by AICRP-PM to set the threshold of 42 parts per million (ppm) iron and screen all new hybrid IPM candidate varieties to equal or exceed the level before promoting to the next level of testing and approving their release. HarvestPlus supported the varietal release process in Bangladesh and Rwanda by helping to implement and fund necessary multi-locational trials and their analysis.

Strategy: Advocating for enabling policies/Contribution to policy support for biofortification

Finding 5: Biofortification and the three case crops are supported in policy documents in all three countries. Perhaps not surprisingly, the direct contribution of HarvestPlus to the policy process appears to have depended on the size of the country. In India and Bangladesh – two large countries – the main policy conduits were the national lead organization for biofortification, that is, ICAR - AICRP-PM for India and BRRI for Bangladesh. In Rwanda, a much smaller country in which the HarvestPlus intervention was much more significant, HarvestPlus appears to have had more direct influence, together with RAB. Iron beans are supported more often and more specifically in Rwanda's policy documents.

Strategy: Generating policy windows/Holding a global conference on biofortification and crop meetings

Finding 6: This review did not have the resources to identify specific policy windows that led to the policy support described under the previous finding. Policy windows for biofortification will likely have resulted from working collaboratively with country networks. In Rwanda, it is likely that they were generated by a global conference held on biofortification. Respondents flagged the importance of crop meetings in influencing policy in all three countries.

Findings relevant to immediate outcome: Change in capacity

Strategy: Increasing and using capacity to carry out advocacy/Strengthening the capacity of biofortification champions

Finding 7: The review found no evidence of an overt strategy to build the capacity of champions in either of the three cases, as Policy Window theory might suggest.

Strategy: Increasing and using capacity to carry out advocacy/Key trajectory actors using their professional links and expertise to engage in national and international meetings and conferences
Finding 8: Senior researchers working on the three respective breeding programs, and working for HarvestPlus globally, were supported by HarvestPlus to make the case for biofortification at conferences and in meeting with senior government officials and other key stakeholders, using and building their innate capacities in the process.[1]

Strategy: Capacity development/Capacity development across the respective biofortified crop value chains
Finding 9: HarvestPlus facilitated training and capacity development across the three value chains in two main areas: for breeding and for value chain actors. Much of the capacity development targeting end users (producers and consumers) happened as part of the communications strategy, see Finding 18 and Finding 19.

Findings relevant to immediate outcome: Shifting social norms

Strategy: Identifying and framing the problem/ Identifying and framing micronutrient malnutrition as a global problem
Finding 10: This strategy did not apply to the three cases because by the time HarvestPlus began funding the three biofortification breeding programs, micronutrient malnutrition had already been established as a global priority health concern, in particular for women and children.

Strategy: Framing and demonstrating the viability of the solution/Framing and demonstrating at a global level the viability of biofortification as a solution to the problem of micronutrient malnutrition
Finding 11: As with the previous finding, the general strategy did not apply to the three cases. Biofortification had been established globally as a solution to micronutrient malnutrition prior to 2009, in part through HarvestPlus running a 'gold standard' effectiveness study on orange flesh sweetpotato in Mozambique and Uganda[2] and the resonance the results found, manifest in the Copenhagen Consensus ranking biofortification as the fifth best investment[3] to tackle the world's most pressing development issues.

Strategy: Framing and demonstrating the viability of the solution/Breeding and distributing biofortified crops in country as proof of concept of delivery at scale
Finding 12: At country level, the most important step to establish biofortification as a viable solution to micronutrient malnutrition in the minds of trajectory actors was to breed and distribute biofortified crops and show their level of acceptance. Of the three cases, the first release of an approved biofortified variety was in Rwanda in 2010. One of the five varieties released, MAC-44, went on to become the most widely distributed high iron climbing bean variety in the region.

Strategy: Framing and demonstrating the viability of the solution/Carrying out commercialization assessments and market research for biofortified crops
Finding 13: In India, HarvestPlus and the Global Alliance for Improved Nutrition (GAIN) commissioned the global consultancy firm Dalberg to carry out a commercialization assessment,

[1] Respondent 5
[2] https://www.sweetpotatoknowledge.org/project/harvestplus-reaching-end-users-orange-fleshed-sweetpotato-project/
[3] https://en.wikipedia.org/wiki/Copenhagen_Consensus#Copenhagen_Consensus_2008

published in 2019, too late to influence establishment of breeding programs but potentially relevant to their sustainability. The report estimated that by 2024, about 60% of on-farm consumption and 85% of rural and urban consumption will be of varieties with greater than 42 ppm of iron. The fact that all 17 of the pearl millet varieties released through government channels since 2017 have greater than 42 ppm supports the estimate. HarvestPlus' global baseline to be called IPM is 47 ppm of iron and breeding target is 77 ppm of iron. In India, the baseline and breeding target are 42 ppm and 72 ppm of iron, respectively.

Finding 14: The barrier to commercialization identified in the Dalberg report that no competitive biofortified alternatives exist for farmers using OPVs would appear to be at odds with the launch and promotion of the Dhanashakti OPV by HarvestPlus as the first IPM, that performed better than the variety it was bred from. Moreover, the adoption of IPM reported by HarvestPlus was largely of this variety. Adoption of nine hybrid varieties supported by ICRISAT/HarvestPlus, was delayed by difficulties in licensing public-sector-bred varieties to the private sector, a high-level issue that deserves attention.

The value of ICAR's relatively low iron threshold of 42 ppm of iron may be to signal that the government seed system will set more and higher thresholds in two or three years and seed companies would do well to start breeding accordingly.

Finding 15: HarvestPlus took a much more proactive commercialization approach in Rwanda because of the challenges faced in distributing iron bean varieties to farmers. The program intervened directly in the seed value chain, becoming the largest seed distributer in the country for a period of time. The HarvestPlus Rwanda team experimented with a number of options to rapidly produce and distribute seed to farmers. Two of the most successful were swapping farmers' seed with theirs and providing seed through agronomic training and the extension service.

HarvestPlus' approach was very successful in providing iron bean seed to farmers – by 2018 an estimated 420,000 farmers were growing iron beans with 15% of the population of Rwanda eating them in 2018. This took place in the context of a very low seed replacement rate among bean farmers. However, becoming a large institutional buyer and then leaving the market created, or at least led to the return of, a number of seed value chain issues, not least poor communication between institutional buyers and seed producers and the high cost of certified seed, unaffordable to most farmers.

Strategy: Framing and demonstrating the viability of the solution/Carrying out trials to establish the efficacy of biofortified crops in producing positive health outcomes in the target country
Finding 16: HarvestPlus supported at least four efficacy trials in the three cases (crop x country), carried out either by Cornell University or the Swiss Federal Institute of Technology. Only two studies provided links to published results, which found significant positive health effects. Of the other two, no mention of their existence was found in the information HarvestPlus has made easily available on the Internet. In contrast, much mention is made by HarvestPlus of the two positive studies, to help frame biofortification as an effective solution to hidden hunger.

Strategy: Framing and demonstrating the viability of the solution/Carrying out adoption studies
Finding 17: In each case HarvestPlus conducted adoption studies in part to document and understand the popularity of the respective biofortified crops. In all three cases, multiple studies were conducted in each country and adoption rates varied from one study to the next. For example, in Bangladesh, estimates published in 2018 and 2019 ranged from 250,000 farmers who had ever grown the crop to 500,000 farmers to 1.5 million farmers.

In Rwanda, published papers and reports agree that about 15% of the population was eating iron beans in 2018, a level of adoption that is an order of magnitude higher than in the other two cases.

Strategy: Communication/Field demonstrations, field days and shows
Finding 18: While field demonstrations, field days and shows were important communication and awareness building strategies in all three cases, how they were run and by whom differed from country to country in terms of the role of the public versus the private sector, and the level of direct engagement by HarvestPlus.

Strategy: Communication/Consumer marketing using print, radio, TV and social media
Finding 19: HarvestPlus employed consumer marketing using print, radio, TV and social media in all three cases. As with the previous finding, the specific strategies used varied from case to case. Bangladesh made most use of print media and television. India relied heavily on the private sector, and on one company in particular. In Rwanda, much of the marketing happened in local markets, helped by celebrity endorsement.

Findings related to Evaluation Question 2

The question "how and to what extent can the respective biofortification breeding programs be scaled and made more sustainable?" was answered by evaluating the three cases against three dimensions of sustainability. The three dimensions were: competitiveness of biofortified varieties compared to conventional varieties with respect to agronomic and market traits; political support for biofortification in the respective countries; and, the extent to which the biofortification program is able to mainstream biofortification traits into breeding materials used by NARES and the private sector.

Bangladesh

Respondents expressed their confidence that breeding for zinc rice would be continued, given that Bangladesh faces a challenge in feeding its growing population, rice is the main staple, and tackling micronutrient malnutrition is a political priority. It was felt that additional funding is needed for the purchase and maintenance of equipment needed for screening when biofortification traits become mainstreamed across the conventional breeding programs. Funding of varietal trials would also help fast-track the release of biofortified varieties.

The analysis suggests zinc rice could also be scaled up, at an appropriate rate, through carrying out an adoption study to show the popularity or otherwise of the second and subsequent waves of zinc rice. In particular, the study should establish if the latest zinc rice variety, Bangladesh Rice Research Institute (BRRI) dhan 100 is indeed a 'game changer.' Given the variability in methods used, and results produced from previous studies, any future adoption study will need to be rigorous, peer-reviewed, and undertaken with a commitment to publish, share, and respond to the findings, whatever they might be.

Rwanda

Eight years after the first introduction of iron beans, an estimated 15 percent of the population were consuming them. The HarvestPlus Rwanda team and partners achieved a level of scaling an order of magnitude higher than in other countries. This was brought about through a well-funded direct marketing strategy that involved subsidizing the price of iron bean seed (see Finding 15) while making thousands of tons of seed available. Iron bean seed availability fell when HarvestPlus stopped intervening in the seed market, such that the scaling challenge is to maintain levels of adoption before any further increase can be expected. This will require finding more sustainable ways to provide farmers with quality seed, at the right time, the right price, and the right place. This

challenge is being tackled by a multi-stakeholder platform that HarvestPlus helped establish, consisting of RAB, local nongovernmental organizations (NGOs), and seed multipliers.[4]

India

The IPM breeding program at ICRISAT and those operating in the SAUs under the AICRP-PM umbrella have been mainstreamed. Scaling up of pearl millet in general will be helped if R&D being carried out by ICAR and Corteva to develop IPM with a shelf life of processed grain greater than six months is successful. Pearl millet flour, whether IPM or otherwise, goes rancid within 10 days, limiting its use in products such as bread. Improvements in postharvest handling will also increase shelf life.[5] Scaling up of high IPM, that is, varieties with more than 77 ppm iron, will depend upon increases in the minimum iron threshold for new varieties, and for government procurement, for example as part of the government's food procurement system.

At the current threshold of 42 ppm iron, and the numbers of new varieties that have equal or higher levels (see Finding 13), it is likely that by 2024, about 85 percent of rural and urban consumption will be of varieties greater than 42 ppm iron, which ICAR refers to as nutrient-rich pearl millet. Most documents written on biofortified pearl millet refer to IPM. It is not clear in these documents what level of iron qualifies a pearl millet variety to be classed as IPM. It follows that it is unclear as to whether 85 percent of rural and urban consumption of nutrient-rich pearl millet is an IPM scaling success or not.

Ultimately, scaling up of high IPM will depend on commercial seed producers that account for more than 90 percent of pearl millet production each year. In this regard, it will be important that ICRISAT continue to make high IPM lines and hybrid parents available to the private sector through the PMHPRC, with a particular focus on smaller growing companies (see Finding 14).

Findings related to Evaluation Question 3

The third evaluation question "what are the implications of this evaluative review to how CGIAR researchers work with NARES breeding programs to accelerate the planting and consumption of biofortified crops?" is answered with reference to the answers to the two questions before it.

The continuing need for coordination

A number of respondents[6] were concerned about the future of biofortification under the new CGIAR structure. A common concern was that the marriage of agriculture and nutrition that HarvestPlus brought about and supported will break apart, leading to essential functions being fragmented into different institutional homes. In the new CGIAR structure, nutrition is separate from genetic innovation and, without a bridging organization such as HarvestPlus, it is difficult to see how they will connect and influence each other in the future.[7]

There is a similar need for a bridging and coordinating initiative at country level to maintain a commitment to mainstreaming multiple biofortification traits into conventional breeding programs, as well as to push for greater focus on meeting the needs of the commercial food processors.

Pros and cons of the HarvestPlus approach

[4] https://www.pabra-africa.org/better-beans-for-africa/
[5] Respondent 14
[6] Respondents 1, 12 & 14
[7] Respondent 1

A donor view of CGIAR is that it "drops the ball when the rubber hits the road," meaning it is generally not good at taking research to scale.[8] The findings above show that HarvestPlus strove to do better. They also suggest that the approach taken was different from country to country, and at times was a double-edged sword. The implication is that moving forward, CGIAR should learn from the experience to do more of what worked well and less of what did not.

Conclusions

Conclusion 1: Functioning breeding programs are in place and have good potential to be sustainable for zinc rice in Bangladesh, iron beans in Rwanda and IPM in India. The programs were successful in reaching tens to hundreds of thousands of farmers. Trajectory actors in Rwanda were phenomenally successful, with 15 percent of the population eating iron beans after less than 10 years. The programs continue despite a reduction in HarvestPlus funding since 2018. It is highly unlikely that the programs would have been established without HarvestPlus and the support the program received from its donors.

Conclusion 2: HarvestPlus implemented a series of strategies that were consistent with the Policy Window theory. The strategies contributed to a strengthened support base for biofortification in the respective countries; changes in capacity of trajectory actors; and a shift in norms of trajectory actors and the broader public. Most of the strategies appear to have been successful. Where they were not, they may still contribute in the longer term (e.g., seed quality standards, commercialization findings).

Conclusion 3: The way that strategies led to outcomes in each country is consistent with the concept of an outcome trajectory – which HarvestPlus helped establish and support in each country – that is, an interacting and co-evolving system of actors, knowledge, technology, and institutions increasingly sharing a common purpose.

Conclusion 4: Taken together, Conclusions 1 to 3 support the claim that HarvestPlus was a driving force behind the establishment and implementation of the biofortification breeding programs in the three countries. While few might find this surprising given the role HarvestPlus played in the development of biofortification, the way the contributions happened, resulting from many different activities undertaken by HarvestPlus over time and for different objectives, gives a much more nuanced view of what it takes for research to influence policy outcomes. The influence strategies documented in this report are much broader than HarvestPlus anticipated when this evaluation was originally commissioned.

Conclusion 5: HarvestPlus had some difficulty in convincingly demonstrating that biofortified varieties benefit farmers and consumers. Adoption studies painted a different picture of farmer benefit and acceptability, depending on the timing, method and assumptions used. An adoption study of the first zinc-rice varieties was seen as misleading and not made publicly available. Efficacy trials did not always work, and when they did not, the reasons were not published. HarvestPlus' own publicity tended to highlight the more positive findings. Failing to acknowledge negative or inconclusive findings could diminish HarvestPlus' credibility. It could also contribute to biofortification being overly supported and as a result overshadowing other approaches to reduce hidden hunger, such as promoting more diverse diets.

Conclusion 6: Further scaling depends critically on different actors engaging in different strategies in the three countries. In India, it depends upon commercial seed producers that account for more

[8] Respondent 5

than 90 percent of pearl millet production each year, breeding and selling IPM on a large scale. In Bangladesh, it depends upon whether or not the new zinc rice varieties can compete on yield and agronomic performance with popular conventional varieties. In Rwanda, it depends upon providing iron bean seed at an affordable price to farmers, in sufficient quantities.

Conclusion 7: In all three cases, respondents thought CGIAR and the NARES worked well together and there was little, substantively, that could have been improved. Most spoke of strong ownership of the breeding programs by the NARES.

Conclusion 8: Mainstreaming is happening in the three sets of NARES and the respective CGIAR Centers supporting them. However, both sets of actors are concerned that with the reduction in funding and advocacy since the end of HarvestPlus' third phase, momentum may be lost. With the withdrawal of HarvestPlus, funding from national governments will be particularly important to cover the additional equipment, staff capacity, and funding required to screen seed samples for biofortification traits as part of breeding new varieties and subsequent national seed release processes.

Conclusion 9: There is a need for coordinating biofortification work in CGIAR and in the three countries. At CGIAR-level, there is a concern that without HarvestPlus, or a similar mechanism, holding nutrition and genetic innovation together, the two will retreat into their different institutional homes in CGIAR moving forward, to the detriment of both. There remains a similar need for a bridging and coordinating initiative at country level to maintain a commitment to mainstreaming multiple biofortification traits into conventional breeding programs, as well as to push for greater focus on meeting the needs of commercial food processors.

Conclusion 10: HarvestPlus pursued a determined, results-driven approach that was tempered by the country in which it worked. In Rwanda, where HarvestPlus' investment was a significant portion of the NARES budget, HarvestPlus itself became an actor in the supply chain, becoming the largest seed multiplier in the country for a period of time. While HarvestPlus was very successful in Rwanda, the program's exit from the market led to a gap in the institutional market for certified seed, the main market for seed producers. In contrast, in India, HarvestPlus worked as part of the PMHPRC and AICRP-PM consortia and, as a member of the latter, was party to a compromise decision to set an iron threshold level for nutritionally-rich pearl millet, much lower than HarvestPlus' 77 ppm iron target breeding level, which risks damaging the prospects for high IPM in the future. What will likely be achieved is that, by 2024, about 85 percent of rural and urban consumption will be of varieties greater than 42 ppm iron.

Introduction

Rationale for the study

The CGIAR Research Program (CRP) on Agriculture for Nutrition and Health (A4NH), led by the International Food Policy Research Institute (IFPRI), is conducting a series of evaluative studies and reviews to document lessons from both phases of the CRP (2012-2021). The studies should inform future research and development (R&D) efforts, mainly but not exclusively, in CGIAR. Findings can inform both what the programs do and how they work. This study looks at lessons learned from HarvestPlus' work with National Agricultural Research and Extension Systems (NARES) to develop and implement sustainable biofortification breeding programs. HarvestPlus is part of A4NH.

Scope and focus

CGIAR and NARES have collaborated on crop improvement programs for decades.[9] Starting in the late 1990s, CGIAR breeders began looking at the potential for breeding to increase the micronutrient concentration in staple crops (aka biofortification) in an effort to contribute to a reduction in micronutrient malnutrition, also known as hidden hunger. Once proof of concept was established (see Finding 11), HarvestPlus collaborated with a range of stakeholders, including national agricultural systems, to operationalize biofortification and scale it up.

HarvestPlus is interested in documenting its multi-year investments in collaborating with the NARES during the period 2009-2020 to develop biofortification breeding programs that breed, test, and release biofortified varieties of key staple crops. The main evaluation questions are:

EQ 1: How and to what extent did HarvestPlus contribute to the establishment and implementation of sustainable biofortification breeding programs in Bangladesh, India, and Rwanda?

EQ 2: How and to what extent can the respective biofortification breeding programs be scaled and made more sustainable?

EQ 3: What are the implications of this evaluative review for how CGIAR researchers work with NARES on breeding programs for biofortified crops?

The outcome trajectories to be described, modeled, and evaluated are the establishment and implementation of three biofortification breeding programs, namely:

- Zinc rice in Bangladesh with the Bangladesh Rice Research Institute (BRRI),
- Iron beans in Rwanda with the Rwanda Agriculture and Animal Resources Development Board (RAB), and
- IPM in India with the All India Coordinated Research Project on Pearl Millet (AICRP-PM).

These were chosen prior to contracting the work, based on recommendations from HarvestPlus. The idea was to look at mineral crops (iron and zinc) in different 'crop x country' contexts. In all cases,

[9] For the purposes of this document, CGIAR and HarvestPlus are used interchangeably to describe the work with NARES on breeding programs for biofortified crops. HarvestPlus was established as a joint venture between two CGIAR Centers, IFPRI and the International Center for Tropical Agriculture (CIAT), in 2003. HarvestPlus is part of A4NH and is based at IFPRI. HarvestPlus' crop research and breeding work draws on the expertise and resources of partner CGIAR Centers for breeding the respective biofortified crops, which, for the focus of this evaluation, are the International Rice Research Institute (IRRI), (zinc rice for Bangladesh), CIAT (iron beans for Rwanda), and the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), (IPM for India).

the programs were considered successful, and it was felt that sufficient information would be available on which to base the evaluative review.

In all three countries, the outcomes are assumed to be policy outcomes, where we understand a policy to be "a high-level overall plan embracing the general goals and acceptable procedures, especially of a government body."[10] We understand that policy is expressed in bodies of law, regulations and policy frameworks, and is implemented through programs and projects (FAO, 2015). Following Renkow (2018, p. 2), we acknowledge five types of policy-oriented outcomes to which CGIAR research contributes:

- **Changes in laws and regulations** governing economic incentives in agriculture or natural resource management—for example, agricultural, macro, trade, nutrition/health policies, and environmental policies;
- **Creation of institutions**—for example, the formation of the Ethiopian Commodity Exchange or the agreement between India, Nepal, and Bangladesh to share rice varietal evaluation data among their respective countries to facilitate more rapid release and commercialization;
- **Changes in government investment priorities and budget allocations**—for example, increases in the share of budgets devoted to agricultural research associated with the Comprehensive Africa Agriculture Development Programme (CAADP);
- **Innovations to the operations and management (O&M) for government agencies and programs**—for example, monitoring and evaluation activities associated with operating social safety net programs like the Mexican PROGRESA conditional cash transfer program or the Ethiopian Productive Safety Net Programme;
- **International treaties, declarations, or agreements among parties reached at major policy conferences**—for example, contributions of IFPRI's trade policy research to the Doha Round of trade negotiations among the World Trade Organization membership or the substantial involvement of the CRP on Climate Change, Agriculture, and Food Security (CCAFS), (via multiple Centers) in crafting international climate treaties.

Intended audience and use

The main audience for this review are the key people planning, working on, and funding national biofortification breeding programs, to help them identify lessons learned from more than 10 years of biofortification-oriented partnerships between CGIAR and NARES. This review is particularly timely given that CGIAR is transforming its structure, a change that is expected to shift the way research is funded and implemented by CGIAR and by CGIAR *with* partners. New organizational structures and pipeline investments are being negotiated in this new structure. The purpose of this review is to provide insights and understanding of underlying causal mechanisms that have played out in practice to guide decision-making with respect to the future of biofortification breeding programs and CGIAR and NARES partnerships. While the focus of this review is biofortification breeding, the findings may also have implications for CGIAR breeding programs more generally in terms of how they work with national breeding programs.

Evaluation approach

Conceptual framing

This study takes a theory-driven evaluation approach, specifically Outcome Trajectory Evaluation (OTE; Douthwaite et al., forthcoming) developed as part of policy outcome evaluation carried out by the CRP on Roots, Tubers and Bananas (RTB) with support from A4NH on biofortification in Africa (Douthwaite, 2020). OTE is based on two core concepts. The first is the idea that outcomes, such as a

[10] Merriam Webster

biofortification breeding program being put in place, are not single, one-off events, but rather are generated and sustained over time by an interacting and co-evolving system of actors, knowledge, technology, and institutions. These systems are called *outcome trajectories* (Paz & Douthwaite, 2017). Outcome trajectories are different from impact pathways (as defined by Mayne & Johnson, 2015) in their starting point. The former are constructed by working backwards from existing outcomes, while the latter generally begin with project activities and outputs to describe how they are expected to produce outcomes and impact in the future. Impact pathways tend to be project-centric and look to the future, while outcome trajectories are built by first looking backwards.

OTE adopts the outcome-harvesting definition of an outcome (Wilson-Grau, 2019): "A change in the behavior, relationships, actions, activities, policies or practices of an individual, group, community, organization or institution."

The second key concept is the idea of *middle-range theories* (Pawson, 2010 & Pawson, 2013) that are positioned between universal social theories and more location- and context-specific program theories and/or theories of change (ToCs). Middle-range theories apply to clusters of similar programs and can therefore help develop program ToCs that are comparable at cluster level, and so can aid cross-case learning and insight. A number of middle-range theories exist in the policy realm (Sabatier, 2007) that have been simplified and described such that policy advocates and evaluators can choose which will best help their understanding and navigation of the policy processes in which they are involved (Stachowaik, 2013).

Steps taken

OTE involves going through six steps.

Step 1: Select middle-range theory to focus description and understanding of the respective outcome trajectories

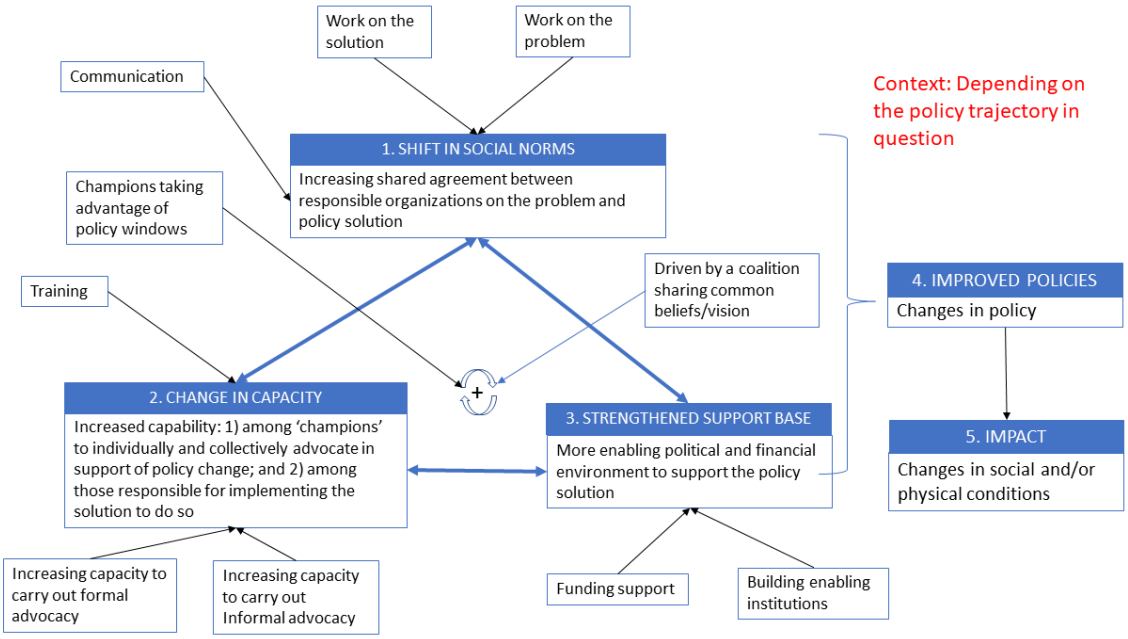
Accordingly, the first step in our evaluative review was to select a middle-range theory to provide a framework to help construct and make sense of the three outcome trajectories (crop x country breeding programs) and the contexts in which they operated. We chose one that was adapted and specified in a recent, similar RTB-led evaluation (Douthwaite et al., forthcoming) to describe how CGIAR contributed to four CGIAR policy outcome trajectories (Figure 1). One of the outcome trajectories was on biofortification, specifically on the development of a Continental Declaration of biofortification developed by the African Union Commission. The middle-range theory is Kingdon's (1984) Policy Window theory, as interpreted by Stachowiak (2013). The theory proposes that changes in policy-related outcomes occur during *windows of opportunity,* which help champions successfully connect two or more components of the policy process. The components are the way a *problem* is defined; the *policy solution* to the problem; and the *politics* surrounding the issue (Stachowiak, 2013; Zahariadis, 2008). Windows of opportunity are moments when progress can be made. They can be created by natural events such as pandemics, droughts, or earthquakes. They can also be changes in government, budget cycles, or landmark meetings and summits held as part of ongoing national, regional, and global processes. Policy windows are often short in duration and may or may not be predictable.

We assumed that the establishment and sustainable implementation of biofortification breeding programs could be expected to entail all five of Renkow's (2018) policy-oriented outcomes listed above.

The attraction of using a theory specified and adapted from a similar previous study was that it allowed us to learn from and build on it. Using an existing, specified, and relevant theory made it less likely that we would overlook key elements because we did not immediately recognize their relevance. For example, HarvestPlus initially proposed to focus this evaluation just on the contributions of their capacity development efforts with NARES breeders to the establishment of

sustainable NARES breeding programs. In terms of building on existing ToCs, we would be able to identify the different strategies that had proven useful to achieve outcomes 1 to 3 in Figure 1, in different contexts for different types of policy-related outcomes (i.e., establishment and functioning of biofortified breeding programs in three countries). Our expectation was that this would make our modified version of Figure 1 more broadly generalizable for future outcome evaluations of policy-oriented outcomes of CGIAR and partner research.

Figure 1: A middle-range ToC describing how CGIAR and partner interventions contribute to changes in policy-related outcomes (Douthwaite et al., forthcoming)



Step 2: Identify and describe the outcome trajectory that has led to the existence of the respective biofortification breeding programs

We developed timelines for the three respective outcome trajectories, based on interviews and reviews of available reports and online publications. Included in the data gathering was a detailed review of project documents carried out by HarvestPlus staff so as to identify:

- The investments made into the respective breeding programs over the study period, including investments in technical capacity;
- The main outputs of the breeding programs in terms of the release of new biofortified varieties and provision of breeding material to other breeding programs; and
- Information relating to the three components of sustainability:
    - The competitiveness of new varieties released measured in farmer and consumer preference and rates of adoption, e.g., adoption studies;
    - Political support in terms of awareness raising, extension and advocacy activities and outcomes associated with these, e.g., identification of policy documents that support biofortification; and

- Progress, such as advances in ability to test for micronutrients, e.g., the arrival of a new X-ray fluorescent (XRF) machine.[11]

We interviewed a total of 18 people about the three cases. They represented organizations involved in the respective biofortification breeding programs and individuals knowledgeable of the broader value chain context in which the breeding programs existed.

The information from different sources was 'braided' together to ensure a greater understanding of the respective outcome trajectories. Where pieces of data did not appear to fit, further clarification was sought and understanding adjusted. Interviews were recorded and detailed notes made of them. Anonymized, detailed referencing was used to establish an audit trail such that facts and assertions made in the report can be checked back to their sources.

Our approach was essentially a case study one in which understanding flowed from rich, thick picture descriptions of events gleaned from interviews. We used the ToC shown in Figure 1 as the 'theory of the case' (Rule & John, 2015) to help focus inquiry as we built annotated timelines of the three respective outcome trajectories (Appendices I, II & III).

Step 3: Validate the outcome trajectory timelines with key stakeholders

The evaluator sent out the annotated outcome trajectory timelines for each case to the respective interviewees to validate, challenge and add to the timelines. The annotated timelines were adapted based on this feedback.

Step 4: Specify the strategies used in the process to develop a ToC for all three cases, and validate it in a workshop

Specifying the middle-range ToC (Figure 1) involved identifying the specific strategies that contributed to outcomes 1 to 3 shown in Figure 1 – *shift in social norms*, *change in capacity*, and *strengthened support base*. For example, under 'shift in social norms' we looked for ways in which trajectory actors in each case attempted to raise awareness of biofortification as a solution to problems of micronutrient malnutrition, and how increased awareness may or may not have affected the establishment and growth of the respective breeding programs. A specified ToC was developed for the three cases in the form of a specification of Figure 1, that is, identification of the specific strategies used under each of the broad strategy types (the boxes in Figure 1 with no numbers).

The evaluation team (an evaluator and members of A4NH's Program Management Unit organized a workshop for interviewees to validate, challenge and add to the specific strategies feeding into the ToC.

Step 5: Use the validated timelines and three-case ToC to answer the evaluation questions and sub-questions

For each outcome trajectory, the evaluator used the conceptual framing, the case-specific timelines, the adapted ToC, notes from the in-depth interviews, and information from the document reviews to answer the three evaluation questions listed above.

Step 6: Subject the draft report to review for fact and inference checking before finalizing

A first draft of the full evaluative review was provided to the evaluation managers in October to coordinate a review process to check facts and the legitimacy of inferences made. Comments and

[11] The use of the XRF machine in breeding began in the early 2010s. The XRF machine accelerates the screening process for target minerals and is also used to confirm mineral levels in bred varieties.

suggestions from reviewers outside the evaluation team were collated and considered. The changes made and not made were recorded and explained.

Overview of outcomes and HarvestPlus' contributions

Key information on HarvestPlus activities in each country, including outcomes achieved, is summarized in Table 1 drawing upon the timelines in Appendices I to III.

In all three, the policy-oriented outcome sought was a national biofortification breeding program established in each country for each crop. A biofortification breeding program was established in each case, evident in the breeding work undertaken and the biofortified varieties released by relevant authorities in the respective countries. The marginal return on this investment in each case appears to have been very large. An investment of US$800,000 in BRRI over ten years contributed to zinc rice reaching an estimated 2,454,000 households. In Rwanda, an investment of US$1.2 million in RAB over a similar time period led to an estimated 20 percent of beans consumed in the country being biofortified with iron, produced by 420,000 households. In India, an investment of US$1.9 million led to adoption of IPM by 240,000 farmers in 2018. The IPM case is unique in benefiting from investment made by 37 seed companies as members of ICRISAT's PMHPRC, established in 2000[12] (Table 1).

The level of investment by HarvestPlus in each trajectory fell sharply at the end of the program's third phase in 2018. In Rwanda, HarvestPlus judged that it had met its objectives with respect to promoting and making iron bean seeds available and reduced investment to fund an ongoing liaison with the government and maintaining the XRF machine to test for iron levels in beans. The number of NARES bean breeders working in the country declined from five in 2018 to two in 2021. Nevertheless, breeding of iron bean varieties remains a priority for the national bean breeding program.[13]

In India, separate biofortified hybrid trials for IPM were stopped in 2018 when ICAR's AICRP-PM agreed in its annual meeting to screen all promising varieties and hybrids in national trials for iron and zinc content, set at 42ppm and 32ppm, respectively. HarvestPlus funding since 2018 was used to fund the screening of about 8000 to 9000 lines a year, together with soil, at a cost of US$2.50 per sample.[14] HarvestPlus funding for IPM was much higher than for iron beans in Rwanda and zinc rice in Bangladesh. The difference is that funding was distributed among 30 organizations, including SAUs and private sector seed companies – see Finding 3.

[12] https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.119.7946&rep=rep1&type=pdf
[13] Respondent 7
[14] Respondent 7

Table 1: Characteristics of the three biofortification breeding programs, achievements to date, and potential for impact

	Zinc Rice in Bangladesh	Iron Beans in Rwanda	IPM In India
Policy-oriented outcome sought	Sustainable zinc rice breeding program at BRRI	Sustainable iron bean breeding program at RAB	IPM mainstreamed into ICAR (through AICRP-PM) and private sector breeding programs
Year trajectory began	2004	2009	2004
Key trajectory actors	More than 30 including: Host org: BRRI Research: CGIAR, BSMRAU, BINA, BRRI	More than 30 including: Host org: RAB Research: CGIAR	More than 40 including: Facilitating org: ICRISAT Host org: ICAR, Research: ICRISAT, SAUs, 37 seed companies, FPOs, NGOs for product development and dissemination
HarvestPlus investment	US$800,000 from 2010 to 2020[15]	US$1.2 million from 2009 to 2019[16]	US$1,914,000 from 2009 to 2022[17]
Breeding outputs	9 high zinc rice varieties released, 6 by BRRI, two BSMRAU and one by BINA	18 iron bean varieties released by RAB	1 open pollinated variety (OPV) bred by ICRISAT; 8 hybrids produced by SAUs; 1 hybrid bred by private sector seed company
Future direction	BRRI to continue with dedicated high zinc and iron breeding program before transitioning to the mainstreaming of biofortification breeding in about 7 years (by 2028)	- RAB to continue breeding iron bean varieties - RAB to work to reduce the cost of good quality seed, and make it more available, with private sector	- To work under AICRP-PM umbrella screening varieties for notification and release, while helping to increase benchmark - To push for policies that create a demand for IPM
Other outcomes achieved	Zinc rice varieties reached 2,454,000 households directly from 2013 to 2020	15% of beans consumed in Rwanda are high in iron, 20% of beans grown high in iron. 420,000 households growing iron beans (as of 2018)[18] Biofortification successfully embedded into the country's food system.	- 240,000 farmers growing IPM (largely Dhanashakti)[19] in 2019 - 65,000 farmers growing IPM in 2020[20] - High iron (>42 ppm) set as national benchmark for AICRP system. biofortification in NARES pipelines

[15] https://www.dropbox.com/s/nt6a6mbyxscjlm8/India%20Fe%20Pearl%20Millet%20-FinalVersion%20v2.xlsx?dl=0

[16] https://www.dropbox.com/s/6ogdutdhpc4ar0b/Rwanda%20Fe%20Beans%20-FinalVersion.xlsx?dl=0

[17] https://www.dropbox.com/s/nt6a6mbyxscjlm8/India%20Fe%20Pearl%20Millet%20-FinalVersion%20v2.xlsx?dl=0

[18] 20% of beans consumed in Rwanda are high in iron

[19] From Foley et al., 2021, p. 121. Source of the data was "HarvestPlus Monitoring and Evaluation Team. HarvestPlus database. Published online 2019"

[20] The drop from 2019 was attributed to Covid-19 restricting people's movement

EQ1: How and to what extent did HarvestPlus contribute to the establishment and implementation of sustainable biofortification breeding programs in Bangladesh, India and Rwanda?

ToC Part A: Diagram

The evaluator developed a ToC diagram to explain how and to what extent HarvestPlus and other outcome trajectory actors contributed to establishing biofortification breeding programs in Bangladesh, India and Rwanda, as described under Step 4. The ToC is made up of two parts: A) Figure 2, based on policy window theory, which shows how general strategies implemented by trajectory actors mapped onto immediate outcomes and B) written descriptions of how the specific strategies, mapped onto general strategies, worked in each case. Table 2 links the two, by showing how the specific strategies map onto general ones and by providing a link to the descriptions of the specific strategies, called findings. Each finding begins with a summary, in bold.

Figure 2 is an adaptation of Figure 1, to make it specific to the three cases in question. The adaptations are:

- Rewording of the three immediate outcomes (shift in social norms, change in capacity, strengthened support base) to make them specific to the establishment and implementation of NARES biofortification breeding programs;
- Specifying that the impact expected is a reduction in micronutrient malnutrition at national level in three countries;
- With respect to general strategies:
    - Differentiating between capacity development of national breeders and staff to breed competitive biofortified crops, and the capacity development of value chain actors to disseminate and promote adoption, or in other words, take biofortified crops to scale;
    - Adding ‘advocacy’ as a strategy to create more enabling political and financial environments for the breeding, dissemination and adoption of biofortified crops.

Figure 2: ToC part A – overview of how HarvestPlus contributed to the establishment and implementation of biofortification breeding programs in three countries, showing general strategies mapped onto immediate outcomes

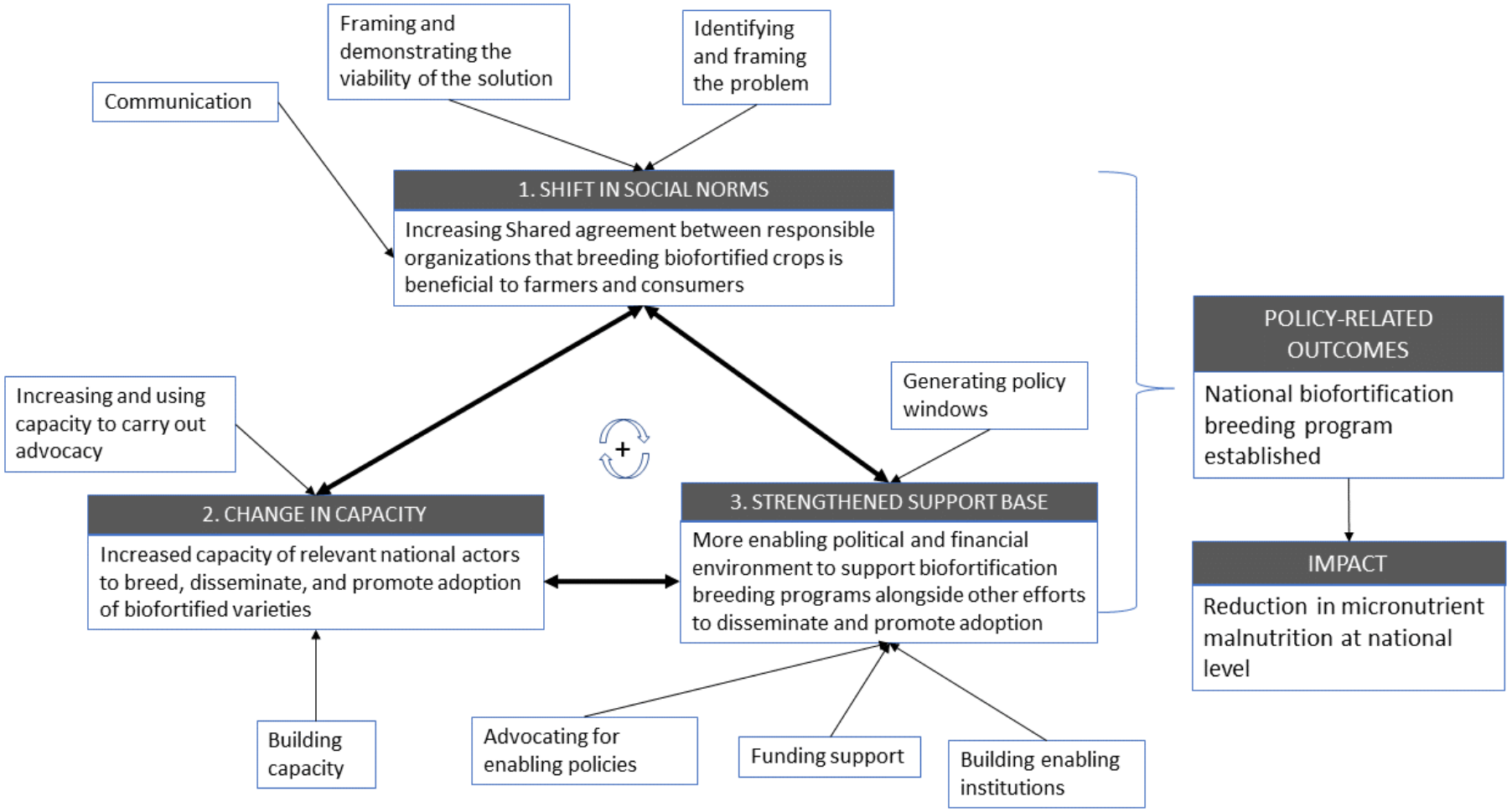


Table 2: Specified strategies used to contribute to changes in the three immediate outcomes in the ToC, with links to relevant findings

General strategies	Specific strategies used	Cases that used it	Relevant findings
For strengthened support base			
Funding support	Funding biofortification breeding in national programs	All	Finding 1
	Subsidizing the price of seed to allow greater farmer access	Bangladesh, Rwanda	Finding 2
Building and working within enabling institutions	Working with (India) or independently (Rwanda) of existing consortia/multistakeholder platforms sharing a similar objective	India, Rwanda	Finding 3
	Support to biofortification seed systems	All	Finding 4
Advocating for enabling standards and policies	Contribution to policy support for biofortification	All	Finding 5
Generating policy windows	Holding of conferences and crop meetings on biofortification	All	Finding 6
For changes in capacity			
Increasing capacity to carry out advocacy	Strengthening the capacity of biofortification champions	None	Finding 7
	Key trajectory actors using their professional links and expertise to engage in national and international meetings and conferences	All	Finding 8
Capacity development	Capacity development across the respective biofortified crop value chains	All	Finding 9
For shifting social norms			
Framing the problem	Identifying and framing micronutrient malnutrition as a global problem	N/A	Finding 10
Framing and demonstrating the viability of the solution	Framing and demonstrating at a global level the viability of biofortification as a solution to the problem of micronutrient malnutrition	N/A	Finding 11
	Breeding and release of biofortified varieties in-country as proof of concept	All	Finding 12
	Carrying out commercialization assessments and market research for biofortified crops	All	Finding 13 Finding 14 Finding 15
	Carrying out trials to establish the efficacy of biofortified crops in producing positive health outcomes in the target country	All	Finding 16
	Carrying out adoption studies	All	Finding 17
Communication	Field demonstrations, field days and shows	All	Finding 18
	Consumer marketing using print, radio, TV and social media	All	Finding 19

ToC Part B: How the specific strategies worked to influence immediate outcomes

We consider in turn how the specific strategies, identified and validated in Step 4, worked to bring about the three immediate outcomes across the three cases. The order in which the specific strategies are presented depends on the general strategies they map onto, which in turn depends on the immediate outcomes the general strategies map onto. Figure 2 shows that the immediate outcomes influence each other and can happen at the same time. In the same way, it can be assumed that the general and specific strategies influence each other and happen simultaneously. To get a sense of the chronology of program implementation in each country, the reader can refer to the timelines in Appendices I to III.

Summaries of findings with respect to specific strategies are given throughout the following text, to help provide an indication of where links between findings exist.

Immediate outcome: Strengthened support base

While the following description of strategies follows no pre-defined chronological order, as just explained, we chose to begin with HarvestPlus' decision to fund biofortification breeding in the countries at the start of its second phase, without which it is unlikely that any national biofortification breeding programs would have been established during the study period. Hence, we begin with strategies that contributed to a strengthened support base for biofortified breeding programs in the three cases.

General strategy: Funding support

Specific strategy: Funding biofortification breeding in national programs

Finding 1: HarvestPlus funded national partners to undertake biofortification breeding starting in 2009 in the three respective countries. Without this funding, it is highly unlikely that the biofortification breeding programs would have ever been set up.

HarvestPlus began funding national biofortification breeding programs in the three countries, from the beginning of HarvestPlus' second phase in 2009, as shown in Table 3. The second phase built on work in the three countries, as shown in the three timelines in Appendices I to IIIWith Bangladesh and Rwanda, funding was provided to the NARES directly, from 2010 in Rwanda and from 2016 in Bangladesh. Prior to 2016, Bangladeshi government regulations meant that HarvestPlus had to channel funding through the International Rice Research Institute (IRRI), as part of a pass-through arrangement. The funding represented 40-50 percent of RAB's bean breeding budget,[21] and a much smaller proportion of the budget in Bangladesh and India.

IPM followed a different model in which funding went to ICRISAT, who passed it on to 32 organizations, largely made up of private sector seed companies, public sector state seed corporations, and SAUs.

Table 3: Payments made by HarvestPlus to support national biofortification breeding programs

	2009 to 2018 (US$) Phase 2&3	After 2018 (US$)	Funding provided to
Zinc rice - Bangladesh	660,000	140,000	BRRI
Iron beans - Rwanda	1,200,000	163,000	RAB
Iron pearl millet - India	1,760,000	153,000	32 organizations via ICRISAT

[21] Respondent 7

Specific strategy: Subsidizing the price of seed to allow greater farmer access

Finding 2: Once the biofortified varieties were approved for release, HarvestPlus subsidized the price of biofortified seed to allow greater farmer access in Rwanda and Bangladesh. While initially very successful in Rwanda, this led to a gap in the market when the indirect HarvestPlus subsidy was removed, and criticism that HarvestPlus should have worked to support value chain actors rather than become one itself. However, if HarvestPlus had been less interventionist, it may not have achieved such high adoption levels in a such a short period of time.

In Rwanda, funding support mainly took the form of replacing farmers' recycled grain used as seed with more expensive iron bean seed. While this helped HarvestPlus reach relatively high adoption levels by 2019, it also led to a market gap when HarvestPlus stopped directly intervening in the bean supply chain. One respondent[22] was critical of the HarvestPlus approach, saying that, as a matter of principle, one should support existing value chain actors rather than becoming one yourself. However, the supply of good quality, affordable seed across all crops was already problematic. In 2018, the Acting Head of the Agricultural Production and Food Security Department in RAB described problems in seed supply in Rwanda in general:

- Low quantities of good-quality seed;
- Limited involvement of the private sector in all components of the seed sector;
- Seed marketing – low effective demand due to low purchasing power of farmers;
- Need for government to shift from the current seed subsidy system.[23]

While HarvestPlus seems to have prioritized rapid adoption of iron beans, rather than trying to sustainably solve problems in the existing bean seed system, it is not clear whether HarvestPlus' interventions have aided or undermined the long-term objective.

In Bangladesh, funding support took the form of supplying farmers with mini-kits of zinc rice seed free of charge. HarvestPlus also initially guaranteed a market for a portion of the private sector production and subsidized the price for any seed that the private sector marketed directly to consumers.

General strategy: Building enabling institutions

Specific strategy: Working with or independently of existing consortia/multi-stakeholder platforms sharing a similar objective

Finding 3: HarvestPlus took different approaches to engaging with other trajectory actors in India compared to Rwanda, depending on the size and governance structure of the country. In India, to reach the states growing pearl millet, HarvestPlus worked through the umbrella of ICAR's AICRP-PM, a consortium of 12 SAUs involved in breeding pearl millet. HarvestPlus also worked through ICRISAT-led PMHPRC that included 30 seed companies. In Rwanda, HarvestPlus could have worked through the long-established CIAT-led PABRA network, but chose instead to work directly with RAB, taking a more interventionist approach to ensure rapid iron bean seed distribution and uptake in Rwanda.

In India, the main way by which HarvestPlus strove to support and build enabling institutions was to work within existing consortia. The establishment and implementation of a system to breed and

[22] Respondent 4

[23] https://www.dropbox.com/s/xgoqr0pfl06rlfi/AM2_Detailed%20MARKET-LED%20BEAN%20SEED%20SYSTEMS%20REPORT.pdf?dl=0

supply IPM took place within the overall structure of the AICRP-PM, functioning under the umbrella of ICAR.

The AICRP system began in 1965 for each of the staple crops grown in India. The AICRP-PM is based on twelve SAUs in Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana and Tamil Nadu. The other center is at the University of Mysore. The 13 centers pursue mandated activities and research on pearl millet in the areas of germplasm utilization, improvement, production, protection and value addition.[24]

The breeding of IPM also took place under the auspices of ICRISAT's PMHPRC, launched in 2000 and engaging approximately 30 seed companies.[25] Private sector companies pay for membership in the consortium, for which they receive free access to view the field performance of hybrid and parental lines, most of which are now high-iron. The companies can request receipt of about 100 lines. In this way, ICRISAT and HarvestPlus have been nudging the private sector to increase the iron content in their varieties.[26]

In Rwanda, CIAT had been working with RAB researchers on beans under the auspices of PABRA prior to HarvestPlus entering the scene in 2010. PABRA was established in 1996 as a multi-stakeholder platform to develop improved beans and complementary technologies.[27] As of 2021, 45 varieties of biofortified beans have been developed and made available to more than 10 million people across PABRA countries, including Rwanda. In total, PABRA says its members have released 536 varieties, including iron bean varieties, and made them available to 30 million farmers.

HarvestPlus chose to take its own approach to working in Rwanda, rather than work in the inclusive 'PABRA way,'[28] which is to support seed value chain actors rather than become one. HarvestPlus judged that this would not work in Rwanda because of a very low seed replacement rate among farmers, which would not allow for rapid uptake of iron bean varieties. HarvestPlus had the funding to intervene in the bean seed system in a way that PABRA could not. PABRA staff were initially included but felt there was pushback, so withdrew. PABRA ended up reducing its involvement in Rwanda.

HarvestPlus' approach toward the Rwanda bean seed system was to intervene directly, as described above, becoming the biggest seed multiplier in the country for a period of time. In a sense, HarvestPlus created its own market institution that faltered once HarvestPlus withdrew financial support.

Specific strategy: Support to biofortification seed systems

Finding 4: In Rwanda, HarvestPlus supported the development of a specification for iron beans to be used as part of iron bean seed certification. In India, the program was party to the decision by AICRP-PM to set the threshold of 42 ppm iron and screen all new hybrid IPM candidate varieties to equal or exceed the level before promoting to next level of testing and approving their release. HarvestPlus supported the varietal release processes in Bangladesh and Rwanda through helping to implement and fund necessary multi-locational trials and their analyses.

Another of HarvestPlus' institution-building interventions was to support the Rwanda Standards Board to develop a specification for iron beans in Rwanda to be part of an iron bean seed

[24] http://www.aicpmip.res.in/aboutus.html
[25] https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.119.7946&rep=rep1&type=pdf
[26] Respondent 17
[27] https://www.cgiar.org/innovations/better-beans-for-africa/
[28] Respondent 3

certification system.[29] A draft document was produced that specified the level of iron in three classes of beans: Class 1, greater than or equal to 90 percent; Class 2, between 80 and 90 percent; and Class 3, between 60 and 80 percent. The document was prepared by the Technical Committee on Pulses and Cereals, specifically by CIAT/HarvestPlus, FARM FRESH Ltd., RAB, SHEKINA Enterprises, University of Rwanda, with the Rwanda Standards Board as the Secretariat. As of 2021, the standard had not been published in the government gazette, which is how such standards are made official. The standard may well be made official in the future and contribute to helping ensure quality in the seed system, a major unresolved issue in the region.

In India, HarvestPlus was part of the decision by AICRP-PM to set the threshold of 42 ppm iron for all new hybrid IPM varieties approved for release – see Finding 13 and Finding 14 for more detail.

General strategy: Advocating for enabling policies

Specific strategy: Contribution to policy support for biofortification

Finding 5: Biofortification and the three case crops are supported in policy documents in all three countries. Perhaps not surprisingly, the direct contribution of HarvestPlus to the policy process appears to have depended on the size of the country. In India and Bangladesh – two large countries – the main policy conduits were the national lead organization for biofortification, that is, ICAR -AICRP-PM for India and BRRI for Bangladesh. In Rwanda, a much smaller country in which the HarvestPlus intervention was much more significant, HarvestPlus appears to have had more direct influence, together with RAB. Iron beans are supported more often and more specifically in Rwanda's policy documents.

HarvestPlus and its key partners engaged in advocating for enabling polices. In Rwanda, this involved members of HarvestPlus' global leadership team meeting with key politicians during scheduled visits.[30] The Rwanda trajectory was helped in this regard by several high-ranking officials, including a Minister of Agriculture, having previously worked for CGIAR.

In Bangladesh, high-level advocacy happened through the Director General of BRRI, who was directly involved in planning processes.[31] For example, on World Food Day in 2021, he presented the Prime Minister with a portrait of the nation's founder made out of the straw and grain of the latest zinc rice variety, BRRI dhan 100. The HarvestPlus global leadership team also visited the Secretaries of the Ministries of Agriculture, Health and Food.

Similarly, in India, much of the high-level policy advocacy, including providing the Prime Minister's office with information about the existence and performance of biofortified crops, was carried out by ICAR.

In each of the three cases, the respective biofortified crops are mentioned in various policy documents. In Bangladesh, the Country Manager identified the five most significant inclusions, and provided URLs for the documents and screen shots of the pages where mentions were made.[32] These were:

1. National Strategy on Prevention and Control of Micronutrient Deficiencies, Bangladesh 2015-2024

[29] https://www.harvestplus.org/sites/default/files/RS%20350-2018%20Ion%20bio-fortified%20dry%20beans%20--%20Specification.pdf
[30] Respondent 5
[31] Respondent 9
[32] https://www.dropbox.com/s/nieei26xqlmm3qw/Biofortification_Zinc%20Rice_Policies_Bangladesh.docx?dl=0

2. Second National Plan of Action for Nutrition 2016-2025
3. Bangladesh Second Country Investment Plan
4. National Food and Nutrition Security Policy of Bangladesh
5. 8th Five-Year Plan

While significant, the references to biofortification in general, and zinc rice in particular, are short. For example, in the 8th Five-Year Plan from 2020 to 2025, biofortification is mentioned or alluded to just twice in an 850-page document. The entry says that the major objective of the crop sub-sector for the 8th Five Year Plan is to adopt and implement food production plans to meet the needs of nutritious, safe and demand driven foods, without specifying biofortification.[33] On page 734 it says: "Bangladesh adopted advanced technologies for biofortified agriculture. The first biofortified rice variety called BRRI dhan 62 (enriched with zinc) has been released. This rice is capable of fighting diarrhea and pneumonia-induced childhood death and stunting…Agricultural research will be enhanced further to promote nutrition-sensitive food production." The last phrase could be taken to imply a commitment to biofortification.

In India, most of the policy-related outcomes have happened either within or through ICAR. With respect to the former, ICAR has set a threshold iron content for all new pearl millet varieties and hybrids. According to ICAR,[34] the push for this came from AICRP-PM as a way of combining resources so that the funds allocated to separate biofortified hybrid trials that HarvestPlus had popularized, and which had begun in 2014, could be used instead to screen all promising lines for iron and zinc.

An example of ICAR advocating for biofortification is manifest in the endorsement that Prime Minister Modi gave to biofortification in 2020 as a cost-effective and sustainable solution to tackle malnutrition in national programs and policies in India. The information on biofortified crops was passed to the Prime Minister's Office by ICAR, specifically from the ICAR Coordinated Research Project on Biofortification, set up to coordinate work on biofortified crops across the AICRP crop projects. As a significant part of this work was supported by HarvestPlus, HarvestPlus has likely influenced how ICAR has decided upon, recommended, and implemented policies.

Rwanda, a smaller country with a greater proportion of its population growing and eating biofortified crops, perhaps not surprisingly had more specific policy-related outcomes concerning iron beans. For example, in the 2018 National Agricultural Plan, under the technology upgrading and skills development pillar, one policy action is to promote research on nutrition-rich crops through biofortification to position Rwanda as a trusted source of biofortified food in the region.[35] Other policy documents were[36]:

1. National Food and Nutrition Policy
2. Nutrition Action Plan
3. National School Health Strategic Plan (Ministries of Health, Local Government and Agriculture and Animal Resources, Education)

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[33] http://www.plancomm.gov.bd/sites/default/files/files/plancomm.portal.gov.bd/files/68e32f08_13b8_4192_ab9b_abd5a0a62a33/2021-02-03-17-04-ec95e78e452a813808a483b3b22e14a1.pdf, p. 297

[34] Respondent 17

[35] https://www.minagri.gov.rw/fileadmin/user_upload/Minagri/Publications/Policies_and_strategies/National_Agriculture_Policy_-_2018___Approved_by_Cabinet.pdf

[36] https://www.dropbox.com/s/o62zi1s9wgxyfbm/National%20policies%20of%20biofortification%20%28Rwanda%20India%20Bangladesh%29.xlsx?dl=0

4. Strategic Plan for Agricultural Transformation
5. Rwanda Country Strategic Review of Food and Nutrition Security.

As described above, HarvestPlus supported the development of a set of iron bean standards, which so far have not been launched.

General strategy: Generating policy windows

Specific strategy: Holding a global conference on biofortification and crop meetings

Finding 6: Policy windows for biofortification will likely have resulted from a combination of global efforts and working collaboratively with country networks. In Rwanda, it is likely that they were generated by a global conference held on biofortification. Respondents flagged the importance of crop meetings in influencing policy in all three countries.

This review did not have the resources to identify specific policy windows that led to the policy support described under the previous finding. Experience would suggest that most of the policy windows for biofortification in the three case countries will have come about through HarvestPlus working collaboratively with country networks (Douthwaite 2020). HarvestPlus would add its weight to these openings during courtesy calls to politicians, policy makers and NARES leadership when members of the HarvestPlus global leadership team visited the respective countries.

HarvestPlus, together with the Global Panel on Agriculture and Food Systems for Nutrition, organized the Second Global Conference on Biofortification held in Kigali in March 2014. Dr. Agnes Kalibata, then the Rwandan Minister of Agriculture and Animal Resources, welcomed participants to Rwanda, saying that they should celebrate biofortification as the best and easiest way to deal with infant nutrient malnutrition.[37] Participants from more than 100 organizations attended. The event likely generated a number of policy windows. One respondent said that once a priority is identified in Rwanda, progress is smooth.[38]

At the same conference, the Directors General of the relevant CGIAR Centers agreed to mainstream iron and zinc in respective target crops over the following eight to ten years. One respondent said that this was not pursued strongly.[39]

HarvestPlus held crop meetings with key trajectory actors in all three countries as a strategy for generating policy windows.[40]

Immediate outcome: Change in capacity

General strategy: Increasing and using capacity to carry out advocacy

Specific strategy: Strengthening the capacity of biofortification champions

Finding 7: The review found no evidence of an overt strategy to build the capacity of champions in either of the three cases, as Policy Window theory might suggest.

The Policy Window theory in Figure 1 hypothesizes that increasing capacity to carry out formal advocacy is important to bring about policy change. Douthwaite (2020) found that a major contributor to the drafting of a continental declaration in support of biofortification by the African Union Commission was the formation and capacity development of a network of biofortification champions at national and regional scale in Africa. The champions were supported by two back-to-

[37] http://paepard.blogspot.com/2014/04/the-second-global-conference-on.html
[38] Respondent 7
[39] Respondent 14
[40] Respondent 7

back projects in which HarvestPlus participated: the Reaching Agents of Change project, led by the International Potato Center (CIP) and Helen Keller International; and the Building Nutritious Food Baskets project, led by CIP with the advocacy component led by the Forum for Agricultural Research in Africa. The projects ran from 2011 to 2018. One of the main strategies used by the champions was to organize and attend side meetings at major conferences to put forward the case for biofortification.

In this assessment, there was no evidence of an overt strategy of supporting a network of champions to advocate for the zinc rice, iron beans and IPM breeding programs.

Specific strategy: Key trajectory actors using their professional links and expertise to engage in national and international meetings and conferences

Finding 8: Senior researchers working on the three respective breeding programs, and working for HarvestPlus globally, were supported by HarvestPlus to make the case for biofortification at conferences and in meeting with senior government officials and other key stakeholders, using and building their innate capacities in the process.[41]

In the three cases considered in this review, advocacy was carried out as part of an implicit rather than an explicit strategy, using the existing capacity of senior staff working on biofortification and their respective networks, from both NARES and CGIAR.

One respondent said that crop meetings in Bangladesh were particularly effective places for advocating for biofortification.[42] The one explicit activity to inform advocacy in Rwanda was the carrying out of a Net-Map exercise to identify and bring together actors that support and block biofortification.[43]

General strategy: Capacity development

Specific strategy: Capacity development across the respective biofortified crop value chains

Finding 9: HarvestPlus facilitated training and capacity development across the three value chains in two main areas: for breeding and for value chain actors. Much of the capacity development targeting end users (producers and consumers) happened as part of the communications strategy, see Finding 18 and Finding 19.

Much of the training and capacity development took place among seed growers, extensionists and farmers as part of the communications strategy described below, see Finding 18 and Finding 19. HarvestPlus provided specific training in two areas in particular: 1) to national breeders and field staff in how to conduct varietal trials of biofortified crops and how to screen for micronutrient levels, including in the use of XRF machines provided by HarvestPlus for screening samples; and 2) to sales, marketing and retail partners on relative advantages of the biofortified crop, including yield, maturation and market demand.

India was notable in relying on private sector seed companies to do much of the training and awareness building. This was because hybrid IPM dominated in India, sold by private sector seed companies.[44] Rwanda was notable in HarvestPlus intervening directly into the iron bean supply chain and in so doing training 5000 lead farmers and over 1000 seed multipliers, agronomists, co-op

[41] Respondent 5
[42] Respondent 11
[43] Respondent 5
[44] Respondent 14

leaders and agri-dealers. Bangladesh reached the majority of farmers (91,000) through farmer field days.

In all three cases, HarvestPlus worked through a large network of partners – 30 in Bangladesh and Rwanda and 45 in India.[45] It is reasonable to assume that employees of these partners will have learned about biofortification in general, and developed specific skills, depending on their level of engagement. HarvestPlus also supported a number of PhD students to work on various aspects of biofortification.

Immediate outcome: Shifting social norms

General strategy: Identifying and framing the problem

Specific strategy: Identifying and framing micronutrient malnutrition as a global problem

Finding 10: This strategy did not apply to the three cases because by the time HarvestPlus began funding the three biofortification breeding programs, micronutrient malnutrition had already been established as a global priority health concern, particularly for women and children.

General strategy: Framing and demonstrating the viability of the solution

Specific strategy: Framing and demonstrating at a global level the viability of biofortification as a solution to the problem of micronutrient malnutrition

Finding 11: As with the previous finding, the general strategy did not apply to the three cases. Biofortification had been established globally as a solution to micronutrient malnutrition prior to 2009, in part through HarvestPlus running a 'gold standard' effectiveness study on orange flesh sweetpotato in Mozambique and Uganda[46] and the resonance the results found, manifest in the Copenhagen Consensus ranking biofortification as the fifth best investment[47] to tackle the world's most pressing developmental issues.

Specific strategy: Breeding and distributing biofortified crops in country as proof of concept of delivery at scale

Finding 12: At country level, the most important step to establish biofortification as a viable solution to micronutrient malnutrition in the minds of trajectory actors was to breed and distribute biofortified crops and show their level of acceptance. Of the three cases, the first release of an approved biofortified variety was in Rwanda in 2010. One of the five varieties released, MAC-44, went on to become the most widely distributed high-iron climbing bean variety in the region.

In all three cases, the first step in framing biofortification as a solution to micronutrient malnutrition at the national level was to develop and certify biofortified crops. The idea of biofortification as a solution to micronutrient malnutrition began in 1994 when Howarth Bouis, working at IFPRI, provided IRRI, CIAT and the International Maize and Wheat Improvement Center (CIMMYT) with limited funding to assess whether there was sufficient genetic diversity in their respective gene banks, and whether the traits of interest, e.g., iron, were sufficiently stable to breed nutrient-rich crops. This work was carried out as part of the CGIAR Micronutrient Project. The results of the work led to the establishment of HarvestPlus in 2002, allowing for the continuation and expansion of this work to other CGIAR Centers and NARES partners.

[45] https://www.harvestplus.org/where-we-work/rwanda
[46] https://www.sweetpotatoknowledge.org/project/harvestplus-reaching-end-users-orange-fleshed-sweetpotato-project/
[47] https://en.wikipedia.org/wiki/Copenhagen_Consensus#Copenhagen_Consensus_2008

HarvestPlus took a similar breeding approach for all the biofortified crops it worked on. During its first phase (2003 – 2008), also known as the 'Discovery Phase,' CIAT, ICRISAT and IRRI, among other CGIAR Centers, selected lines that could be exploited for genetic improvement. Promising lines were tested in several locations across target environments to determine the genotype x environmental interaction (GxE) – the influence of the growing environment on micronutrient expression. The most promising lines were selected for multi-locational testing over multiple seasons by national research partners and then were submitted to national government agencies for testing for agronomic performance and release.

It should be noted that the public sector funding and resources available to breed biofortified crops was much less than that for breeding conventional varieties.[48] This was part of the motivation to mainstream breeding for biofortification traits into conventional breeding programs.

The following box describes the approach to breeding iron beans in Rwanda.

A brief history of iron bean breeding

While the CGIAR Centers involved in HarvestPlus took the same overall approach, there were differences depending on the crop and countries to which the promising lines were sent. In the case of iron beans, IFPRI and Howarth Bouis provided CIAT with US$14,000 in the late 1990s. CIAT, led by Steve Beebe, screened 1400 accessions, selected to represent the genetic diversity across CIAT's entire genebank of 25,000 accessions. CIAT sent samples to Australia to screen for high iron and zinc. Further screening was carried out to establish if the trait was stable in different countries, in different environments. Both investigations were successful. In an interview, Beebe said that the first attempts to develop promising lines were poorly adapted because they involved wide crosses between the Andean gene pool, where high iron was found, and the Mexican gene pool. Wide crossing inevitably leads to unwanted traits that took a number of years to remove. By 2010, the problem had been largely resolved. RAB, in collaboration with CIAT and HarvestPlus, released five iron bean varieties in 2010 and another five in 2012. One of these, MAC-44, went on to become the most widely distributed high-iron climbing bean variety, helped by having higher yield than the varieties it was competing against, while being palatable and producing beans of an attractive size and color. Eight more varieties were released in 2021.

CIAT, through regional networks and PABRA, has released iron beans in other countries in Africa, including Kenya, Tanzania, Zambia, Malawi and Ethiopia. HarvestPlus has concentrated on Rwanda, DRC and Uganda.

Beans have numerous market classes according to grain types, including white, cream, red, small red and small black. Beebe said that work is still needed to breed high iron bean varieties with a greater range of grain types, and this is currently doable at 75 ppm. Two breeding cycles of two to three years each are required to breed a small gene pool from which crosses can be made without iron drifting down. This will help reaching the target iron content set by HarvestPlus of 96 ppm.

Specific strategy: Carrying out commercialization assessments and market research for biofortified crops

Finding 13: In India, HarvestPlus and the Global Alliance for Improved Nutrition (GAIN) commissioned the global consultancy firm Dalberg to carry out a commercialization assessment, published in 2019, too late to influence establishment of breeding programs but potentially relevant to their sustainability. The report estimated that by 2024, about 60 percent of on-farm

[48] Respondents 5 & 14

consumption and 85 percent of rural and urban consumption will be of varieties with greater than 42 ppm of iron. The fact that all 17 pearl millet varieties released through government channels since 2017 have greater than 42 ppm supports the estimate. HarvestPlus' global baseline to be called IPM is 47 ppm or iron and breeding target is 77 ppm of iron. In India, the baseline and breeding target are 42 ppm and 72 ppm of iron, respectively.

HarvestPlus worked with GAIN to commission the global consultancy company Dalberg to carry out commercialization assessments for zinc rice in Bangladesh and pearl millet in India. The assessments set out to map potential routes to scale while identifying barriers, rather than being comprehensive reviews of all aspects of the value chain.[49]

The Dalberg IPM assessment found that the major constraint to broader planting and consumption of IPM was that there was no price incentive for farmers to pay more for IPM seed, nor for seed companies to breed it. However, the assessment was optimistic that this barrier will be overcome by ICAR having set the threshold of 42 ppm of iron in all new varieties for government approval. The threshold will apply to future government purchases of pearl millet as part of its Public Procurement System. The Dalberg report estimates that by 2024, about 60 percent of on-farm consumption and 85 percent of rural and urban consumption will be of varieties with greater than 42 ppm of iron. This estimate would appear to be supported by the fact that 17 pearl millet varieties were approved from 2017 to 2020, all exceeding the threshold level. The lowest was 43 ppm of iron, and the highest 71 ppm of iron (Bayer 9450) sold by the agri-chemical giant Bayer. The average was 58 ppm of iron. This compares to an average of 80 ppm of iron[50] for the nine hybrid IPM varieties released from 2015 to 2019 with support from HarvestPlus.

The Dalberg report (2019) said that 70 percent of current seed varieties fall below the 42 ppm of iron threshold and that reaching it for new seed varieties will require a major R&D push (p. 20). This is at odds with Rai et al., (2016) who found that of the 15 hybrids screened, iron content ranged from 46 to 56 ppm. Of the 18 OPVs screened, iron ranged from 42 to 67 ppm.[51] Rai et al., (2016) findings would suggest that ICAR has set the threshold low. HarvestPlus' initial breeding target was 77 ppm of iron.[52]

Finding 14: The barrier to commercialization identified in the Dalberg report that no competitive biofortified alternatives exist for farmers using OPVs would appear to be at odds with the launch and promotion of the Dhanashakti OPV by HarvestPlus as the first IPM, which performed better than the variety it was bred from. Moreover, the adoption of IPM reported by HarvestPlus was largely of this variety. Adoption of nine hybrid varieties supported by ICRISAT/HarvestPlus, was delayed by difficulties in licensing public sector-bred varieties to the private sector, a high-level issue that deserves attention.

The value of ICAR's relatively low iron threshold of 42 ppm of iron may be to signal that the government seed system will set more and higher thresholds in the next two or three years and seed companies would do well to start breeding accordingly.

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[49] https://nutritionconnect.org/sites/default/files/2020-01/191213_India_Iron%20Pearl%20Millet_Report_vFINAL%20%28002%29.pdf

[50] This calculation takes the nine hybrid varieties identified by HarvestPlus as IPM varieties and the iron level provided by ICAR which are about 12% higher than those provided by HarvestPlus -- http://www.aicpmip.res.in/Micronutrient%20Pearl%20Millet.pdf. This is done to be consistent in making the comparison.

[51] https://cgspace.cgiar.org/handle/10568/82731

[52] http://www.unscn.org/layout/modules/resources/files/HarvestPlus_Pearl_Millet_Strategy.pdf

The Dalberg assessment identified three main barriers to commercialization of IPM:

1. No competitive biofortified alternatives exist for farmers using OPVs;
2. That pearl millet's short post-grain shelf-live and immature supply chain have prevented processors from using pearl millet, including IPM, to develop products.
3. Limited incentives of seed producers to exceed ICAR's relatively low iron content benchmark of 42ppm.

The first barrier appears to somewhat at odds with Govindaraj et al., (2019) that say that the Dhanashakti OPV, developed by ICRISAT from the intra population variability within ICTP-8203, gives 11 percent higher yield and 9 percent higher iron than the original. Dhanashakti provides 71ppm of iron, well above the 42 ppm of iron threshold.[53] The seed production and adoption figures provided in ICRISAT/HarvestPlus literature on IPM is largely of Dhanashakti. Dhanashakti was announced by ICRISAT, HarvestPlus and ICAR as the first ever IPM. According to surveys of areas growing IPM, nearly a third of farmers purchased biofortified seed (i.e., Dhanashakti) for its nutritional value and a large proportion planted it instead of conventional varieties.[54]

With respect to the second barrier, the Dalberg report pointed to promising work being carried out by ICAR and Corteva to develop IPM varieties capable of shelf lives greater than six months that would potentially increase the pearl millet market by 1 or 2 percent.

With respect to the third barrier, one respondent said that the value of the admittedly low threshold is to signal that the government seed system will set more and higher thresholds in the next two or three years and seed companies would do well to start breeding accordingly.[55] The Dalberg assessment recommended supporting smaller seed companies to develop IPM varieties as the large companies are already doing. This is happening in practice in that ICRISAT continues to provide IPM lines to the members of its PMHPRC of which approximately 30 seed companies are members.[56]

A fourth barrier to the adoption of IPM to date is related to the market for pearl millet seed being dominated by private sector seed producers selling hybrid varieties. ICRISAT/HarvestPlus invested in working with several SAUs to develop nine hybrid varieties, released between 2015 and 2019. Legal issues make it difficult for SAUs to license their varieties to the private sector. In 2020-2021, three companies were allowed to begin commercial seed production of HHB 299 and HHB 311. Maharashtra State Seeds Corporation started multiplying two other varieties – ADB 1200 of iron and ADB 1269 of iron – at the same time.[57]

Finding 15: HarvestPlus took a much more proactive commercialization approach in Rwanda because of the challenges faced in distributing iron bean varieties to farmers. The program intervened directly in the seed value chain, becoming the largest seed distributer in the country for a period of time. The HarvestPlus Rwanda team experimented with a number of options to rapidly produce and distribute seed to farmers. Two of the most successful were swapping farmers' seed with theirs and providing seed through agronomic training and the extension service.

HarvestPlus' approach was very successful in providing iron bean seed to farmers – by 2018 an estimated 420,000 farmers were growing iron beans with 15 percent of the population of Rwanda

[53] http://oar.icrisat.org/8602/1/Indian%20Farming_October%202014.pdf
[54] https://journals.sagepub.com/doi/pdf/10.1177/0379572120982501 p 121
[55] Respondent 17
[56] Respondent 17
[57] Respondent 14

eating them that year. This took place in the context of a very low seed replacement rate among bean farmers. However, HarvestPlus becoming a large institutional buyer and then leaving the market created, or at least led to the return of, a number of seed value chain issues, not least poor communication between institutional buyers and seed producers and the high cost of certified seed, unaffordable to most farmers.

When RAB and CIAT released the first iron varieties in 2010, the bean seed system in Rwanda did not favor quick uptake of new varieties. The first issue was that farmers saved seed from year to year and consequently variety and seed replacement rate was very low. A second issue was that certified seed was more expensive than non-certified seed, meaning nearly all farmers purchased the latter.[58] This is reflected in the informal seed sector supplying about 98 percent of seed to farmers.

In response, and helped by CIAT being granted international status in Rwanda, HarvestPlus was granted permission to directly engage in in the bean value chain in Rwanda.[59] The first five iron bean varieties were released by CIAT in 2010, followed by five more in 2012. Intensive dissemination of iron beans also began in 2012. HarvestPlus contracted seed multipliers to produce the seed and distributed it through authorized dealers, and rented and professionally ran a seed warehouse, becoming the largest seed multiplier in the country for a period of time.[60] The HarvestPlus country team experimented with a number of marketing options, including working with schools, offering farmers the options of paying only for part of the seed up front, paying for all the seed at harvest, and swapping their seeds for iron bean seeds. As a result, approximately half a million households grew an iron-fortified variety between 2010 and 2015.[61]

The HarvestPlus team coordinated a number of other activities to overcome constraints to adoption of iron bean varieties. By 2018, these included training 5,000 lead farmers and 1,000 agri-extension workers to support smallholder farmers in cultivating, marketing and understanding the nutritional benefits of iron beans. One-third of beans provided to farmers were through agronomic training and the extension service.[62] Other interventions included providing irrigation for the production of breeder and foundation seed, and providing stakes for climbing beans that cost about US$500 per ha, that farmers paid back after harvest.[63]

Efforts to make iron bean seed available were helped by the funding of the Scaling up Biofortified Beans in Rwanda project that ran from 2015 to 2018. The project set out to facilitate the production and distribution of approximately 5,000 metric tons of seed that would put an additional 80,000 ha of beans under production.[64] By 2018, an online article from HarvestPlus claimed that an estimated 1.8 million Rwandans, or about 15 percent of the total population, were eating iron beans,[65] and the crop was being grown by 420,000 farming households. Adoption was helped by iron bean varieties yielding about 20 percent more than other available varieties, providing $57–78 additional profit per ha for smallholder farming families growing them.[66]

[58] Respondent 5
[59] Respondent 5
[60] Respondent 5
[61] http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130809/filename/131020.pdf
[62] https://www.harvestplus.org/rwandasuccess
[63] Respondent 7
[64] https://ciat.cgiar.org/ciat-projects/scaling-up-of-biofortified-beans-in-rwanda/
[65] https://www.harvestplus.org/knowledge-market/in-the-news/video-how-iron-beans-gained-ground-rwanda
[66] https://www.pabra-africa.org/better-beans-for-africa/

In 2018, at the end of its third phase, HarvestPlus declared that it had achieved its mandate of catalyzing the uptake of iron beans in Rwanda and that biofortification was successfully embedded in the country's food system. Accordingly, HarvestPlus handed over the program to RAB, with whom it had co-developed a multi-stakeholder platform – consisting of RAB, local NGOs, and seed multipliers – to encourage and sustain private sector engagement and further scale up delivery.[67] The Rwanda HarvestPlus team declined from 10 people to two: a liaison officer and an XRF machine operator.

In August and September 2020, HarvestPlus conducted a rapid assessment of the sustainability of the systems that it had handed over to RAB when the program ceased its interventions in the iron bean value chain.[68] The study found that production of certified iron bean seed had increased by 10 percent among seed growers interviewed. Their combined production increased from 64 to 71 tons. The main constraint facing them was inadequate supply of early generation seed (EGS). In 2020, the Rwanda government had allowed private sector involvement in the production of EGS to address this problem. HarvestPlus' seed delivery models were being used by partners, such as the United States Agency for International Development (USAID) Hinga Weze.

The study also found a number of challenges, including the local demand for certified seed exceeding supply, weak coordination of iron bean value chain actors, in particular orders for seed being placed in time, and high price of seed making it not affordable to farmers. Overall, the study found that:

- The iron bean systems HarvestPlus had put in place were largely functional one year after handover;
- The iron bean seed business relies on the institutional market (i.e., projects and programs purchasing seed to give to farmers) with only 3 percent of farmers buying seed from the market;
- Rwanda was becoming a regional hub for seed, with buyers from DRC paying more than locals, thus contributing to a shortage; and
- Iron beans procured by retailers declined since 2018 due to demand from neighboring countries, and retailers not being able to retain customers because of irregular supply.

The first finding is somewhat at odds with the view of one participant, who said that HarvestPlus, in purchasing seed from a number of producers, created a market that collapsed when it withdrew. [69] Other institutional buyers/seed aggregators did not fill the gap. Some seed growers dropped the varieties. There is a view that HarvestPlus should have reviewed market conditions before it decided it had achieved its mandate.[70] The rapid assessment clearly identified improved communication among value chain actors as a priority.

Specific strategy: Carrying out trials to establish the efficacy of biofortified crops in producing positive health outcomes in the target country

Finding 16: HarvestPlus supported at least four efficacy trials in the three cases (crop x country), carried out either by Cornell University or the Swiss Federal Institute of Technology. Only two studies provided links to published results, which found significant positive health effects. Of the

[67] https://www.pabra-africa.org/better-beans-for-africa/

[68] https://www.dropbox.com/s/wt4ruq64d74edzb/Rwanda%20Post%20Exit%20Assessment%20of%20HIB%20continuity_11.02.21%20%28002%29.pptx?dl=0

[69] Respondent 4

[70] Respondents 2, 3 & 4

other two, no mention of their existence was found in the information HarvestPlus has made easily available on the Internet. In contrast, much mention is made by HarvestPlus of the two positive studies, to help frame biofortification as an effective solution to hidden hunger.

The timelines show that all three cases carried out efficacy trials, consistent with the HarvestPlus Phase 2 (2009—2013) priority to do so.[71] The trials had differing degrees of success.

In India, an efficacy study was published in the *Journal of Nutrition* in 2015, titled "A randomized trial of iron-biofortified pearl millet in school children in India."[72] In the study, about 120 children were fed IPM containing 86 ppm iron, with the control group being fed millet containing 22 ppm iron. The control level was low compared to the average iron content of conventional hybrid pearl millet, 42 ppm iron. The treatment level was higher than ICMH 1301, the IPM variety with highest iron levels so far release at 78 ppm. The study concluded that eating IPM significantly improved iron status in children after 4 months. The trial was carried out by Cornell University, supported from a grant from HarvestPlus and was also registered at clinicaltrials.gov. The study was reported in the *Economic Times* under the title "'Magic millet' gets an enrichment boost to cure anemia."[73]

In Rwanda, Cornell University also led a study, published in the *Journal of Nutrition* in 2016, which concluded that the consumption of iron-fortified beans led to significantly higher iron status in Rwandan women after 128 days.[74] The women consumed either 86 mg of iron/kg, or standard unfortified beans (Control Beans), with 50 mg of iron/kg. The treatment iron level was realistic for iron bean varieties released in 2012, and lower than the average of varieties released in 2021. The study has generated at least four journal articles.[75]

HarvestPlus collaborated with the Swiss Federal Institute of Technology, who ran the Bangladesh study, to carry out an earlier study in Rwanda titled "Nutrition Study of Effect of High Iron Beans on Iron Status." The study ran from August 2012 to August 2014. No results were posted to clinicaltrials.gov.[76]

In Bangladesh, the research showcased on the A4NH website[77] included a study titled "The Efficacy of Zinc-biofortified Rice in Improving Zinc Status in Young Bangladeshi Children, a Double Blind Randomized Controlled Trial" led by the Swiss Federal Institute of Technology together with BRAC University in Bangladesh and HarvestPlus. The study began in April 2018 and was supposed to be completed in the following year.[78] The study was completed by July 2021, according to clinicaltrials.gov,[79] however no results were posted on that website by the time of this writing.

Specific strategy: Carrying out adoption studies

Finding 17: In each case, HarvestPlus conducted adoption studies in part to document and understand the popularity of the respective biofortified crops. Adoption rates varied from one

[71] https://www.harvestplus.org/about/our-history
[72] https://academic.oup.com/jn/article/145/7/1576/4644387
[73] https://economictimes.indiatimes.com/news/science/magic-millet-gets-an-enrichment-boost-to-cure-anaemia/articleshow/47662487.cms
[74] https://pubmed.ncbi.nlm.nih.gov/27358417/#affiliation-1
[75] https://clinicaltrials.gov/ct2/show/NCT01594359?term=iron+biofortified+beans&cntry=RW&draw=2&rank=1
[76] https://clinicaltrials.gov/ct2/show/NCT01594359?term=iron+biofortified+beans&cntry=RW&draw=2&rank=1
[77] https://a4nh.cgiar.org/bangladesh-2/
[78] https://a4nh.cgiar.org/bangladesh-2/
[79] https://clinicaltrials.gov/ct2/history/NCT03079583?V_7=View#StudyPageTop

study to the next. For example, in Bangladesh, estimates published in 2018 and 2019 ranged from 250,000 farmers who had ever grown the crop, to 500,000 farmers, to 1.5 million farmers.

In Rwanda, published papers and reports agree that about 15 percent of the population was eating iron beans in 2018, a level of adoption that is an order of magnitude higher than in the other two cases.

After release and widespread dissemination, a strategy across all three cases was to carry out adoption surveys to assess, in part, how popular biofortified varieties were becoming. The surveys were carried out as part of HarvestPlus monitoring and evaluation and fed into numerous publications, including two commercialization reports carried out by Dalberg, for zinc rice in Bangladesh[80] and IPM in India.[81]

HarvestPlus' current approach to estimating the number of adopting households in a country was to survey seed suppliers to know the quantity of biofortified seed distributed to farmers. Adoption is calculated based on a number of assumptions, including the amount of seed received by an average farmer, how much of the seed they retained for the following season, the number of other farmers they gave or sold it to, and the rate of dis-adoption.[82]

The case timelines show that adoption rates proved to be variable, in part depending on the method used to calculate them and assumptions used.

Iron pearl millet in India

Bouis & Saltzman (2017) said that IPM had reached 125,000 households in India in 2015. Foley et al. (2021) said that in 2019, approximately 240,000 farmers were growing IPM in India and an estimated 0.7 percent of total pearl millet area was allocated to IPM. A HarvestPlus presentation suggested adoption by 65,000 farmers in 2020,[83] due in part to Covid-19 restricting movement of seed. The numbers refer to the adoption of OPV IPM, largely of the variety Dhanashakti, first released in 2014. Hybrid IPM varieties released from 2015 are only currently entering the seed multiplication phase – see Finding 14. Adoption is expected to increase greatly when hybrid IPM varieties become more widely available.

Zinc rice in Bangladesh

In Bangladesh, an adoption survey, led by the Science Policy Research Unit of the University of Sussex in the UK, was carried out in the Boro season in 2018,. Sampling was led by a World Bank sampling expert.[84] The results of the study were never published. They do appear in a HarvestPlus PowerPoint presentation[85] and were quoted in a Dalberg commercializing report published in December 2019.[86] The Dalberg report said that zinc rice was being grown by 100,000 farmers at time of survey and that an estimated 250,000 farmers had ever grown zinc rice. Only 10 percent of farmers chose to grow it for a second time. The rest cited dissatisfaction with agronomic

[80] https://nutritionconnect.org/sites/default/files/2020-01/191213_Bangladesh_Zinc%20Rice_Report_vFINAL.pdf
[81] https://nutritionconnect.org/sites/default/files/2020-01/191213_India_Iron%20Pearl%20Millet_Report_vFINAL%20%28002%29.pdf
[82] Respondent 8
[83] HarvestPlus's Operations and Biofortification Research in India – PowerPoint presentation
[84] https://www.dropbox.com/s/bgr2ny47t6e9b7v/BD_AdoptionStudy_071119_Final.pptx?dl=0
[85] https://www.dropbox.com/s/bxkhgi73v44oq00/BD_AdoptionStudy_071119_Final.pptx?dl=0
[86] https://nutritionconnect.org/sites/default/files/2020-01/191213_Bangladesh_Zinc%20Rice_Report_vFINAL.pdf

performance. This was despite zinc rice (BRRI dhan 64) being described in the national press in 2014 as highly productive in the Boro season.[87]

HarvestPlus explained that the survey underestimated adoption because it had surveyed farmers who had adopted the first two zinc rice varieties released – BRRI dhan 62/64 in 2013 and 2014 respectively – and did not reflect farmer opinion of BRRI dhan 74/78 that was released in 2015 and proved much more popular.

HarvestPlus commissioned TechnoServe to carry out a value chain analysis of zinc rice, similar in scope to the Dalberg assessment, that was published in March 2018. The TechnoServe analysis said that "in the absence of reliable data on continuation and diffusion rates, we have simulated estimates through interviews and review of reports."[88] The authors conclude that there was greater than 70 percent retention rate (compared with 10 percent reported by Dalberg). The report concludes that "compiling the reach through all channels, our best estimate of the total reach is approx. 500,000." This number included continuation and diffusion.

The figures used in a post on the HarvestPlus website in November 2018 were that HarvestPlus had distributed zinc rice seed to 650,000 farmers directly and indirectly to an additional 870,000 households though seed sharing.[89] HarvestPlus' target for its donors was for zinc rice to be adopted by one million households in total by 2018.

Iron beans in Rwanda

In Rwanda, an iron bean impact assessment was carried out by HarvestPlus, Virginia Tech, and RAB. The first step was to carry out a nationally representative listing exercise that was conducted across 120 rural villages in 29 provinces of Rwanda and was administered to a total of 19,575 households.[90] The aims of the listing exercise were to determine the adoption rate of high iron beans and to inform second-stage sampling for the main impact assessment survey that was to follow.

The second-stage sampling was a more detailed household survey, which was conducted among a subsample of nearly 1,400 bean-farming households, immediately after harvest had taken place in 2015.[91] The impact assessment found that a third of all bean-growing households had grown iron beans since their release in 2010, and more than two-thirds reported knowing about them. Overall, the impact assessment was very positive. Some of its findings include:

- In the 2015 (B) season, an estimated 350,000 farm households were growing iron beans, equating to about 20 percent of the total number of farms growing beans in Rwanda;
- A significant amount of diffusion of iron beans had occurred through farmers' social networks;
- Iron bean adopters increased their proportion of bean land area to iron beans over time;
- In season 2015 (B), when the survey was carried out, iron bean varieties made up approximately 12 percent of national bean output among smallholder bean farmers; and

[87] https://www.thedailystar.net/another-variety-of-zinc-enriched-rice-released-38067

[88] https://www.dropbox.com/s/escrxy0fe0ejt3l/180313%2018h00%20HarvestPlus%20BD%20Final%20Report%20%28Extended%20Version%29.pdf?dl=0 p 32

[89] https://www.harvestplus.org/knowledge-market/in-the-news/harvestplus-talks-zinc-rice-farmers-southeastern-bangladesh

[90] http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130809/filename/131020.pdf

[91] https://www.ifpri.org/publication/assessing-adoption-high-iron-bean-varieties-and-their-impact-iron-intakes-and-other-0

- Yields of iron beans were relatively high.

By 2019, an online article by HarvestPlus said that about 400,000 farmers were growing iron beans, which is probably low given the 2015 figure and the finding that a significant amount of diffusion was happening.[92] A 2018 report said that by 2018, iron beans had 'reached' more than 1,610,000 farmers.[93] There was general agreement, however, that 15 percent of Rwanda's population (1.8 million out of 12.4 million) were eating them, a level of adoption that is an order of magnitude higher than in the other two cases.

One respondent said an important strategy to changing social norms had been engaging women in participatory varietal selection, particularly in Rwanda.[94]

General strategy: Communication

Specific strategy: Field demonstrations, field days and shows

Finding 18: While field demonstrations, field days, and shows were important communication and awareness building strategies in all three cases, how they were run and by whom differed from country to country in terms of the role of the public versus the private sector, and the level of direct engagement by HarvestPlus.

In Bangladesh, HarvestPlus reported that it reached nearly 170,000 people through field days, pop songs, courtyard meetings and school programs. These events were organized through five government organizations, 25 NGOs, and 300 private sector seed companies in 62 out of Bangladesh's 63 districts.[95]

In India, seed companies played an important role. 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 the Dhanashakti variety. Other seed companies have since used this strategy to promote other IPM.

Every two years, ICRISAT conducted a field day as part of HPRC-PM, to which hundreds of breeders gather from across the globe, including India, to select the genetic variations for different traits including IPM at Pantancheru. These events have led to the sharing of several thousand IPM lines to various public and private organizations since 2016.

From 2015 to 2020, thousands of farmers and technical staff have attended these demonstrations.[96] HarvestPlus and ICRISAT supported seed companies to market biofortified crops by co-developing promotion and nutrition messages, providing biofortification-branded package labelling and seeds for product demonstrations.

In Rwanda, as described above under Finding 15, communicating the nutritional benefits of iron beans was led by 5,000 lead farmers and 1,000 agri-extension workers. They built the capacity of smallholder farmers to cultivate, market and understand the nutritional benefits of iron beans.[97]

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[92] https://www.harvestplus.org/rwandasuccess

[93] https://www.dropbox.com/s/xgoqr0pfl06rlfi/AM2_Detailed%20MARKET-LED%20BEAN%20SEED%20SYSTEMS%20REPORT.pdf?dl=0

[94] Respondent 8

[95] https://www.dropbox.com/home/A4NH%20Studies%202021/NARS/HarvestPlus%20background%20docs/India?preview=BD_AdoptionStudy_071119_Final.pptx

[96] https://journals.sagepub.com/doi/pdf/10.1177/0379572120982501

[97] https://www.harvestplus.org/rwandasuccess

Specific strategy: Consumer marketing using print, radio, TV and social media

Finding 19: HarvestPlus employed consumer marketing using print, radio, TV and social media in all three cases. As with the previous finding, the specific strategies used varied from case to case. Bangladesh made most use of print media and television. India relied heavily on the private sector, and one company in particular. In Rwanda, much of the marketing happened in local markets, helped by celebrity endorsement.

In Bangladesh, HarvestPlus reported that between 2012 and 2017, zinc rice was mentioned in 1,730 articles in the print media, including in *The Independent*, *Financial Express* and *Daily Sun*. Zinc rice also featured on 165 TV shows.[98] Bangladesh took the unique approach of holding a biofortification awareness workshop in 2014 for journalists working for *The Daily Star, the largest circulating English-language newspaper in the country*.

In India, consumer marketing appears to have happened mainly through promotion campaigns run by private sector seed companies, as described above. An Internet search shows that most of the print media articles on biofortification focus on improving nutrition, and more recently on Prime Minister Modi's dedication of biofortified crop varieties to the nation to fight malnutrition. Apart from articles arising from a successful efficacy study in which college-level women were given IPM to eat, the source of these articles was ICAR, who run the Coordinated Research Programme on Biofortification.

In Rwanda in 2015, HarvestPlus and RAB took the unique approach of co-producing a music video promoting iron beans involving three of the country's top musicians.[99] According to one blog, the campaign took the musicians on a series of road shows across the country where they performed live for more than 30,000 people over the course of the campaign. The road shows included exhibitions and sales of iron bean seeds.[100] The impact assessment found that much of the marketing of iron bean seeds happened in local markets. In November 2019, *The New Times* ran a feature on iron beans in Rwanda titled "Farmers and consumers adopt high-iron beans for better nutrition, health, incomes."[101]

Summary answer to EQ1

The findings allow for the following summary description as to how HarvestPlus contributed to setting up biofortification breeding programs in the three countries. The numbers refer to the three immediate outcomes involved – (1) shift in norms; (2) changes in capacity; and (3) strengthened support base.

Biofortification was established as a viable solution to micronutrient malnutrition prior to and during HarvestPlus' first phase (1). During HarvestPlus's second phase, which started in 2009, in each of the three cases, HarvestPlus provided funding support (3) and capacity development (2) to support national programs to work on biofortified breeding with CGIAR Centers. As varieties were developed and released, HarvestPlus engaged with trajectory actors in the value chain, including seed systems,

98 https://www.dropbox.com/home/A4NH%20Studies%202021/NARS/HarvestPlus%20background%20docs/India?preview=BD_AdoptionStudy_071119_Final.pptx

99 https://www.globalcitizen.org/en/content/there-are-beans-in-rwanda-that-earned-their-own-ra/?template=next

100 http://paepard.blogspot.com/2014/11/the-nutritional-benefits-of-new-high.html

101 https://www.newtimes.co.rw/news/featured-farmers-and-consumers-adopt-high-iron-beans-better-nutrition-health-incomes

to build capacity (2) and strengthen the support base for biofortification at scale (3). HarvestPlus did this through capacity development (2), advocating for policies to support biofortification (3), securing funding to support biofortification (3), and building enabling institutions with other trajectory actors (3). These efforts at building institutions were complemented by efforts to build capacity (2) of key trajectory actors within their institutions to carry out and to advocate for biofortification (3). These actions led to changes in how trajectory actors viewed biofortification as a viable solution to micronutrient malnutrition (1). These widespread changes in awareness and perception influenced the enabling environment for the technology (3). The three trajectories were also driven forward by results-focused interventions by HarvestPlus backed by its main donors.

EQ 2: How and to what extent can the respective biofortification breeding programs be scaled and made more sustainable?

During initial conversations with key HarvestPlus staff at the beginning of this evaluative review, the evaluator identified three factors upon which sustainability of a breeding program depends:

1. Competitiveness: The extent to which biofortified varieties produced by the breeding program are able to compete against non-biofortified varieties with respect to agronomic and market traits.
2. Political support: The extent to which the government supports biofortification as part of the national strategy to improve nutrition.
3. Mainstreaming: The extent to which the national biofortification program is able to mainstream the biofortification traits into breeding materials used by NARES and the private sector.

This framing of sustainability was then verified during Step 4 of the OTE process. The performance of the three cases against the three dimensions of sustainability is considered country by country, before addressing how and to what extent the respective programs can be scaled and made more sustainable.

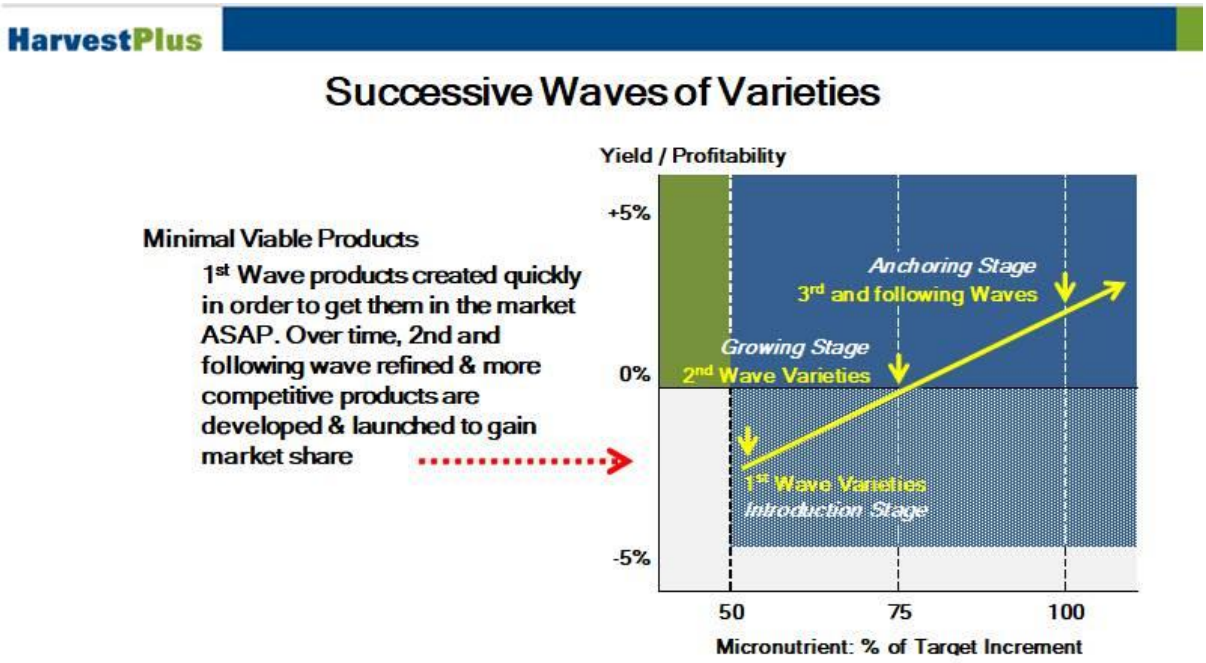
Bangladesh

Competitiveness

The first two zinc rice varieties (BRRI dhan 62 & 64) were not competitive in terms of yield (see Finding 17). They were released as a first wave to introduce them into the market as quickly as possible while more competitive waves were developed, as part of a HarvestPlus strategy described in Figure 3. Evidence that they were uncompetitive came from an adoption study that found only 10 percent of farmers chose to plant them again. Subsequent varieties have proven more popular, according to respondents, one of whom said that the 9th variety released by BRRI, BRRI dhan 100, is a 'game changer.'[102] Trials suggest that it can compete with the two most popular varieties, BRRI dhan 28 & 29. Other varieties have proven more popular than the first wave, particularly BRRI dhan 4 & 84.

[102] Respondent 12

Figure 3: HarvestPlus' 'successive waves of varieties' strategy



Political support

Political support for biofortification exists in Bangladesh, including for zinc rice, as discussed under Finding 5. One respondent, however, suggested that having broad and overarching support for biofortification in policy documents does not necessarily drive acceptance at all government levels, with differences of approach between ministries.[103] According to another respondent, as of 2021, BRRI leadership is very supportive of biofortification.[104]

Mainstreaming

Breeding zinc rice is carried out in one of BRRI's 19 divisions. BRRI adopted mainstreaming of biofortification traits into its breeding lines as a policy in 2020.[105] However, this will take an estimated 7 years to happen. In the meantime, BRRI's zinc rice team under the Plant Breeding division will continue to carry out targeted breeding and to share breeding materials with the other institutes. According to Virk et al. (2021), targeted breeding gradually leads to mainstreaming, as the latter capitalizes on the progress made in the former.

How can the zinc rice breeding program in Bangladesh be scaled up and made more sustainable?

Respondents expressed their confidence that breeding for zinc rice would continue, given that Bangladesh faces a challenge in feeding its growing population, rice is the main staple, and tackling micronutrient malnutrition is a political priority. It was felt that additional funding is needed for the purchase and maintenance of equipment needed for screening when biofortification traits become mainstreamed across the conventional breeding programs. Funding of varietal trials would also help fast-track the release of biofortified varieties.

[103] Respondent 16
[104] Respondent 9
[105] Respondent 9

The analysis above suggests zinc rice could also be scaled up, at an appropriate rate, through carrying out an adoption study to show the popularity or otherwise of the second and subsequent waves of zinc rice. In particular, the study should establish if the latest zinc rice variety, BRRI dhan 100 is indeed a 'game changer.' Given the variability in methods used, and results produced from previous studies, any future adoption study will need to be rigorous, peer-reviewed and undertaken with a commitment to publish, share and respond to the findings, whatever they might be.

India

Competitiveness

In 2012, ICRISAT bred the first IPM variety, called Dhanashakti, which was an OPV. From then on, ICRISAT concentrated on developing hybrid IPM because more than 80 percent of pearl millet produced in India is from hybrids, which give higher yields. The breeding work took place as part of the ICRISAT-led PMHPRC under the AICRP-PM umbrella. Nine hybrid varieties were subsequently released from 2014 to 2019. As discussed under Finding 14, none of these varieties has yet been widely adopted.

Adoption figures provided in published papers and reports are largely for Dhanaskati. They range from 125,000 households adopting IPM in India in 2015 (Bouis & Saltzman, 2017) to 240,000 farmers in 2019 (Foley et al., 2021) to an estimated 65,000 farmers in 2020.[106] Adoption numbers are largely for Dhanashakti.

The variability in reported adoption rates makes it hard to say whether Dhanaskati is competitive with other OPVs or not. OPVs yield less than hybrid pearl millet but are better adapted to marginal areas with very low rainfall. The fact that the Nirmal Seed Company invested in a large-scale demand-creation campaign in 2012, and other companies followed suit, suggests that it was (see Finding 18). Evidence that it is not comes from the Dalberg report (2019) concluding that a barrier to the competitiveness of IPM is that no competitive OPV is available.[107]

The 42 ppm of iron threshold for new pearl millet varieties means that there will be no competitive advantage in selling to government food programs for varieties with higher iron levels, unless and until the threshold is raised further.

Political support

Pearl millet has political support in India because it is the only staple crop that can grow in areas of Rajasthan and other states with extremely low rainfall. One respondent thought that climate change and population growth will increase support because of increasing droughts and the growing demand for nutritious food. Prime Minister Modi and the government of India are very interested in millets for food security for the poor. Hybrids offer the possibility of increasing yields.[108] Biofortification is supported in ICAR, evident in the setting up and running of a coordinated research project on the topic.[109]

[106] HarvestPlus's Operations and Biofortification Research in India – PowerPoint presentation
[107] https://nutritionconnect.org/sites/default/files/2020-01/191213_India_Iron%20Pearl%20Millet_Report_vFINAL%20%28002%29.pdf
[108] Respondent 14
[109] https://www.icar-iirr.org/index.php/downloads/archived-articles/11-news/150-virtual-crp-biofortification-progress-and-planning-meeting-organized-at-iirr-during-july-5-6-2021

Mainstreaming

In 2020, ICRISAT decided to merge its IPM breeding program with its regular pearl millet breeding program, and mainstream biofortification traits into elite lines used for all pearl millet breeding.[110] The decision by AICRP-PM to set a 42 ppm of iron threshold, and to screen all new pearl millet varieties to equal or exceed the threshold, has effectively mainstreamed IPM breeding under the ICAR varietal testing and release system. As discussed under Finding 14, the value of setting a threshold is to signal that the government seed system may set more and higher thresholds in the coming two or three years and seed companies would do well to start breeding accordingly.

How can the IPM breeding program in India be scaled up and made more sustainable?

The IPM breeding program in ICRISAT and those operating in the SAUs under the AICRP-PM umbrella, have been mainstreamed. Scaling up of pearl millet in general will be helped if R&D being carried out by ICAR and Corteva to develop IPM with a shelf life of processed grain greater than six months, is successful. Pearl millet flour, whether IPM or otherwise, goes rancid within 10 days, limiting its use in products such as bread. Improvements in postharvest handling will also increase shelf life.[111] Scaling up of high IPM, that is, varieties with more than 77 ppm iron, will depend upon increases in the minimum iron threshold for new varieties, and for government procurement, for example as part of the government's food procurement system.

At the current threshold of 42 ppm iron, and the numbers of new varieties that equal or have higher levels (see Finding 13), it is likely that by 2024, about 85 percent of rural and urban consumption will be of varieties greater than 42 ppm iron, which ICAR refers to as nutrient-rich pearl millet. Most documents written on biofortified pearl millet refers to IPM. It is not clear in these documents what level of iron qualifies a pearl millet variety to be classed as IPM. It follows that it is unclear as to whether 85 percent of rural and urban consumption of nutrient-rich pearl millet is an IPM scaling success or not.

Ultimately, scaling up of high IPM will depend on commercial seed producers that account for more than 90 percent of pearl millet production each year. In this regard, it will be important for ICRISAT to continue to make high IPM lines and hybrid-parents available to the private sector through the PMHPRC, with a particular focus on smaller growing companies (see Finding 14).

Rwanda

Competitiveness

Large adoption rates of iron beans in Rwanda were achieved after a relatively short period of time (see Finding 15). This is in part because even the first wave of iron beans gave significantly higher yields and were also favored for their color, shape and palatability. An impact assessment carried out in 2015 found significant farmer to farmer sharing of the seed. Iron beans yield 17 to 22 percent more in volume than other types of beans grown in the country giving an additional US$57–78 of profit per hectare.[112]

Political support

Iron beans have enjoyed strong political support in Rwanda, as described under Finding 5, that is stronger and more specific than in the other two cases.

[110] https://www.icrisat.org/well-designed-strategy-drives-pearl-millet-mainstreaming-nutrition-initiative/
[111] Respondent 14
[112] https://www.harvestplus.org/rwandasuccess

Mainstreaming

CIAT is mainstreaming iron and zinc traits into its bean breeding material, with the help of genomic selection.[113] Biofortification bean breeding will continue in RAB, albeit with two bean breeders, reduced from a team of five, as part of a restructuring of RAB.[114]

How can the iron bean breeding program in Rwanda be scaled up and made more sustainable?

Eight years after iron beans were first introduced, an estimated 15 percent of the population was consuming them. The HarvestPlus Rwanda team and partners achieved a level of scaling an order of magnitude higher than in other countries. This was brought about through a well-funded direct marketing strategy that involved subsidizing the price of iron bean seed (see Finding 15) while making thousands of tons of seed available. Iron bean seed availability fell when HarvestPlus stopped intervening in the seed market, such that the scaling challenge is to maintain levels of adoption, before any further increase can be expected. This will require finding more sustainable ways to provide farmers with quality seed, at the right time, the right price and the right place. This challenge will be addressed by a multi-stakeholder platform that HarvestPlus co-developed, consisting of RAB, local NGOs, and seed multipliers.[115]

EQ 3: What are the implications of this evaluative review to how CGIAR researchers work with NARES breeding programs to accelerate the planting and consumption of biofortified crops?

In all three cases, CGIAR and NARES interviewees agreed that the respective biofortification programs worked well and there was little, substantively, that could have been improved. Most spoke of strong ownership of the breeding programs by NARES. Objectively, all three cases were successful and are continuing to operate despite receiving much less funding from HarvestPlus after the end of its third phase in 2018. Acceleration has a similar meaning to scaling, therefore the case-specific answers to the previous question also apply to this one.

This section addresses cross-cutting issues, namely: the need for continued coordination across CGIAR and country teams; and the pros and cons of HarvestPlus' determined results- and numbers-driven approach.

The continuing need for coordination

A number of respondents[116] were concerned about the future of biofortification under CGIAR's new structure beginning in 2022. A common concern was that the marriage of agriculture and nutrition that HarvestPlus brought about and supported will break apart, leading to essential functions being fragmented into different institutional homes. In the structure, nutrition is separate from genetic innovation and without a bridging organization such as HarvestPlus, it is difficult to see how they will connect and influence each other in the future.[117]

There is a similar need for a bridging and coordinating initiative at country level to maintain a commitment to mainstreaming multiple biofortification traits into conventional breeding programs, as well as to push for greater focus on meeting the needs of the commercial food processors.

[113] Respondent 3
[114] Respondent 7
[115] https://www.pabra-africa.org/better-beans-for-africa/
[116] Respondents 1, 12 & 14
[117] Respondent 1

Specifically, there is a need to maintain the XRF machines in the country programs, for proficiency testing between laboratories to keep standards high and to check for data anomalies.[118] The mainstreaming of biofortification traits into national breeding programs depends on the ability to screen large numbers of crop and soil samples for micronutrients.

Pros and cons of the HarvestPlus approach

A donor view of CGIAR is that it "drops the ball when the rubber hits the road," meaning it is generally not good at taking research to scale.[119] The findings above show that HarvestPlus strove to do better. They also suggest that the approach taken was different from country to country, and at times was a double-edged sword.

In Bangladesh, the focus on scale was manifest in a large-scale promotion of zinc rice that began before more competitive second wave varieties were available. A large adoption study led by an internationally recognized university department was unpublished. The adoption figures cited varied from report to report (see Finding 17). Experience from elsewhere is that promoting a technology that does not work as claimed, creates a reluctance to adopt improved versions of it (Douthwaite, 2002). Perhaps if HarvestPlus had been able to pace itself more appropriately, there would be a broader belief in the claims made of the technology.[120]

In India, HarvestPlus worked with ICRISAT within the overall structure of the AICRP-PM, functioning under the umbrella of ICAR, one of the largest and most powerful NARES in the world. This shaped what HarvestPlus could do. HarvestPlus/ICRISAT was able to obtain AICRP-PM approval to run special varietal trials for IPM beginning in 2014. The trials were stopped in 2018, in part due to a concern of AICRP-PM that a parallel system was in place, and that resources were being wasted. In its place, the AICRP-PM annual meeting established the threshold level of 42 ppm iron and agreed that all new varieties should be screened at this level or above. HarvestPlus' resources for running the separate trials were to go to support this process. HarvestPlus was party to a decision to set a threshold level much below its target breeding level (Finding 14). In this case, the HarvestPlus approach was tempered by the institutional structure in which it worked, in a way that may prove to reduce the incentive to breed for high levels of iron in pearl millet.

In Rwanda, HarvestPlus was a big fish in a comparatively small pond. It was able to obtain approval from the government to engage directly in the bean value chain and experiment with different ways of providing biofortified seed to farmers while creating a market for it at the same time. This helped achieve levels of adoption orders of magnitude higher than in the other two cases but has also created market problems once HarvestPlus stopped the intervention (see Finding 15). In retrospect, HarvestPlus might have done better to have worked through in a more consultative and paced manner, working more to strengthen existing institutions than creating parallel ones. On the other hand, maybe not.

Conclusions

Conclusion 1: Functioning breeding programs are in place and have good potential to be sustainable for zinc rice in Bangladesh, iron beans in Rwanda and IPM in India. The programs were successful in reaching tens to hundreds of thousands of farmers. Outcome trajectory actors in Rwanda were phenomenally successful with 15 percent of the population eating iron beans after

[118] Respondent 12
[119] Respondent 5
[120] Two respondents said the data they had seen to support claims made about zinc rice varieties had so far not been convincing

less than 10 years. The programs are continuing despite a reduction in HarvestPlus funding since 2018. It is highly unlikely that the programs would have been established without HarvestPlus and the support the program received from its donors.

Conclusion 2: HarvestPlus implemented a series of strategies that were consistent with the Policy Window theory. The strategies contributed to a strengthened support base for biofortification in the respective countries; changes in capacity of trajectory actors; and a shift in norms of trajectory actors and the broader public. Most of the strategies appear to have been successful. Where they were not, they may still contribute in the longer term (e.g., seed quality standards, commercialization findings).

Conclusion 3: The way that strategies led to outcomes in each country is consistent with the concept of an outcome trajectory, that HarvestPlus helped establish and support in each country, that is, an interacting and co-evolving system of actors, knowledge, technology and institutions increasingly sharing a common purpose.

Conclusion 4: Taken together, Conclusions 1 through 3 support the claim that HarvestPlus was a driving force behind the establishment and implementation of the biofortification breeding programs in the three countries. While few might find this surprising given the role HarvestPlus played in the development of biofortification, the way the contributions happened, resulting from many different activities undertaken by HarvestPlus over time and for different objectives, gives a much more nuanced view of what it takes for research to influence policy outcomes. The influence strategies documented in this report are much broader than HarvestPlus anticipated when this evaluation was originally commissioned.

Conclusion 5: HarvestPlus had some difficulty in convincingly demonstrating that biofortified varieties benefit farmers and benefit consumers. Adoption studies painted a different picture of farmer benefit and acceptability, depending on the timing, method and assumptions used. An adoption study of the first zinc-rice varieties was seen as misleading and not made publicly available. Efficacy trials did not always work, and when they did not, the reasons were not published. HarvestPlus' own publicity tended to highlight the more positive findings, potentially risking credibility and contributing to overuse of biofortification at the expense of other approaches to reduce hidden hunger, such as promoting more diverse diets.

Conclusion 6: Further scaling depends critically on different actors engaging in different strategies in the three countries. In India, it depends upon commercial seed producers, that account for more than 90 percent of pearl millet production each year, breeding and selling IPM on a large scale. In Bangladesh, it depends upon whether the new zinc rice varieties can compete on yield and agronomic performance with popular regular varieties. In Rwanda, it depends upon providing iron bean seed at an affordable price to farmers, in sufficient quantities.

Conclusion 7: In all three cases, respondents thought CGIAR and the NARES worked well together and there was little, substantively, that could have been improved. Most spoke of strong ownership of the breeding programs by NARES.

Conclusion 8: Mainstreaming is happening in the three sets of NARES and the respective CGIAR Centers supporting them. However, both sets of actors are concerned that with the reduction in funding and advocacy since the end of HarvestPlus' third phase, momentum may be lost. With the withdrawal of HarvestPlus, funding from national governments will be particularly important to cover the additional equipment, staff capacity and funding required to screen seed samples for

biofortification traits as part of breeding new varieties and subsequent national seed release processes.

Conclusion 9: There is a need for coordinating work on biofortification in CGIAR and in the three countries. At CGIAR-level there is a concern that, without HarvestPlus or a similar mechanism holding nutrition and genetic innovation together, the two will retreat into their different institutional homes in the new CGIAR structure, to the detriment of both. There remains a similar need for a bridging and coordinating initiative at country level to maintain a commitment to mainstreaming multiple biofortification traits into conventional breeding programs, as well as to push for greater focus on meeting the needs of commercial food processors.

Conclusion 10: HarvestPlus pursued a determined, results-driven approach that was tempered by the country in which it worked. In Rwanda, where the HarvestPlus investment was a significant portion of the NARES budget, HarvestPlus itself became an actor in the supply chain, becoming the largest seed multiplier in the country for a period of time. While HarvestPlus was very successful in Rwanda, the program's exit led to a gap in the institutional market for certified seed, the main market for seed producers. In contrast, in India, HarvestPlus worked as part of the PMHPRC and AICRP-PM consortia and as a member of the latter was party to a compromise decision to set an iron threshold level for nutritionally-rich pearl millet, much lower than HarvestPlus' 77 ppm iron target breeding level, and which risks damaging the prospects for high IPM in the future. What will likely be achieved is that by 2024, about 85 percent of rural and urban consumption will be of varieties greater than 42 ppm iron.

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Appendix I: Zinc rice in Bangladesh

2001

- IRRI launches 'Breeding for Iron Dense Rice Project' until 2003, funded by the Asian Development Bank
    - BRRI an active partner, screening for zinc and iron starts with University of Adelaide doing mineral analyses
    - Khondoker Aminul Kabir, Principal Scientific Officer, Grain quality and Nutrition Division and Alamgir Hossain, Senior Plant Breeder of BRRI were involved

2003

- HarvestPlus Phase 1 begins to identify target populations and conducted proof-of-concept research to prove feasibility of biofortification for five crops (rice, wheat, maize, cassava and common beans)
    - Receives US$25 million for Phase 1 from the Bill & Melinda Gates Foundation (BMGF)
    - Co-administered by IFPRI and CIAT

2004

- HarvestPlus partners with BRRI to develop biofortified rice in Bangladesh
- IRRI reviewed and concluded that genetic variation for iron concentration is not sufficient through conventional breeding. However, genetic variation for zinc concentration was promising to develop high zinc rice.

2007-2008

- Survey on zinc and health status among children at risk of zinc deficiency carried out (link)
    - Initial project of HarvestPlus research program in Bangladesh

2009

- HarvestPlus starts routing funds to national breeding programs through CGIAR Centers, IRRI for rice
- BRRI wins a separate fund from BMGF under HarvestPlus (link)
- Screening and parent breeding of material from BRRI gene bank

2010

- HarvestPlus starts investing in BRRI, initially through IRRI because government regulations do not allow direct foreign funding
    - US$125k in 2010, most for direct labour and operations
- HarvestPlus raises interim breeding target level of 24 mg per kg to 28 mg per kg milled rice.
- 20 lines >24mg/kg of zinc in polished grains evaluated by BRRI in 2010-2011 boro season for agronomic performance

- 86 advanced breeding lines from IRRI evaluated by BRRI for zinc/iron under local conditions

2012

- Difference of opinion emerges between HarvestPlus and IRRI as to relative priority of zinc rice breeding programs in Bangladesh, Philippines, and Cambodia
- HarvestPlus establishes a country office in Bangladesh to work on delivery, scaling up and support to breed, test, and release of biofortified rice
    - Initially through partnership between BRRI and IRRI

2013

- First zinc rice Aman (rain-fed) season variety, "BRRI dhan 62" released (link)
    - 20 ppm compared to interim zinc target level of 24 ppm
    - Shortest duration (100 days) Aman rice variety ever released that better allows for a third crop between wet and dry season rice crops
- HarvestPlus/IRRI provide no funding to BRRI

2014

- HarvestPlus begins Phase 3 funded largely by BMGF and the UK's Department for International Development, until 2018
- CGIAR makes a full commitment to mainstreaming breeding for mineral and vitamin traits into conventional food crop development programs at Second Global Conference on Biofortification in Kigali, Rwanda
- Push to create public awareness of zinc rice begins in Bangladesh
- *Daily Star* Workshop held to create awareness of zinc rice and plans for seed delivery of BRRI dhan 64
    - Daily Star article announces launch of second zinc rice variety BRRI dhan 64 for aman season (link)

2015

- National Strategy on Prevention and Control of Micronutrient Deficiencies, Bangladesh 2015-2024 launched (link)
    - Includes biofortification of zinc in implementation plan framework for strategy area 2: Micronutrient intervention (dietary diversity) p. 60
- IRRI develop transgenic rice that has high zinc and iron content as a proof of concept (link)
    - Zinc 12ppm and Iron 35ppm in same product
- Two varieties released - BRRI dhan72 for Aman season and BRRI dhan74 for Boro season
- *Daily Star* reprints 2014 article (link)
- Second X-ray fluorescence machine installed in Bogra at HarvestPlus facility (link)

National Strategy on Prevention of Micronutrient Deficiency Bangladesh 2015-2024

http://iphn.dghs.gov.bd/wp-content/uploads/2016/01/NMDCS-.pdf

Intervention Strategy	Micronutrient (s)	Target Group	Priority Areas of Action
Bio-fortification of zinc	Zinc, vitamin A	Whole population	• Consider cross breeding of high zinc-containing mega variety of rice with indigenous varieties • Establishing quality control for fertilizers in terms of zinc content and minimizing adulteration of Zn fertilizers • Promoting the production and consumpt of high β-carotene-containing sweet pot (komola sundari) • Promoting a new variant of zinc-enriche developed in Bangladesh

2016

- Launch of Second National Plan of Action for Nutrition, which mentions biofortification (link)
- Launch of Second Country Investment Plan (link)
- HarvestPlus starts routing funds straight to BRRI, who assumes greater leadership
- HarvestPlus and partners deliver the seeds of four zinc rice varieties across 62 of 64 districts across the country (link)

Second National Plan of Action for Nutrition

https://bnnc.portal.gov.bd/sites/default/files/files/bnnc.portal.gov.bd/download/ddabde0d_3bfc_4e05_92fe_8ef33a73a235/2019-12-15-13-55-3e877e2d46e08834d7e1353cd4b86ffb.pdf

#	Strategy of NNP	Sub-Strategy	Key Action Area	Major Activities	Time-line	Responsible Ministries	Partners
6.2	**Ensure availability of adequate, diversified and quality safe food and promote healthy feeding practices**						
6.2.1	Encourage coordinated homestead gardening and small-scale livestock and poultry rearing, at family level or collectively, to increase the availability of diverse, safe and nutritious food		Strengthening of integrated homestead food production (fruits and vegetables, small livestock, aquaculture, comprehensive nutrition education) with emphasis on indigenous, underutilized and nutritious varieties/species/breeds) and gender sensitive and climate smart technologies	1. Conduct ToT for relevant government staff 2. Conduct trainings that promote diversified homestead gardening (fruits and vegetables) and backyard poultry/ small livestock production/aquaculture supported by strong nutrition education for diet diversity namely farmer field school, village based organization etc. 3. Promote horticulture through rooftop garden and Promote healthy nutritious feeding practices 4. Introduce the recent area-based home gardening technologies (such as hydroponic, floating gardens) through trainings and aquaculture and social forestry in the unused land 5. Conduct trainings that promote small fish rearing and indigenous species (like mola, carplet) linked to nutrition education 6. Develop/Adopt/Disseminate nutrition sensitive training resources and information materials 7. Scale up diversified and integrated homestead food production (fruits and vegetables small livestock +small fish) linked with nutrition education) through provision of necessary inputs 8. Conduct trainings (ToT and training of beneficiaries) on techniqaes/tools to reduce postharvest losses (PHL) in horticultural, fishery and livestock commodities 9. Construct or impeove 'Storage and Marketing Facilities' at local/national level 10. Undertake relevant research activities on biofortification e.g., legumes, orange fleshed sweet potato)/evaluate impacts on health 11. Accelerate the release and adopt Zn biofortified rice to target HHs for production and consumption/)/evaluate impacts on health 12. Undertake relevant research activities on climate smart technologies 13. Develop/Distribute nutrition sensitive information	LT	MOA-DAE/ BIRTAN MOFL-DLS MOFL-DOF NARS-BARC LGRD MOHFW MOWR	IPHN PSB Selected DPs NGOs INGOs

Second Country Investment Plan

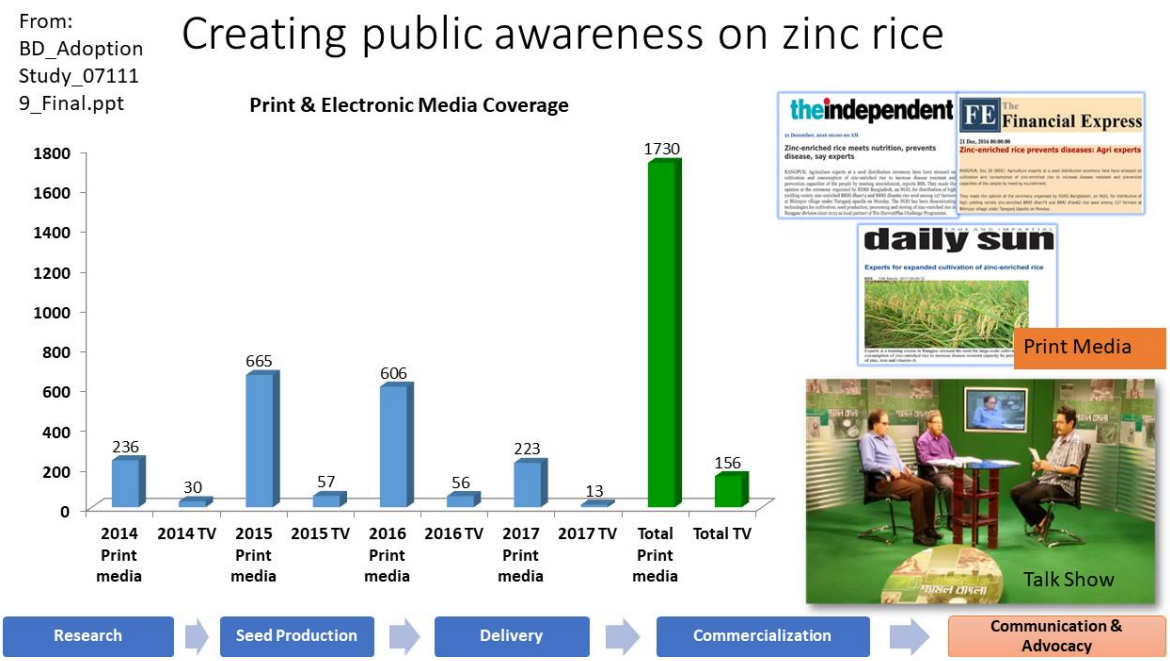
http://fpmu.gov.bd/agridrupal/sites/default/files/file/CIP2FinalPDFPrintedCopy.pdf

- New high-impact technologies e.g. biotechnology, biofortification, and nanotechnology
- Develop PPPs
- Expand of solar power
- Introduce/develop crops most adapted to new conditions in terms of their nutritional content but also their income generating value e.g. commercial seaweed cultivation in coastlines
- Trials in the vulnerable climatic regions based on NAPA and BCCSAP priorities

2017

- Push to create public awareness of zinc rice by HarvestPlus and BRRI leads to 1730 mentions in print media and 156 on TV over previous four years
- HarvestPlus provides US$75k directly to BRRI through nutrition contracts

From: BD_Adoption Study_071119_Final.ppt



2018

- National Agricultural Policy launched
- HarvestPlus aimed to reach 1 million farmers by 2018, through working with 30 partners from the public, private and civil society sectors, 25 local NGOs, World Vision, and more than 350 small and medium-sized seed companies. (link)
    - HarvestPlus says that biofortified seed was distributed to 630,000 households and assume it reached 1.5 million farmers because farmers give seed to neighbors (link)
- Dalberg produces a report for GAIN and HarvestPlus that finds 100,000 farm households reported to be growing zinc rice comprising less than 1 percent of total rice grown (link)

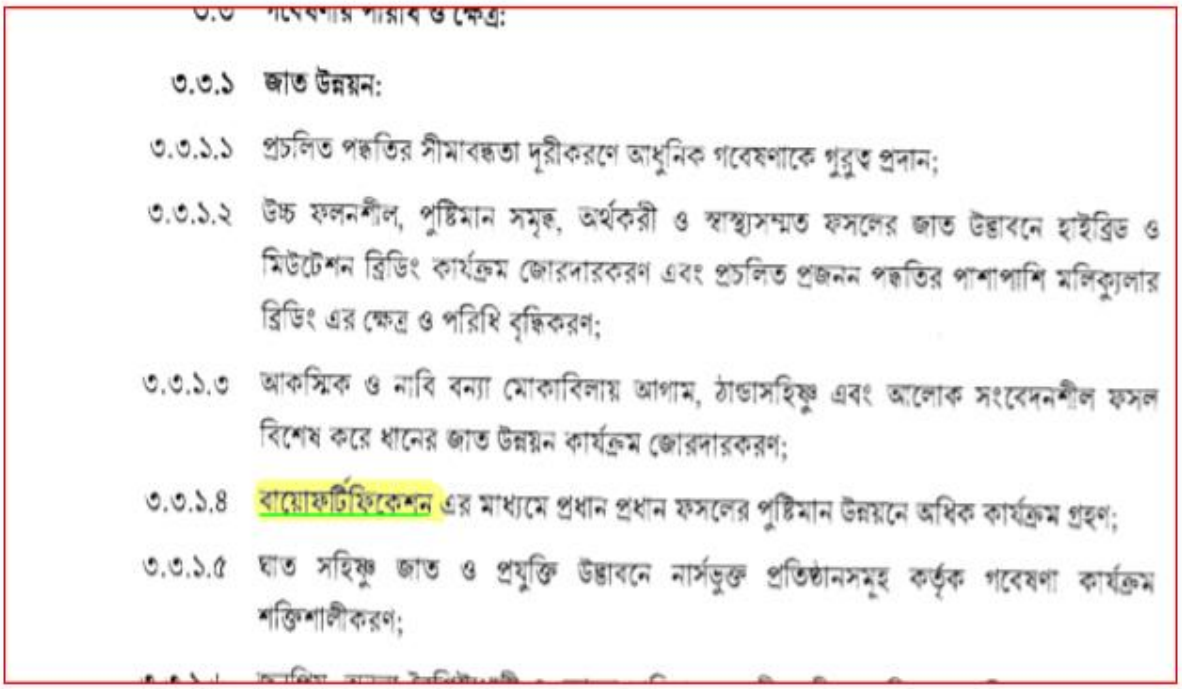
- Only 10 percent chose to grow it for a second time, rest cited dissatisfaction with agronomic performance of zinc varieties

- Main varieties grown were BRRI dhan 62/64 which are reported to perform less well compared to BRRI dhan 74/84. See p. 11 of Dalbeg report for details
    - Survey finds 250k households had ever grown zinc rice
    - The report references "Results from the Bangladesh High Zinc Rice Adoption Study," 2019
- Technoserve and HarvestPlus carry out a value chain assessment for zinc rice
    - Says that "in the absence of reliable data on continuation and diffusion rates, we have simulated estimates through interviews and review of reports."
        - Concludes that there is a greater than 70 percent retention rate (compared with 10 percent reported by Dalberg)
    - Reference: HarvestPlus Bangladesh Final Report, Extended Version, March 13, 2018

- HarvestPlus provide US$75k directly to BRRI

National Agricultural Policy 2018

https://moa.portal.gov.bd/sites/default/files/files/moa.portal.gov.bd/policies/69304e3a_05f2_4e17_b369_92e2285171f0/krishi_nity_2018%20(1).pdf



৩.৩.১ জাত উন্নয়ন:

৩.৩.১.১ প্রচলিত পদ্ধতির সীমাবদ্ধতা দূরীকরণে আধুনিক গবেষণাকে গুরুত্ব প্রদান;

৩.৩.১.২ উচ্চ ফলনশীল, পুষ্টিমান সমৃদ্ধ, অর্থকরী ও স্বাস্থ্যসম্মত ফসলের জাত উদ্ভাবনে হাইব্রিড ও মিউটেশন ব্রিডিং কার্যক্রম জোরদারকরণ এবং প্রচলিত প্রজনন পদ্ধতির পাশাপাশি মলিকুলার ব্রিডিং এর ক্ষেত্র ও পরিধি বৃদ্ধিকরণ;

৩.৩.১.৩ আকস্মিক ও নাবি বন্যা মোকাবিলায় আগাম, ঠান্ডাসহিষ্ণু এবং আলোক সংবেদনশীল ফসল বিশেষ করে ধানের জাত উন্নয়ন কার্যক্রম জোরদারকরণ;

৩.৩.১.৪ বায়োফর্টিফিকেশন এর মাধ্যমে প্রধান প্রধান ফসলের পুষ্টিমান উন্নয়নে অধিক কার্যক্রম গ্রহণ;

৩.৩.১.৫ ঘাত সহিষ্ণু জাত ও প্রযুক্তি উদ্ভাবনে নার্সভুক্ত প্রতিষ্ঠানসমূহ কর্তৃক গবেষণা কার্যক্রম শক্তিশালীকরণ;

2019

- HarvestPlus launches three-year business plan that prioritizes mainstreaming of biofortification into CGIAR breeding programs, to achieve full integration by 2030 (link)
    - BMGF funding to HarvestPlus is for value chain work and monitoring CGIAR mainstreaming of biofortification but not for dedicated breeding programs

- March: Accelerating Genetic Gain in Rice Alliance launches as a 5 year 30-million-dollar initiative, funded by BMGF led by IRRI (link)
    - Brings two projects, Transforming Rice Breeding and Stress Tolerant Rice for Africa and South Asia, under one initiative
- Study to assess the efficacy of zinc rice in young Bangladeshi children began but not completed (link)
- Salinity and drought tolerant high zinc germplasm is identified
- HarvestPlus provide US$71k directly to BRRI

2020

- Bangladesh 8th Five-Year Plan July 2020 - June 2025 (link)
    - Food security and nutrition feature prominently
    - BRRI dhan 62 is mentioned (p 734) noting its release and its ability to fight diarrhea and pneumonia-induced childhood death and stunting
        - Mentioned together with fortification and increasing dietary diversity
- BMGF shift funding behind biofortification mainstreaming by CGIAR Centers
- CIMMYT officially integrated zinc targets into core wheat breeding program (link)
- HarvestPlus provide US$71k directly to BRRI

2021

- BRRI dhan100 released (link)
    - On paper competes with the two most popular varieties. BRRI dhan100' has a higher yield than that of BRRI dhan29 and the lifespan is similar to that of BRRI dhan28, which is a reflection of our long-standing aspirations

Overall

- HarvestPlus invested US$800,000 in BRRI from 2010 to 2020
    - Emergent strategy
        - Focus on rice varieties with attractive agronomic properties
            - I.e., short duration so can grow a third crop of lentils or other crop between first and second cropping seasons
        - Robust demonstration program
        - HarvestPlus initially guarantees a market for a portion of private sector production and subsidizes sale of seed from private sector to farmers
        - Give packets of free seed to NGOs
- Nine varieties released
    - Six varieties released by BRRI (BIRRI dhan 62, 64, 72, 74, 84 & 100)
    - One hybrid and one inbred variety released by Bangabandhu Sheikh Mujibur Rahman Agricultural University
    - One inbred variety released by Bangladesh Institute of Nuclear Agriculture

- Claim by HarvestPlus that it has reached 2,454,000 Bangladeshi households directly since 2013 through its core program and three main projects (link)
    - Enhancing Nutrition Services to Improve Maternal & Child Health Project (2016-2020)
    - Bangladesh Initiative to Enhance Nutrition Security and Governance Project (2018-2022)
    - Commercialization of Biofortified Crops Program (2019-2022)

Appendix II: Iron beans in Rwanda

1994

- CGIAR micronutrient project starts: Howarth Bouis, working at IFPRI, persuades IRRI (rice), CIAT (beans and cassava) and CIMMYT (maize and wheat) to provide limited funding to explore feasibility of enhancing vitamin and mineral content using conventional breeding

1996

- PABRA established to facilitate breeding and introduction of new bean varieties in Africa

2003

- HarvestPlus Phase 1 begins
    - CIAT begins breeding iron beans funded by HarvestPlus
    - Sources are wide crosses between Andean and Mexican bean varieties, which bring unwanted traits that made breeding difficult

2009

- HarvestPlus Phase 2 begins
- Breeding for iron in beans begins in Rwanda

2010

- The predecessor to RAB, in collaboration with CIAT and HarvestPlus, release five iron-biofortified bean varieties (link)

2011

- RAB formed through merger of research and extension in Rwanda

2012

- Intensive dissemination of iron-biofortified beans begins (link)
    - Through authorized agri-dealers
        - HarvestPlus contracted seed multipliers to grow the seed
    - Direct marketing by Rwanda HarvestPlus country team
    - Exchange of local varieties for iron-fortified bean seeds
    - Approximately half a million households grow an iron-fortified bean variety between 2010 and 2015
- Five additional varieties released, three climbing and two bush
- HarvestPlus prioritizes seed production becoming the largest seed producer in Rwanda (Respondent 5)
    - Also had mechanisms in place to buy seed, buying high and selling low
        - Some seed producers subsequently dropped the varieties when HarvestPlus stopped intervening in the market

2013

- National Food and Nutrition Policy published supporting interventions to support "(sic.) improved availability, affordability and quality of nutritious food including extension and input support to producers of biofortified bean and maize seeds and sweet potato vines as well as communication campaigns to promote planting and consuming of biofortified foods." p. 31

2014

- Publication of Rwanda National Food and Nutrition Policy (link)
    - Mentions iron deficiency as a problem
    - Mentions Rwanda moving ahead with biofortified crops, giving the example of iron beans (p 15)
- HarvestPlus begins Phase 3
- Second Global Conference on Biofortification is held in Kigali in March
- Seed system progress
    - 51 new and 179 continuing farmers trained on seed multiplication
    - 36 agronomists, 37 co-op leaders and 45 agronomists trained

2015

- High Iron Bean Impact Assessment is carried out (link)
    - In the first stage, a listing exercise is conducted across 120 villages in 29 provinces in Rwanda and administered to 19,575 households
    - Purpose of listing exercise was to determine adoption rate of high iron beans and inform second stage sampling for main impact assessment survey
- USAID Feed the Future Scaling up of Biofortified Beans in Rwanda Project begins, until 2018 (link)
    - Project expects that over the life of the activity up to 400,000 new households in not less than 16 districts will be planting and using high-iron beans. The activity will facilitate the production and distribution of approximately 5,000 metric tons of seed that will put an additional 80,000 ha of beans under production
- HarvestPlus and RAB co-produce a music video involving three of the top musicians in Rwanda, promoting iron beans (link)
- Seed system progress
    - 170 seed multipliers trained
- 740 people trained in seed distribution (Including agronomists, co-op leaders and agro-dealers

2016

- Seed system progress

    - 52 new seed multipliers and 170 current seed multipliers trained; 33 extension officers trained on agronomic best practices, pest and diseases, nutrition and marketing
    - 41 agro-dealers; 22 co-op leaders and 33 agronomists trained

2017

- Publication in *Journal of Nutrition* (link)
    - 150 female Rwandan college students ate two meals of iron beans per day for 18 weeks (link)
        - Enhanced cognitive ability
- *African Journal of Food, Agriculture, Nutrition and Development* article published on iron beans in Rwanda (link)
    - Estimated that more than 800,000 Rwandan farm households are growing and consuming iron beans
- National Agriculture Policy published (link)
    - Ongoing efforts to improve the nutritional content of food staples such as biofortification will be scaled up and present an opportunity for exports throughout the region (p 18)
        - Only mention - iron beans not mentioned specifically
        - Livestock seen as main way to bridge the iron gap (p 15)
            - Rwanda has one cow per family policy
- Eight iron bean varieties in pipeline for release
- Seed production, promotion and distribution
    - Agro-dealers model; payback (phased out); seed swap; institutional partners and cooperative and community-based demonstrations.
        - Seed swap and institutional partners most successful

2018

- African Union Commission funds a project in East Africa to enhance the nutrition and health of smallholder farmers through increased productivity of biofortified common bean and improved postharvest handling
    - Partners are RAB, CIAT and Università Politecnica delle Marche
    - Budget is €722,000 for three years
- 13 August - Workshop held, titled "Achieving a Sustainable Market-led Bean Seed Industry in Rwanda"
    - MinAg, RAB, PABRA, HarvestPlus, CIAT
    - At least 94 percent of bean seed supplied informally
    - HarvestPlus Africa Region Manager acknowledges that no businessperson could run their business like HarvestPlus by buying at a high price and selling at a loss. Also says that overlaps in responsibilities causes tension between public and private sector

- Rwanda Standards Board produces standards for iron-biofortified dry beans (link)
    - Not gazetted as of July 2021
- HarvestPlus supports establishment of grain aggregation centers (link)
    - One-third of beans provided to farmers through agronomic training and extension service
    - 5,000 lead farmers and 1,000 agri-extension workers trained to support small holder farmers in cultivation, marketing and understanding the nutritional benefits
- Between 2012 and 2018 season A 4,647 MT of seed had been produced and 1,611,978 farming households reached
    - Iron beans yield 17-22% more volume and give an additional US$57-78 of profit per hectare (link)

2019

- HarvestPlus begin working according to 2019 to 2022 3-year plan as part of 2019 to 2023 Strategy (link)
    - HarvestPlus decides that its seed distribution objectives have been reached
        - Breeding is ongoing
    - HarvestPlus team in Rwanda shrinks from 10 people to two
        - Liaison officer on bean value chain and XRF machine operator remain
            - No activities on the ground in 2020 or 2021
- Various adoption claims made by HarvestPlus
    - 420,000 households growing them (link)
    - 1.8 million people eating high iron beans (link)
    - 20 percent of all beans produced in Rwanda are iron fortified (link)
        - A unique achievement in a short period of time, as a result of aggressive marketing
    - 5,000 tonnes of seed produced
        - At one point, HarvestPlus was largest producer of bean seed in the country
        - A reflection is that it might have been better to have put more effort into coordination of existing actors rather than become directly involved in seed provision

2020

- Public Rationalization Process takes place which reduces the number of bean breeders in Rwanda from five to two

2021

- *World Development* paper finds that RWR2245 is the most widely adopted iron bush bean variety (link)
    - Provides a yield gain of 20 to 49 percent over traditional bush bean varieties

    - RWR2245 has also been the most widely disseminated variety; in most seasons, it represents over 70 percent of iron-biofortified bean planting material delivered via formal approaches
    - Finds that iron beans can increase nutritional outcomes in two ways
        - By substituting less nutrient dense beans from the market
        - Increased income through reduced purchase of beans and more likelihood of selling them that can be spent on more nutritious food

- Eight varieties in pipeline since 2017 released
    - Main reason for delay was that seed law stipulated approval was needed from a committee that had not been set up
    - Illustrates importance of supporting multi-locational trials and other prerequisites before release
    - More candidates in pipeline

- RAB research policy is to breed for nutritious varieties

- Beans in Africa becomes one of CGIAR's 'golden eggs.' (link); Rwanda features heavily
    - "To date, PABRA members have released 536 varieties of beans and made them available to more than 30 million households."
    - 45 iron bean varieties made available to 10 million households

Appendix III: Iron pearl millet in India

1965

- AICMIP Improvement Project established at India Agriculture Research Institute in New Delhi (link)

1970s

- Downy mildew epidemic in the early 1970s due to over-reliance on a few hybrids (link)

1985

- AICPMIP was established with its headquarters at Pune (link)

1995

- Headquarters of AICPMIP shifts to Jodhpur in Rajasthan under the Agricultural University (link)
    - The state which occupies nearly half of pearl millet area of the country
    - A network of 13 AICRP centers in Rajasthan, Gujarat, Maharashtra, Karnataka, Andhra Pradesh, Madhya Pradesh, Punjab, Haryana and Tamil Nadu, ofwhich 12 project centers are located at different SAUs and funded on 75% (Central Sector share) and 25% (State share).
    - The AICRP-PM centers located in 12 SAU's and University of Mysore pursue mandated activities and research on pearl millet in the area of germplasm utilization, improvement, production, protection and value addition.

2000

- PMHPRC launched by ICRISAT that engages approx. 30 seed companies (link)
    - Identification of identified high-iron hybrid-parents from amongst those initially not bred for high-iron as a target trait, several high-yielding and high-iron hybrids have been developed (p 5) (link)

2004

- ICRISAT receive small US$10,000 grant from HarvestPlus to do groundwork/feasibility study (Respondent 14)
    - To see if it can be a candidate for biofortification
        - Looking at variability in germplasm and whether trait is stable
    - Generate screening tools, how to sample

2005

- Breeding of IPM begins at ICRISAT with US$75,000 grant from HarvestPlus (link)

2006

- PhD dissertation titled “Genetic Variability, Stability and Inheritance of Grain Iron and Zinc Content in Pearl Millet (*Penniserurn glaucum* (L.) R. Br.)” submitted to Tamil Nadu Agricultural University, India.

2008

- Product orientated breeding begin with start of HarvestPlus Phase 2 (2008 – 2013)

- First study on variability for grain iron and zinc contents in pearl millet hybrids published (link)
    - Decision made to promote pearl millet as a 'fast-track' crop after high levels of iron found in existing varieties
- Breeding high-iron cultivars using existing high iron lines (Respondent 14)
- Iron and zinc staining method for pearl millet samples established

2009

- Only a few of the seed companies that were part of HarvestPlus crop meetings were initially interested in IPM (Respondent 5)

2010

- First XRF lab established at ICRISAT supported by HarvestPlus, the result of a lot of work by HarvestPlus to find a method to screen for micronutrients that was fast, cheap, with a high throughput and not affected by contamination.

2011

- Beginning of major partnership led by ICRISAT involving the public and private sector, including the state ag. universities and AICRP-PM (Respondent 14)
- ICMH 1201 hybrid in 48 field trials 2011—2013 giving 75 mg per kg (similar to ICTP 8203) but with a grain yield of 3.6 t/ha (38 percent higher than ICTP 8203) (link)
    - Grain yield of this hybrid was lower than the yielding check hybrids and hence not recommend for by Central Variety Release Committee for official release (Respondent 14)

2012

- First OPV of IPM bred by ICRISAT using the intra-population variability within ICTP-8203 cultivated in India since 1990, known as "Dhanshakti" (link)
- Commercialized by Nirmal Seeds (link)
    - Also commercialized by MPKV-Dhule, AICRP-PM and Mondore
        - Reaching more than 60,000 farmers in India
    - Selling truthfully labelled seed (link)
- Nirmal Seeds leads a large-scale demand-creation campaign for IPM (link)
    - Includes farmer training and establishment of multilocation demonstration lots to showcase superior agronomic and nutritional status of Dhanashakti
        - Other companies followed suit

2013

- HarvestPlus collaborated with ICRISAT and Mahatma Phule Krishi Vidyapeeth Rahuri university to release (ICTP-8203 Fe) as Dhanashakti in Maharashtra (link)
- ICRISAT/HarvestPlus breeding effort shift to IPM hybrids

2014

- Dhanashakti released and notified by Central Variety Release Committee for cultivation in all pearl-millet growing states (link)
    - World's first high IPM
- AICRP-PM initiates special biofortified hybrid trail in 2014 to encourage NARES breeding programs (link)
    - Stopped in 2018 after (low) 42 ppm of iron threshold set for all new varieties notified through AICRP-PM system

2015

- Efficacy study of eating IPM compared to conventional PM (link)
    - Concludes that IPM improved iron status after four months and is an efficacious way to improve iron levels in school children
        - Compared 86 ppm to 22 ppm
- Impact assessment commissioned by ICRISAT of PMHPRC (link)
- HarvestPlus database referenced as showing that 125,000 household were reached (implication that they adopted IPM (Table 2) (link)

2016

- Incorporation of biofortification in the Sustainable Nutrition Revolution policy (link)
    - Influenced by HarvestPlus' contribution to the National Coalition of Food and Nutrition Security
- Study finds a small preference for IPM in Maharashtra (link)
- Standard ED-XRF screening lab methodology published using very large no. of trials and samples (link)

2018

- ICAR mandates that all newly released hybrid pearl millet seed must be biofortified to 42 ppm (low compared to HarvestPlus initial breeding target of 77 ppm) (link)
    - Will amount to 60 percent on-farm consumption and 85 percent of rural and urban consumption
    - First crop in the world to introduce a benchmark level
    - Special trials stopped
- Pearl millet included in public food distribution system procurement (link)
- 500,000 people from farming households consuming IPM (link)
- Study in 3 districts in Maharashtra state found 89 percent are growing IPM OPV only, suggesting a high rate of replacement over non-IPM varieties (link)
- Declared Year of the Millets by Indian government

- Publication of 2015 efficacy study in print media (link)

2019

- Digital XRF lab services established at ICRISAT and all HarvestPlus partners screen their samples at subsidized price (US$2/sample for iron and zinc)
- Additional XRF machine added to the ICRISAT-XRF lab for breeding efficiency and support other crops
- Dalberg reports on the commercialization of pearl millet in India published (link)
- Nine hybrid and 1 OPV IPM developed
    - About 370 MT of OPV seed produced by 2 public sector seed companies
- A 2019 study conducted in three Talukas in three districts of Maharashtra state showed that:
- Overall, 51 percent of the farming households planted IPM at least one since its introduction in 2014
    - 22 percent of the farming households in the study area had planted IPM in 2018 alone.
    - The nutritional benefits and good yield of IPM were the two important factors that motivated farmers to plant IPM varieties — 93 percent of the households that planted IPM did not plant other non-IPM varieties in 2020.
    - Farmers who planted IPM allocated 84 percent of their pearl millet (PM) land to IPM with each household planting 0.63Ha, on average.
    - IPM varieties have a significant yield advantage over non-IPM varieties grown by smallholder farmers – IPM varieties are perceived superior in terms of dry fodder yield, nutritional value, aroma, color, taste and texture of Roti, and days to maturity.
- Approximately 240 000 farmers were growing IPM (major share is of Dhanshakti) in India and an estimated 0.7 percent of total pearl millet area was allocated to IPM (link)
- Hybrid IPM yields less than commercially available hybrid PM
    - ICMH 1201 sold by Shaktivardhak Seed Company as Shakti-1201 has 70 mg/kg iron and yields 85 to 90% of 86M86 sold by Pioneer that has 56 mg/kg Fe
    - New wave of IPM hybrids is bred with higher yield potential

2020 (link)

- HarvestPlus' biofortification platform includes 20 private and public sector partners
- Government to include millets in the public food distribution system, alongside rice and wheat
- Through mainstreaming, approximately 50 percent of ICRISAT's pearl millet elite lines carry high-iron trait
- ICRISAT encourages private sector to use its high-iron lines to develop their hybrids for commercialization
- Focus on supply chain development going forward

- Prime Minister Shri Narendra Modi endorses biofortification and dedicates 17 new biofortified varieties of eight crops to the nation on World Food Day 2020, saying it is an important step in strengthening the government's campaign to improve nutrition
    - IPM not included as list includes only those varieties released in 2020 (Respondent 14)
- Seed production increases from 206MT in 2016 to 513MT in 2020
    - In 2020 65,000 farming households grew IPM
- An average of 370MT OPV produced annually (link)
- ICAR publishes *Micronutrient Rich Pearl Millet for Nutritionally Secure India* (link)
- Part of ICRISAT's core pearl millet collection characterized for grain micronutrients and published for global reference (link)

2021

- Publication of review in *Fronters in Plant Science*, Genetic Gains in Pearl Millet in India: Insights into Historic Breeding Strategies and Future Perspective
- ICRISAT with partners generated a large iron and zinc rich lines >60 ppm for iron and 40 ppm for zinc to make mainstreaming these nutrients possible (link), (p 11)
- Two-Day Nutri-Cereal Multi Stakeholders' Mega Convention 3.0 Inaugurated In Hyderabad To Prepare Blue Print To Celebrate The "International Year Of Millets In 2023"
- More than 10 high-IPM having 60-88ppm with grain yield of 3.4 to 4.8t/ha under national trials
- Pearl millet calcium feasibility report is published.
- As part of HPRC-PM and IPM mainstreaming, a scientist field day is conducted and field displayed IPM lines and hybrids (~40) for selection by partners

Appendix IV: List of interviewees and participants in the validation workshop

Name	Gender	Affiliation	Role	Case
MD. Abdul Kader	M	BRRI	Principal Investigator, Golden Rice and HarvestPlus Project	Zinc rice
Jairo Arcos	M	HarvestPlus	Agricultural Engineer/Research Associate	All
Khairul Bashar	M	HarvestPlus	Country Manager, Bangladesh	Zinc rice
Steve Beebe	M	Alliance*	Principal Scientist, Crops for Nutrition and Health	Iron beans
M Govindaraj	M	ICRISAT	Senior Scientist - Sorghum Breeding	IPM
Enid Katungi	F	Alliance	Scientist II, Crops for Nutrition and Health	Iron beans
Jean Pierre Mbagurire	M	HarvestPlus	Country Manager, Rwanda	Iron beans
Bho Mudyahoto	M	HarvestPlus	Head, Monitoring and Evaluation	All
Floride Mukamuhirwa	F	RAB		Iron beans
Clare Mukankusi	F	Alliance	Senior Scientist, Crops for Nutrition and Health	Iron beans
Wolfgang Pfeiffer	M	HarvestPlus	Director, Research and Development	All
Mohammad Rafiqul	M	IRRI	Country breeding lead, Bangladesh	Zinc rice
Russell Reinke	M	IRRI	Program Lead, Healthier Rice	Zinc rice
Jean Claude Rubyogo	M	Alliance/ PABRA	Program Leader, Crops for Nutrition and Health	Iron beans
C. Tara Satyavathi	F	AICRP-PM/ ICAR	Project Coordinator, Pearl Millet	IPM
L. D. Sharma	M	RARI	Professor of Plant Breeding	IPM
Mallikarjuna Swamy	M	IRRI	Senior Scientist, Rice Breeding and Biofortification	Zinc rice
Parminder Virk	M	HarvestPlus	Head of Crop Development	Zinc rice

* CIAT is now known as the Alliance of Bioversity International and CIAT or the Alliance.

The CGIAR Research Program on Agriculture for Nutrition and Health (A4NH) is built on the notion that agriculture has the potential to do much more than contribute to basic food and income needs. A4NH is designed to fill the existing gap between agricultural development and its unfulfilled health and nutritional benefits, with research flagships focusing on food systems for healthier diets; biofortification; food safety; supporting policies, programs, and enabling action through research; and improving human health. Headquartered in Washington, DC, USA, A4NH is led by the International Food Policy Research Institute (IFPRI).

For more information, please contact IFPRI, 1201 I Street NW, Washington, DC, 20005, USA

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