Agenda item 3

Version: 12 September 2018

3- Year System Business Plan Companion Document
Action 1 - CGIAR Five-Year Biofortification Strategy 2019-2023

Prepared by:	HarvestPlus (Howdy Bouis) and Center DDGs Research (led by Jackie Hughes and Oscar Ortiz)
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Business Plan Companion: Biofortification Strategy, SMB10-BP1f
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CGIAR Five-Year Biofortification Strategy 2019-2023

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CGIAR Five-Year Biofortification Strategy

PREAMBLE

More than two billion people in developing countries are subject to mineral and vitamin deficiencies. Women and preschool children are particularly at risk for these deficiencies due to greater requirements for reproduction and growth, respectively. These deficiencies cause untold misery – more frequent and more serious sickness, sometimes leading to death; impaired cognitive abilities; blindness; constrained work performance; and smaller physical stature (stunting), all of which result in slower economic growth and more prolonged and more widespread poverty. Vitamin A, iron, and zinc deficiencies are recognized by the World Health Organization as the most prevalent and serious mineral and vitamin deficiencies.

The fundamental, underlying cause of these deficiencies is poor dietary quality. Due to low incomes and persistently rising non-staple food prices over the past four decades, the poor simply cannot afford to buy the vegetables, fruits, pulses, and animal products necessary for proper nutrition and good health. It is typically these non-staple foods that are most dense in bioavailable provitamin A, iron, and zinc.
The international nutrition community has responded to this failure of food systems to provide an affordable supply of minerals and vitamins, primarily by implementing supplementation and supplemental food fortification programs to fill the gap between the minerals and vitamins that are required and those that are supplied through foods. For example, 10 billion vitamin supplements have been provided to preschool children over the past twenty years at an average cost of $1 per capsule distributed. Vitamin A supplements when administered consistently have been shown to lower preschool mortality by an average of 23%.

Sixteen years ago, in 2002, the CGIAR made a commitment to join the fight against vitamin and mineral deficiencies by approving the "Biofortification Challenge Program," later renamed HarvestPlus, which built on scientific evidence generated by the CGIAR Micronutrients Project that ran from 1995 to 2002. In an effort to further strengthen and better coordinate projects across crops and centers, this document articulates an overall CGIAR strategy for fighting malnutrition through biofortification. Biofortification is a means of bringing agricultural and nutrition science and agricultural policy to bear on reducing malnutrition – by increasing levels of provitamin A, iron, and zinc in staple foods at no additional cost to consumers once biofortified crops become an integral part of the agri-food systems. Those whose diets are largely restricted to staple foods will thus have specific vitamin and mineral intakes boosted, and health improved, even in the absence of a diversified diet.

Through plant breeding, high mineral and vitamin densities are combined with the best agronomically-performing germplasm developed by CGIAR Centers and partners, with National Agricultural Research System (NARS) and, once the varieties are released, are shared more widely with extension, development oriented and private organizations interested in dissemination of biofortified crops. By mainstreaming these mineral and vitamin traits in high-yielding varieties, eventually almost all the available new varieties of crops will be biofortified, ensuring adoption of biofortified varieties by farmers, and also means that seed, grain, root or tuber prices will be equal to those of the currently most popularly produced and consumed non-biofortified staple food varieties.

Over the past sixteen years, the CGIAR cumulatively has spent approximately $500 million (the ***annual*** cost of vitamin A capsule distribution) to:

- develop breeding pipelines of seven food staples – sweetpotato, beans, pearl millet, cassava, maize, wheat, and rice. 290 biofortified varieties across these seven food staples have been released in 35 countries. It is anticipated that biofortified varieties will be available to farmers in 60 countries within five years across Africa, Asia and Latin America;
- conduct nutrition efficacy trials on the various biofortified crops and their processed products to demonstrate that vitamin A, iron, and zinc are bioavailable to determine the levels required and improve the status of these nutrients. In addition, improved functional outcomes have been shown such as improved cognition and work performance (iron beans and pearl millet), reduced morbidity (vitamin A Orange Fleshed Sweetpotato (OFSP) and zinc wheat), and improved sight adaptation to darkness (vitamin A maize). Additionally, evidence has shown that 120g of OFSP in the daily diet can provide the necessary daily vitamin A intake, reduce significantly its deficiency and contribute to the reduction in stunting.
- In partnership with the NARS and the private sector, begin the process of scaling up adoption of biofortified varieties. An estimated 10 million farm households now grow and consume biofortified varieties of these seven crops;
- In partnership with the private sector, develop value chain processing opportunities for small to larger businesses to process and market products from biofortified crops;
- monitor and measure the impact of biofortification both on nutrition and health, and on poverty reduction;
- advocate for the use of biofortification to help in the fight against mineral and vitamin deficiencies – among national governments, regional and multi-lateral organizations, non-governmental organizations, and the private sector.

The stage has been set for scaling up. However, the full potential of the cost-effective impact of biofortification (tens of billions of dollars expressed in economic value) will be realized only when biofortified varieties account for a high percentage of total staple food production – just as today most cereal production in South and Southeast Asia is largely derived from rice and wheat varieties developed by IRRI and CIMMYT, respectively. Ten, twenty, thirty years from now, independent of the originator, most staple food hybrids and varieties grown today will have to be replaced by newer, better varieties which are adapted to climate change, higher yielding, and disease and pest resistant – in Africa, in Asia, and in Latin America. These future hybrids and varieties should also be biofortified.

To make biofortification sustainable and to realize such broad impact, it is still necessary to:

- mainstream breeding for mineral densities (invisible and tasteless) at CGIAR Centers and NARS so that all germplasm developed in the future is biofortified (this must be a major effort of the Centers in their breeding programs)
- create demand for visible orange staple foods which contain provitamin A – make orange varieties for human consumption the norm
- develop a number of partnerships with private companies and public-sector institutions which will incorporate biofortification in their core activities
- raise the funding necessary to undertake activities to ensure that these final three objectives are met

Reaching one billion people with biofortified foods by 2030 will represent a partial realization of the ultimate goal of all staple foods being biofortified. For example, if biofortified foods account for 25% of the major staple food supply in 30 target developing countries, this goal of one billion will have been met. The

CGIAR Biofortification Strategy below describes the steps that will need to be taken over the next five years on the way to realize this vision.

In conclusion, biofortification of staple crops can be pointed to as one of the CGIAR's recent successes and should be a major theme that cuts across the CGIAR. Biofortification should be a very public commitment by the CGIAR to improve the nutrition and health of vulnerable people. In this work, Centers must reach out to a broader community, both to do the work and to gain support. Donors and the public need themes and major goals to better understand the important work of the CGIAR.

1. INTRODUCTION

This document sets out a new strategic plan for biofortification within the CGIAR, and provides an overview of the research, delivery, communications and capacity strengthening activities that will be taken on under the CGIAR Biofortification Strategy to facilitate the global scale-up of biofortification. The plan focuses on the next five years but finishes with a twelve-year projection of the wider investments that will enable biofortification to reach its full potential in tackling hidden hunger by 2030.

2. BACKGROUND

The CGIAR Biofortification Challenge Program (BCP) was launched in 2002 with the mandate to drive the development of biofortification as a natural, sustainable, solution to tackle micronutrient malnutrition.

PROBLEM

***Micronutrient deficiency** or 'hidden hunger' affects two billion people worldwide and is particularly prevalent in rural populations in developing countries who rely on staple food crop based diets that are deficient in vitamin A, iron, and zinc. These deficiencies contribute significantly to the global disease burden and reduce productivity by limiting cognitive development, impairing physical development and vision, and increasing susceptibility to infections and diseases.*

SOLUTION

***Biofortification** is the process of increasing the density of vitamins and minerals in staple food crops through conventional breeding, fertilizer applications or bioengineering so that, when consumed regularly, the biofortified crops will generate measurable improvement in vitamin and mineral nutritional status.*

Initially, the following sixteen crops were considered for investment:

Crop	**Center(s)**
Sweetpotato	International Potato Center (CIP)
Potato	International Potato Center (CIP)
Barley	International Center for Arid Dryland Agriculture (ICARDA)
Lentils	International Center for Arid Dryland Agriculture (ICARDA)
Yams	International Institute for Tropical Agriculture (IITA)
Cowpea	International Institute for Tropical Agriculture (IITA)
Banana/Plantains	International Institute for Tropical Agriculture (IITA) and Bioversity
Groundnuts	International Center for Research in the Semi-Arid Tropics (ICRISAT)

Chickpea	International Center for Research in the Semi-Arid Tropics (ICRISAT)
Pigeonpea	International Center for Research in the Semi-Arid Tropics (ICRISAT)
Sorghum	International Center for Research in the Semi-Arid Tropics (ICRISAT)
Pearl Millet	International Center for Research in the Semi-Arid Tropics (ICRISAT)
Beans	International Center for Tropical Agriculture (CIAT)
Cassava	International Center for Tropical Agriculture (CIAT) and International Institute for Tropical Agriculture (IITA)
Maize	International Center for Maize and Wheat Improvement (CIMMYT) and International Institute of Tropical Agriculture (IITA)
Wheat	International Center for Maize and Wheat Improvement (CIMMYT)
Rice	International Rice Research Institute (IRRI) and AfricaRice

Through a process of screening germplasm for high-nutrient parents, consulting with nutritionists on what levels of extra provitamin A, iron, and zinc would likely have a public health impact, and consulting with economists where the greatest returns on investment would be realized, the following seven crop-nutrient combinations and Centers were identified for major investments across six Centers:

Crop	**Nutrient**	**Center(s)**
Sweetpotato	Provitamin A	CIP
Beans	Iron	CIAT
Pearl Millet	Iron	ICRISAT
Cassava	Provitamin A	CIAT, IITA
Maize	Provitamin A	CIMMYT, IITA
Wheat	Zinc	CIMMYT
Rice	Zinc	IRRI

The following four crop-nutrient and Center combinations were identified for minor investments, adding two Centers to the list above. If additional funding could be raised (see Table 3 below), then a head start would have already been made for these crops:

Crop	**Nutrient**	**Center(s)**
Potato	Iron	CIP
Lentils	Iron	ICARDA
Banana/Plantains	Provitamin A	IITA and Bioversity
Sorghum	Iron and Zinc	ICRISAT

Biofortification Investments in all of the above crops involve only conventional plant breeding. In 2009, IRRI took primary responsibility for development of transgenic Golden Rice biofortified with provitamin A, and now very promising events with high levels of iron and zinc have been added to the program:

Crop	**Nutrient**	**Center(s)**

Transgenic Rice	Provitamin A, Iron, Zinc	IRRI

To be successful, biofortification activities must involve several disciplines and types of activities, Centers, and multiple institutions outside of the CGIAR. For example, with the centers working with academic and research institutions, civil society organizations, and the public and private sector. Coordinated by the International Center for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI) and is part of the CGIAR Research Program on Agriculture for Nutrition and Health (A4NH), HarvestPlus, has played a major role in the biofortification of most of the crops listed, bringing together agricultural, nutrition, and social scientists to work collectively on reducing hidden hunger.

For the last fifteen years, HarvestPlus and CIP, along with their partners have been leading the global effort to develop biofortified staple crops, prove their acceptability, efficacy and effectiveness, and scale up their availability to rural populations. By setting nutrition- led crop development and delivery priorities and partnering directly with the NARS in developing countries, we have ensured that farmers get easy access to more nutritious varieties of staple crops at no extra cost.

Since 2010, the vitamin A orange-fleshed sweetpotato (OFSP) program managed by CIP has operated independently of HarvestPlus, but in a similar inter-disciplinary and inter-institutional way. For example, through the Sweetpotato for Profit and Health Initiative (SPHI) in Africa that involves activities in more than 15 countries, numerous partners, CIP has made great strides, especially in Africa, in developing and releasing biofortified sweetpotato varieties, spreading them to farmers, and developing value chains for commercial products in rural and urban areas. To many people, biofortification is synonymous with OFSP.

Thus, the three intervention modalities – HarvestPlus, CIP-OFSP, and IRRI Transgenic Rice -- constitute the main efforts within the CGIAR ***to improve mineral and vitamin deficiencies through biofortification***. The Golden Rice events of IRRI are de-regulated in New Zealand, Australia, Canada and USA, and the regulatory process is in process in other countries – transgenic rice is poised for deployment.

3. EVIDENCE AND RESULTS

Back in 2003, the biofortification effort set out to answer three essential research questions:

Q1. Is it possible to add essential nutrients into staple crops without compromising productivity, climate resilience and other essential commercial qualities of current varieties?

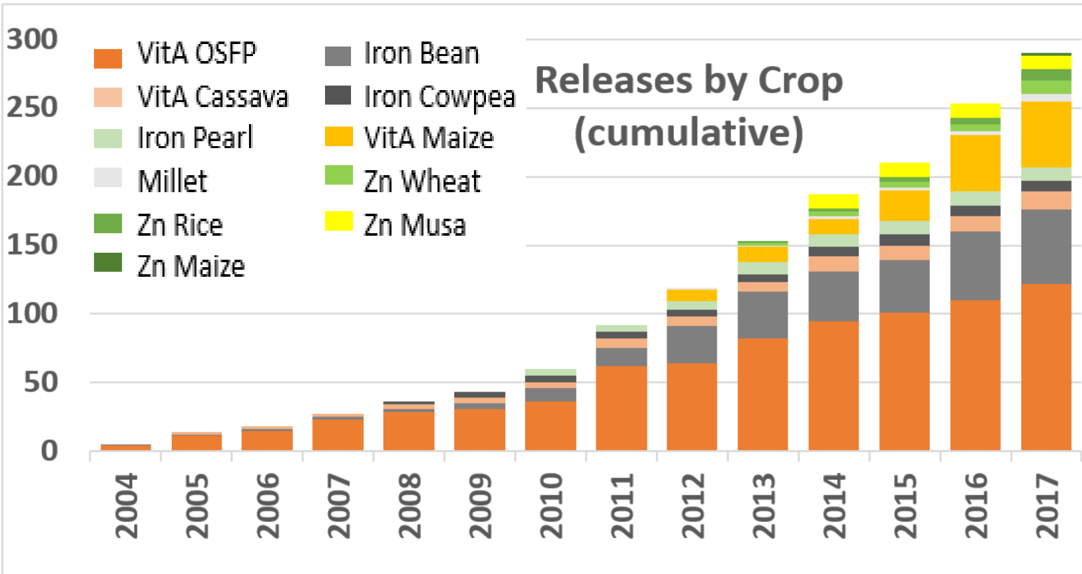
Q2. When consumed, can the increase in nutrient levels in these crops make a measurable and significant impact on human nutrition and health – particularly in women and children? And;

Q3. Are farmers willing to switch to these biofortified crops and are consumers willing to eat them?

By 2017, the evidence indicated that the answer to all three questions was a resounding yes and the CGIAR biofortification interventions moved into Phase II: to take biofortification to scale.

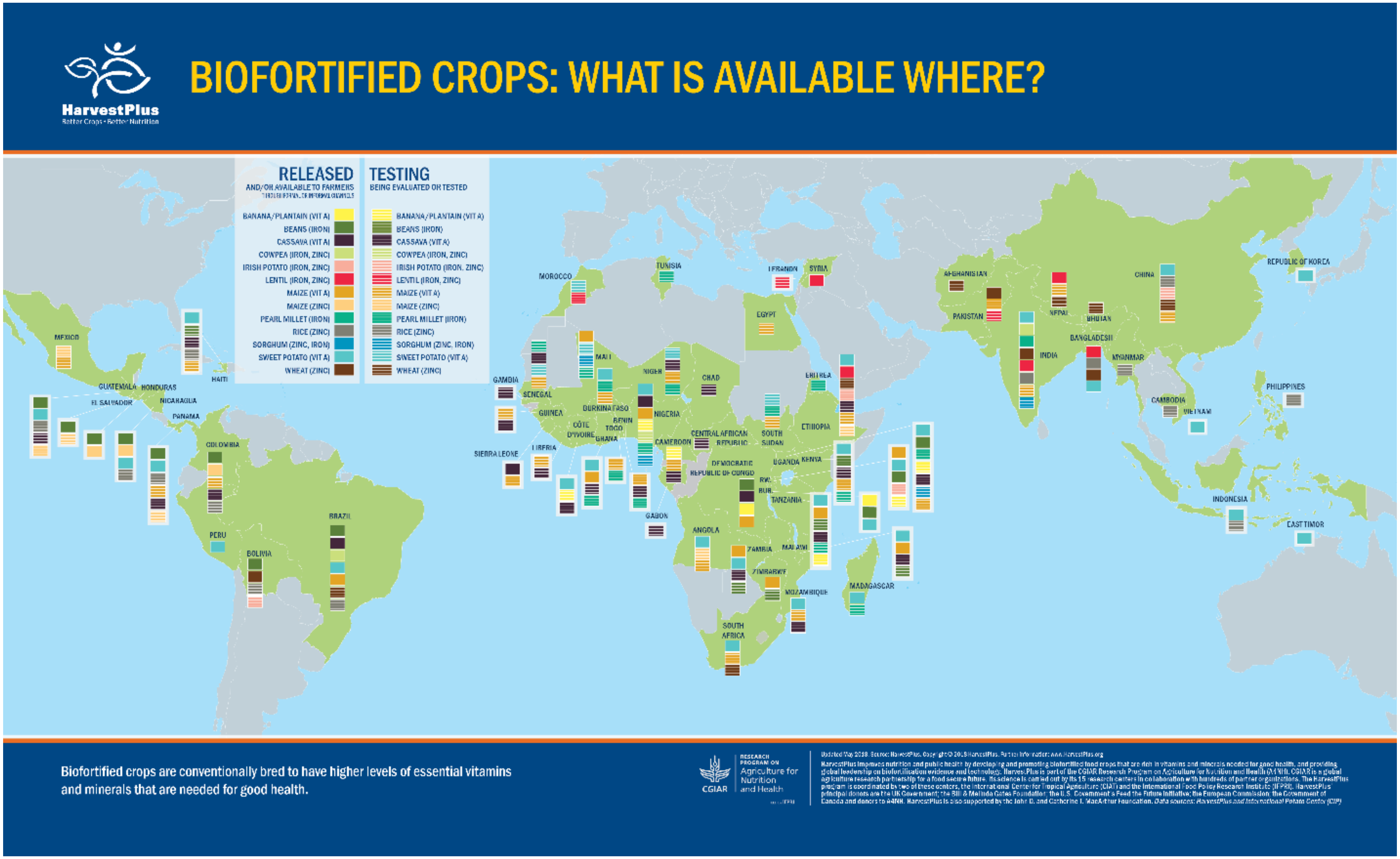
Thanks to successful breeding programs by eight CGIAR centers and NARS partners, more than 290 biofortified varieties of 10 different crops have been released and distributed in more than 30 countries (see Figure 1).

Figure 1: Releases of Biofortified Varieties by Year



Additional testing is underway in these 30 countries and in 30 additional countries where biofortified crops have not yet been released. These activities will lead to additional releases of 12 staple crop varieties that meet farmers' demands for yield, quality and climate tolerance in these countries (see Figure 2).

Figure 2: Countries Where Biofortified Crops Have Been Released and Are in Testing for Release



Monitoring by HarvestPlus and CIP has shown that by the end of 2017, 10 million households (33 million people) were already benefitting from these more nutritious foods and that an exponential trend is expected for 2017.

Efficacy and effectiveness trials have provided strong evidence that the consumption of crops biofortified with iron and vitamin A improves not only micronutrient status but also functional and health outcomes among target populations. A World Health Organization (WHO) Cochrane review committee was assembled in 2016 to review the scientific evidence and country experiences of scaling up biofortification. Eight papers were published in the Annals of the New York Academy of Science as part of the consultation and a WHO recommendation on biofortification is expected in 2019.

For example, a recent systematic review of three randomized efficacy trials on iron-biofortified crops concluded that iron-biofortified interventions significantly improve iron status—particularly among women and children in low-income communities who need it most.[1] Biofortified iron beans were found to have a significant effect on cognition in young women in Rwanda: iron deficient women who ate biofortified beans experienced improved memory and ability to pay attention. The study also measured physical performance and results suggest improvements in iron status were accompanied by improved work performance due to increased energy and a reduction in time spent in sedentary activity.[2] Iron pearl millet was demonstrated to be an efficacious approach to improve iron status in adolescent children through a six-month study conducted in rural Maharashtra, India, and results indicate cognitive performance improved for school children who consumed iron pearl millet flat bread twice daily.

Consumption of OFSP can result in a significant increase in vitamin A body stores across age groups.[3] [4][5] In Mozambique, consumption of OFSP by children under five significantly reduced the burden of diarrhea, the second leading cause of death in this age group globally; the likelihood of experiencing diarrhea was reduced by 39% and duration of diarrhea episodes was reduced by more than 10%.[6] Vitamin A reduces childhood blindness and contributes to reduce stunting. Beta-carotene in orange maize is an efficacious source of vitamin A when consumed as a staple crop, and decreased night blindness among children who were vitamin A deficient at baseline.[7] In an efficacy trial in India, high zinc wheat has been shown to reduce morbidity in women and preschool children.[8]

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

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

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

[4] Hotz C, Loechl C, Lubowa A, Tumwine J, Ndeezi G, Masawi AN, Baingana R, Carriquiry A, de Brauw A, Meenakshi JV and DO Gilligan A Large Scale Intervention to Introduce Beta Carotene Rich Orange Sweet Potato Was Effective in Increasing Vitamin A Intakes among Children and Women in Rural Uganda. Journal of Nutrition 2012, 142: 1871-1880.

[5] Low, J., R. Mwanga, M. Andrade, E. Carey, and A-M. Ball. 2017 "Tackling vitamin A deficiency with biofortified sweetpotato in sub-Saharan Africa". *Global Food Security*. Vol. 14: 23-30.

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

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

[8] Sunil Sazawal, Usha Dhingra, Pratibha Dhingra, Arup Dutta,Saikat Deb, Jitendra Kumar, Prabhabati Devi,Ashish Prakash. Efficacy of high zinc biofortified wheat consumption in improvement of micronutrient status, and prevention of morbidity among preschool

Benefit-cost analysis has shown that biofortification is a cost effective, efficient and scalable solution to addressing micronutrient deficiency. The Copenhagen Consensus ranked interventions that reduce micronutrient deficiencies, including biofortification, among the highest value-for-money investments for economic development. For every dollar invested in biofortification, as much as $17 USD of benefits may be gained.[9]

4. A GLOBAL CALL TO ACTION

In 2016, at the launch of the UN Decade of Action on Nutrition, the international community called on the CGIAR to lead a collaborative global effort to drive mass-scale adoption of biofortification and deliver long-term sustainability of this proven solution. To achieve this, a new strategy is required, one that honors the vision of the original Challenge Program and the work done by all Centers and their partners while defining new roles, resources and partnerships for this next phase of scale up. The vision, mission and global objective of the CGIAR biofortification strategy are:

Vision statement: A world free of hidden hunger

Mission Statement: We work with partners to tackle hidden hunger on a global scale by breeding vitamins and minerals into everyday food crops. Together, we build sustainable food systems and bridge the gap between agriculture and nutrition.

Global Objective: To reach 20 million farming households by 2020 and one billion consumers by 2030 through the development of inclusive and sustainable markets for biofortified crops.

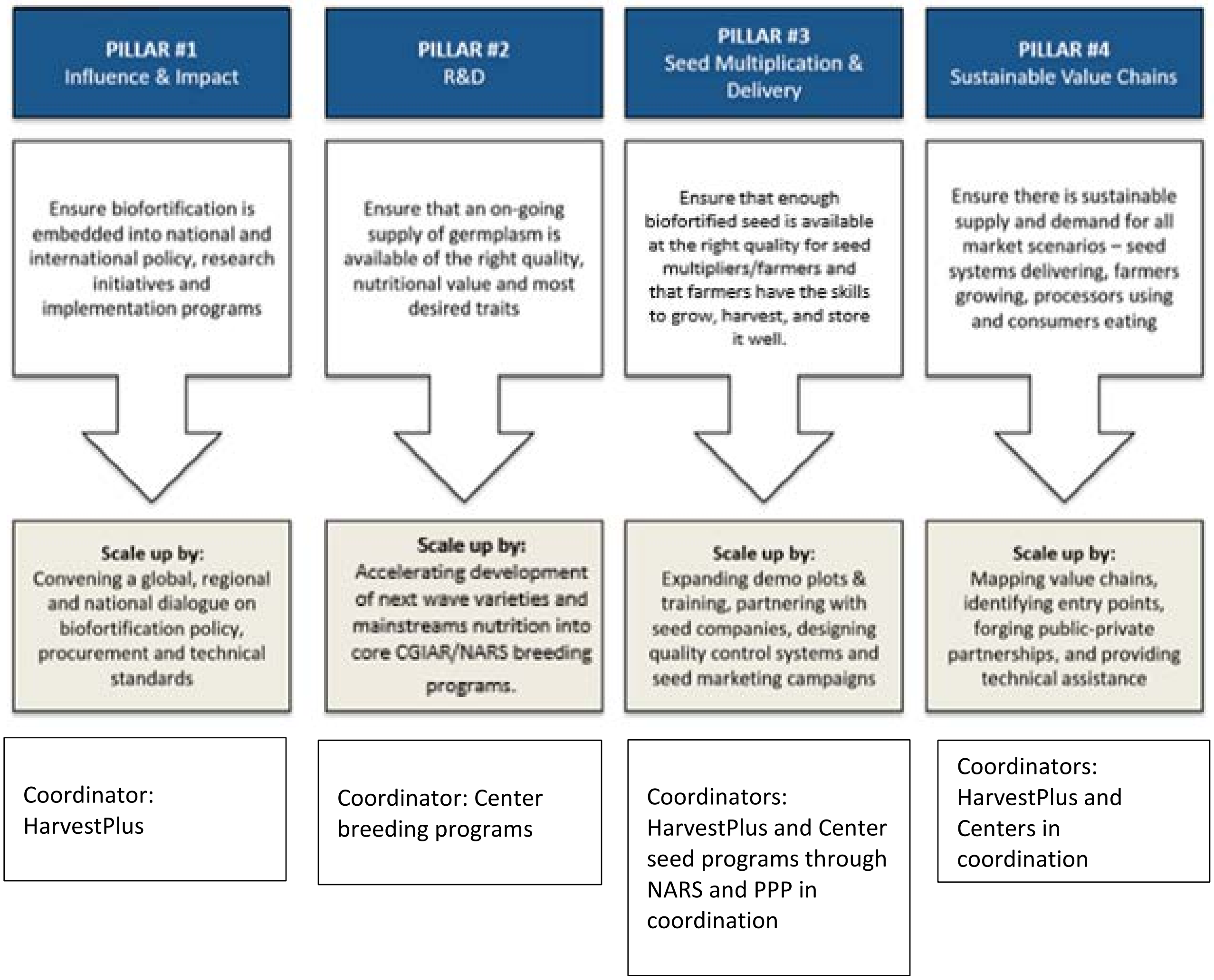
5. A FOUR PILLARED STRATEGIC PLAN

Over the next five years, the CGIAR will continue work with partners to coordinate four essential clusters of activity that will leverage both the *supply* and the *demand* for biofortified foods. These pillars can be summarized as follows:

children (aged 4-6 years) and women of child bearing age- a double masked, randomized, controlled trial. Accepted for publication. BMC Nutrition.

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

Figure 3: Four-pillared strategy to achieve scale



PILLAR 1: Influence & Impact

The first step in going to scale is to define what this means in terms of *who* will be reached and *how* they will benefit. The CGIAR remains committed to targeting the rural poor in developing countries who are not being reached adequately by other micronutrient interventions, while at the same time contributing to the availability of healthy diets in urban communities is a critical spill-over effect not to be ignored.

By 2017, M&E data from HarvestPlus and its partners showed that 33 million people in poor farming households were already benefitting from biofortified crops. By 2020, the CGIAR aims to have 100 million farmers growing these more nutritious varieties and, by 2030, one billion people in both rural and urban areas are expected to be consuming biofortified foods.

Creating demand through policy is an essential first step in any new country, and this relationship-building takes time, involving a careful balance of top-down and bottom-up conversations based on trust. HarvestPlus and to a lesser extent, CIP and IRRI, already act as a global and regional conveners, building awareness about micronutrient deficiency and biofortification, and linking interested governments and organizations with the technical resources needed to advance biofortification in both policy and in practice. And, other centers, for example, CIP's OFSP program has also conducted - and will continue doing so - advocacy and policy oriented interventions to promote the cultivation and utilization of vitamin A rich sweetpotato.

Biofortification is already included in the national nutrition strategies of many countries as well as in regional and global processes. These results reflect the CGIAR's ability to form strong relationships between international, national and district-level counterparts in the public and private sectors. This advocacy is underpinned by the most rigorously collected evidence.

Over the last decade, HarvestPlus and CIP have developed monitoring, evaluation and learning systems that generate credible data to reliably and accurately estimate the impact, reach and cost- effectiveness of biofortification initiatives. Specialists will continue to collect data for process and output level variables from all project areas, and the results will be fed into a suite of innovative models that are designed to estimate national level values for each of the outcome and impact level variables. The teams will continue to evaluate, learn from, and plan country level biofortification programs.

In 2018 and beyond, the CGIAR must strengthen its role as the global innovator and standard-bearer for nutrient targets while working in close partnership with the NARS to ensure that biofortified crops are widely available at the right nutritional standards. The scaling up of governance, policy and advocacy efforts will help to ensure that more countries include biofortification in all relevant government-run nutrition and agriculture programs and that standards are consistent. HarvestPlus, CIP, IRRI and other relevant centers will take the lead for policy advocacy for specific biofortified crops according to the country contexts; but coordination and cross-learning must take place to take advantage of policy development experiences. Such policies will include evidence-based nutritional standards across processed products.

PILLAR 2: Research & Development

Crop improvement is a necessary ongoing process, driven by ever-changing climatic conditions and consumer preferences. The CGIAR centers have worked with research partners at international, national and community levels for more than fifteen years to develop lines that have been tested and further developed by NARS. Behind each of the 290 varieties lies a complex story of collaboration in both the lab and the field between the CGIAR, its donors, and its crop-breeding partners in the NARS in priority countries.

To achieve its goals by 2022, the CGIAR centers will continue to work with partners, NARS and private sector companies to continuously improve the pipeline of germplasm through targeted breeding programs while encouraging the global mainstreaming of zinc, iron and vitamin A into core breeding programs.[10] The bulk of crop development work will continue to be hosted by six research partners in the CGIAR: CIAT, CIMMYT, CIP, ICRISAT, IITA, and IRRI.

[10] It will be important to consider strategically the addition of other vitamins and/or minerals to the portfolio, beyond vitamin A, iron, and zinc in cases where deficiencies are a public health problem and there is considerable potential to exploit the diversity in existing germplasm.

Biofortified Crop Development

The primary objective over the next decade for each Center with respect to biofortification breeding for each crop (see Figure 4 for estimated investment levels) is to ***mainstream*** breeding for particular minerals or vitamins for each crop. This process will take 8-10 years. The eventual goal is that all (or nearly all) germplasm coming out of Centers and provided to National Programs (NARES) contains the mineral or vitamin trait for a particular crop at an appropriate minimum biofortification target level (for example, +40% of the Estimated Average Requirement). Thus, over time, all (or nearly all) breeding parental lines at Centers should contain the genes that confer the trait(s) of interest; progeny of any crosses of these breeding parents should also contain the desired trait.[11] The result is that biofortification traits become embedded, non-negotiable traits in Center breeding programs. It is important that biofortified varieties in breeding pipelines continue to be released with improved yield, disease and agronomic traits with higher densities of minerals and vitamins, so that delivery/scaling up can proceed unabated, without any without any negative trade-offs that significantly reduce the acceptability and uptake of the biofortification technology and innovations to come. This is especially important as there is rarely any additional direct monetary value associated with the biofortified trait (despite the huge societal value) to compensate for any loss of yield or other value characteristics. A breeding strategy that addresses mainstreaming is not risk free as incorporating biofortified traits in a broad germplasm, at an appropriate density level, and balancing it with yield, agronomic and disease resistant traits, and organoleptic traits is a complex task.

In the start-up phase of biofortification, CGIAR Centers, as the custodian of genebanks, played a crucial role in assessing the genetic variation for micronutrients in the genetic diversity spectrum and transferring the micronutrient density to locally adapted genetic backgrounds. Various approaches have since been explored by the leading CGIAR Centers, with each crop and trait requiring a unique timeline and investment model.

Mainstreaming Breeding

One vital mechanism towards the tipping point on the journey to sustainability is the mainstreaming of biofortification into CGIAR breeding programs. Good progress has already been accomplished at CGIAR Centers and several NARS but adding micronutrients alongside agronomic, end-use quality and crop marketing attributes – as with any additional trait – comes with an incremental cost.

Substantial investment from donors will be required to achieve full mainstreaming by 2030. This must be accompanied by a significant effort in advocating for the inclusion of biofortification as an integral part of nutrition agendas and regulatory frameworks for biofortified crops.

For major crops (rice, wheat, and maize), it is desirable to accelerate mainstreaming goals by integrating micronutrient density into all relevant parental breeding lines and hence future germplasm. For invisible minerals traits such as iron and zinc, this is the stealth approach or 'fluoride in the water' option that lends itself particularly well to wheat and rice. The size of this 'big push' and the timeline to mainstreaming will be determined by the availability of resources.

Mainstreaming strategies differ considerably for crops such as pearl millet. In India, for example, as much as 95% of the area is planted to commercial hybrids, biofortification mainstreaming would be directed to

[11] Quality traits are quantitative in nature with involvement of many minor genes/QTLs and highly influenced by the soil quality and other environmental factors. This requires investment in precision phenotyping and genotyping across the crops. We may identify center of excellence for biofortification within the CG centers for phenotyping and genotyping services. This requires committed funding of higher scale.

hybrid development. This requires a different strategy compared to, for example, West Africa where adoption rates of modern pearl millet varieties are low, and therefore new varieties would have to respond better to end-user demands to improve adoption rates.

For other crops and traits, particularly the visible vitamin A enhanced crops, it will be necessary to adopt both a supply and a demand strategy for mainstreaming and delivery. It is unlikely that markets will allow for the integration of vitamin A into all product profiles. For example, in the case of cassava, white color cassava will continue to be required for the starch industry and white flour for composite flours for bread.

Targeted Breeding

Targeted breeding entails breeding for a given agro-ecological zone defined by abiotic and biotic environmental factors, production conditions, and end-use preferences. Targeted breeding has been successfully used by the Centers and partners. The >290 biofortified varieties developed to date were developed via targeted breeding. With a clear focus on specific crops and countries, targeted breeding is tightly linked to specific results. Country-crop scenarios require different approaches because probability of success varies by a number of factors including crop, trait, and country.

Mainstreaming capitalizes on progress in targeted breeding -- incorporating additional traits requires an additional effort and added resources, in particular during initial breeding, when gene donors are in non-adapted genetic backgrounds and pre-breeding is required. When the trait is transferred to ‘’breeder friendly’’ high yielding breeding lines and varieties via targeted breeding, their use as parents facilitates and accelerates mainstreaming and moving the trait for breeding for other agro-ecological zones. Next wave versions of micronutrient dense elite breeding lines and varieties used as progenitors are improved, displaying increased micronutrient density combined with additional agronomic properties and profitability. Hence, with targeted breeding, mainstreaming not only moves faster; it is also more efficient.

Assuming aggressive breeding, it takes about 9-10 years until varieties from a mainstreaming approach (which involves simultaneous selection for all traits of interest) are released in target countries. Hence, targeted breeding is vital to assure a continuous flow of varieties until products from special mainstreaming effort with additional funding are available.

The key role of NARS

Any discussion concerning mainstreaming and targeted breeding must consider the key role of NARS in variety testing and release, and increasingly in the development of biofortified varieties. NARS and local seed companies subject germplasm introduced from Centers to local testing and frequently to additional selection. Once pre-varieties are identified among introduced and locally developed leads, NARS and in instances private seed companies submit candidates to local authorities for official testing to initiate the formal release process. CG-Centers cannot submit or release varieties.

NARS breeding programs are in general responsible for the production of early generation seed, breeder and foundation seed. Since early generation seed is further multiplied to commercial seed, early generation volumes and production schedules drive scaling and time-to-market and are crucial factors on the path to impact.

It is necessary to continue to support local trials, selection, adaptive breeding, and release by NARS in countries unable to support these activities by themselves. While new generation crop development may be incorporated into mainstreaming at the Centers, varietal selection, adaptive breeding, genotype-by-environment interaction (GxE) trials and release of new biofortified varieties must continue to be undertaken at the local or regional level.

Capacity building at CG-Centers and NARS is crucial must go-on

Training and capacity building in micronutrient diagnostics and biofortification breeding at CG –Centers and NARS have been essential for success. Breeding programs as well as e.g. national variety release authorities must be able to measure micronutrients to consider Fe, Zn, or pVAC as value added trait and in variety release. Coordination across crops and partners – using the same equipment and team for sample analysis for different crops – assures high efficiency. Labs also provide analysis for activities further down the value chain for samples from the demand side. Continuing future support for these activities is essential.

Should targeted breeding come to a halt, in the absence of products and their produce, activities including farmer extension, nutrition education and marketing regarding nutritional benefits would be reduced, and eventually phased out. Efforts to develop certification and inspection programs to protect the identity of the biofortified content would slow down at best. This also applies to advocacy.

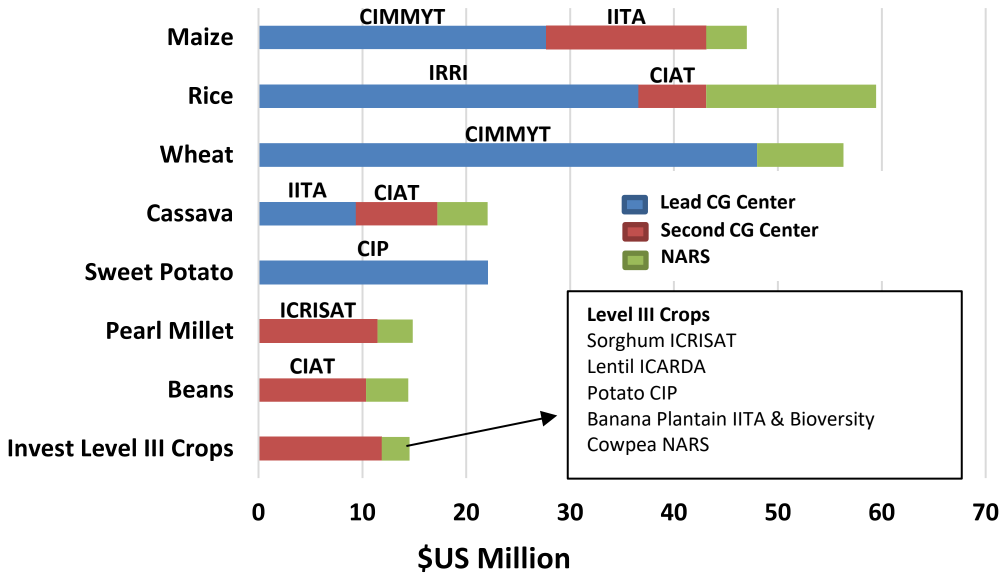
Nutrition Research

HarvestPlus and CIP will also continue to coordinate and commission a pipeline of food technology and nutrition research on vital areas such as the degradation of provitamin A along the value chain and processed products and the development of biomarkers for measuring zinc outcomes in humans. They will also define clear target levels of vitamins and minerals required in order for a crop to be considered biofortified based on the levels of bio assimilation within different age groups and value chain products to be consumed. Findings will be translated into breeding objectives to guide all crop development investments and to fuel collective knowledge on innovations such as the effect/trait value of high phytase wheat on minerals bioavailability.

Biofortified Crop Development Investment Levels

Figure 10 below assumes that the bulk of the crop development research will continue to be led by six key research partners in the CGIAR: CIAT, CIP, CIMMYT, ICRISAT, IITA, and IRRI. This is a preliminary list and will be further developed in a joint effort with the range of R&D partners.

Figure 4. Twelve Year Breeding Investments: 2019-2030



*Estimates are based on an optimistic budget scenario shown in Table 6.

PILLAR 3: Seed multiplication and delivery

The scaling up of seed multiplication and delivery is essential if biofortification is to reach one billion people by 2030. However, the scaling approach differs widely from country to country and crop to crop. Significant rates of adoption as well as diffusion have been measured in all target countries, where market research has shown that farmers like both the agronomic as well as the consumption traits of biofortified crops. This provides new marketing options and is generating income for smallholder farmers.

Research has shown that certain product attributes are relevant for successful multiplication, storage, and distribution of biofortified planting material. For example, a key feature is the propagation method of the crop. For instance, open-pollinated varieties (OPVs) allow for easy and de-localized production of seed, whereas hybrid seeds require professional seed production and a distribution system. For vegetative propagation, low multiplication rates and in particular the short shelf life and large volume of planting material limits centralized production and distribution.

The key to success has been to empower Centers to work closely with local partners and NARS to evaluate the enabling environments for each crop and seed system. By understanding the entry points and barriers for sustainable adoption, CGIAR programs like HarvestPlus and CIP have deployed a range of successful farmgate strategies to ensure sustainable diffusion at scale, which includes partnerships with government, non-government, research and development oriented organizations, and particularly private sector that is required for sustainable biofortified-crop seed busineses. The combination of partners and main orientation would need to be defined on a country or regional basis. In country partners also can use existing seed systems established through leading NARS partners – there is an additional opportunity to support these partners to enhance their extant seed systems. In addition, since partnering with the seed private sector is one of the ways to reach the levels of scaling needed to achieve impact, and taking into account that centers may have different strategies of engagement with the private sector for seed production and commercialization, consultation should take place with relevant centers to reduce any risk involved in potential misuse of biofortified materials, and make sure that all relevant stakeholders are aware of, and learn from, seed-related commercial interventions.

A fully hands-off advisory approach to program design and delivery is not viable, but it is also important to lead only where the CGIAR has a clear comparative advantage. This is very evident, for example, in the delivery of Vitamin A OFSP by CIP. In many cases, the management or implementation of delivery activities, including the provision of farming extension services, can eventually be delegated and handed off to existing civil, public or private entities, especially once the capacities of these partners for biofortification interventions have been developed and strengthened by the CGIAR. The success of each project relies heavily on project assessment, set-up, leadership, coordination and technical support.

PILLAR 4: Sustainable value chains

To be fully sustainable, it is vital that biofortified crops and ingredients become embedded in the food system. There are many different ways that biofortification can be 'brought to market' and the CGIAR has learned that successful strategies vary from country to crop.

Sustainable farming and consumption of biofortified crops will ultimately rely on well-functioning food systems and profitable markets. The CGIAR is working with partners to ensure that these markets are inclusive of its main target group, namely the nutritionally vulnerable farming households, who both grow and consume staple crops. Existing systems in some countries are still ineffective and while it may be tempting to hot-wire or improvise in-house solutions (for instance to meet short-term delivery targets), it's clear that these shortcuts represent unsustainable one-off stopgaps that can be ineffective and expensive, and hence unsustainable in the long run. In most instances, it is necessary to use and – if required – strengthen and de-risk existing systems.

Work is required to map the ever-changing seed and food systems within the targeted countries and define the appropriate sustainable solution. The ultimate aim is for the CGIAR to gradually remove itself once delivery is self-sustaining - i.e. when biofortification is anchored, and to move from implementer to technical assistance provider and finally to an advisory role.

The good news is that foods made with biofortified crops are well-liked by target consumers. In many cases this preference is expressed in blind trials in the absence of information about the food's nutritional benefits. However, it is apparent that different marketing strategies must be deployed for biofortified crops that exhibit a color change. In these instances, the CGIAR has found that a carefully targeted campaign that links agriculture, nutrition, health and education can leverage the color as a compelling marketing tool, as demonstrated by CIP with orange fleshed sweetpotato across sub-Saharan Africa and by Harvest Plus in Zambia with orange maize and Nigeria with yellow cassava. This is driving consumers in several countries to switch to the more nutritious varieties especially when they see the health benefits in their children.

6. SUSTAINABLE DELIVERY

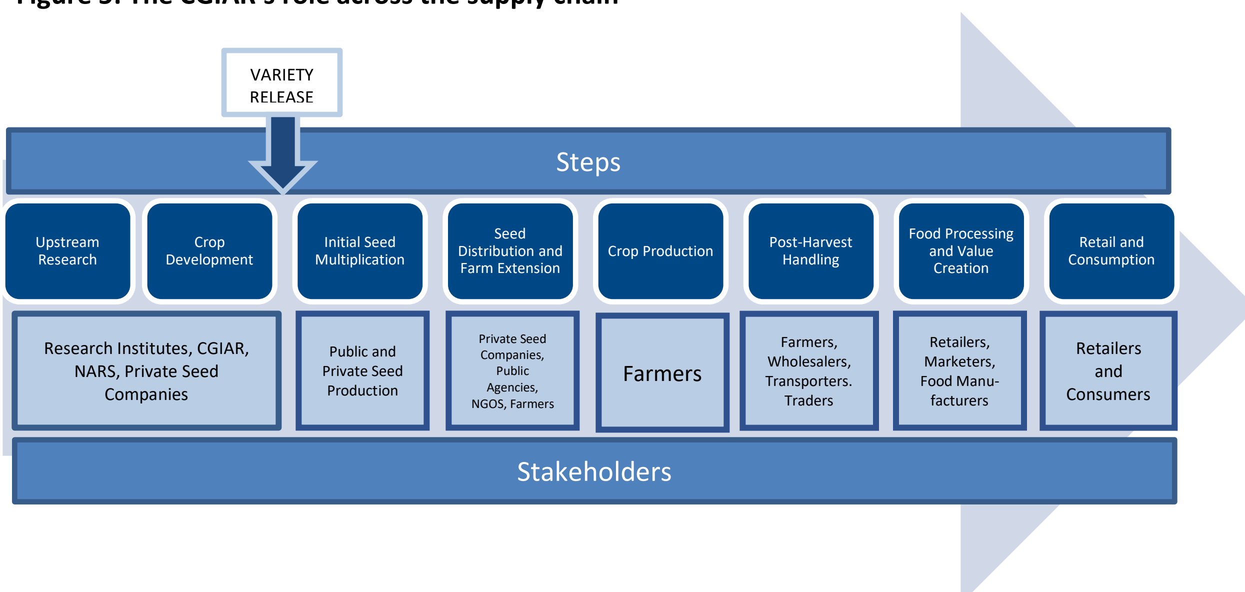
6.1 STRENGTHENING PARTNERSHIPS

If biofortification is to be self-sustaining, biofortification must be fully embedded into existing food systems as an ongoing, inclusive solution without the need for significant sustained investment. To drive expansion across multiple geographies, markets and into food chains, partnerships will be even more essential in both the public and private sector, as too will the need for well-governed standards.

From the start, the CGIAR's biofortification efforts have pioneered a global effort to bridge the gap between agriculture and nutrition - in both policy and practice. This remains an ongoing priority for the next five years and the new strategic plan emphasizes the essential role that partnerships will play in establishing biofortification as a default setting in both agriculture and health agendas, considering a value chain strategy (Figure 5).

Getting biofortified foods to those who need them most is complicated, requiring activities across three complex systems: seed systems, crop systems and food systems. Over the last decade, the CGIAR has worked with partners across the length of the supply chain to map different value chains, identify entry points, address barriers to market, provide technical assistance and extension services for farmers, and design and implement consumer marketing for both commercial and informal markets.

Figure 5: The CGIAR's role across the supply chain[12]



This experience suggests that a combination of supply and demand strategies are needed for biofortification to truly have an impact in any new market and/or country. Investments in **crop development** and **advocacy** (to embed biofortification into government policies) are essential strategies but the availability of biofortified seeds alone does not guarantee sustainable adoption. As with any new technology, experience has shown that significant catalytic effort is required to create and sustain consumer demand.[13]

In all successful instances of taking biofortification to scale, initial leadership from HarvestPlus and CIP and partners has been required to build an end-to-end value chain for biofortified crops so that farmers are not just benefitting from consuming these more nutritious varieties but are also finding a viable market. The CGIAR and its partners have invested in additional successful strategies, including:

[12] Most of steps are a continuum with overlap on either side rather than distinct activities.

- encouraging multipliers and seed companies to adopt and commercialize biofortified varieties;
- educating farmers on growing, selling and consuming biofortified crops;
- incentivizing food processors and manufacturers to develop markets for biofortified foods; and
- encouraging consumers to buy and enjoy these naturally-nutritious products.

Without combined efforts in these areas, adoption of biofortification will either not happen or happen too slowly to help reduce hidden hunger in our lifetime**.**

6.2. STANDARDS

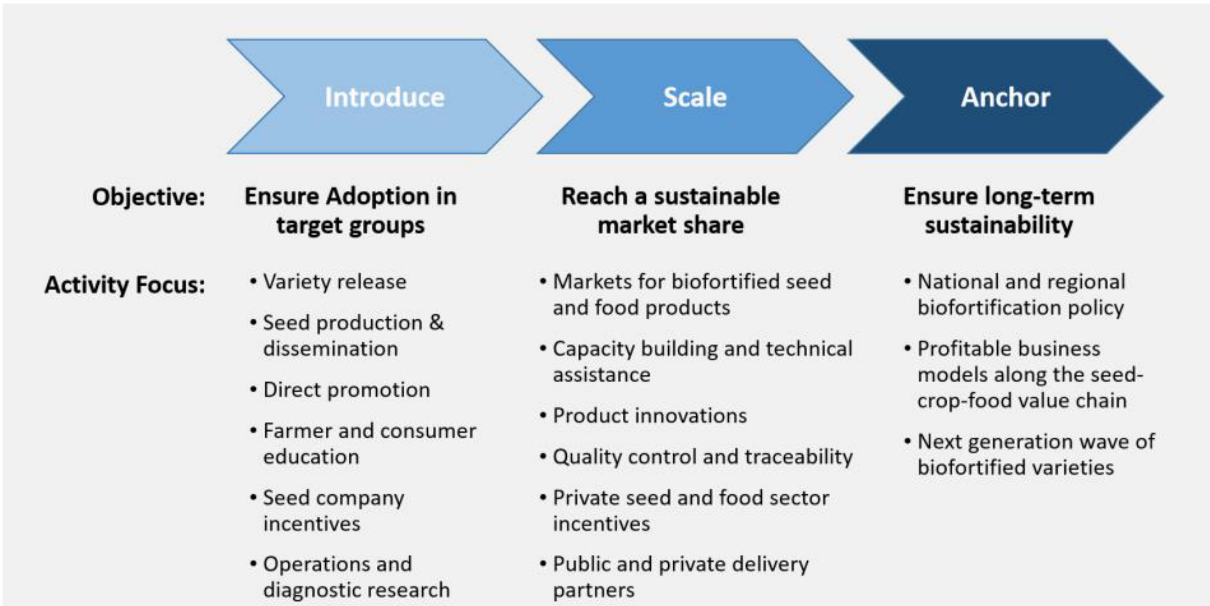
As biofortification continues to gain traction as a commercially viable intervention, it is anticipated that market forces will play a positive role in accelerating demand for most biofortified crops. For self-pollinated and hybrid crops, this in turn will speed up integration of nutrition into major crop lines as private seed companies respond to their customers. This comes with one inevitable downside. In the absence of clearly defined or regulated standards for production and consumption of biofortified crops, the competition for market share may give rise to a proliferation of diluted standards and false claims. This could be damaging for biofortification unless steps are taken to mitigate this risk. However, as mainstreaming strengthens, the role of market forces will become largely irrelevant as all the available commodity will be biofortified.

The CGIAR, through HarvestPlus, is working with the Codex Alimentarius Committee on Nutrition and Foods for Special Dietary Uses prepare a definition for biofortification. In the meantime, the CGIAR will continue to use its diverse network of international organizations, research institutes and civil society organizations to drive a single, integrated conversation on standards and governance, and to deliver the best possible return on investment for society.

6.3 LEARNINGS ON DELIVERING BIOFORTIFICATION

One important insight from the decade of ‘learning by doing’ is that in-country operations tend to follow three distinct stages (See Figure 4). The first, **introductory** stage, aims at achieving adoption by farmers in selected target groups. The second aims at **scaling up** operations with the objective of reaching a sustainable market share; and the third stage involves establishing or **anchoring** the conditions for long-term sustainability of biofortified crops. The CGIAR’s role and activities differ across the three stages and in different countries for different crops and, while HarvestPlus, CIP, IRRI and partners have accumulated significant experience and know-how in the introduction phase, there is still analysis and experimentation required in the scale and anchor phases. With the OFSP case, the most advanced in terms of scaling, from lessons could be learned and used in other contexts. Some donors are interested in supporting the efforts of scaling by CGIAR centers in coordination with HarvestPlus, because there is a clear need to have conceptual, methodological and applied support to implement scaling of biofortified crops more efficiently.

Figure 6: CGIAR's role at each stage of scaling



6.4 WHERE TO WORK

A major part of CGIAR strategic planning has been to define which countries and crops to focus on in the next five years. The process has been evidence-led and non-subjective, with all decisions resting on the twin criteria of targeting populations with greatest nutritional need and the ability for biofortified crops to have the greatest impact. There is no single index that can adequately provide these answers, so analysts have adopted a combination of different indices to identify a list of 33 priority countries (see Table 1).

In order to define 'need' they drew from the Biofortification Priority Index (BPI), which ranks countries in terms of their full biofortification potential based on the production and consumption of micronutrient-dense crops and country-specific micronutrient deficiency profiles. In defining the ability of biofortification to have an impact, they used a combination of crop readiness and HANCI (Hunger and Nutrition Commitment Index, an annual index that ranks governments on their political commitment to tackling hunger and undernutrition).

Table 1: 33 priority countries, crops 2019-2021

Country	Biofortified Crops Released	Biofortified Crops in Testing
Angola	-	maize, OFSP
Bangladesh	OFSP, rice, lentils	wheat
Benin	pearl millet	maize
Brazil	maize, cassava, OFSP, beans, cowpea	wheat, rice
Cambodia	-	rice
China	OFSP, wheat, rice, potato	maize
Colombia	beans	maize, cassava, rice
DR Congo	maize, cassava, banana, plantain, beans	-
Egypt	OFSP	wheat
Ethiopia	OFSP, lentils	maize, cassava, wheat, potato
Ghana	maize, cassava, OFSP	pearl millet
Guatemala	beans	cassava, OFSP, rice
India	OFSP, wheat, rice, pearl millet, cowpea,	maize, sorghum
Indonesia	OFSP	rice
Kenya	OFSP, beans	maize, cassava
Laos	-	rice
Madagascar	OFSP	rice
Malawi	maize, cassava, OFSP, beans	-
Mali	maize	OFSP, pearl millet, sorghum
Mexico	-	maize
Mozambique	OFSP	maize, cassava
Myanmar	-	rice
Nepal	lentils	maize, wheat
Niger	pearl millet	maize
Nigeria	maize, cassava, OFSP, banana, sorghum	pearl millet, cowpea
Pakistan	wheat	maize, lentils
Philippines	-	rice
Rwanda	maize, OFSP, beans	banana, plantain, potato
Tanzania	OFSP	maize, cassava, banana, beans
Uganda	OFSP, beans	maize, cassava, banana, plantain
Vietnam	OFSP	-
Zambia	maize, OFSP	cassava
Zimbabwe	maize, beans	-
Total		

All biofortified crops released in a country are also undergoing testing for better second and third wave releases.

With the priority countries identified, a flexible crop delivery plan has been or will be designed for each country with phasings based on existing capacity, need, current and future crop readiness, and public-private partnerships (see Table 2).

Table 2: Five-year phasing plan based on 1st crop introduction*

B – Iron Beans; **C** – Vitamin A Cassava; **CP** – Iron & Zinc cowpea; **GR:** Golden Rice; **ZR:** high-zinc rice; **L:** Iron Lentil; **M** – (Pro)Vitamin A Maize; **OFSP** – Vitamin A (Orange fleshed) Sweetpotato; **PM** – Iron Pearl Millet; **R** – Zinc Rice; **S** – Iron & Zinc Sorghum; **W:** Zinc Wheat

COUNTRY	2018	2019	2020	2021	2022
India	PM, W, R, L, CP, ZR, OFSP	PM, W, R, L, CP, ZR, OFSP	PM, W, R, L, CP, ZR, S, M, OFSP	PM, W, R, L, CP, ZR, S, M, OFSP	PM, W, R, L, CP, S, M, OFSP
Uganda	B, OFSP	B, OFSP	B, M, OFSP	B, M, OFSP	B, M, OFSP
Rwanda	B, M, OFSP	B, M, OFSP	B, M, OFSP	B, M, OFSP	B, M, OFSP
DR Congo	B, C, M	B, C, M	B, C, M	B, C, M, OFSP	B, C, M, OFSP
Nigeria	C, M, OFSP, PM	C, M, OFSP, PM	C, M, OFSP, PM	C, M, OFSP, PM	C, M, OFSP, PM
Zambia	M, OFSP	M, OFSP	M, OFSP	M, OFSP	M, OFSP
Pakistan	W	W, M	W, M	W, M	W, M
Bangladesh	R, L, OFSP, ZR	R, L, OFSP, ZR, GR	R, L, W, OFSP, ZR, GR	R, L, W, OFSP,	R, L, W, OFSP, ZR,
Guatemala	B	B	B, M	B, M	B, M
Tanzania	OFSP	OFSP	C, M, OFSP	C, M, OFSP	C, M, OFSP
Zimbabwe	B, M	B, M	B, M	B, M, OFSP	B, M, OFSP
Mali	M, OFSP, PM	M, OFSP, PM	M, OFSP, PM	M, OFSP, PM	M, OFSP, PM
Ghana	M, OFSP	M, OFSP, PM	C, M, OFSP, PM	C, M, OFSP, PM	C, M, OFSP, PM
Malawi	B, C, M, OFSP	B, C, M, OFSP	B, C, M, OFSP	B, C, M, OFSP	B, C, M, OFSP
Ethiopia	OFSP	OFSP	OFSP	M, OFSP	M, OFSP
Madagascar	OFSP	OFSP	OFSP	OFSP	OFSP
Mozambique	OFSP	C, OFSP	C, OFSP	C, M, OFSP	C, M, OFSP
Benin	PM	PM	PM, OFSP	M, PM, OFSP	M, PM, OFSP
Niger	PM	PM	PM	M, PM, OFSP	M, PM, OFSP
Kenya	B, OFSP	B, OFSP	B, OFSP	B, C, M, OFSP	B, C, M, OFSP
Brazil	C, M, OFSP, B, CP,	C, M, OFSP, B, CP,	C, M, OFSP, B, CP, R	C, M, OFSP, B, CP, R	C, M, OFSP, B, CP, R
Colombia	B	B, M, R	B, M, R, C	B, M, R, C	B, M, R, C
China	OFSP, M	OFSP, M	OFSP, M, W	OFSP, M, W	OFSP, M, W
Nepal		W, L	W, L	W, L, OFSP	W, L, OFSP
Philippines		R	R, OFSP, GR	R, OFSP, GR	R, OFSP, GR
Indonesia			R, OFSP	R, OFSP, GR	R, OFSP, GR
Myanmar			R	R	R
Cambodia			R	R	R
Laos			R	R	R
Vietnam			R, OFSP	R, OFSP	R, OFSP
Egypt			W, OFSP	W, OFSP	W, OFSP
Angola			M, OFSP	M, OFSP	M, OFSP
Mexico			M, B	M, B	M, B

*Countries in which at least one crop entered anchoring phase.

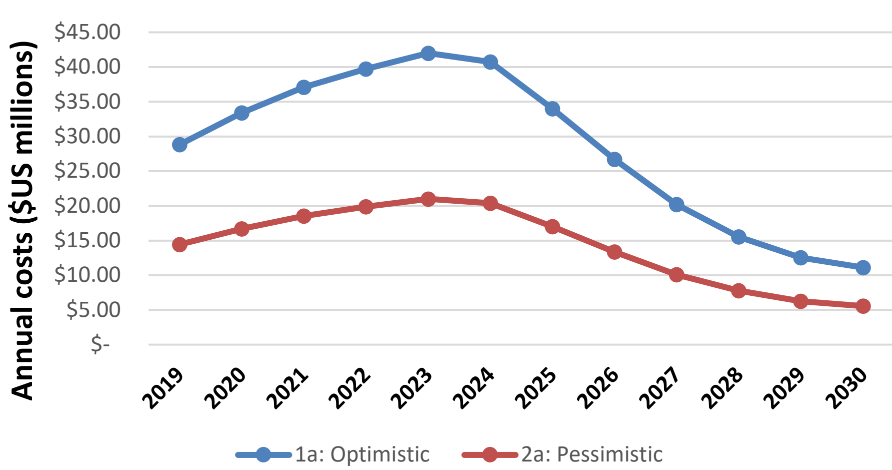
7. Households Reached Under Alternative Levels of Investments in Biofortification

Through various dissemination efforts by HarvestPlus, CIP, and their partners, it is estimated that 10 million farm households (50 million people in farm households) are growing and eating biofortified crops. This represents only 5% of an ambitious goal of reaching 1 billion people by 2030. What levels of public investments in CGIAR plant breeding and catalytic delivery activities are required to reach 1 billion people by 2030 – which, as explained above, will stimulate complementary investments by private sector actors such as seed companies and food processors and retailers, and by NGOs, and public sector actors such as multi-lateral banks, FAO, the World Food Program, and others.

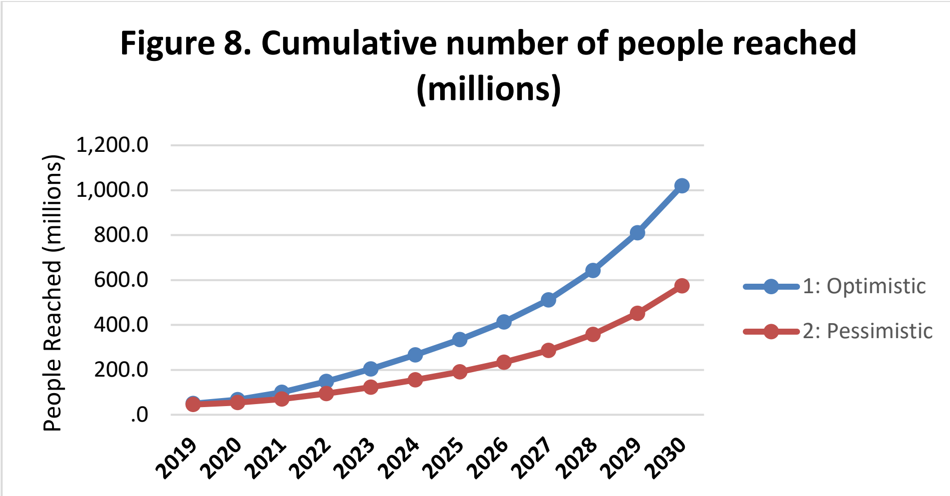
Below are simulation results based on an algorithm using parameters developed/estimated from experience derived from the breeding of biofortified crops during 2003-2017 and from the initial delivery of biofortified crops over the past seven years. The optimistic scenario assumes that $235 million are invested in plant breeding during the twelve-year period 2019-2030 ($19 million/year total both for mainstreaming and targeted breeding), and $340 million are invested in delivery ($28 million per year). The pessimistic scenario assumes both breeding and delivery investments that are 50% lower than the optimistic assumption. The pessimistic scenario represents current annual expenditures by HarvestPlus and all centers and partners on plant breeding and delivery.

Note the pattern of delivery investments over time in Figure 7. It is anticipated that delivery efforts will require ongoing funding, but that this investment is expected to first increase, then to decline rapidly after 2022, eventually to much lower levels than presently, as market forces drive demand for commercial crops such as wheat, maize, and rice. Some ongoing investment will be required in less developed countries until sufficient concentrations of biofortified varieties are diffused into seed systems, and for crops that do not have a well-developed private sector seed sector.

Figure 7. Annual Delivery Budget



As shown in Figure 8, at more optimistic levels of funding, 1 billion people can be reached by 2030. About 600 million people will be reached at present levels investment, although even this pessimistic scenario assumes a short-run increase in delivery funding through 2023. It is important to emphasize that in the algorithm, higher breeding investments also contribute to more people reached through the more rapid release of higher numbers of high-yielding varieties. Farmers require choice.



Why is more rapid deployment important? For two fundamental reasons. First, better nutrition and so health benefits are realized for more people more quickly. Second, often the biofortified varieties are based on superior agronomic traits developed by breeding programs at the CGIAR Centers. Economic values can be derived for both factors.

As an example, some data are now available for iron beans in Rwanda (developed by CIAT and RAB) from a nationwide survey conducted by HarvestPlus in the second bean growing season in 2015. Analysis of the survey data indicate that production of high iron bush beans is $50 more profitable per hectare than production of all other types of bush beans, and that production of high iron climber beans is $25 more profitable per hectare than production of all other types of climber beans. This represents an additional total production value of $2 million for all high iron bean production in 2015 for Rwanda, not counting any health benefits.

8. TRANSGENIC BIOFORTIFIED CROPS

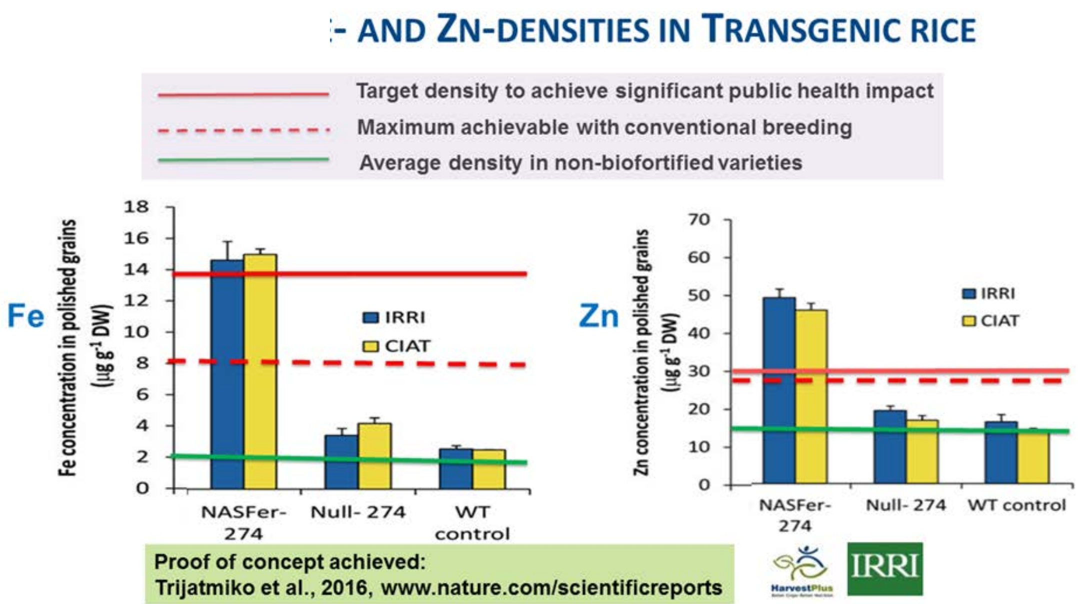
Because conventional plant breeding does not face the same regulatory hurdles as transgenic criticism, and is widely accepted. However, one of the very significant limitations thus far to conventional plant breeding is that the density of a *single* nutrient has been increased for each staple food crop – and that particular nutrient has been dictated by the variation of the nutrient density available in varieties stored in germplasm collections maintained by agricultural research centers.

In crops where the target nutrient does not naturally exist at the required levels in the breeding material available to breeders, transgenic plant breeding is a promising approach to produce biofortified crops with the desired nutrient and agronomic traits – for single nutrients and for multiple nutrients as well.
For example, transgenic iron and zinc rice has been developed and tested in confined field trials that can provide +30% of the EAR for iron and +50% of the EAR for zinc in the same event (Trijatmiko *et al.* 2016). As can be seen in Figure 5, the event tested in two locations (IRRI in the Philippines and CIAT in Colombia) meets the iron target of (14 ppm Fe total or +12 ppm Fe) and exceeds the target for zinc by a very large margin (45 ppm Zn or +30 ppm Zn), in a high-yielding background.

Golden Rice, which contains beta carotene, can provide as much as 100% of the EAR for vitamin A. While

being available as a prototype since early 2000, Golden Rice has now been de-regulated in Australia, New Zealand, Canada and USA. It is in field trials and been submitted for regulatory approval in Bangladesh and the Philippines. High iron-zinc and high provitamin A rice can be crossed to give transgenic rice with high levels of all three nutrients.
These transgenic varieties have tremendous potential for nutritional impact, release to farmers and producers depends on approval through very strict national biosafety and regulatory processes, based on scientific evidence and recommendations.

Figure 9: Iron and Zinc Densities in Transgenic Rice



9. ORGANIZATION AND COORDINATION OF THE BIOFORTIFICATION STRATEGY

As described above, there are three independently administered programs within the CGIAR which focus on biofortification:

- HarvestPlus (which channels funds to breeding programs of Bioversity, CIAT, CIMMYT, CIP, IITA, IRRI, ICARDA, and ICRISAT)[14]
- CIP Orange Fleshed Sweetpotato (OFSP)
- IRRI Transgenic Rice

Under the CGIAR Biofortification Strategy, all three programs will continue to be administered independently. However, the management teams of the three programs will meet in person once a year, and will have additional teleconference if needed to coordinate and review progress on CGIAR level biofortification strategy. Prior to the annual meetings, each team will provide in writing to the others, the activities undertaken and planned over the next 12-18 months. These discussions will cover strategic items such as:

[14] Regarding ICRISAT, Annex 2 describes their interest in biofortification in grain legumes ad dryland cereals. Regarding ICARDA, Annex 3 describes its approach to biofortification in key crops.) Information on CIP, IRRI, and IITA breeding programs can be found in Annex 4.

- breeding progress on achieving biofortification targets
- coordination of delivery/scaling up activities
- documentation of experiences related to the four pillars
- coordinated advocacy and messaging strategies on biofortification
- funding strategies

There will be a Coordination Group with a representative from HarvestPlus, one from CIP and one from IRRI to set a common agenda and provide overall coordination.

In addition to CIP and IRRI and HarvestPlus, any Center participating in CGIAR biofortification activities under this Strategy wishing to do so, may appoint a representative to the Coordinating Group. The representative in charge of organizing the annual meeting of the Coordinating Group will rotate among all members of the Coordinating Group

HarvestPlus will organize the annual meeting in 2019, then CIP for 2020, and IRRI for 2021, then other participating Centers after 2021. The hosting representative will cover the local meeting costs, and each Center will cover the travel costs of its representative."

Coordination of delivery by scaling through seed systems, food industries and value chains

Scaling up of biofortified crops in Africa, Asia, and Latin America is a huge challenge, resource intensive, and will require many players and actors.

Currently, Centers working under the HarvestPlus Program either do not participate at all in delivery/scaling up activities for biofortified crops, or do so at a very modest level. However, in the future Centers may want to seek increased funding directly for delivery/scaling up of biofortified crops. For efficiency, it will be important to coordinate efforts of HarvestPlus, Center, and other partners in delivery/scaling up activities.

CIP will continue its delivery/scaling up activities of orange fleshed sweetpotato and will contribute with its considerable experience to support the scaling efforts of other centers working on other biofortified crops. In some cases, it will be more efficient to coordinate delivery/scaling up activities where CIP/orange fleshed sweetpotato and biofortified crops under the HarvestPlus Program are being delivered in the same country, and even more, the coordination could be wider among several CGIAR centers with presence in specific countries, in line with the country collaboration approach agreed by the CGIAR. Arrangements initially for this coordination will be worked out through the CGIAR Biofortification Strategy meetings, with details being developed by their respective country-level staff. Delivery/scaling up of IRRI transgenic rice is still some years in the future, but the processes for managing the delivery and scaling of transgenic rice are already embedded in the currently-funded activities and will also require specific, targeted advocacy.

IRRI will continue to progress Golden Rice and other transgenic rice through regulatory processes and will, when the product(s) are approved for food, feed and commercialization, be ready to begin delivery and scaling-up activities with national partners.

The principles of interaction and synergy with the private sector for scaling biofortified crops (from the seed side, but also from the processing side), will be an integral part of the biofortification strategy. Depending on the specific context of countries, CGIAR centers will establish diverse mechanisms of interaction with the private sector for seed production, but also for processing and product development. Some centers have already established mechanisms or semi-private branches to facilitate seed business of targeted crops, other centers are establishing contractual arrangements to take advantage of the private sector interest (breeding and seed companies). Therefore, depending on the comparative advantages and presence of centers in targeted countries, public-private partnerships (PPP) will be established.

Coordination of policy work, advocacy and communications

HarvestPlus has undertaken the primary work globally in policy, advocacy, communications, and branding of biofortification, and will continue to take primary responsibility for this. CIP has played a strong role regarding advocacy and policy on OFSP, and IRRI for biofortified rice. Therefore, HarvestPlus, CIP (see Annex 5 for a summary of HarvestPlus and CIP collaboration to date) and IRRI will coordinate with the comparative advantages of the centers according to presence in the countries. IRRI will continue to take primary responsibility in this area for transgenic biofortified rice as this technology needs a different approach to policy and advocacy and, if not handled separately, can impact public perception of conventionally bred biofortified crops.

Approach to nutritional standards and build the case for biofortification

HarvestPlus has initiated a process in CODEX to develop a definition and standards for biofortified crops. HarvestPlus will continue to take responsibility for this effort and coordinate closely with the relevant centers for crop-specific needs.

In addition, HarvestPlus has requested that WHO/FAO undertake an evaluation of the evidence on biofortification as an efficacious, cost-effective intervention to reduce mineral and vitamin deficiencies. The process will be completed in 2019 when WHO/FAO will issue an official recommendation. HarvestPlus has and will continue to make a concerted effort to accelerate the finalization of this evaluation, providing technical resources and expert input as needed.

Resource Mobilization

The CGIAR Biofortification Strategy presents a harmonized concept about what the Centers can do in a coordinated fashion, and which areas or pillars of biofortification should be taken by which Center. Depending on the definition of roles and responsibilities, donors could be approached in different ways. There are some measures that can be taken to mitigate competition.

Funding for mainstreaming breeding will continue to be sought by Centers directly from donors. As requested by Centers, HarvestPlus will assist with providing justification for investments in mainstreaming breeding including concept development.

HarvestPlus in coordination with the Centers will continue to seek funding for targeted breeding from donors, which will be allocated to Centers for through contracts as has been the practice since 2003. Individual Centers and HarvestPlus will continue seeking funding for work on all pillars of the strategy in order to reach the target number of households defined in this document.

Generating significant "non-traditional" sources of funding

- CGIAR donors are agricultural donors. Biofortification has a nutrition (and health) objective. Thus far, most of the investment in biofortification in the CGIAR has been provided by agricultural donors. We need to do a better job of tapping nutrition and health donors e.g. the Global Alliance for Improved Nutrition (GAIN).

Funding Among CGIAR Donors

As described above, historically HarvestPlus has taken on the task of assembling funding for biofortification ($400 million - since 2003) and distributing contracts for various activities to CGIAR institutions, with the exception of the CIP orange fleshed sweetpotato and IRRI transgenic rice activities.

Going forward, mainstreaming of breeding will be funded directly to Centers. This process is already underway. This type of funding has high priority —for without successful mainstreaming, the biofortification strategy will not be completely sustainable.

With respect to Delivery/Scaling Up, as some Centers now are more interested in becoming directly involved in disseminating biofortified varieties (following CIP's example), most Centers and HarvestPlus will seek direct funding for delivery and scaling up in coordination.

However, in contrast with mainstreaming of breeding which only the Centers themselves can undertake, there is so much work to do with delivery/scaling up, that numerous partners must be involved to get the job done across dozens of countries for each crop. This will require information exchange, planning, cooperation, and coordination, and should be an integral part of the breeding initiative, and the country collaboration effort that has been already initiated.

HarvestPlus will continue to raise its own funding — to be distributed across various crops and activities — for targeted breeding, nutrition research, impact policy analysis, advocacy communications and delivery, and each center will continue seeking for funding to mainstream biofortification in their breeding programs.

10. PROPOSED BUDGET AND DESIGNING OUTCOMES AND OUTPUTS FOR EACH STRATEGIC PILLAR

The goal of reaching one billion people by 2030 requires a new and collaborative fundraising effort as described in the previous section. An estimated five-year revenue plan is provided in Table 6. This depicts the total funds required to meet all in-country targets for all twelve crops, starting with the 2020 goal of reaching 100 million people with biofortified crops and ensuring that biofortification movement stays on track to reach one billion people by 2030.

Table 3: Projected Funding Requirements for 2019-2023

Budget (US$ Million)	**2018**	**2019**	**2020**	**2021**	**2022**	**TOTAL**
Pillar 1: Influence & Impact (incl. M&E)	13.0	12.4	12.7	12.1	11.9	62.1
Pillar 2: Research and Development	17.5	23.5	24.9	28.2	31.3	125.4
Pillar 3: In-Country Delivery	28.8	33.4	37.1	39.7	42.0	181.0
Pillar 4: Sustainable Value Chains	7.4	7.8	8.1	9.9	10.4	43.6
Foundation Activities*	11.2	11.6	11.8	12.3	12.8	59.7
Total Funding Requirement	**77.9**	**88.7**	**94.6**	**102.2**	**108.4**	471.8

*HarvestPlus central management and governance

Below, a logic model is presented to frame activities and investments for the next five years. A measurable outcome has been defined for each of the four Strategic Pillars and a set of outputs, activities and resources have been developed that will operationalize the plan. A suite of foundation or cross-cutting activities underpin the four pillars and completes the strategic model.

Table 4: Impacts and outcomes

IMPACTS	OUTCOMES
In all priority countries: **Nutrition:** Improved health outcomes associated with micronutrient deficiency **Economic:** Improved livelihoods and sustainable incomes for smallholder farmers	**PILLAR 1: Influence & Impact** Biofortification included in all international and national policy and programs, as a proven, scalable and sustainable solution to hidden hunger
	PILLAR 2: Research & Development Continuous pipeline of biofortified germplasm with appropriate levels of nutrients and most desirable traits
	PILLAR 3: Seed Multiplication & Delivery Biofortified seed consistently available and accessible for seed multipliers and farmers in target countries
	PILLAR 4 Sustainable Value Chains Farmers growing, manufacturers using, retailers selling and consumers eating biofortified crops
	Foundation and cross-cutting activities Effective governance and systems to ensure cost-effective scale up of biofortification

Table 5: From outcomes to outputs

OUTCOMES	OUTPUTS
PILLAR 1: Influence & Impact Biofortification included in all international and national policy and programs, as a proven, scalable and sustainable solution to hidden hunger	1. Proof that biofortification addresses hidden hunger, that it's scalable, cost effective and sustainable 2. Awareness and understanding of biofortification among key stakeholders 3. Inclusion of biofortification in International & national policies & programs 4. Inclusion of biofortification in International & national public and private sector plans and investments
PILLAR 2: Research & Development Continuous pipeline of biofortified germplasm with appropriate levels of nutrients and most desirable traits	1. Clearly defined & proven nutrient targets for breeding objectives and standards for Biofortification 2. Priority Biofortified crops developed and delivered in all priority countries 3. Nutrition traits as default standard in all relevant CGIAR & NARS breeding pipelines
PILLAR 3: Seed Multiplication & Delivery Biofortified seed consistently available and accessible for seed multipliers and farmers in target countries	1. Breeder/Foundation Seed available through public or private seed systems 2. Multipliers and farmers have easy access to sufficient, affordable quality seed in a timely manner 3. Farmers have the knowledge, skills and tools to grow biofortified crops 4. Farmers growing and earning revenues from biofortified crops
PILLAR 4 Sustainable Value Chains Farmers growing, manufacturers using, retailers selling and consumers eating biofortified crops	1. Food manufacturers producing and retailers selling biofortified foods 2. Rural and urban households & consumers eating biofortified foods 3. Markets for biofortified foods and ingredients strengthened

OUTCOMES	OUTPUTS
Foundation and cross-cutting activities Effective governance and systems to ensure cost-effective scale up of biofortification	1. Sufficient levels of funding to deliver scale and meet objectives by 2030. 2. Easy and consistent access to timely, accurate data, research & information. 3. Fit-for-purpose systems and controls in place to empower staff, manage risk and deliver cost-effective programs.

11. CONCLUSION

Biofortification has truly reached a defining moment. Twenty years ago, it was just an idea. Ten years ago, it was an exciting R&D program with a lot to prove. Today, it is a unique and scalable solution to one of the world's biggest problems. The CGIAR has developed a five-year strategy that will scale up biofortification in 33 priority countries by 2023. In coming years, the CGIAR will strengthen its role as a trusted standard-setter and leading voice of biofortification and will continue to serve as a global thought leader and honest broker so that biofortification may contribute to the UN Sustainable Development Goals to End Hunger, Achieve Food and Nutrition Security, and Promote Sustainable Agriculture.

ANNEX 1: LIST OF PARTNERS

ANNEX 2. ICRISAT BIOFORTIFICATION STRATEGY: GRAIN LEGUME AND DRYLAND CEREALS

1. **ICRISAT Crops:** Grain legumes (chickpea, pigeonpea, groundnut) and dryland cereals (sorghum, pearl millet and finger millet) are important crops for smallholder farmers in low-income countries in the arid and semi-arid tropical regions of Africa and Asia. These countries are home to millions of poor smallholder's households living in harsh agroecology. These crops are important sources of dietary carbohydrates, energy, protein, and important minerals such as calcium, iron and zinc. Considering inherent high nutritional values and climate resilient nature, demand for these grain legumes and dryland cereals for food uses is projected to grow strongly in Asia, West and Central Africa and East and South Africa. The communal importance of these crop is presented in Table 1.

Table 1: Importance of ICRISAT's grain legumes and dryland cereals

Crop	Global area (million ha)	Area in Asia (million ha)	Area in Africa (million ha)	% of global area in Asia & Africa	Important nutritional quality traits
Chickpea	12.7	10.7	0.61	89	Protein, iron, zinc, and carotenoids
Pigeonpea	7.0	6.2	0.6	97	Protein, iron and zinc
Groundnut	29.2	12.2	14.1	90	oils, protein, iron and zinc,
Sorghum	42.3	8.0	25.0	78	iron, zinc, calcium
Pearl millet	26.3	9.0	16.0	95	iron, zinc, folate, and calcium
Finger millet	3.6	1.5	2.0	98	iron, zinc, and calcium

2. **The problem:** Almost all the GLDC crops growing countries are reported with higher prevalence of micronutrient malnutrition, which is a major public health problem, particularly in women and children. The most common deficiencies are iron (Fe), zinc (Zn) and Vitamin A. So far, crop breeding programs of ICRISAT and NARS (in India and Africa) have largely focused on grain yield, phenology and stress tolerance and less emphasis was given to nutritional quality traits (iron and zinc) in the core line/cultivar development process. Consequently, narrow range of such micronutrients exhibited in most of the released cultivars that are being used for consumption in poor households.
3. **The nutrients:** Almost all the commercially grown cultivars of grain legumes and dryland cereals have narrow range of these nutrients in the grains. Briefly, commonly grown chickpea varieties contain 40-55 ppm of Fe and 25-35 ppm of Zn, sorghum varieties generally have 30 ppm Fe and 20 ppm Zn, pearl millet hybrids have 46–56 ppm Fe and 37-44 ppm Zn and pigeon pea varieties contain 25-40 ppm Fe and 25-35 ppm Zn. Recent studies at ICRISAT showed large genetic variability for Fe and Zn contents in the germplasm of these crops (Table 2). Thus, opportunities exist for genetic enhancement of Fe, Zn and Ca and oleic acid levels (only in groundnut). Alike yield gain achieved in these crops, micronutrient improvement is feasible through breeding/genomic tools in a cost-effective and sustainable way to provide essential micronutrients to the poor people in Asia and Africa.

Table 2. Genetic variability for micronutrient traits in ICRISAT mandate crops

Crops	Nutrient trait	Range (ppm)	ICRISAT-PCN	Current breeding viability
Chickpea	Iron	30-120	60 ppm	Yes
	Zinc	25-60	40 ppm	Yes
	Protein	12-28	27%	Yes
Pigeon pea	Iron	25-65	50 ppm	Yes
	Zinc	20-50	40 ppm	Yes
	Protein	15-30	>25%	Yes
Groundnut	Iron	31 - 68	No	Yes
	Zinc	44 - 95	No	Yes
	Oleic acid	73-80 %	>70%	Yes, in progress
Sorghum	Iron	20 -70	Yes	Yes, in progress
	Zinc	15 - 60	Yes	Yes, in progress
Pearl millet	Iron	30- 160	>55 ppm	Yes, in progress
	Zinc	25- 95	>35 ppm	Yes, in progress
	Calcium	42 - 400	No	Yes
Finger millet	Iron	22 - 65	Yes	Yes
	Zinc	17 - 25	No	Yes
	Calcium	1840 -4890	Yes	Yes, in progress

4. Breeding progress at ICRISAT:

A total of 1034 varieties and hybrids have been released in 81 countries from the breeding materials and germplasm supplied by ICRISAT. These include 309 varieties and hybrids of pearl millet, 263 varieties and hybrids of sorghum, 92 varieties and hybrids if pigeonpea, 190 varieties of groundnut, 166 varieties of chickpea and 14 varieties of finger millet. These varieties and hybrids have been widely adopted and contributed to enhancement of productivity and production of these crops.

This new research and development paradigm of CGIAR biofortification will elevate the grain legumes and dryland cereals to the greater heights through strong collaborations with other CG-centres and NARS to address food and nutritional security simultaneously. Current breeding stage of our crops are briefly given in Table 3.

Table 3. Current breeding stage towards micronutrient traits at ICRSIAT

Crop	Target nutrient as in PCN	Trait discovery	Trait incorporation	Line development	Mainstreaming
Chickpea	Fe, Zn				
Pigeon pea	Fe, Zn				
Groundnut	Fe, Zn				
Sorghum	Fe, Zn				
Pearl millet	Fe, Zn				
Finger millet	Ca, Fe, Zn				

	Complete
	In-progress
	In-planning
	Not reached

5. ICRISAT commitments on micronutrient mainstreaming

ICRISAT leads the Agri-food system CRP on GLDC which includes 9 crops, of which, 6 crops are in ICRISAT research portfolio. It's indispensable role of CRP on Agri-food systems to provide the micronutrients, vitamins and other compounds that are essential for good human health. The only way to contribute is mainstreaming these traits into ICRISAT crop breeding programs. In continuation of CGIAR Consortium and its members agree to develop mainstreaming breeding plans for mineral and vitamin traits at the global consultation meeting held on 31 March 2014 in Rwanda. ICRISAT included important micronutrient traits into core Product Concept Notes (PCN) in 2017. This commitment to mainstreaming of mineral traits will gradually improve the target nutrients in breeding lines and cultivars bred at ICRISAT and its partner's centers. Currently, the investment (at ICRISAT) for these activities is inadequate from CRPs, however, ICRISAT breeding program will continue to develop medium to long-term mainstreaming proposal with CG-centers (including HarvestPlus) and NARS partners. Currently, HarvestPlus supports the targeted breeding program for sorghum and pearl millet, and delivered large number of iron and zinc rich advanced breeding lines, germplasms and cultivars to India and west Africa. In these two crops, it was demonstrated that there was no yield penalty when concentration of iron and zinc was enhanced in grain. This mainstreaming will be enhanced if HarvestPlus extends, at least, initial support by increasing crops annual budgets. From 2019 onwards, part of mainstreaming, high-iron and zinc elite breeding lines used as parents in new crosses (in sorghum and pearl millet), then derived-progenies should have the target level of iron and zinc as per PCN. The additional cost to mainstreaming could be the precision phenotyping, hence, ICRISAT requires an additional XRF machine to support all our crops mainstreaming. On the other side, ICRISAT is pioneer in public-private consortia based research and development, thus, ICRISAT has advantage of having consultation meeting to deliberate mainstreaming at partner's center. Therefore, after 8-10 years of mainstreaming investment at ICRISAT, advanced breeding lines, germplasms and cultivars shared to partners (including HPRC partners) should have target levels of these micronutrients in addition to high yield, desired agronomic traits and tolerance to biotic and abiotic stresses.

6. Use of biofortified crops in food product formulations

- The key element, in addition to breeding for the biofortified traits that needs to be incorporated in the overall strategy of working between ICRISAT and HarvestPlus is to explore the use these biofortified crops in food product formulations and further validating the efficacy of the biofortified micronutrients in the food products, first at the laboratory stage and subsequently also establish the impact of consumption of these food products on nutritional recovery/status, e.g. nutritional intervention studies using the appropriately formulated food products in government run supplementary nutrition programs, against a control group, among malnourished and anemic women and children. Adopting this approach will generate evidence that in the long run will enable the entry of biofortified crops into various supplementary nutrition programs as well as in emergency aid programs, across the globe.
- ICRISAT has the capability to design and validate food products for nutritional intervention as well as the expertise to carry out nutritional intervention studies (http://www.icrisat.org/wp-content/uploads/2017/11/Tackling-Malnutrition-Through-Affordable-Nutri.pdf).
- Further along with food product development and nutritional intervention studies, there is a need to explore a mechanism for commercialization of these food products towards creating a sustained "demand pull" for these biofortified crops from the health and wellness market, by targeting the food industry. The proven model established by the Agribusiness and Innovation Platform (AIP) of ICRISAT on business incubation leading to technology transfer of the value-added products to entrepreneurs/industry can be adopted and leveraged.

Annex 3: CONTRIBUTION OF ICARDA TO BIOFORTIFICATION ON KEY CROPS

Lentil

Development of Lentil cultivars with high concentration of Iron and Zinc)

Background:

Lentil is in food, feed and farming systems in many developing countries, most particularly in South Asia and east Africa. It is an important pulse crop in Ethiopia, Bangladesh, India and Nepal where hidden hunger (deficiency of micronutrients) is also prevailing. There is an opportunity to address this issue by providing Fe and Zn rich lentil varieties to its consumers.

The International Center for Agricultural Research in the Dry areas (ICARDA) has a world mandate from CGIAR for lentil improvement, and is collaborating with >35 countries. Since 2004, under the HarvestPlus Challenge Program of CGIAR, ICARDA has initiated research to develop micronutrient-dense lentil genotypes as 2nd Tire crop with 3rd priority crop as member of CGIAR consortium on HarvestPLus. ICARDA's gene bank is holding >12,000 cultivated and wild germplasm and breeding lines, which is the building block of all genetic enhancement activities. In preliminary screening of more than 2200 lentil accessions, enormous variability is recorded for Fe and Zn content in lentil seed. Fe content varied from 41 to 168 ppm and Zn content ranged from 22 to 103.7 ppm, which suggest scope of improvement in these traits through genetic manipulation.

Parents with high concentration of Fe and Zn have been identified and used in cross breeding programs at ICARDA and at a few national programs. Primary, secondary and final products have been generated and released as varieties. The intermediate products (segregating populations) are being carried forward at ICARDA HQ and with national partners of South Asia. The high Fe and Zn varieties are in fast tracking in Bangladesh (6), India (3) Nepal (8), Ethiopia (1), Syria (2), etc. Recently, Bangladesh released Barimasur-8 and Barimasur-9 lentil varieties with Fe content>75ppm and Nepal released Khajurah Masuro-3 through crossing high x high parents.

Micronutrients to be enhanced: Iron and Zinc

Partners: At the beginning of lentil biofortification research, the program was being carried out from Aleppo, Syria, in partnership with the national programs of Ethiopia, Bangladesh, Nepal, Syria and Morocco. Through discussion with HarvestPLus, the program was shifted to ICARDA-South Asia & China regional program, and Bangladesh, Nepal and India are engaged as partners. However, the following national partners can be involved in 2018-2022 workplan.

Bangladesh Agricultural Research Institute (BARI, Joydebpur, Bangladesh

Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh, Bangladesh

Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethippia

INRA, Morocco

ICAR-Indian Institute of Pulses Research, Kanpur, India

ICAR-NEH Center, Tripura, India

Pantnagar University of Ag.& Technology, Pantnagar, India

Nepal Agricultural Research Council, Kathmandu, Nepal

National Agricultural Research center (NARC), Islamabad, Pakistan

Faba bean

Improving faba bean for high concentration in microelements (Iron, Zinc and Magnesium) and reducing Vicine covicine

Background:

Faba bean has specific significance to food, nutrition, and income security and livelihood options for smallholder farming communities in many countries and particularly major producing countries in North and East Africa. In these regions, agriculture is the primary source of livelihoods for more than 70% of the poor people living in rural areas of many countries of Sub-Saharan Africa and West Asia and North Africa (WANA) regions where faba bean crop is grown in rotation with cereals by the small-holder farmers. Improving agricultural productivity in general and faba bean in particular is critical for the delivery of the Sustainable Development Goals (SDGs) and the CGIAR SLOs in WANA regions and Sub-Saharan Africa

Faba bean is produced under rainfed and irrigated agriculture as parts of 38 different diversified cropping systems. Faba bean seeds are rich in digestible proteins (250 g protein/kg seed), energy (320 kcal/100 g dry weight), vitamins, and minerals and antioxidants. Faba bean is consumed in combination with cereals for a balanced diet by millions of people. Many people in the Mediterranean region and Ethiopia consume green faba bean which could help to protect falciparum malaria during the rainy season that coincide with outbursts of seasonal malaria. Besides food, feed and nutrition, faba bean is a source of incomes to small holder farmers in local markets, especially in Ethiopia where out of one million tons of faba bean produced, 60% is used for domestic consumption; 14% for seeds for planting; 24% for sale and the rest for other purposes including animal feed (CSA, 2015). Studies on the value chain of pulses (IFPRI, 2010) in Ethiopia showed that the profitability of growing faba bean (1286 dollars/ha) was much higher than wheat (725) and *Tef* (595 USD).

Table 1. Population growth of Faba bean bean-consuming and producing countries in north and East Africa:

	2018		2030		2050		Population increase /year
	Total pop (x1000)	**Urban Pop (%)**	**Total pop (x1000)**	**Urban Pop (%)**	**Total pop (X1000)**	**Urban Pop (%)**	
Ethiopia	107535	21.66	139620	27.83	190870	38.68	**2.42**
Egypt	99375.7	38.73	119746	39.97	153433	44.88	**1.7**
Sudan	41511.5	35.26	54842.5	39.01	80385.6	47.75	**2.93**

	2018		2030		2050		Population increase /year
	Total pop (x1000)	**Urban Pop (%)**	**Total pop (x1000)**	**Urban Pop (%)**	**Total pop (X1000)**	**Urban Pop (%)**	
Morocco	36191.8	59.93	40873.6	64.24	45659.9	69.47	0.82
Tunisia	11659.2	66.98	12841.6	69.06	13884	72.81	0.6
Syria	18284.4	45.41	26608.5	59.32	34021.1	69.25	**2.69**
Algeria	42008.1	73.44	48822	76.95	57436.7	77.98	1.15
South Sudan	12919.1	17.73	17254.4	23.42	25366.2	35.52	**3.01**
Yemen	28915.3	39.99	36815.3	47.56	48304	59.59	2.1

In addition, faba bean is a preferred legume for roughly 400 million inhabitants in North and East Africa, mainly in Ethiopia, Egypt, Sudan, Morocco and Tunisia (Table 1). Several countries in Africa present levels of population growth above 1.5% per year, except Morocco, Tunisia and Algeria. In South Sudan and Sudan, the population growth is roughly 3%, followed by Syria, Ethiopia and Egypt. Due to high population growth rates, Africa and the Middle East are projected to have the strongest growth in food demand and trade over the coming decade (Alene 2012). Population growth of faba bean-consuming countries is in average 2% annually. Genetic improvement could keep pace readily if the goal were to maintain the status quo. However, growth in faba bean production has lagged behind population growth for several years, and prices are currently prohibitive. A higher rate of yield gain is needed to put prices within the reach of the poor.

The African countries are hotspot of poverty and malnutrition, and faba bean producing and consuming countries are no exception, presenting from 40% to more than 70% poverty, based on per capita earning of less than US$1.90 per day. Rates of anemia range from 29-82% in children under 5, and in pregnant women from 24-63%, although this is due to both iron deficiency and to disease load, especially malaria. Stunting of under-5's ranges from 11.3-51.2, implying chronic undernutrition often associated with protein and/or zinc deficiency (Table 2)

Table 2: Parameters of nutritional status of populations in the Faba bean- producing and -consuming countries.

	Malnutrition Stunting, % of children under age 5	**Anemia in Children under age 5 (%)**	**Anemia in Pregnant women(%)**	**Non-pregnant women (%)**	**Underweight % of children under age 5**
Algeria	12.6	30	39	36	3.1
Egypt	23.6	32	23	29	7.7

	Malnutrition Stunting, % of children under age 5	Anemia in Children under age 5 (%)	Anemia in Pregnant women(%)	Non-pregnant women (%)	Underweight % of children under age 5
Eritrea	51.2	57	41	38	38.1
Ethiopia	**41**	**50**	**24**	**23**	**24.8**
Morocco	15.8	34	40	37	3.1
South Sudan	33.1	58	39	34	30.4
Sudan	NA	57	34	30	NA
Syrian	28.4	35	36	34	11.5
Tunisia	11.3	29	37	31	3.2
Yemen	47.9	84	63	70	40.9

The International Center for Agricultural Research in the Dry areas (ICARDA) has a world mandate from CGIAR for Faba bean improvement, and is collaborating with >32 countries. The study on genetic variability of only 129 Turkish accessions on microelements (Baloch et al., 2014) has shown wide range of variability for Fe (29.7–96.3 mg kg–1), Mn (15.5–29.2 mg kg–1), Cu (10.3–33.0 mg kg–1), and Zn (10.4–49.3 mg kg–1), which does not affect the grain yield of this crop (Baloch et al., 2014), indicating the possibility of enhancing faba bean bio fortification for increased levels of available mineral elements and better yield.

ICARDA's gene bank is holding >10036 accessions, which is the building block of all genetic enhancement activities. Screening a large number of accessions and landraces collected from North and East Africa would result in the identification of sources high iron and zinc content that are adapted to of variability for iron and zinc and therefore suitable to the target regions

In other hand, Faba bean (Vicia faba L.) seed contains glycosides, vicine and convicine (v-c), Crépon et al. 2010). In humans with a genetic mutation in G6PDH (glucose-6-phosphate dehydrogenase), v-c causes many functional and clinical disorders, e.g., a hemolytic disease called favism (Cappellini and Fiorelli 2008) in population deficient in 6GPD enzyme. Several cases of favism were reported recently in middle and North Africa where there is major consumption of green faba bean (Reading et al., 2016). Gutierrez et al. (2006) at IFAPA, Corodoba Spain, developed RAPD (random amplified polymorphic DNA) markers that were converted into CAP (cleavage amplified polymorphism) markers linked to the low v-c locus. And more recently, Khazaei et al. (2018) reported a high-throughput low-cost KASP (Kompetitive Allele Specific PCR) marker for low v-c concentration in faba bean at University of Saskatchewan, Canada. The KASP assay successfully distinguished low and high v-c lines of faba bean. This marker is a significant and valuable molecular tool for faba bean breeding programs aiming to reduce v-c from faba beans worldwide.

Micronutrients to be enhanced: Iron and Zinc

Antinutritional component reduced: Vicine and covicine

Partners: Ethiopia, Egypt, Tunisia, India, Iran, Syria and Morocco.

The following national programs and advanced research Institute can be involved in the workplan 2018-2022 for faba bean enhancement for microelements and reduction of vicine co-vicine

- Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia
- National Research Institute of Morocco (INRA, Morocco)
- National Research Institute of Tunisia (INRAT, Tunis)
- Agriculture Reseach Center (ARC-Egypt)
- SPII-Gorgan-Iran
- ICAR-Indian Institute of Pulses Research, Kanpur, India
- ICAR-NEH Center, Tripura, India
- IFAPA, Cordoba, Spain
- University of Saskatchewan, Canada

Barley

Objectives

Barley is considered as one of the heart savoring, high energy, healthy food. In ancient time, Roman Gladiators were fed with Barley to maintain good health and strength thereby known as "Hordearii" or "Barley Man" (Percival, 1921). Based on modern science and knowledge on nutritive value of this crop, no one will doubt about major advantages of incorporating barley in diets. The nutritive value of barley is considered superior to other small grains rice, wheat and maize. Barley flour is often mixed with wheat flour in rural areas of dryland systems to improve the nutritive value of breads (Cavallero et al. (2002)). The effectiveness of high β-Glucan content of barley based food products in lowering blood cholesterol and glucose (Behall et al., 2004; Fadel et al., 1987; Newman et al., 1989); the benefits of glycemic index (Braaten et al., 1991; Cavallero et al., 2002; Wood et al., 1990); high tocols contents of barley, including tocopherols and tocotrienols, which are known to reduce serum LDL cholesterol through their antioxidant action (Qureshi et al., 1986, 1991) are well documented (AnnexTable 2). Recent approval by the Food and Drug Administration (FDA) of the USA, of claims of soluble β-Glucan in barley for health benefit, has boosted consumer's interests towards the use of barley based food products in their diets. The β-Glucan content of barley grains is mainly determined by genetic factors (Powell et al., 1985) and less by environmental factors (Henry, 1986; Morgan and Riggs, 1981; Stuart et al., 1988). However, Perez-Vendrell et al. (1996), Fastnaught et al. (1996) and Yalcin et al. (2007) reported that there exists significant genotype-by-location interaction on β-Glucan content during grain filling. The industrial and health benefits of various chemical properties of barley grain are listed in Annex 1.

Rationale for project implementation:

ICARDA has the global mandate for barley research and development while it has developed a very strong relationship with National Agricultural Research Systems (NARS) and advanced institutes across world. The rational for this proposal is especially true, because in recent decades, the value of food barley did not get full attention as compared to "Oat" and "Millets" despite the very high level of health benefits of β-Glucan, low phytate contents and high Fe and Zn (micronutrients), high soluble fibers content in barley. In the past, barley was valued and used as "**Gladiators Food or Miracle food**" because of its superior health benefits. In the long run, this project will contribute to achieve a milestone for reviving the lost value of barley as food crop and improving nutritional security of rural and urban populations in developing world.

1. ICARDA has one of the largest collection of >30000 barley accessions (wild barley, landraces and improved genetic stocks) including both hulled and hulless. At ICARDA we have identified high Fe and Zn and beta glucan containing barley germplasm which are potential donors for bio-fortification of food and feed barley germplasm.
2. ICARDA has developed strong partnerships with various national research programs in countries from dryland areas. Since beginning of the barley research programs at ICARDA, hulless barley improvement program was developed as one of the integral components. Each year researchers around the world are provided with opportunities to select and use the best genetic resources for food barley but due to recent financial crisis first in CRP Dryland cereals funding and later its removal from phase-II Grain Legumes and Dryland Cereals (GLDC) CRP, the food barley program is lagging behind.
3. ICARDA's low and high input programs offers international nurseries of improved genetic stocks for both hulled and hulless food and feed barley, each year. Nearly 600 improved barley germplasm are supplied to more than 60 collaborators from 40 countries (mostly developing and few developed countries). ICARDA has strong network with NARS partners, advanced research institutes, and universities for barley research at global level.
4. ICARDA has recently established strong relationship with Small Grain and Potato Research Center at Aberdeen Idaho, USA, which is one of the centers of excellence for research on quality traits for small grains, especially food barley. Several barley varieties have been developed and released by this center, which is of superior quality such as high β-Glucan contents. "**Julie"** (Obert et al. 2012) and "**Transit**" (Obert et al. 2011) are two barley cultivars released by this center which have high β-Glucan content. These are involved as the parents for superior food barley germplasm improvement program at ICARDA. Recently Gongshe Hu (2014) reported that β-Glucan in improved lines (developed by ARS, USDA Aberdeen, using mutation breeding) has been achieved nearly 15%. ICARDA has signed Materials Transfer Agreement with USDA to access this cutting edge technology and incorporate high β-Glucan into ICARDA's germplasm.
5. Recent investment of ICARDA's quality laboratory in Morocco facilitates use of advanced technologies currently available or used in assessment and development of food and/or quality related traits in barley.

The barley programs will target to combine high β-Glucan with high Fe and Zn content together with superior bread making qualities into improved barley germplasm at ICARDA. This activity is one of the important components towards "**Increased consumption of nutritious dryland cereals by the poor, especially among nutritionally vulnerable women and children"**. The current activities proposed in this proposal will contribute to achieve 10% increase in the use of high β-Glucan, Fe and Zn fortified barley grain as food by nutritionally vulnerable women and children in rural and urban areas and for individuals with special dietary requirements in North Africa including Morocco, Algeria, and Tunisia; South Asia including India, Nepal and Pakistan; Iran, and South East Africa including Ethiopia, Eritrea and Kenya.

Objective 1. : Allele mining and genetic improvement of barley for food and nutritional qualities and to develop agronomically and nutritionally superior food barley.

Objective 2. Improvement of physiochemical and functional properties of food barley and its integration with agronomic traits.

Objective 3. Scaling up and scaling out of food barley improvement technologies, production, and market linkages in North and East Africa and South Asia.

Objective 4. Establishment community based truthfully labelled quality seed production and lobbying for policy frameworks supporting informal seed systems.

Partners:

At the beginning of barley bio-fortification research, the program will be carried out from Rabat Morocco, in partnership with the national programs of Morocco, Tunisia, Ethiopia, India, Nepal, and Iran. However, the following national partners can be involved in 2018-2022 work plan.

INRA, Morocco

INRAT Tunisia

Ethiopian Institute of Agricultural Research (EIAR), Addis Ababa, Ethiopia

ICAR-Indian Institute of Wheat and Barley Research, Karnal, India

Bangladesh Agricultural Research Institute (BARI, Joydebpur, Bangladesh

Nepal Agricultural Research Council, Kathmandu, Nepal

Seed and Plant Improvement Institute, Karaj, Iran

Dryland Agricultural Research Institute Maragheh, Iran

National Agricultural Research center (NARC), Islamabad, Pakistan

Expected outputs

The high β-Glucan content trait in barley (currently available at USDA-ARS Aberdeen, USA) will be recombined with high Fe and Zn controlling genes currently available within ICARDA Germplasm. The high β-Glucan, Fe and Zn containing advanced lines generated through double haploid and conventional RIL mapping population will be made available to plant breeders from developing country in to contribute nutritional security in rural-urban communities across globe.

By the end of the project high β-Glucan, Zn and Fe containing hull less barley will be produced and food barley with superior bread making quality germplasm will be available to test and integrate into food barley breeding programs, and for mass scale production in the farmers field.

Food industry based on food barley in North and East Africa and South Asia will incorporate both bread making and highly nutritive food barley into their value added products of wheat to improve overall nutritional value.

The area and production of food barley will be doubled by the end of the project benefiting small-scale farmers, seed producers and entrepreneurs in the rural areas. While the project activities will have long term impact on increasing and expanding food barley production currently occupied either by feed barley or by durum or bread wheat production in dry areas.

Scientists from ICARDA as well as its national partners will improve their skill to integrate and utilize state-of-the-art genomic tools and advance techniques on quality assessments of food barley grain. More than 20 scientists and technicians from NARS will be trained in genetics and genomics research while more than 5000 farmers including 50% women farmers will actively participate, improve their skills in innovation process.

ANNEX 4: CG CENTER BREEDING PROGRAMS: CIP, IRRI, AND IITA

CIP's breeding program: CIP has already mainstreamed orange-fleshed sweetpotato, beta-carotene integration in CIP's sweetpotato breeding program, and the next and more resource intensive step is to mainstream iron enhancement in sweetpotato. In addition, CIP has started its biofortification program towards higher content of iron and zinc in potato.

IRRI's breeding program: IRRI leads the transgenic rice activities within the CGIAR, focusing initially on vitamin A biofortified transgenic rice ('Golden Rice') and is currently expanding into iron and zinc transgenic biofortified rice, and a combined product. Transgenic Golden Rice has received regulatory approval in Australia, New Zealand, Canada and USA and is currently being considered for approval in two target countries. Collaboration has included HarvestPlus and CIAT. IRRI is also continuing to investigate opportunities for improving biofortification in rice through gene editing, and will continue to lead in this field. The public perception of gene edited and transgenic products will continue to influence how this research and the products are managed by the Centers. IRRI continues with transgenic rice activities while continuing its strong program through conventional breeding for high zinc rice and other micronutrients.

IITA's breeding programs (cassava, maize, banana): IITA has mainstreamed biofortified **cassava** into its breeding operations. With the support of HarvestPlus six proVitamin A rich cassava varieties have been released, promoted and disseminated in Nigeria. Similar efforts in DR Congo have resulted in one release and significant dissemination through the HarvestPlus delivery program. Regional biofortification nursery trials have been conducted in West Africa in Sierra Leone, Cote d'ivoire, Benin, Ghana, Cameroun and germplasm development has commenced in East and Southern Africa especially incorporating CBSD resistance in Rwanda, Uganda, Tanzania, Mozambique, Malawi and Zambia. IITA's HarvestPlus project on **maize** aims (i) to develop maize varieties having 80 to 100% of the breeding target of 15 µg/g of provitamin A in the endosperm; (ii) develop maize varieties combining high concentrations of zinc with high yield potential; (iii) channel promising provitamin A enriched maize varieties and hybrids for regional testing and trials required for variety registration and release in collaboration with partners in DRC, Ghana, Mali, and Nigeria; and (iv) multiply breeder seeds of parents of released hybrid and synthetic varieties. Twelve hybrids and synthetic varieties have been released in Ghana, Mali and Nigeria since 2012. IITA is also engaged through support from HarvestPlus in biofortification breeding for high provitamin A **bananas** with a focus on plantain in Nigeria. High provitamin A plantain cultivars have been identified for dissemination in the short term and identified high provitamin A diploids will be used in breeding.

Annex 5: CIP and HarvestPlus Collaboration

HarvestPlus (HP) – International Potato Center (CIP) Collaboration at the Country Level

Country	Presence		Activities and Collaboration				Notes
	HP	CIP	Breeding (support platforms)	Delivery systems	Evidence base	Advocacy	
AFRICA							
DRC							
Ethiopia							HP has no presence but has advocated with the government to include biofortification in the Seqota Declaration; Multi-locations trials for maize are underway
Ghana							No HP presence although Vitamin A maize has been released
Kenya							HP is establishing a regional office in Nairobi; current work is with World Vision (beans and OFSP) Coordination with CIP to be developed
Malawi							CIP has had several projects HP work on vitamin A maize (with seed companies); Coordination work on biofortification is nascent
Mozambique							
Nigeria							HP and CIP actively work together under a BMGF funded advocacy project titled “Building Nutritious Food Baskets” (BNFB) HP and CIP have separate delivery projects
Rwanda							HP and CIP co-located their sites for USAID Feed the Future projects so there is harmonized representation on biofortification
Tanzania							HP works with CIP under the BNFB project, particularly on advocacy and communications
Uganda							HP contracts CIP in research and seed systems
Zambia							Between 2011 and 2013 HarvestPlus and CIP embarked on an Orange Campaign promoting OFSP and VAM
Zimbabwe							
ASIA							
Bangladesh							Areas of operation are different but opportunities to promote biofortification to the government exist
India							CIP is involved with our multi-crop feeding study

HP
CIP
HP and CIP

HP - CIP Collaboration at the Regional and Global Levels

Region	Joint regional Collaboration	Notes
Global		• Dr Barbara Wells (CIP) is on the HarvestPlus Program Advisory Committee
Africa		• HP and CIP with the African Biofortification Champions are advocating into the African Union Commission (AUC) to include biofortification in a continental declaration. • Joint advocacy into the RECS, NEPAD/CAADP, and FARA to promote biofortification • Dr. Anna Marie Ball (HarvestPlus) is a member of the coordination committee for the CIP-led Sweet Potato for Health Initiative[SPHI], and is chair of the project advisory committee for the SASHA project (2011-present).
Asia		

HP
CIP
HP and CIP