A SEMINAR PAPER ON

Biofortification: A new tool to reduce micronutrient malnutrition

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A SEMINAR PAPER

ON

Biofortification: A New Tool to Reduce Micronutrient Malnutrition[1]

By

Md. GolamRasul Miah[2]

ABSTRACT

World underprivileged people drop in a dump namely malnutrition. With the advancement of modern civilization, one of the concern issues is to eliminate malnutrition in the severest starvation areas of the world. Billions of the deprived people experience different physical disabilities due to micronutrient malnutrition. To overcome the under nutrition level, one of the most cost-effective and long-term sustainable technique is an enrichment of nutrition in staple food through biofortification. Several staples fortification techniques are available for nutrient enrichment such as agronomic techniques of fertilization; genetically engineering, conventional breeding and biotechnological approaches. The aim of the fortification technology is lessening primordial morbidity in chronic hunger people. To combat against hidden famine not only fortification is important, but also reflection depends on the distribution of community-based fortified staple food. Thus, establishment of morbidity and malnutrition free rural community in the least developing countries, fortified available staple food would become a wonderful tool to combat.

Keywords: malnutrition, micronutrient, biofortification, staple food crops

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Chapter I

INTRODUCTION

Healthy diet is a fundamental right of all human beings of the world. However, an insufficiency of minerals and vitamins was severely affecting a high proportion of the global population, especially in the developing countries (Stein 2010). Globally, more than 3 billion unprivileged people are acutely affected by the micronutrient malnutrition and such trends becomes worsens in developing countries like, more than 1 billion people mostly go to bed hungry every day (FAO 2009; Kennedy *et al.*, 2009). Every year micronutrient malnutrition causes more than five million childhood deaths (WHO, 2016). WHO (2016) accorded that nutrient malnutrition (both excess nutrient deficiencies and diet-habited chronic diseases) is responsible for the higher mortality rate than any other causes, like accounting more than 20 million death per annum. Malnutrition also reduced national socioeconomic growth as it accellerates undernutrition generation, though increasing the morbidity and physically challenge (FAO, 2015; WHO, 2016). This fighting against hidden hunger becomes one of the major challenges of the world community. Leading global economists have identified that investment to find out strategies to reduce malnutrition become the most valuable planning by the government. (WHO, 2016).

At present, it's a burning question why globally people suffer malnutrition? Inadequate global food security planning is responsible for not to provide all of the essential nutrition and health-promoting factors required for human life (Sobal *et al.*, 2008). Therefore, dysfunctions food system and its associated factors can result in inadequate supplies of nutrients enrich feed to the most vulnerable populations (World Bank, 2007). Food and nutrition systems are largely dependent on agricultural systems and its products, which is greatly contributing to this worldwide quandary in public health (Welch, 2002). Almost 2.1 billion people in the world live on less than US$2 a day, in addition 880 million people per capita income is only <$1/day, the majority of them are related to agriculture-based economy (World Bank 2008). Such, low-income generating people do not have provision to intake balance nutrition and real health care. The increasing world population, which is likely to be projected at 8 billion by 2030, further exaggerates the malnutrition problem and most of this increase will occur in the least developed countries. Thus, Fighting against hidden hunger different human nutrition organizations such as the World Health Organization (WHO) and the Consultative Group on International Agricultural Research (CGIAR) have been developed (WHO 1992).

Micronutrient malnutrition is a continuing and serious public health problem in many countries; various interventions alleviate this problem have been implemented. Linking agriculture to nutrition and health and by formulating agriculture, nutrition, and health policies can be reflect the sustainable solutions to malnutrition(Graham *et al.*, 2015; Hawkes and Ruel, 2006; World Bank, 2007). It is shortsighted if the world once again focuses only on delivering the energy needs of resource-poor people during the current food crisis (Casey and Lugar, 2008) without also giving those affected the crops and other agricultural products needed for adequate nutrition required for healthy and productive lives. To ensure nutritional food security multiple farming system, and agricultural techniques can be used like crop diversification, crop selection, crop intensification, cropping pattern, agronomic management, soil conditioning, small-scale livestock farm, aquaculture etc. (Graham *et al.*, 2015).

Currently one of the most cost-effective strategies to address global malnutrition is biofortification (Go´mez-Galera et al. 2010). Several crush staple food fortification programs (agronomic biofortification, conventional plant breeding, genetic engineering and biotechnology) have been taken by the world scientist to increase nutrient content in staples to pull endanger people from malnutrition. One of the groups HarvestPlus program implemented conventional breeding techniques for enhancing the sufficient levels of Fe, Zn, and provitamin A carotenoid content in different staple crops of Asia and Africa (like wheat, rice, maize, cassava, pearl millet, beans, and sweet potato)(Zhao and Shewry 2011). Boosting the bioavailability of micronutrient content in the edible part of staple crops is the major goal of the biofortification program. Considering the aforesaid facts the seminar paper focusing on the following-

Objectives:

- To review the efficacy and effectiveness of staple food biofortification for combating against hidden hunger.
- To summarize different staple food biofortification techniques for enrichment of mineral nutrition in edible part.
- To address the importance of micronutrients and fortified food for lessening malnutrition.

Chapter II

MATERIALS AND METHODS

This paper is absolutely a review paper; all of the information using in this article has been collected from the secondary sources. Several relevant books, journal publications, proceedings etc finding have been used for preparation of the manuscript. The related topics have been also reviewed with the help of library facilities of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Internet browsing and CD search. According to the objectives of the review article, all of the secondary data have been presented chronologically.

Chapter III

REVIEW OF FINDINGS

Essential human nutrient:

Provision of essential nutrition is necessary in food for ensuring good health. Human body skeleton consists different chemical composition that includes, water, carbohydrates, protein, fatty acids, minerals and nucleic acids (DNA and RNA). The building blocks of these compounds are carbon, hydrogen, oxygen, nitrogen, phosphorus, calcium, iron, zinc, magnesium, manganese, and so on. These compounds are found in the human body and in the different types of organisms that humans eat. Humans require at least 44 known nutrients in adequate amounts and consistently to live healthy and productive lives (Table 1).

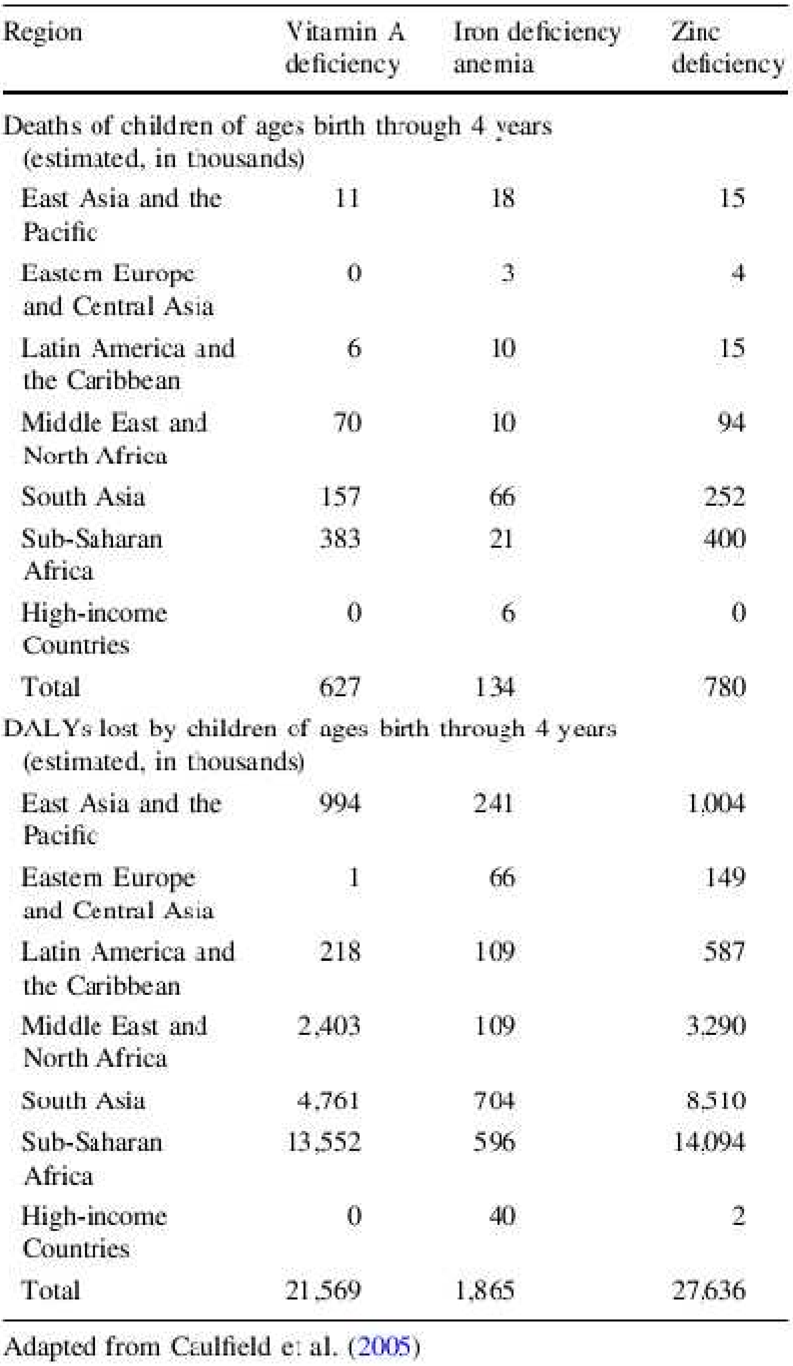
Table 1. The known essential nutrients for human life (Source: Bouis and Walch, 2010)

Air, water, and energy	Protein (amino acids)	Lipids–Fat (fatty acids)	Macrominerals	Essential trace elements	Vitamins
Oxygen	Histidine	Linoleic acid	Na	Fe	A (retinol)
Water	Isoleucine	Linolenic acid	K	Zn	D (calciferol)
Carbohydrates	Leucine		Ca	Cu	E (α-tocopherol)
	Lysine		Mg	Mn	K (phylloquinone)
	Methionine		S	I	C (ascorbic acid)
	Phenylalanine		P	F	B_1 (thiamin)
	Threonine		Cl	Se	B_2 (riboflavin)
	Tryptophan			Mo	B_3 (niacin)
	Valine			Co (in B_{12})	B_5 (pantothenic acid)
				B	B_6 (pyroxidine)
					B_7 (biotin)
					B_9 (folic acid, folacin)
					B_{12} (cobalamin)

Functional foods provide interest the prevention and/or treatment of diseases (Newell-McGloughlin, 2008). However, Plant is the main source for providing essential nutrient elements to the large number of world's population. Major nutrient elements are required in large amount for human nutrition, while trace elements such as iron (Fe), zinc (Zn), copper (Cu), iodine (I), are required in small amounts because higher levels could be harmful. Because every plant has a different nutritional value, due to lack of one or more of micronutrient in dietary food create micronutrient malnutrition (MNM), becomes a great concern in populations that do not have a balanced diet. Fortification program of staple crops has been significantly alleviated MNM in some countries.

Global status of malnutrition:

Table 2. The global impact of malnutrition



Region	Vitamin A deficiency	Iron deficiency anemia	Zinc deficiency
Deaths of children of ages birth through 4 years (estimated, in thousands)			
East Asia and the Pacific	11	18	15
Eastern Europe and Central Asia	0	3	4
Latin America and the Caribbean	6	10	15
Middle East and North Africa	70	10	94
South Asia	157	66	252
Sub-Saharan Africa	383	21	400
High-income Countries	0	6	0
Total	627	134	780
DALYs lost by children of ages birth through 4 years (estimated, in thousands)			
East Asia and the Pacific	994	241	1,004
Eastern Europe and Central Asia	1	66	149
Latin America and the Caribbean	218	109	587
Middle East and North Africa	2,403	109	3,290
South Asia	4,761	704	8,510
Sub-Saharan Africa	13,552	596	14,094
High-income Countries	0	40	2
Total	21,569	1,865	27,636

Adapted from Caulfield et al. (2005)

Collectively, nutrition-derived malnutrition specifically vitamin A, iron, and zinc deficiency cause over 1.5 million children die globally every year, with most of those deaths occurring in South Asia and Sub-Saharan Africa (Table 2). The number of disability-adjusted life years

(DALYs) caused by selected nutritional deficiencies is also very high in South Asia and Sub-Saharan Africa (Table 2). The micronutrients iron, zinc, and vitamin A have been targeted for intervention due to the magnitude of their deficiencies amongst the world’s poor. Worldwide about 2 billion people severely affected iron deficiency related anemia (WHO 2009). Zinc deficiency is also prevalent among children and pregnant women especially in developing countries. It is a major health problem as it contributes to susceptibility and progression to diseases, particularly contagious diseases in children (Cakmak 2008; Go´mez-Galera et al. 2010). Vitamin A deficiency (VAD) is the leading cause of blindness in children and increases the risk of disease and death from severe infections (Greenwald and McDonald 2001).

How can we solved the micronutrient malnutrition at rural level?

Globally micronutrient malnutrition is a continual and serious public health problems. However, different human nutritionist confined that part of the solution to micronutrient deficiencies is convincing the population to make their diets more nutritious. Various interventions to alleviate this problem have been implemented. The success of reducing malnutrition depends upon the intervention programs, including supplementation, food fortification, and dietary diversification.

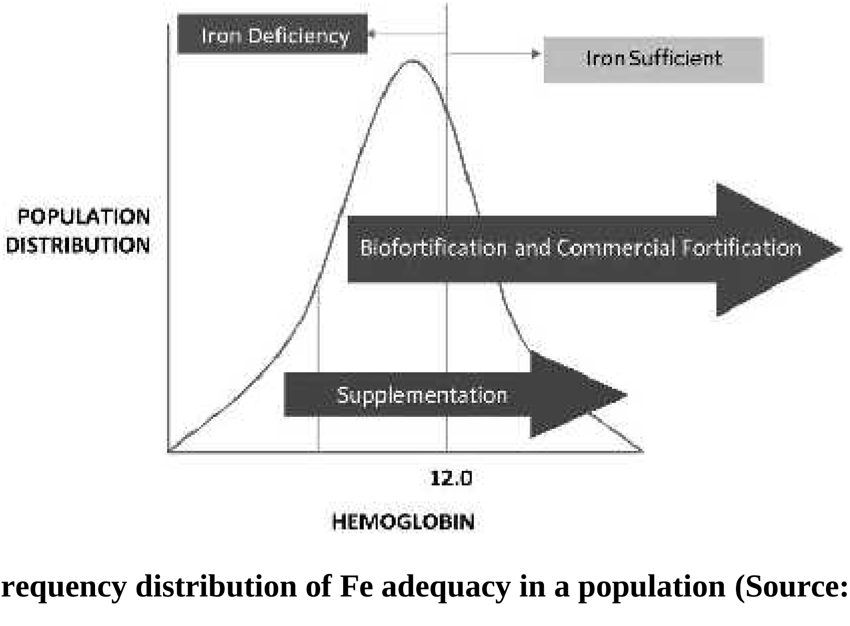


Figure 1. Frequency distribution of Fe adequacy in a population (Source: Bouis, 2011)

The effectiveness of biofortification to lessen miconutrient malnutrition is depends on the the crushed program on fortification and dessimination or supplimentation policy(Fig. 1). Thus, biofortification provide a congenial interventions and is a comparatively inexpensive and cost-effective technique to ensure micronutrient enrich food to the most vulnerable people, using an agricultural intervention that is sustainable (Bouis, 2011;Pfeiffer and McClafferty, 2013).

Similarly at Copenhagen Consensus 2008, the expart panel ranked biofortification as fifth most promising solutions for facing at present and future challenges of the world burning issue of malnutrition and hidden hunger (Fig. 2).

Copenhagen Consensus 2008

The outcome of Copenhagen Consensus in May 2008 is:

The ranked list of solutions (download the results as pdf-file including comments)

	Solution	Challenge
1	Micronutrient supplements for children (vitamin A and zinc)	Malnutrition
2	The Doha development agenda	Trade
3	Micronutrient fortification (iron and salt iodization)	Malnutrition
4	Expanded immunization coverage for children	Diseases
5	Biofortification	Malnutrition
6	Deworming and other nutrition programs at school	Malnutrition & Education
7	Lowering the price of schooling	Education

The Copenhagen Consensus 2008 May meeting is finalized

The outcome of CC08 will provide the base for various follow-ups over the next half year. Please contact Henrik Meyer for further information.

Solutions for the World's Biggest Problems

This book offers a rigorous overview of

Fig. 2 The ranked list of solutions for taking challenges of malnutrion and hunger

Sourec: (Horton et al., 2008; www.copenhagenconsensus.com)

Globally hungry people are out of reach in the micronutrient enriches food. Because malnutrition vulnerable people primarily rely on carbohydrate rich foods for their energy instead of intake high in micronutrients such as vegetables, fruits, dairy, and meats etc because those are expensive. Thus, it is possible increase micronutrient intakes in general, and among the poor in particular the by ensuring fortified energy-rich staple foods.

How does biofortification work?

a. Agronomic biofortification through fertilization

Application of both macronutrient and micronutrient fertilizers have an effective role on the accumulation of nutrients in staple food crops (Allaway, 2009; Grunes and Allaway, 2008).

Other micronutrient fertilizers have very little effect on the amount of the micronutrient accumulated in edible seeds and grains when they are applied to soils or when used as foliar sprays. This is especially true for those micronutrient elements with limited phloem sap mobility such as Fe (Welch, 2002). Increasing soil-available essential micronutrient elements (e.g., Zn, Ni, I, and Se) become one of the fesible ways in significant increases in nutrient concentrations in edible plant products (Graham *et al.*, 2015). Effectiveness of mineral fertilizer application on crop biofortification is influenced by the fertilizer type and application method. In cereals and leafy vegetable, foliar fertilization with micronutrients is more effective than soil fertilization for nutrient uptake and efficient allocation in the edible plant parts (Lawson et al., 2015). Dimpka and Bindraban (2015) ascribed that the effective techniques for Fe and Mn micronutrient fortification is foliar applied while N Zn, B, Cl, Ni, Mo and Cu can be applied by both techniques.

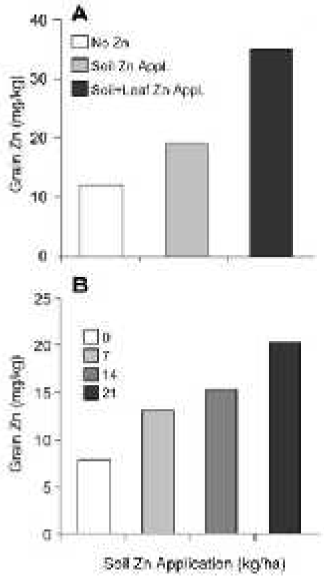


Figure 3. Wheat grain Zn concentrations after different fertilization techniques (A) and application rates of $ZnSO_4$ (B); from a study on soils highly deficient in Zn in Central Turkey (Source: Cakmak, 2010).

Like, Zn fertilization seems to be more effective though the foliar pathway as this avoids possible problems of immobilization of Zn in the soil. The combination of soil and foliar application is the most effective method for many biofortification pathways (Cakmak et al., 2010) (Fig. 3).

Biofortification increases the nutritional value of crops through either ***selective breeding*** or ***genetic modification*** (**Fig. 3**). For producing multiple plant stains with enrich nutrition value selective breeding begins with a plant variety that already contains some amount of the vitamin or mineral of interest. For crops that are difficult to breed, genetic modification may be a better option than selective breeding (Bayer, 2010). Since it’s such a popular staple crop, rice is a good target for biofortification; however, rice plants do not contain any vitamin A or vitamin A precursors, so selective breeding of rice cannot be used to prevent VAD.

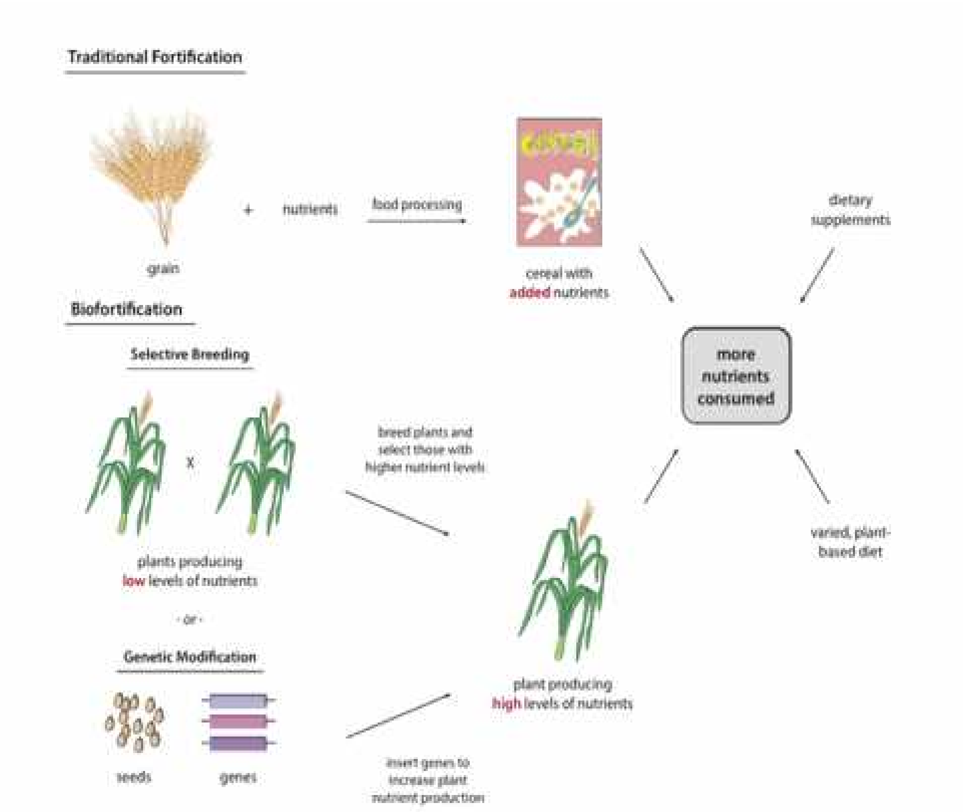


Figure 4. There are multiple ways to obtain necessary micronutrients. Micronutrients can be obtained through a varied diet rich in fruits and vegetables or through supplements. Staple food fortification adds micronutrients to commonly eaten foods. Biofortified crops are bred or engineered to produce micronutrients. (Gearing, 2015)

To address micronutrient malnutrition by producing staple food crops with enrich levels of bioavailable essential minerals and vitamins, plant breeding becomes an intervention strategy. It can provide comphrehenseable improvement of micronutrient status of target populations, primarily resource-poor people in the least developing countries (Bouis *et al.*, 2009). The "impact pathway for bio-fortified crops" as suggested by HarvestPlus is divided into the following three stages 1) discovery 2) development and 3) dissemination of the newly developed plant variety (Fig. 3). Three primary issues have been identified that are required to make biofortification successful: (i) a biofortified crop must be high yielding and profitable to the farmer, (ii) the biofortified crop must be shown to be efficacious and effective at reducing micronutrient malnutrition in humans, and (iii) the biofortified crop must be acceptable to both farmers and consumers in target regions where people are afflicted with micronutrient malnutrition (Bouis *et al.*, 2009).

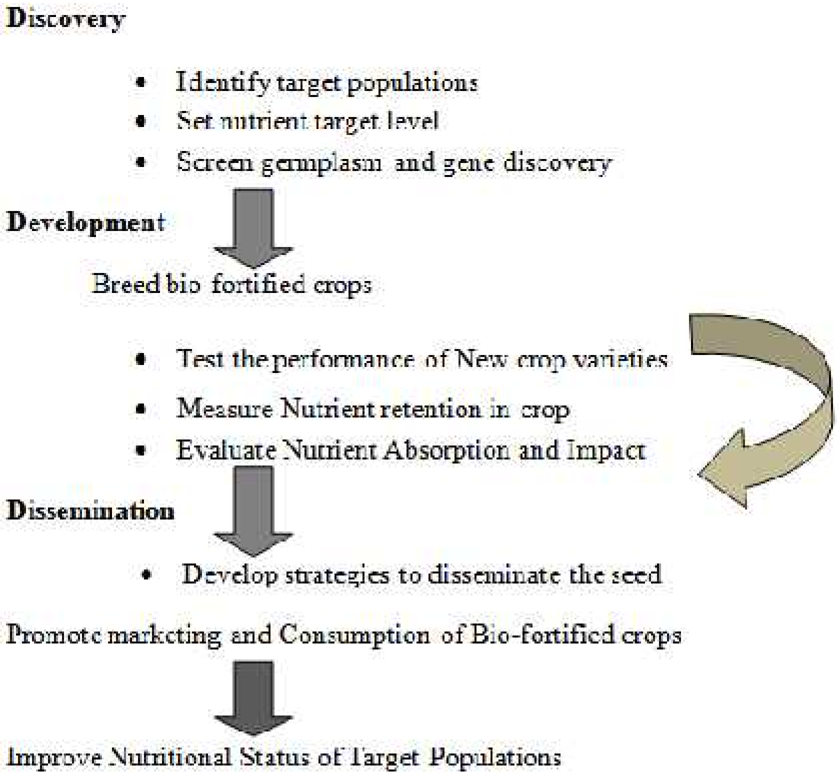


Fig. 5. Simplified diagram of the pathway for bio-fortified crops (Source: Harvestplus, 2009)

CONVENTIONAL BREEDING TO BIOFORTIFY STAPLE FOOD CROPS

The main goal of plant breeders to biofortify staple food crops is to increase the micronutrient level in the edible product of a staple food crop. The fortified food have efficacy on improving the nutritional health of individuals at high risk of developing micronutrient malnutrition. Mineral nutrition absorbed from soil by root systems, translocation, remobilization in vegetative parts of plants and deposited in the grain may be controlled by numerous genes in plant cell.

Table 3. Variation in Fe and Zn concentrations and correlation coefficients between Fe, Zn concentrations and others traits in wheat grain (Source: Xu et al., 2010)

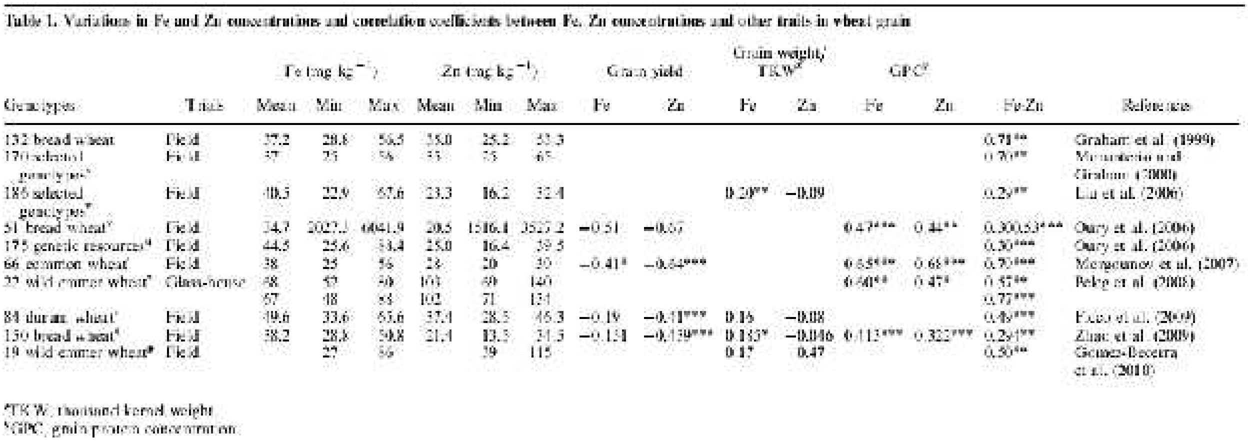


Table 1. Variations in Fe and Zn concentrations and correlation coefficients between Fe, Zn concentrations and other traits in wheat grain

		Fe (mg kg^{-1})			Zn (mg kg^{-1})			Grain yield		Grain weight/ TKW^{a}		GPC^{b}			
Genotypes	Trials	Mean	Min	Max	Mean	Min	Max	Fe	Zn	Fe	Zn	Fe	Zn	Fe-Zn	References
132 bread wheat	Field	37.2	28.8	56.5	35.0	25.2	53.3							0.71**	Graham et al. (1999)
170 selected genotypes^{a}	Field	37	25	56	35	25	65							0.70**	Monasterio and Graham (2000)
185 selected genotypes^{b}	Field	40.5	22.9	67.6	23.3	16.2	32.4			0.20**	−0.09			0.29**	Liu et al. (2006)
51 bread wheat^{c}	Field	34.7	2027.3	4041.9	20.5	1516.4	3527.2	−0.51	−0.67			0.47***	0.44**	0.300.53***	Oury et al. (2006)
175 genetic resources^{d}	Field	44.5	25.6	83.4	25.0	16.4	39.5							0.30***	Oury et al. (2006)
66 common wheat^{e}	Field	38	25	56	28	20	30	−0.41*	−0.64***			0.65***	0.65***	0.70***	Morgounov et al. (2007)
22 wild emmer wheat^{f}	Glass-house	68 67	52 48	90 88	103 102	69 71	140 134					0.60**	0.47*	0.57** 0.77***	Peleg et al. (2008)
84 durum wheat^{c}	Field	49.6	33.6	65.6	37.4	28.5	46.3	−0.19	−0.41***	0.16	−0.08			0.49***	Ficco et al. (2009)
150 bread wheat^{g}	Field	38.2	28.8	50.8	21.4	13.5	34.5	−0.131	−0.139***	0.185*	−0.046	0.113***	0.322***	0.294**	Zhao et al. (2009)
19 wild emmer wheat^{h}	Field		27	86		39	115			0.17	0.47			0.50**	Gomez-Becerra et al. (2010)

^{a}TKW, thousand kernel weight

^{b}GPC, grain protein concentration

Further, phenotypic expression is controlled by environmental factors and cultural practices can interact with plant-gene expression to influence the amount of a micronutrient accumulated in a seed or storage organ (Hotz *et al.*, 2007; Ortiz-Monasterio *et al.*, 2007). A number of studies detected that there was a significant positive correlations between grain Fe, Zn and protein concentration and genotype environmental interactions (Table 3). Thus it is clear that some genetic factors controlled the higher Fe, Zn, and grain protein concentration traits in grain and vegetative parts, simultaneously can be improved by breeding strategies (Welch and Graham 2004).

After addressing these issues, the HarvestPlus program has set needed levels for Fe, Zn, and provitamin A carotenoids in target crops. Table 4 list these target levels and assumptions used to set levels for target populations in the developing world (Bouis *et al.*, 2009). These target levels are very conservative estimates and are estimates and will be changed if deemed necessary as new data and information merits adjustment.

Table 4. Information and assumptions used to set target levels for micronutrient content of biofortified staple food crops (Source: Bouis and Walch, 2010)

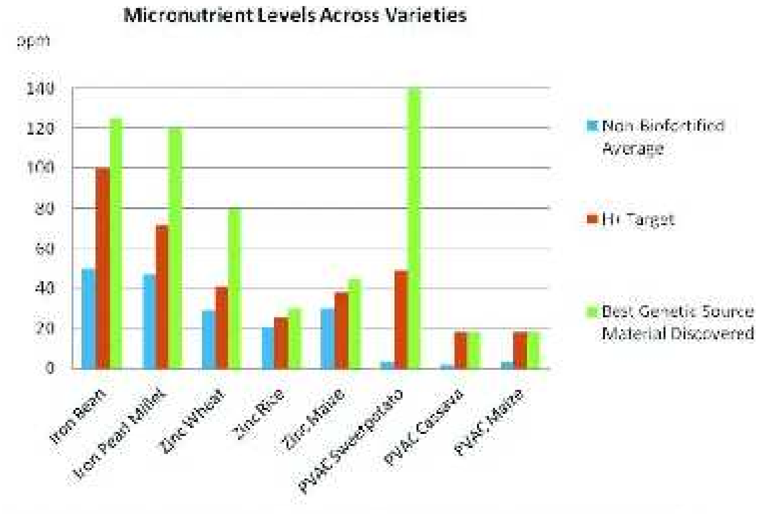
Amount eaten or nutrient	Criteria	Rice (polished)	Wheat (whole)	Pearl millet (whole)	Beans (whole)	Maize (whole)	Cassava (fresh wt.)	Sweet potato (fresh wt.)
Per capita consumption	Adult women (g/d)	400	400	300	200	400	400	200
	Children 4–6 yr (g/d)	200	200	150	100	200	200	100
Fe	Micronutrient retention after processing (%)	90	90	90	85	90	90	90
	Bioavailability (%)	10	5	5	5	5	10	10
	Baseline micronutrient content (µg/g)	2	30	47	50	30	4	6
	Additional content required (µg/g)	11	22	30	44	22	11	22
	Final target content (µg/g)	13	52	77	94	52	15	28
Zn	Micronutrient retention after processing (%)	90	90	90	90	90	90	90
	Bioavailability (%)	25	25	25	25	25	25	25
	Baseline micronutrient content (µg/g)	16	25	47	32	25	4	6
	Additional content required (µg/g)	8	8	11	17	8	8	17
	Final target content (µg/g)	24	33	58	49	33	12	23
Provitamin A	Micronutrient retention after processing	50	50	50	50	50	50	50
	Bioavailability ratio (µg:RE)	12:1	12:1	12:1	12:1	12:1	12:1	12:1
	Baseline micronutrient content (µg/g)	0	0	0	0	0	1	2
	Additional content required (µg/g)	15	15	20	30	15	15	30
	Final target content (µg/g)	15	15	20	30	15	16	32

Figure 6 and Table 5 summarize the progress being made in the HarvestPlus program to develop biofortified crops. Once high-yielding biofortified crop cultivars are developed that meet target nutrient levels, they will be disseminated widely (Bouis, 2011). HarvestPlus will disseminate the biofortified seeds through established partnerships with country agencies for delivering biofortified seeds to farmers and, ultimately, to the consumer. The HarvestPlus program will do this in several stages. First, include national agricultural research and extension programs to multiply the seeds and multilocation trials of the biofortified lines to determine environmental × genetic interactions on expression of the high-micronutrient traits in the biofortified crops. Promising selected lines will be formally submitted to the Varietal Release Committees for further testing and, once approved, will be officially released within the target country.

Table 5. Breeding progress as of 2007–2008 (iron, zinc, provitamin A expressed as percent of breeding target in lines at indicated stage of breeding) (Source: Bouis and Walch, 2010)

	Screening	**Crop improvement**			**G × E testing**	**Launch**
Crop	Screening gene/trait identification validation	Early development parent building	Intermediate product development	Final product development	Performance G × E testing in target countries	Release prelaunch seed multiplication
Sweet potato			NARS Uganda Program		Introduction	NARS Uganda
Breeding	Provitamin A	100% target	100%	100%	100%	100%
Fast-track	Uganda, Mozambique				100%	100%
Maize						
Breeding	Provitamin A	100% target	60%	50%	NA	
Cassava						
Breeding	Provitamin A	100% target	>75%	>75%	50%	≥30%
Fast-track	Democratic Republic of Congo					NA
Bean						
Breeding	Fe	100% target	60%	40–50%	40–50%	
Fast-track	Rwanda					40–50%
Rice, polished						
Breeding	Zn	100% target	100%	75–100%	75–100%	≥30%
Wheat						
Breeding	Zn	100% target	100%	≥30%	≥30%	
Pearl millet						
Breeding	Fe	100% target	100%	75–100%	50–75%	

To facilitate seed dissemination establish market chain, production capacity for seed increases, consumer acceptance studies, and development of a favorable policy environment for the production of biofortified crops will also be required for successful and sustainable implementation of the biofortification strategy.



Note: PVAC in sweetpotato is estimated to exceed scale and is estimated at over 300 µg/g.

Figure 6. Micronutrient content of staple crops (Source: Graham et al., 2007)

PROMOTER SUBSTANCES

Dietary substances that promote/enhance the bioavailability of micronutrients in the presence of antinutrients are also known whose levels are controlled by genes but also influenced by environmental factors (Table 6). Therefore, it is highly recommended that plant breeders and molecular biologists closely scrutinize the strategy of increasing promoter substances in food crops when attempting to improve food crops as sources of micronutrients for people (Gaham *et al.*, 2015; Welch and Graham, 2004).

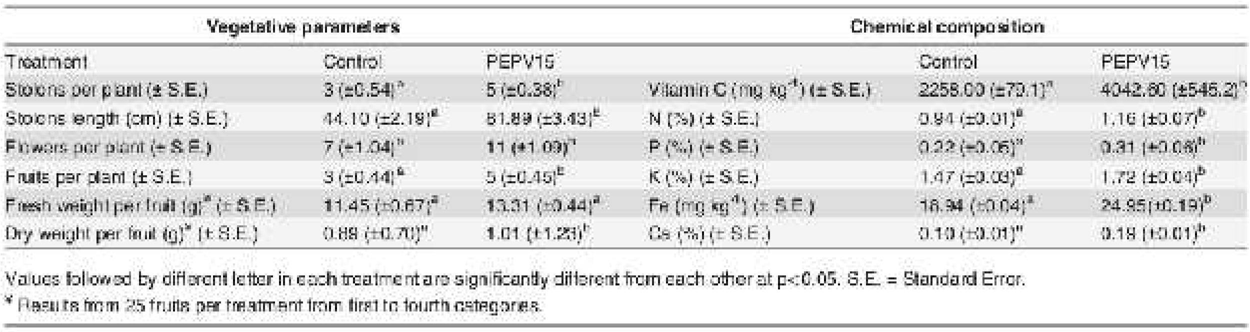
Table 6. Examples of substances in foods reported to promote Fe and Zn bioavailability and examples of major dietary sources (modified from Graham *et al.*, 2015)

Substance	Trace element	Major dietary sources
Certain organic acids (e.g., ascorbic acid, fumarate, malate, citrate)	Fe and/or Zn	Fresh fruits and vegetables
Se	I	Seafoods, tropical nuts
β-carotene	Fe	Green and orange vegetables
Inulin and other nondigestible carbohydrates (prebiotics)	Fe, Zn	Chicory (*Cichorium intybus* L.), garlic (*Allium sativum* L.), onion (*Allium cepa* L.), wheat, Jerusalem artichoke (*Helianthus tuberosus* L.)

PREBIOTICS AS PROMOTERS OF MICRONUTRIENTS

It is well-known that Fe promoter and antioxidant ascorbate could be increased in staple crops, although it is not stable because it can be oxidized to dehydroascorbate and lost during storage and food preparation (Combs, 2014). The strain PEPV15 has significantly increased number of plant growth related parameters of strawberry. The strain PEPV15 significantly increased the yield in stolons, flowers and fruits of the strawberry indicating, act as a good plant probiotic. The plant treated with the strain PEPV15 showed significantly higher content of N, P, K, Fe, Ca and Vit-c content in fruit as compared to control (Table 7). Thus, it can concluded that strain PEPV15 increased not only the yield of strawberry plants but also the quality of their fruits.

Table 7: Results from greenhouse experiment using *phyllobacterium* as plant probiotics in strawberry plants (Source: Flores-Félix et al., 2015)



Vegetative parameters			Chemical composition		
Treatment	Control	PEPV15		Control	PEPV15
Stolons per plant (± S.E.)	3 (±0.54)^a	5 (±0.38)^b	Vitamin C (mg kg^{-1}) (± S.E.)	2258.00 (±70.1)^a	4042.80 (±546.2)^b
Stolons length (cm) (± S.E.)	44.10 (±2.19)^a	81.89 (±3.43)^b	N (%) (± S.E.)	0.94 (±0.01)^a	1.16 (±0.07)^b
Flowers per plant (± S.E.)	7 (±1.04)^a	11 (±1.09)^b	P (%) (± S.E.)	0.22 (±0.06)^a	0.31 (±0.08)^b
Fruits per plant (± S.E.)	3 (±0.44)^a	5 (±0.45)^b	K (%) (± S.E.)	1.47 (±0.03)^a	1.72 (±0.04)^b
Fresh weight per fruit (g)* (± S.E.)	11.45 (±0.67)^a	13.31 (±0.44)^a	Fe (mg kg^{-1}) (± S.E.)	16.94 (±0.04)^a	24.95(±0.19)^b
Dry weight per fruit (g)* (± S.E.)	0.89 (±0.70)^a	1.01 (±1.23)^b	Ca (%) (± S.E.)	0.10 (±0.01)^a	0.18 (±0.01)^b

Values followed by different letter in each treatment are significantly different from each other at $p<0.05$. S.E. = Standard Error.
* Results from 25 fruits per treatment from first to fourth categories.

THE SHORT AND LONG-TERM ACHIEVABLE GOALS

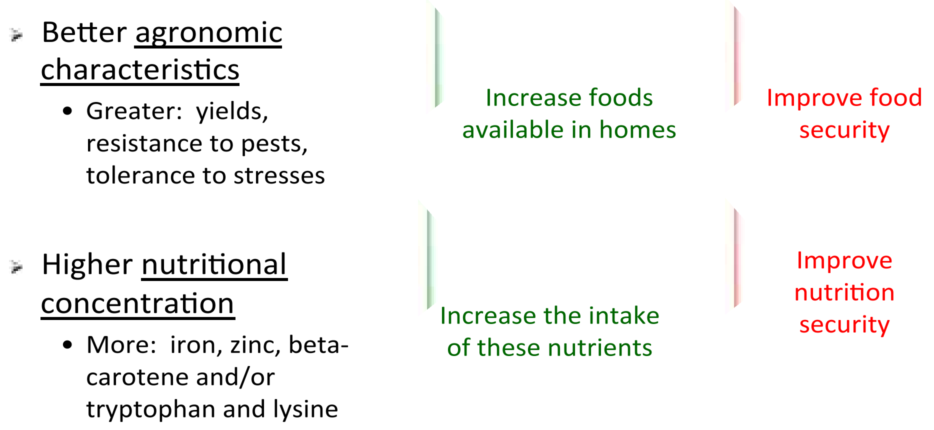
HarvestPlus's experience in the dissemination of biofortified crops is limited to provitamin enrich orange sweet potato (*Ipomoea batatas* L.). A pilot study in Mozambique showed that (i) behavior can be changed among farmers by switching from production of white to orange cultivars, and change the food habit by their families; and that (ii) vitamin A deficiency can be improved (Low *et al.*, 2007). As a result, vitamin A deficiency among preschool children in treatment villages declined from 60 to 38%, while vitamin A deficiency remained constant in control villages. The main target of HarvestPlus is to identifying low-cost activities and messages that will effect similar type of food habit change. Given progress to date, HarvestPlus can now anticipate release dates for the biofortified products (Table 8).

Table 8. Schedule of product release for biofortified products (Source: Mulualem, 2015)

Crop	Nutrient	Countries of first release	Agronomic trait	Release year
Sweet potato	Provitamin A	Uganda, Mozambique	High yielding, virus resistance, drought tolerance	2007
Bean	Fe, Zn	Rwanda, Democratic Republic of Congo	Virus resistance, heat and drought tolerance	2010
Pearl millet	Fe, Zn	India	Mildew resistance, drought tolerance	2011
Cassava	Provitamin A	Nigeria, Democratic Republic of Congo	High yielding, virus resistance	2011–2012
Maize	Provitamin A	Zambia	High yielding, disease resistance, drought tolerance	2011–2012
Rice	Zn, Fe	Bangladesh, India	Disease and pest resistance, submergence tolerance	2012–2013
Wheat	Zn, Fe	India, Pakistan	Disease resistance, lodging	2012–2013

How Biofortified Crops Improve Food and Nutrition Security-

Compared with conventional (non-biofortified crops), biofortified crops have-



- Better agronomic characteristics
  - Greater: yields, resistance to pests, tolerance to stresses

Increase foods available in homes

Improve food security

- Higher nutritional concentration
  - More: iron, zinc, beta-carotene and/or tryptophan and lysine

Increase the intake of these nutrients

Improve nutrition security

HOW TO INCREASE PUBLIC PARTICIPATION IN BIOFORTIFICATION PROGRAM-

There are several ways to transfer the biofortification program to the underprivilage people like (i) a donar-based long-term program implementation, and (ii) public participatory establisment of CGIAR Centers. However, All of the decision must be highly participatory decision-making process, the decision was approved by a large majority. Time has proven that this was a good decision.

Chapter IV

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSION

Based on the aforesaid discussion it has been concluded that-

- Bio-fortification enrich mineral nutrition content of the edible portions of new crop varieties in addition to yield and other agronomic characteristics
- Both short-term and long-term biofortification of staple crops through agronomic management and genetic modification can intentified grain nutrition enrichment, helps solving malnutrition on a global scale.
- Success of the biofortification program depends on the dessimination policy of fortified seeds and germplasms as well as national and international funding for micronutrient issues.
- Improving the nutritional status of malnourished populations throughout the world, bio-fortification becomes a promising agriculturally based strategy. Therefore, major resources should be allocated to bio-fortification programs.

RECOMMENDATIONS

- Interdisciplinary communication between agricultural and human nutrition Scientists’ must be prerequisite for sustainable biofortification program.
- Plant breeders to be aware of both the major influence on nutrient utilizations and improvement of nutrients for sustainability of fortified varieties.

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