We are IntechOpen, the world's leading publisher of Open Access books
Built by scientists, for scientists

6,600
Open access books available

177,000
International authors and editors

195M
Downloads

154
Countries delivered to

Our authors are among the
TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Chapter

Perspective Chapter: Crop Biofortification – A Key Determinant towards Fighting Micronutrient Malnutrition in Northern Ghana

Addison Baajen Konlan, Isaac Assumang and Vincent Abe-Inge

Abstract

Globally, more than 2 billion people suffer from iron (Fe), zinc (Zn), calcium (Ca), and other micronutrient deficiencies. In Sub-Saharan Africa, these micronutrient deficiencies are responsible for 1.5–12% of the total Disability Adjusted Life Years (DALYs). Ironically, these deficiencies often lead to invisible health conditions thus not often recognized in most low- and middle-income countries in terms of nutrition interventions to curb this anomaly. Therefore, there are alarming levels of iron deficiency in some Sub-Saharan countries like Ghana, which affects more than half of the female population. In the Northern part of Ghana, where the level of micronutrient malnutrition is high, some common staples including maize, millet, rice, and beans contain very low amounts of micronutrient. Biofortification is a novel nutrition-specific intervention that has proven to be an effective way to supply these micronutrients through the staples available whiles reducing the cases of micronutrient deficiency. This review aims to assess the potential role of biofortification in the prevention of micronutrient malnutrition in Northern Ghana. A thorough search of available data on the topic was conducted using Google Scholar, PUBMED, and ScienceDirect. Articles were accepted for review after thorough screening. Biofortification was found to have an effective potential in preventing micronutrient malnutrition in Northern Ghana. In conclusion, the incorporation of the three main types of biofortification in the Northern region of Ghana can enhance the production of food crops with adequate nutritional content that can improve the health status of the people in the region.

Keywords: micronutrient malnutrition, biofortification, Northern Ghana, nutrient-sensitive, nutrient-specific

1. Introduction

Malnutrition remains a big challenge in most developing countries most especially, in Sub-Saharan Africa (SSA) with children most affected. Fifty percent of all childhood deaths worldwide occur because of this challenge [1]. Globally, more than 2 billion people, representing one-third of the world population, are deficient in one or more mineral elements [2, 3]. The problem is very serious in low and middle-income countries, especially in Africa where the approximated risk for micronutrient deficiency is high for Ca (54% of the continental population), Zn (40%), Se (28%), I (19%) and Fe (5%) [4]. Lack of micronutrients in one's diet can lead to dire but often-invisible health problems, especially among women and young children [5]: this is often referred to as micronutrient malnutrition or 'hidden hunger. Hidden hunger hinders children and adolescents' mental and physical development and can lead to lower intelligent quotient (IQ), stunting, and blindness; women and children are the most affected [6]. In countries like DR Congo, Ghana, Mali, Senegal, and Togo, there are alarming numbers of iron deficiency anemia (IDA), which affects more than half of the female population [5].

In the past few years, Ghana has made significant progress in fighting malnutrition. Among few other Sub-Saharan African countries, they achieved their millennium development goals (MDGs) targets on stunting, wasting, and underweight in 2015 [7]. Nevertheless, they are yet to achieve their main target of bridging the nutritional and socioeconomic gaps between the Northern and Southern parts of Ghana, where the rate of malnutrition continues to be a challenge [8].

In Ghana's Northern, Upper East, and Upper West regions, malnutrition remains a major challenge. Based on statistics, children between the ages of 0–59 months in the three regions, found 18.4% of them being underweight, 11% having wasting, and 36.1% being stunted, as of 2012 [8, 9]. Meanwhile, nationally, based on statistics, 11% are underweight, 19% stunting, 5% wasting respectively [10]. Furthermore, the 2016 UN Global Nutrition report indicated that over $2.6 billion is lost annually in Ghana due to poor nutrition in children.

Vitamin A deficiency affects about 20% of children in Ghana with a higher prevalence in Ghana's Northern belt (31%) and lowers among children living in wealthier households (9%) [10].

Furthermore, according to the 2017 Ghana Micronutrient Survey, anemia was markedly high in the Northern belt (53.2%) compared to the middle (28.2%) and southern (32.3%) belts. A similar disparity was seen with iron deficiency and IDA as the prevalence in the Northern belt was significantly higher than in the other belts of Ghana [10]. According to [10], IDA was approximately 30% in the northern belt and below 8% in the middle and southern belts. Another data from [10] recorded that, 35% of anemic children had a severe iron deficiency, which is quite above the 28% estimate in a meta-analysis for Sub-Saharan African countries. This implies that Iron deficiency continually increases the rate of anemia among children in Ghana.

In a cross-sectional study that was conducted by [11, 12], 500 healthy blood donors were carefully chosen from three topographically varied regions in Ghana. They ranged in age from 17 to 55 years. They were 27.97 and 8.87 years old on average. The overall vitamin D deficiency rate was 43.6%. However, 41.2% , 45.3%, and 45.7% were discovered to be vitamin D deficient in the Northern, Middle, and Southern Sectors, respectively.

For the past years, several traditional interventions of reducing micronutrient malnutrition in Ghana, and most especially, in the Northern part of Ghana have been performed. They are iron-folic acid supplementation, vitamin A supplementation, fortification of flour and oil, complementary feeding, and exclusive breastfeeding [1]. The majority of these methods have principally reduced the morbidity and mortality of micronutrient malnutrition worldwide [13]. Nonetheless, these intervention strategies require more infrastructure, purchasing power, or access to markets and

DOI: http://dx.doi.org/10.5772/intechopen.104460

healthcare systems for their triumph [13]. It is often not available to people living in remote rural areas because of inconsistency in funding. Beyond doubt, money spent on these interventions is money well spent, both intervention strategies depend on uninterrupted funding. However, in some instances, funding can change, making it difficult to control micronutrient malnutrition. In the Northern part of Ghana, most diets are often low in diversity and dominated by staple crops such as maize, rice, cassava, sorghum, millet, and sweet potato. Such diets have an insufficient amount of micronutrients (minerals and vitamins) and hence leading to the increase in micronutrient deficiencies when consumed [14].

Micronutrient malnutrition, also known as 'hidden hunger, can be assuaged by direct (nutrition-specific) and indirect (nutrition-sensitive) intermediacies [15]. Nutrition-specific interventions center on consumption behavior and include dietary diversification, micronutrient supplementation, modification of food choices, and fortification. These interventions are effective, but not too sustainable in most rural communities in Ghana because of low funding. In Northern Ghana, such interventions have not reached a higher percentage of most malnourished people in rural communities. Indirect interventions address the underlying determinants of malnutrition, which include biofortification. Biofortification is a novel intervention in preventing micronutrient malnutrition. It involves the process of escalating the content and/or bioavailability of important nutrients in crops during plant maturation through genetic and agronomic pathways [16]. Genetic biofortification entails either genetic engineering or classical breeding whereas agronomic biofortification involves the proper application of micronutrient-rich fertilizer to the soil or unto the leaves through foliar means [17]. Biofortification targets starchy staple crops with low micronutrient content, such as rice, wheat, maize, sorghum, millet, sweet potato, and legumes. The reason for this is that they dominate diets around the world—particularly among the rural poor in developing and underdeveloped countries—and provide an affordable way to reach malnourished populations [17].

Biofortification has the potential of improving the nutritional content of the staple foods (maize, millet, rice, legumes) poor people in Northern Ghana consume, providing a comparatively inexpensive, cost-effective, sustainable, extended means of giving more micronutrients to the rural poor, especially in northern Ghana. This approach not only will lower the number of severely malnourished people who require treatment by complementary interventions, but also will help them maintain improved nutritional levels [16]. Biofortified crops are vital since they may serve as a nutritional buffer during economic shocks because the poor normally reduce their intake of higher-value food commodities when economic challenges occur [18]. Hence, the poor in Northern Ghana, who suffer from economic drought, are

Micronutrient	Rate of deficiency (%)
Ca	54
Zn	40
Se	28
I	19
Fe	5

Table 1.
Table indicating the rate of deficiency of essential micronutrients like Ca, Zn, Se, I, and Fe in Africa [4].

	Northern belt	Southern belt	Middle belt
Rate of anaemia (%)	53.2	28.2	32.3
IDA (%)	30	<8	<8

Table 2.
Table indicating the rate of anemia and IDA in the Northern, Middle, and Southern belts of Ghana [10].

	Stunting (%)	Overweight (%)	Wasting (%)
Upper east	36.1	18.4	11
Upper west	36.1	18.4	11
Northern	36.1	18.4	11

Table 3.
Table representing the rate of malnutrition among 0–59 months old children in the three Northern Regions of Ghana using stunting, overweight, and wasting as indicators [8, 9].

protected against severe micronutrient malnutrition. Biofortification moreover, gives a practical means of extending to malnourished rural populations in Northern Ghana, who may have limited access to commercially merchandised fortified foods and supplements. Most rural populations in Northern Ghana cannot afford to consume fortified foods and supplements, hence the need for the cultivation of biofortified crops. Compared to other micronutrient malnutrition interventions like food fortification, iron supplementation, among others, biofortification is highly cost-effective and very sustainable [19]. Nutritional targets for biofortification include elevated mineral content, improved vitamin content, increased essential amino acid levels, improved fatty acid composition, and increased antioxidant levels in crops [20].

Therefore, the primary goal of this systematic review is to discuss the three basic forms of biofortification, their significance, and how each type is capable of contributing to the prevention of micronutrient deficiency in the northern part of Ghana. This study will also suggest possible measures that need to be put in place to ensure the effective application of biofortification towards preventing micronutrient malnutrition in northern Ghana (**Tables 1–3**).

2. Types of biofortification

2.1 Biofortification through transgenic means

This strategy typically relies on simple access to a large genetic pool for the movement and expression of desired genes across two plant types that are not related to each other in terms of evolutionary or taxonomic standing [21]. When some micronutrients are lacking in crops, transgenic approaches is an effective way of fortifying the crop with those nutrients [22]. Transgenic approaches include genes that increase micronutrient concentration and bioavailability while decreasing anti-nutrient concentration, which reduces plant nutrient bioavailability.

Developing biofortified crops through the transgenic method requires a significant amount of time, effort, and investment during the research and development stage, but it is a cost-effective and sustainable approach in the long run, unlike nutrition-based organizational and agronomic biofortification programs [22–24]. Transgenic developed crops with enhanced micronutrient contents are capable of reducing micronutrient malnutrition among their consumers, most specifically, poor people in developing countries. In Northern Ghana, this method of biofortification has the potential to reduce micronutrient malnutrition.

Ever since the introduction of genetically modified (GM) crops in Ghana in 2013, there have been several debates regarding the health implications of these crops. Some advocacy groups in Ghana kicked against its introduction and they argue that GM food is not conducive to good health. Proponents also argue that GM crops, engineered to resist common pests, increase yield, and hence lead to rising incomes for farmers and the country in general.

In Northern Ghana, there is little knowledge about the advantages of GM seeds. Because of the counter debates on GM crops, most rural farmers have the perception that it is unhealthy for consumption. Some groups, such as The National Seed Trade Association of Ghana (NASTAG), are outspoken supporters of the use of GM seeds in Ghana. They hope it will boost agricultural development and help offset the consequences of climate change [25]. According to them, the incorporation of GM seeds in West Africa will help reduce the number of pesticides and time it takes for farmers to spray, which is proven scientifically to be true [26].

There is a need for more education and advocacy in Northern Ghana on the benefits of GM crops. Farmers should be given education about GM crops and their advantages. A couple of advances has been made in transgenic biofortification. The development of transgenic rice, maize, wheat, potatoes, beans among others have helped reduce the rate of micronutrient malnutrition in many underdeveloped communities. In northern Ghana, since most of their staple crops are maize, millet, beans, and potatoes, the use of transgenic maize, beans, millet, and potatoes rich in iron, vitamin a, zinc and other essential micronutrients will help in the fight against micronutrient malnutrition.

2.1.1 Transgenic maize

Maize is one of the most important staple crops grown in Northern Ghana. Just like other staple crops, maize contains very little amount of vitamin. However, provitamin A (carotenoid) is present in its endosperm due to the production of bacterial crtB [27] and several carotenogenic genes [28, 29]. Vitamin E and its synthetic analogs are powerful antioxidants with good effects on human health, and several research organizations are focusing biofortification of these constituents in maize. The iron content of maize has been increased by expressing soybean ferritin and Aspergillus phytase [29], soybean ferritin [30], Aspergillus Niger phyA2 [31], as well as inhibiting the expression of the ATP-binding cassette transporter and the multidrug resistance-associated protein [32]. A notable example is the BVLA4 30101 cultivar, which was released by Origin Agritech China and is biofortified transgenically for phytate decomposition. Maize's amino acid balance has been improved by the presence of milk protein-lactalbumin [33].

2.1.2 Transgenic common beans

One of the most important grain legumes used for human consumption is the common bean. In northern Ghana, it is one of the common crops grown by farmers. Most people consume it in its whole form. The expression of methionine-rich storage albumin from Brazil nut has helped to increase the methionine content of common bean [34].

2.1.3 Transgenic sweet potato

The nutritional properties of sweet potato have further been enhanced transgenically by increasing the contents of carotene, lutein, and total carotenoids by overexpressing the orange IbOr-Ins gene in white-fleshed sweet potato [35].

2.2 Biofortification through agronomic means

This method involves the physical application of nutrients to temporarily improve the nutritional and health status of crops and consuming such crops improves the human nutritional status [36]. This method is very common among farmers in Ghana. For instance, in the Northern part of Ghana, most peasant farmers buy fertilizers that contain macronutrients like nitrogen (N), phosphorus (P), and potassium (K) and apply them to staple crops like maize, to improve the crop yield and its nutritional composition. Macrominerals like nitrogen, phosphorus, and potassium (NPK) contribute a lot to the attainment of higher crop yields [37]. Through the application of NPK-containing fertilizers, agricultural productivity increased in many countries around the world in the late 1960s, resulting in Green Revolution, and saving them from starvation [38]. These fertilizers are vital in improving crop yield and are capable of saving the human population from starvation.

Agronomic biofortification is simple and inexpensive but needs special attention in terms of source of nutrients, application method, and effects on the environment [21]. It must therefore be applied frequently in every season to ensure maximum yield of the crops.

Some soil that promotes the development of microorganisms is utilized to raise the nutritional quality of plants by improving nutrient mobility from soil to edible sections. Some soil microbes, including Bacillus, Pseudomonas, Rhizobium, and Azotobacter species, are utilized to boost the phytoavailability of mineral elements [39, 40]. Some examples of crops that have been targeted through agronomical biofortification to improve the human nutritional status include the following:

2.2.1 Rice

Rice staples usually contain a low amount of micronutrients like iron and zinc. One way that can help incorporate such micronutrients into rice staples is through rice agronomic biofortification. Biofortification of rice plants by foliar spray of iron was an effective way to promote iron concentration in rice grains [41–43]. Similarly, the fortification of germinating rice plantlets with ferrous sulfate increases the iron concentration in germinated brown rice up to 15.6 times more than the original [42]. The foliar application of zinc is a successful agronomic approach that increases the concentration and bioavailability of zinc in rice grains [43–49]. The effective use of these agronomic rice biofortification techniques in northern Ghana has the potential to reduce micronutrient deficiency, particularly in rural areas.

2.2.2 Maize

The role of zinc in obtaining nutrient-enriched and high-yield grains like maize cannot be overemphasized. To achieve this, various zinc fertilizer treatments and foliar applications have been carried out in the maize crop [50–53]. These methods have proven to be an effective way of increasing the nutritional content of staple maize crops. The use of maize crops with increased zinc content will help reduce zinc deficiency in northern Ghana.

2.2.3 Common bean

Beans are a good vehicle for zinc biofortification and have been enriched with zinc by the application of foliar zinc fertilizer [49, 54]. This method is an effective way of enriching common beans with zinc, however, because of the cost; most farmers in northern Ghana are not able to afford it.

There is therefore the need for government to leverage the above innovations to support rural farmers in Northern Ghana and beyond. Controlled application of agronomic biofortification in Northern Ghana will increase the nutrient density and crop yield of common staple crops like maize, millet, beans, sorghum, and rice.

2.2.4 Sweet potato

An increase in beta-carotene in orange-fleshed sweet potato has been observed with irrigation and chemical fertilizer treatments [55]. This is also a very effective method of reducing micronutrient malnutrition in northern Ghana. Several studies have been conducted in Ghana about orange-fleshed sweet potato and its effectiveness in reducing vitamin A deficiency. Therefore, building on available evidence to advocate the consumption of orange-fleshed sweet potato in northern Ghana will help fight chronic vitamin A deficiency.

2.3 Biofortification through breeding

Compared to transgenic and agronomic strategies, biofortification through breeding is more cost-effective and sustainable [21]. In conventional plant breeding, parent lines with high nutrients are crossed with recipient lines with desirable agronomic traits over several generations to produce plants with desired nutrient and agronomic traits [21]. Several organizations are working hard to reduce micronutrient malnutrition using biofortification through breeding. For example, HarvestPlus is investing heavily to boost three key nutrients-vitamin A, iron, and zinc and is targeting the staple crops, wheat, rice, maize, cassava, pearl millet, beans, and sweet potato in Asia and Africa. They are carrying out several projects to produce staple food crops with improved levels of bioavailable essential minerals and vitamins that will have a measurable impact on improving the micronutrient level of target populations, primarily resource-poor people in the developing world, just like in northern Ghana. Because of better acceptability, several staple crops have been targeted for biofortification through crop breeding. They include the following:

2.3.1 Rice breeding

Milled rice has a poor source of minerals and essential micronutrients. Different old rice varieties with a high amount of iron and zinc content in grain have been screened and the higher mineral trait has been combined with improved agronomic traits by breeding methods [21]. In Asia, countries like India, Indonesia, and Bangladesh cultivate zinc rice varieties. Among the Caribbean, Nicaragua, El Salvador and Colombia also cultivate Rice variety. The government of Ghana must therefore invest in rice breeding to help in the fight against micronutrient malnutrition.

2.3.2 Millet breeding

The cheapest source of iron and zinc is pearl millet [56] and large variation has been seen in its germplasm for these micronutrients [57]. Iron pearl millet is currently being tested in Ghana. The development of this variety has the potential of reducing Iron deficiency in Northern Ghana.

2.3.3 Maize breeding

Maize is a cash crop grown for animal feed, industrial purposes (source of sugar, oil, starch, and ethanol), and use for human consumption [21]. Maize is genetically diverse, and for that matter, it has been a basis for the breeding programs that have helped generate highly nutritious maize crops. The majority of farmers in northern Ghana grow maize. Proper education on maize breeding to these farmers will help in the fight against

	Iron pearl millet	Vitamin A cassava	Vitamin A maize	Vitamin A orange sweet potato
Ghana	Under testing	Released	Released	Released

Table 4.
Table indicating a variety of Biofortified crops released or under testing in Ghana, developed through breeding [58].

Figure 1.
Biofortified rice. Source: Passion in Food and Field (Wordpress.com).

Figure 2.
Vitamin A Biofortified maize. Source: Crop Trust.

'hidden hunger' in northern Ghana. Furthermore, the Government must invest in maize breeding in northern Ghana to help prevent micronutrient deficiency (**Table 4**).

Examples of biofortified crops that are commonly consumed in Northern Ghana (**Figures 1** and **2**).

3. Methodology

3.1 Search strategy

A thorough search of available data on the topic was conducted using GOOGLE SCHOLAR. Other articles were obtained from PUBMED and ScienceDirect. The year limit was from 2007 to 2021. This was done to identify the latest publications on the topic. However, two articles published in 1999 and one paper from 2003 were included because of their level of relevance to the topic. A manual search was also conducted in the reference list of relevant literature related to the main research topic. The search terms used include, "Biofortification" and "Malnutrition", "Micronutrient Deficiency" and "Ghana", "Biofortification" and "Africa", "Micronutrient Malnutrition" and "Northern Ghana", "Biofortification" and "Types", "Northern Ghana" and "Malnutrition"

3.2 Inclusion and exclusion criteria

Papers were excluded if they did not fall within the year range, 2007–2021 except for two important articles published in 1999 and one paper from 2003. Only papers published in the English language were considered for review. Much priority was given to articles published in developing and underdeveloped countries since such countries record higher cases of malnutrition globally, of which Ghana is an example. In addition, the study focused on common staple foods available in Northern Ghana, which can easily be biofortified with essential micronutrients. Staples were excluded if they are not commonly cultivated in Northern Ghana. All study designs qualified for inclusion and there was no discrimination on gender.

4. Results

4.1 Search results

Hundred papers were obtained from the electronic search. A Thorough search for duplicates was conducted to ensure papers were not represented twice. Forty-one duplicates were removed, leaving 59 papers. Twenty-four papers were removed after screening all titles and abstracts. After a thorough screening, 35 papers for accepted for review. Some of the articles were thesis publications, others were review papers and the remaining were research papers.

4.2 Data extraction

- Publication details (author, date of publication),
- Country
- Population

- Language
- Results

4.3 Main findings

It was discovered from the reviewed articles that, the rate of micronutrient malnutrition is quite high, most especially in developing and underdeveloped countries. Major micronutrients like iron, zinc, iodine, and vitamin A are deficient in most diets worldwide. Biofortification was found to be an innovative technology that is capable of fighting micronutrient malnutrition in most developing and underdeveloped countries. All the studies recorded that, there are three major types of biofortification, which include, transgenic, breeding, and agronomic biofortification. About five studies from the review recorded that, micronutrient malnutrition was highest in Northern Ghana (Northern, Upper East, and Upper West regions), compared to other regions in Ghana. One study compared the three types of biofortification and discovered that biofortification through breeding is more cost-effective and sustainable compared to agronomic and transgenic biofortification. Other studies recorded that, several misconceptions exist about the consumption of crops developed through the transgenic method. They have a bad perception of its health implications. Finally, from the review, it was discovered that, few crop research centers exist to study all three types and how they can help prevent micronutrient malnutrition in Northern Ghana.

5. Conclusion and recommendations

All three major types of biofortification have a great potential in contributing to the fight against malnutrition in Northern Ghana as they are applicable in improving the nutritional quality of millet, rice, maize, sweet potato, and common beans which are staples common in the region. To achieve this, there is a need for more crop research centers to be set up in this region to develop more improved varieties that can help improve the nutritional status of the indigenous people in the region. Again, more education on the benefits of biofortified crops should be done in the region to encourage a shift towards the production and consumption of these nutrient-rich varieties. More research on the health benefits of transgenic biofortified crops is needed to ensure effective application of the method towards fighting micronutrient malnutrition in Northern Ghana. Current data on micronutrient malnutrition in Northern Ghana is needed to ensure the effective implementation of governmental policies.

Authors' contribution

ABK developed the research concept, formulated the research outline and carried out the systematic review of the paper. IA carefully reviewed the abstract, introduction and conclusion of the review. VA carefully scrutinized all aspects of the research to check for mistakes and make corrections to the paper.

Funding information

The authors declare that no funding was given for this review.

Conflict of interest

There was no conflict of interest recorded in this review.

Author details

Addison Baajen Konlan[1*], Isaac Assumang[1] and Vincent Abe-Inge[2]

1 Department of Food Science and Technology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana

2 Department of Agriculture for Social Change, Regentropfen College of Applied Sciences, Namoo, UER, Ghana

*Address all correspondence to: konlanaddison6@gmail.com

IntechOpen

© 2022 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the Creative Commons Attribution License (http://creativecommons.org/licenses/by/3.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

References

[1] Briend A, Collins S, Golden M, Manary M, Myatt M. Maternal and child nutrition. The Lancet. 2013;**382**(9904): 1549

[2] Wakeel A, Farooq M, Bashir K, Ozturk L. Micronutrient Malnutrition and Biofortification: Recent Advances and Future Perspectives: Molecular and Genomic Perspectives in Crop Plants. Sciencedirect; 2018. pp. 225-243. DOI: 10.1016/B978-0-12-812104-7.00017-4

[3] Black R. Micronutrient deficiency - An underlying cause of morbidity and mortality. Bulletin of the World Health Organization. 2003;**81**(03808):79

[4] Joy EJM, Louise Ander E, Young SD, Black CR, Watts MJ, Chilimba ADC, et al.. Dietary mineral supplies in Africa. 2013. DOI: 10.1111/ppl.12144

[5] De Valença AW, Bake A, Brouwer ID, Giller KE. Agronomic biofortification of crops to fight hidden hunger in sub-Saharan Africa. Global Food Security. 2017;**12**:8-14. DOI:10.1016/j.gfs.2016.12.001

[6] Sharma P, Aggarwal P, Kaur A. Biofortification: A new approach to eradicate hidden hunger. Food Reviews International. 2017;**33**(1):1-21. DOI: 10.1080/87559129.2015.1137309

[7] International Food Policy Research Institute (IFPRI) Synopses. From promise to impact: Ending malnutrition by 2030 Global Nutrition Report. 2016

[8] Sienso G, Lyford C. Assessing the factors affecting malnutrition in Northern Ghana 2018;**8**(3). DOI: 10.4172/2161-0509.1000235

[9] Zereyesus YA, Ross KL, Amanor-Boadu V, Dalton TJ. Baseline feed the future indicators for Northern Ghana 2012. 2014. Pdfs.semanticscholar.org

[10] Ghana Statistical Service (GSS); Ghana Health Service (GHS); ICF international. Ghana Demographic and Health Survey. Rockville, Maryland, USA; 2014. Pdfs.semanticscholar.org

[11] Wegmüller R, Bentil H, Wirth JP, Petry N, Tanumihardjo SA, Allen L, et al. Anemia, micronutrient deficiencies, malaria, hemoglobinopathies and malnutrition in young children and non-pregnant women in Ghana: Findings from a national survey. PLoS One. 2020;**15**(1):e0228258. DOI: 10.1371/journal.pone.0228258

[12] Sakyi SA, Antwi MH, Fondjo LA, Laing EF, Dadzie Ephraim RK, Kwarteng A, et al. Vitamin D deficiency is common in Ghana despite abundance of sunlight: A multicentre comparative cross-sectional study. Journal of Nutrition and Metabolism. 2021;**2021**. DOI: 10.1155/2021/9987141

[13] Mayer JE, Pfeiffer WH, Beyer P. Biofortified crops to alleviate micronutrient malnutrition. Current Opinion in Plant Biology. 2008;**11**(2): 166-170. DOI: 10.1016/j.pbi.2008.01.007

[14] Thompson B, Amoroso L, editors. Combating Micronutrient Deficiencies: Food-Based Approaches. CABI; 2011

[15] Ruel MT, Alderman H. Nutrition-sensitive interventions and programs: How can they help to accelerate progress in improving maternal and child nutrition? (and the Maternal and Child Nutrition Study Group). Lancet. 2013;**382**:536-551. Available

from: http://refhub.elsevier.com/S2211-16)30048-sbref53

[16] Bouis HE, Hotz C, BMC, Meenakshi JV, Pfeiffer WH. Biofortification: A new tool to reduce micronutrient malnutrition. Food and Nutrition Bulletin. 2011 March;**32**(suppl. 1):31-40 The United Nations University

[17] Saltzman A, Birol E, Bouis HE, Boy E, De Moura FF, Islam Y, et al. Biofortification: Progress toward a more nourishing future. Global Food Security. 2013;**2**:9-17. Available from: eprints.crisis.ac.in; http://refhub.elsevier.com/S2211-16)30048-sbref54

[18] Qaim M, Stein AJ, Meenakshi J. Economics of biofortification. Agricultural Economics. 2007;**37**(s1): 119-133

[19] Meenakshi J, Johnson NL, Manyong VM, DeGroote H, Javelosa J, Yanggen DR, et al. How cost-effective is biofortification in combating micronutrient malnutrition? An ex-ante assessment. World Development. 2010;**38**(1):64-75

[20] Hirschi KD. Nutrient biofortification of food crops. Annual Review of Nutrition. 2009;**29**:401-421. DOI: 10.1146/annurev-nutr-080508-141143

[21] Garg M, Sharma N, Sharma S, Kapoor P, Kumar A, Chunduri V, et al. Biofortified crops generated by breeding, agronomy, and transgenic approaches are improving lives of millions of people around the world. Frontiers in Nutrition . Available from: http://www.ncbi.nlm.nih.gov/. 2018. DOI: 10.3389/fnut.2018.00012

[22] Perez-Massot E, Banakar R, Gomez-Galera S, Zorrilla-Lopez U, Sanahuja G, Arjo G, et al. The contribution of transgenic plants to better health through improved nutrition: Opportunities and constraints. Genes & Nutrition. 2013;**8**(1): 29-41. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1007/s12263-012-0315-5

[23] Hefferon KL. Can biofortified crops help attain food security? Current Molecular Biology Reports. 2016;**2**(4):180-185. DOI: 10.1007/s40610-016-0048-0

[24] White J, Broadley MR. Biofortifying crops with essential mineral elements. Trends in Plant Science. 2005;**10**:586-593. Available from: ndianfarmer.net. DOI: 10.1016/j.tplants.2005.10.001

[25] GMO technology can turn around Ghana's fortunes-seed producers. 2017. Available from: https://en.wikipedia.org/ [Accessed: December 22, 2017]

[26] Zegeye WA. A review on concerns and benefits of genetically modified organisms. 2014. ISSN: 2348-8069. Available from: https://en.wikipedia.org/

[27] Aluru M, Xu Y, Guo R, Wang Z, Li S, White W, et al. Generation of transgenic maize with enhanced provitamin A content. Journal of Experimental Botany. 2008;**59**(13):3551-3562. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1093/job/ern212

[28] Decourcelle M, Perez-Fons L, Baulande S, Steiger S, Couvelard L, Hem S, et al. Combined transcript, proteome, and metabolite analysis of transgenic maize seeds engineered for enhanced carotenoid synthesis reveals pleiotropic effects in core metabolism. Journal of Experimental Botany. 2015;**66**(11):3141-3150. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1093/job/erv120

[29] Zhu C, Naqvi S, Breitenbach J, Sandmann G, Christou P, Capell T. Combinatorial genetic transformation generates a library of metabolic phenotypes for the carotenoid pathway in maize. Proceedings of the National Academy of Sciences of the United States of America. 2008;**105**(47):18232-18237. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1073/pnas.0809737105

[30] Aluru MR, Rodermel SR, Reddy MB. Genetic modification of low phytic acid 1-1 maize to enhance iron content and bioavailability. Journal of Agricultural and Food Chemistry. 2011;**59**(24):12954-12962. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1021/jf203485a

[31] Chen R, Xue G, Chen P, Yao B, Yang W, Ma Q, et al. Transgenic maize plants expressing a fungal phytase gene. Transgenic Research. 2008;**17**(4):633-643. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1007/s11248-007-9138-3

[32] Shi J, Wang H, Schellin K, Li B, Faller M, Stoop JM, et al. Embryo-specific silencing of a transporter reduces phytic acid content of maize and soybean seeds. Nature Biotechnology. 2007;**25**(8):930-937. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1038/nbt1322

[33] Yang SH, Moran DL, Jia HW, Bicar EH, Lee M, Scott MP. Expriallyession of a synthetic porcine alpha-lactalbumin gene in the kernels of transgenic maize. Transgenic Research. 2002;**11**:11-20. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1023/A:1013996129125

[34] Aragao FJL, Barros LMG, De Sousa MV, Grossi de Sa MF, Almeida ERP, Gander ES, et al. Expression of methionine-rich storage albumin from Brazil nut (*Bertholletia excelsa* H.B.K., Lecythidaceae) in transgenic bean plants (*Phaseolus vulgaris* L., Fabaceae). Genetics and Molecular Biology. 1999;**22**(3):445-449. DOI: 10.1590/S1415-47571999000300026

[35] Kim SH, Kim YH, Ahn YO, Ahn MJ, Jeong JC, Lee HS, et al. Downregulation of the lycopene ε-cyclase gene increases carotenoid synthesis via the β-branch-s pathway and enhances salt-stress tolerance in sweet potato transgpecificenic calli. Physiologia Plantarum. 2013;**147**(4):432-442. DOI: 10.1111/j.1399-3054.2012.01688.x

[36] Cakmak I, Kutman UB. Agronomic biofortification of cereals with zinc: A review. European Journal of Soil Science. 2017;**69**:172-180. DOI: 10.1111/ejss.12437

[37] Erisman JW, Sutton MA, Galloway JN, Klimont Z, Winiwarter W. How a century of ammonia synthesis changed the world. Nature Geoscience. 2008;**1**:636-639. DOI: 10.1038/ngeo325

[38] Cakmak I. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification. Plant and Soil. 2008;**302**:1-17. DOI: 10.1007/s11104-008-9584-6

[39] Rengel Z, Batten GD, Crowley DE. Agronomic approaches for improving the micronutrient density in edible portions of field crops. Field Crops Research. 1999;**60**:27-40. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1016/S0378-4290(98)00131-2

[40] Smith SE, Read DJ. Mycorrhizal Symbiosis. 3rd ed. London, UK: Elsevier (2007)Retrieved 2017-12-22 http://www.ncbi.nlm.nih.gov/.

[41] He W, Shohag MJ, Wei Y, Feng Y, Yang X. Iron concentration, bioavailability, and nutritional quality of polished rice affected by different forms

of foliar iron fertilizer. Food Chemistry. 2013;**141**(4):4122-4126. DOI: 10.1016/j.foodchem.2013.07.005

[42] Yuan L, Wu L, Yang C, Quin LV. Effects of iron and zinc foliar applications on rice plants and their grain accumulation and grain nutritional quality. Journal of the Science of Food and Agriculture. 2013;**93**(2):254-261. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1002/jsfa.5749

[43] Fang Y, Wang L, Xin Z, Zhao L, An X, Hu Q. Effect of foliar application of zinc, selenium, and iron fertilizers on nutrients concentration and yield of rice grain in China. Journal of Agricultural and Food Chemistry. 2008;**6**(56):2079-2084. DOI: 10.1021/jf800150z

[44] Wei Y, Shohag MJ, Yang X. Biofortification and bioavailability of rice grain zinc are affected by different foliar zinc fertilizers. PLoS One. 2012;**7**(9):e45428. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1371/journal.pone.0045428

[45] Boonchuay P, Cakmak I, Rerkasem B, Prom-U-Thai C. Effect of different foliar zinc application at different growth stages on seed zinc concentration and its impact on seedling vigor in rice. Soil Science and Plant Nutrition. 2013;**59**(2):180-188. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1080/00380768.2013.763382

[46] Jiang W, Struik PC, Keulen HV, Zhao M, Jin LN, Stomph TJ. Does increased zinc uptake enhance grain zinc mass concentration in rice? Annals of Applied Biology. 2008;**153**(1):135-147. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1111/j.1744-7348.2008.00243.x

[47] Mabesa RL, Impa SM, Grewal D, SEJ B. Contrasting grain-Zn response of biofortification rice (*Oryza sativa* L.) breeding lines to foliar Zn application. Field Crops Research. 2013;**149**:223-233. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1016/j.fcr.2013. 05.012

[48] Shivay YS, Kumar D, Prasad R, IPS A. Rice's relative yield and zinc uptake from zinc sulfate and zinc oxide coatings onto urea. Nutrient Cycling in Agroecosystems. 2008;**80**(2):181-188. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1007/s10705-007-9131-5

[49] Ram H, Rashid A, Zhang W, Duarte AP, Phattarakul N, Simunji S, et al. Biofortification of wheat, rice, and common bean by applying foliar zinc fertilizer along with pesticides in seven countries. Plant and Soil. 2016;**1**(403):389-401. Available from: http://www.ncbi.nlm.nih.gov/. DOI: 10.1007/s11104-016-2815-3

[50] Alvarez JM, Rico MI. Effects of zinc complexes on the distribution of zinc in calcareous soil and zinc uptake by maize. Journal of Agricultural and Food Chemistry. 2003;**51**(19):5760-5767. DOI: 10.1021/jf030092m

[51] Fahad S, Hussain S, Saud S, Hassan S, Shan D, Chen Y, et al. Grain cadmium and zinc concentrations in maize influenced by genotypic variations and zinc fertilization. Clean—Soil, Air, Water. 2015;**43**(10):1433-1440. DOI: 10.1002/clen.201400376

[52] Wang J, Mao H, Zhao H, Huang D, Wang Z. Different increases in maize and wheat grain zinc concentrations caused by soil and foliar applications of zinc in Loess plateau, China. Field Crops Research. 2012;**135**:89-96. DOI: 10.1016/j.fcr.2012.07.010

[53] Zhang YQ, Pang LL, Yan P, Liu DY, Zhang W, Yost R, et al. Zinc fertilizer

placement affects zinc content in maize plant. Plant and Soil. 2013;**372**:81-92. DOI: 10.1007/s11104-013-1904-9

[54] Ibrahim EA, Ramadan WA. Effect of zinc foliar spray alone and combined with humic acid or/and chitosan on growth, nutrient elements content, and yield of dry bean (*Phaseolus vulgaris* L.) plants sown at different dates. Scientia Horticulturae. 2015;**184**:101-115. DOI: 10.1016/j.scienta.2014.11.010

[55] Laurie SM, Faber M, Van Jaarsveld PJ, Laurie RN, Du Plooy CP, Modisane PC. β-Carotene yield and productivity of orange-fleshed sweet potato (*Ipomoea batatas* L. Lam.) as influenced by irrigation and fertilizer application treatments. Scientia Horticulturae. 2012;**142**:180-184. DOI: 10.1016/j.scienta.2012.05.017

[56] Rao PP, Birthal PS, Reddy BVS, Rai KN, Ramesh S. Diagnostics of Sorghum and pearl millet grain-based nutrition in India. International Sorghum and Millets Newsletter. 2006;**47**:93-96

[57] Velu G, Rai KN, Muralidharan V, Kulkarni VN, Longvah T, Raveendran TS. Prospects of breeding biofortified pearl millet with high grain iron and zinc content. Plant Breeding. 2007;**126**:182-185. DOI: 10.1111/j.1439-0523.2007.01322.x

[58] HarvestPlus 2020. Biofortified Crop Varieties Released or in Testing by Country. HarvestPlus, International Potato Center; 2020

IntechOpen