



Staple Crops Biofortification Linking Agriculture, Food and Nutrition towards Eliminating Hidden Hunger

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Agriculture is the mainstay of most of people globally. Despite the fact that agriculture has been a traditionally food and nutrition source, people go to bed without food and suffer from malnutrition even within the same households. Similarly, hunger and hidden hunger remains a worldwide widespread challenge. In response, researchers have tried to enhance micronutrients through staple food crops biofortification. The promotion of biofortified crops and unintended narrowed food choices might have been the underlying factor for the coexisting forms of malnutrition: undernutrition, obesity and increased incidence of non-communicable diseases; a malnutrition double burden problem. Therefore, this paper provides views to rethinking critically in order to take steps towards integrating nutrition education in modern agriculture crop biofortification programs more effectively.

Keywords: Agriculture; biofortification; food security; hidden hunger; minerals; nutrition; vitamins.

1. INTRODUCTION

Agriculture is the mainstay of most of people globally, and especially crucial in rural areas where the majority poor and vulnerable

population live [1]. Agriculture, not only provides food and nutrition to support human life, but also constitutes a major source of income to many people around the world [1–3]. Moreover, agriculture determines food availability and

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access, affects food price as well as community health and nutrition status. According to Food and Agriculture Organization [4] about 815 million people are chronically hungry and go to bed without food. Recently, hunger has increased from 777 to 815 million people in 2015 and 2017, respectively [4]. At the same time, micronutrient deficiencies have become a global burden, as every third person is malnourished, reflecting agriculture, food and nutrition systems out of balance [5,6].

The global hidden hunger statistics in 2016, indicated 11% of the population being undernourished, 22.9% children stunted and 33% women at reproductive were anemic [5]. The situation is worsening in sub-Saharan Africa, South-eastern and Western Asia [4]. Whereas, sub-Saharan Africa account for 90% of the burden with 40% stunting, 50% vitamin A deficiency and 30% anemia among pre-school children [7,8]. Micronutrient deficiencies are mainly due to limited access to food rich in vitamins and minerals in the diet, important to support human health [9]. Hidden hunger is the collective term that describes a condition of undernutrition where the body lack vitamins and minerals that keep people healthy [8]. Micronutrients of public health concern includes; iron, zinc, iodine, vitamin A and B9 among others [10]. Consequences of micronutrients deficiencies to human health ranges from low birth weight, poor cognitive potential, weak immune system, anemia, stunting, to incidences of adulthood nutritional non-communicable diseases such as *diabetes mellitus* [11,12]. Collectively, hidden hunger causes irreversible damage to individuals. Yet, one in four children under the age of five years are at increased risks of impaired cognitive and physical performance, stunted and prone to infections [4].

Iron deficiency leads to anemia and stunted growth which contributes to reduced mental development, poor cognitive potential and reduced physical performance in children [9]. Zinc deficiency is indicated with stunting, poor immune system, diarrhea and increased risks of respiratory diseases affecting 2 billion people worldwide [13,14]. Vitamin A deficiency results in poor health, reduced cognitive potential, weak immune, dry eyes and night blindness, a disorder like xerophthalmia [15,16]. Iodine deficiency disorder health effects include; goiter, cretinism, growth retardation, hypothyroidism, and increased pregnancy loss and infant mortality [17]. Moreover, insufficiency maternal iodine

intake may result in neurological and cognitive disorders in children. Folate deficiency during pregnancy is linked to neural tube defect in fetus, diminished deoxyribonucleic acid (DNA) methylation, neuropsychiatric manifestation and cognitive problems [18,19].

Undernutrition, overweight, obesity and nutritional non-communicable diseases throughout the life course, coexisting in different countries, communities and household presents malnutrition double burden challenges [20,21]. For instant, Dietz [21], writes: 'increased use of processed complementary food for children could provide calories without micronutrients, and thereby increase the likelihood of obesity, undernutrition, and stunting and obesity in the same children.' To address the challenges, United Nations member states are committed to end hunger and any form of malnutrition by 2030 under global Sustainable Development Goals (SDGs), SDG2 'zero hunger'[22]. It provides a platform for the United Nations system, governments, private sectors, and other stakeholders for collectively impact agriculture, food and nutrition security in a sustainable manner.

In response, several nutrition sensitive as well as specific interventions have been introduced to alleviate hidden hunger which includes; micronutrient supplementation, food fortification, crops biofortification, promoting dietary diversification, better public health system and diseases control measures [23]. However, food fortification programs proved to be expensive not reaching the majority and people with little access to processed food, especially those scattered and isolated in the rural areas in developing countries [24]. Also, the nutrient supplements are in a medical formulation delivered in form of syrup or tablets following diagnosis or being certain that, an individual has a deficiency [25].

Crops biofortification provides a scientific approach through agronomic, selection breeding and genetic engineering of plant to enhance micronutrients content [26]. It is a food-based approach that offer wide range of nutrients that are essential for human health. Some of biofortified crops include: iron and zinc biofortified beans and millet; β -carotene enhanced orange fleshed sweet potato (OFSP), yellow maize and cassava, orange banana and golden rice among others [27].

Quite a number of agriculture innovations for biofortified crops had been conducted in different region, but little is known about nutrient bioavailability and community perception related to food habits and custom. As the results, people are suffering from hunger and hidden hunger while agriculture has been the best feasible and sustainable means to providing food and nutrition. Therefore, this review intends to create awareness on the potential of biofortified crops and inform the community, researchers and policy makers on unintended narrowed food diversity following several interventions which promote biofortified crops in order to engender better agriculture policies that promote nutrition.

2. CROP BIOFORTIFICATION

Biofortification is the process by which the nutritional quality of food crops is improved through agronomic practices, conventional plant breeding and/ or modern biotechnology techniques [28]. Biofortification differs from food fortification in that crop biofortification aims to increase nutrients level in the crop during plant growth than manual means during food processing [28].

Basically, biofortification intends to enhance micronutrients including trace elements of staple crops and provide a public health benefit with minimal health risks. It is a sustainable intervention that use dietary approach in an initiative to combat hidden hunger [29]. It takes advantages of staple food to reach the majority of undernourished population in the remote areas who depends on agriculture for their food and nutrition. Biofortification may therefore provide a way to reach populations where food fortification and micronutrients supplementation activities may be difficult to implement and/ or limited [28]. Targeted crops include; rice, sweet potato, potato, maize, wheat, common beans, sorghum, tomato, cassava, banana, barley, soy beans, lettuce and carrot.

Agronomic biofortification is achieved by application of nutrient rich fertilizers to foliage or soil to enhance micronutrients concentration in crop edible part hence increased micronutrients intake by consumers[30,31]. Largely, agronomic biofortification depends on the bioavailability of nutrients from the soil to plant. The use of selenium and zinc rich fertilizers had been successful in increasing selenium and zinc in rice and wheat, respectively [29,32]. Biofortification through conventional plant breeding has

successfully increased the level of nutrients in the progeny plant [28]. Moreover, increased levels of iron, zinc, vitamin A and selenium has been achieved by conventional breeding method in most of plants [33,34].

Although, crop biofortification has been achieved through agronomic practices and conventional breeding, in some crops where target micronutrient does not occur naturally, transgenic plant breeding is opted [35,36]. Genetic modification and molecular techniques are used in transferring a specific trait; ability to synthesis micronutrients from a donor organism to recipient organism such as rice, so that it expresses the trait; enhances micronutrients in the edible portion through increased efficiency of biochemical pathways [28,37]. For instance, transgenic iron, zinc and β -carotene biofortified rice have been genetically engineered, representing one of the successful stories of transgenic plant breeding [38]. Other biofortified crops include: pro-vitamin A enhanced soy bean; transgenic enhanced β -carotene and lycopene tomato; enhanced resveratrol antioxidant capacity in apple; enhanced methionine-amino acid in common beans; transgenic β -carotene, ascorbate and folate enhanced maize; transgenic β -carotene potato; enhanced calcium bioavailability in carrot; transgenic lettuce with improved iron content; and pro-vitamin A enhanced yellow cassava, OFSP, golden rice and banana [27,37]. Additionally, transgenic breeding can also be used for incorporation of genes responsible for reduction of antinutritional factors, thereby enhancing micronutrients bioavailability [9,39]. While these transgenic biofortified crops have proved nutritional potential, they have not been introduced in large part due to high risks and regulations imposed on genetically modified crops [40,41].

3. EVIDENCE LINKING CROP BIOFORTIFICATION, FOOD AND NUTRITION

3.1 Vitamins

A number of interventions have been undertaken to achieve crop vitamins enhancement. Provitamin A (β -carotene) crop biofortification is among popular successful biofortification programs. β -carotene is converted in the body to retinol, a form of vitamin A used in the body. It has been demonstrated that increasing provitamin A intake through consuming β -

carotene enhanced crops, results in increased vitamin A body stores in different human age groups [42,43]. For instance, in Uganda and Mozambique intake of OFSP improved vitamin A status in children and women and decreased the prevalence of low serum retinol [44,45]. In Zambia, 5-7 years old children fed with β -carotene enhanced orange maize showed an increased total body store of vitamin A compared with the control group [46]. Children 5-13 years old and women of child bearing age consumed β -carotene biofortified yellow cassava in Kenya and Nigeria, showed a significant improvement in vitamin A status indicated as serum retinol [47-49]. Also, consumption of β -carotene biofortified crops resulted in improved visual performance, increased serum β -carotene and liver retinol concentration in marginal vitamin A deficient children in a study conducted in Zambia [42,46].

Vitamin B6 biofortified transgenic cassava showed 4-14 folds and 3-15 folds increase in vitamin B6 concentration in leaves and storage starchy roots, respectively [50,51]. Similarly, vitamin B1 (thiamine) and B9 (folate) has been enhanced in rice, although affected by processing such as polished rice of which normal practices people consume polished rice [52]. Other crops enhanced with vitamin B through transgenic methods include; tomato, lettuce, maize and potatoes. Moreover, Mène-Saffrané and Pellaud [53], reported development achieved to enhance vitamin E in soybean and maize.

3.2 Minerals

Crop iron, zinc, iodine and selenium biofortification has been achieved in rice, wheat, maize, finger millet and common beans to mention few. Iron biofortified beans in Rwanda showed a significant increase in hemoglobin, total blood iron and improved cognitive potential when iron-depleted women (18-27 years old) were fed with iron biofortified beans [54,55]. Iron biofortified finger millet in India, showed a significant increase in serum ferritin and improved physical performance in school children, adolescent boys and girls who were iron deficient [56]. Moreover, consumption of biofortified crops reported to reduce prevalence and duration of diarrhea, incidences of infection and reduced the likelihood of marginal micronutrient deficiencies in children under five years in Mozambique [57,58].

4. GAPS IN KNOWLEDGE AND PRACTICES LIMITING AGRICULTURE TO IMPROVE NUTRITION

Biofortification requires high adoption by both farmers and community. Indeed, the visibility of traits and infrastructures are critical to technology adoption [59,60]. Biofortified crops with visible traits such as orange-fleshed sweet potatoes and golden rice requires that producers and consumer accept these changes in addition to claimed nutritional potentials [59]. Enhanced β -carotene which intensify the color to yellow and dark orange become problematic for acceptance for many in Africa, where white-fleshed sweet potatoes, cassava, maize and rice are preferred [59,61]. Also, enhanced β -carotene in cassava roots resulted in changed dry matter content in a study conducted in Nigeria [62]. For instance, yellow maize was negatively perceived as food aid which was suitable for animal feed during time of hunger in Zambia and most of the African countries [63]. Also, the contribution of yellow maize to egg yolks, animal fat and poultry skin yellow coloration has attracted their use as animal feed [64].

Likewise, information flow and market networks affect uptake once new improved variety is released. Consequently, affects negatively food diversity as people focus on eating the new improved varieties without considering food diversity for micronutrient bioavailability [65]. That is where a multidisciplinary approach is advised to integrate nutritional education with agriculture research, especially when biofortification alter sensory characteristics [59]. On the other hand, crops with invisible traits do not requires food habit and behavioral changes. However, less educated communities who are vulnerable to micronutrient deficiencies, may be less likely to adopt any new intervention even if they understand the nutritional benefits to their families. At the same time, some people are critical on genetically modified crop such as the golden rice, while not in opposition to biofortification and enhanced nutritional potential [40,41]. They are considerate on human, plant and environmental safety following adoption and consumption of genetically modified food. Another concern is the loss of biodiversity when biofortified crops are produced through genetic modification [66]. Moreover, with genetically modified biofortified crops, there is concern of commercial interests of multinational companies on genetic traits, indigenous community traditional knowledge, breeders' right and policy

makers [65,67]. As the result, staple crop biofortification is perceived as the trap for the multinational corporate to control food and agriculture systems and take over seed market and hence growth for their products [68]. Hence a set of rules and regulations worldwide to control and monitor transgenic plants and genetically engineered crops [69], as most of genetically modified crops are targeted to traditional food crops in developing countries [70]. Also, most of genetically biofortified crops developed so far, lack field as well as agronomic data to support scale up [69]. Moreover, safety concerns, risks and benefits of genetically engineered crops are being debated.

Since the strategy aims to concentrate nutrients on staple starchy crops, may have contributed to overdependence on a few carbohydrate food which is a risky strategy for achieving livelihood and health diet [71]. This may turn into irresponsible intervention as limited access to diverse and balanced diet is the major cause of malnutrition and hidden hunger. This is because, most of crop biofortification programs promote a single crop leading to narrowed food choices [65]. At the same time, the evolution of agriculture and food systems has driven changing dietary preferences and patterns of overconsumption, which is reflected in the increased prevalence of overweight and obesity around the world.

So far, no accepted standards as per Codex Alimentarius for biofortified crops which is necessary for formal and legal integration into regulations to inform policy makers and provide directions for monitoring and evaluation [57,60,69]. Indeed, several questions for nutrients bioavailability and efficacy of biofortified crop are opening possibilities for further research [72,73]. Sportingly, orange fleshed sweet potatoes (OFSP) adoption approach implemented in Mozambique by HarvestPlus, that included disciplinary diversity of agronomists, plant breeders, food processors, applied economists, nutritionist and health practitioners might be of choice for the successful crop biofortification projects [74].

5. CONCLUSIONS AND RECOMMENDATION

Changes in agriculture technologies, food systems and dietary patterns has led to a narrowed food choice to provide nutrients. The increased consumption of highly starch

biofortified food crops in many countries, signal a shift from traditional diverse food diet. However, biofortified crops are either with visible or invisible traits and sometimes changed taste and dry matter content challenging consumer acceptability. Thus, a trend that possibly explains the continuing coexistence of multiple form of malnutritional; undernutrition, hidden hunger, overweight, obesity and nutritional non-communicable diseases within communities and even the same households. But, if crop biofortification programs include nutritional education that promote food diversity, could make it a reality. For instance, the bioavailability of β -carotene depends on oils/fat; iron on vitamin C; and other nutrient-nutrient interactions in the diversified diet. Therefore, it is high time to integrate nutrition education, consumer food and dietary habits, custom and culture to create a need of biofortified crops such that when the project ends, people still see the need to cultivate traditional and biofortified crops, at the same time embraces dietary diversification.

Bringing all together, a supportive multisectoral intervention is suggested to attain food and nutrition security by linking crop biofortification with long term dietary diversity.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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