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MICRONUTRIENT DEFICIENCIES: ADOPTING BIOFORTIFICATION FOR STAPLE CROPS. IS IT SUSTAINABLE?

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Abstract

Biofortification is the genetical improvement of the bioavailable mineral content of food crops, done in three dependent methods of developing Biofortified crops: agronomic Biofortification, conventional plant breeding, and bio-engineering. Over 2 billion people suffer iron deficiency globally with over 250,000 children becoming blind due to vitamin A deficiency. Multiple strategies have been implemented in attempting to help address the issue but still, micronutrient deficiencies are high. This paper examined samples of the existing relevant literature on the progress of Biofortification programs of staple crops concerning its sustainability and cost-effectiveness in developing countries of Asia and African. The reviewed countries included India, Pakistan, Bangladesh, Rwanda, Congo, Kenya, Uganda, Nigeria, and Zambia representing regions where micronutrient deficiencies are still high. A desktop literature review was conducted on the Biofortification of staple crops. The results showed Biofortification as generally successful in alleviating micronutrient deficiencies in Asia and Africa since it is a one-time, cost-effective, long-term and sustainable strategy based on the multiple efficacy studies. The consumption of Biofortified crops increased the micronutrient levels in people thus significantly alleviating deficiencies. However, some evaluation studies are ongoing in some countries. It can thus be concluded that the Biofortification of micronutrients has been implemented with much success. Efficacy studies across the countries have reported high success rates both in addressing the existing nutritional deficiencies and receiving high rates of acceptance among farmers and consumers. There's a need for the establishment of policies to support the national implementation of Biofortification at all levels to ensure it is much more cost-effective and impact-oriented in improving micronutrient content of new varieties of crops at research centers. The Biofortification strategy should also be integrated into main international frameworks that substantially affect national governments.

***Keywords**: (Micronutrient Deficiency, Biofortification, Iron, Zinc, Vitamin A, Recombinants,)*

Introduction

Biofortification is the genitival improvement of the bioavailable mineral content of food crops. Biofortification is carried out in three, dependent methods that are applied in the development of Biofortified crops. These methods include agronomic Biofortification (application of fertilizer), conventional plant breeding, and bio-engineering or genetic modification (including trans-genetic manipulation). Biofortification has been perceived as a strategy to address the problem of micronutrient malnutrition. Micronutrient deficiencies have been rated as public health matters by the World Health Organization (1995). It is estimated that over 250,000 children become blind and some succumb to vitamin A deficiency. The report by King et al. (2015) indicates that over 2 billion persons are affected by iron deficiency globally. Additionally, zinc deficiency is also being recognized as a global public health problem despite the limited global representative data on the prevalence and severity of the deficiency. This can partly be attributed to the lack of reliable biomarkers of the status of zinc. Biofortification is premised on the principle of increasing the micronutrient content level of energy-staple crops which is often consumed by the world's poor people, and by thus reducing the prevalence of micronutrient under nutrition. Several strategies have been used before to address the problem of micronutrient under nutrition. Supplementation has been implemented worldwide but is ineffective due to its high cost and unsustainability (Bouis, Hotz, McClafferty, Meenakshi, & Pfeiffer, 2011). Biofortification has been proved to be the most effective in alleviating micronutrient deficiencies globally because it is one-time, cost-effective, long-term and sustainable. Its successful implementation in different countries has significantly reduced the effect of micronutrient under nutrition in children and adults such as night blindness, low immunity, anemia, low insulin levels, etc. (Saltzman et al., 2013). This paper examined samples of the existing relevant literature on the progress of Biofortification programs of staple crops concerning its sustainability in developing countries, including; India, Pakistan, Bangladesh, Rwanda, Congo, Kenya, Uganda, Nigeria, and Zambia of Asia and Africa continents.

Materials and Method

A desktop literature review was conducted on the Biofortification of staple crops. A literature search indicated that Biofortification programs have been implemented in over 60 countries around the world, most of which were in developing countries of Africa and Asia. The articles included in the review captured the best practices of Zinc, Provitamin A, and Iron Biofortification programs. The reviewed countries included India, Pakistan, Bangladesh, Rwanda, Congo, Kenya, Uganda, Nigeria, and Zambia representing regions where micronutrient deficiencies are still high.

Results and Discussion of best practices on bio-fortification programs targeting staple crops with Zinc, Provitamin A, and Iron in developing countries of Africa and Asia.

Biofortification programs have been used in many countries with much success in addressing the global health burden on micronutrient deficiencies. The results herein are on the success stories, cost-effectiveness, and efficacy of Biofortification programs in preventing micronutrient deficiencies.

Zinc Biofortification programs

India

The CIMMYT developed the high-zinc wheat lines and delivered to NARS and agricultural institutions in India for additional testing and local adaptive breeding. These new varieties (named Ashai, WZ 333, Chitra among others) are 40% higher in zinc concentration (Velu et al., 2015). The study by King et al. (2015) showed that Biofortified crops when consumed increased zinc intake as observed in DNA strands. An efficacy trial on zinc-wheat among children aged 4-6 years and a non-pregnant lactating mother was carried out in Delhi, India. The authors found out that the consumption of Biofortified wheat significantly reduced morbidity, and there was a 17% reduction in pneumonia and vomiting (Sazawal et al., 2018).

Pakistan

Wheat is a staple food in Pakistan with a daily per capita consumption of 302g/d in all age groups. The CIMMYT leads the development of advanced high-zinc wheat in Pakistan with over 37 ppm zinc. Lowe et al. (2018) carried out a double-blind trial to examine the effect of the consumption of Biofortified wheat on the zinc status of women in Pakistan. However, the outcomes are yet to be released. Biofortified zinc-wheat in Pakistan is likely to be sustainable due to the rather high demand for the crop which is fostered by the coordination with the provincial agriculture and health departments, by community health workers among others.

Moreover, the high level of collaboration with multiple public and private sector, and nongovernmental organizations is likely to improve its sustainability.

Bangladesh

Zinc rice is a staple food crop in Bangladesh with a daily per capita consumption of 438g/d. Biofortification of rice in Bangladesh is at advanced stage owing to the Bangladesh Rice Research Institute (BRRI) which carries out breeding programs. Multiple studies have been conducted to ascertain the efficacy of Biofortified zinc-rice in Bangladesh. A double randomized control study was conducted among children in rural Bangladesh to determine the effectiveness of zinc Biofortified rice on the concentration of zinc. The study found out that zinc levels in Biofortified rice were twice higher in the children who consumed the rice compared to those in the control group (Saltzman et al., 2013). Ara et al. (2019) also found out that fortified rice reduced the incidence of anemia and deficiency in zinc. However, the sustainability of Biofortified rice in Bangladesh is at stake because rice breeding is majorly carried out in the public sector and there are no commercial profitable markets for the crop (Haas, 2015).

Iron Biofortification programs

Rwanda

The Rwandan Agricultural Board (RAB) and the International Center for Tropical Agriculture (CIAT) carried out the screening of over 1000 bean germplasm accessions worldwide. This consisted of phase I and phase II stages of pre-breeding and breeding respectively. The iron levels of the breeds were boosted using double-crosses and wide crosses and as a result, there are full breeding lines in Rwanda. In June 2012, five varieties of Biofortified beans with increased levels of iron were produced in Rwanda, and these include the large-seeded bush lines and mid-altitude adapted climbing beans (Mulambu et al., 2017). Multiple efficacy trials have demonstrated the effectiveness of consuming biofortified beans. Haas et al. (2016) conducted an efficacy trial among women aged between 18 and 27 years after consuming biofortified beans. The study found out that the women had increased hemoglobin content and high levels of total body iron. Another efficacy study was conducted in Mexico among primary school children after consuming biofortified black beans for three and a half months. The results showed that the iron status of the students increased (Haas, 2015).

Biofortification of beans in Rwanda is sustainable based on consumer acceptance and cost-benefit analysis studies. The sensory evaluation and willingness to pay (WTP) studies carried out in both rural and urban areas in Rwanda showed that the existing significant sensory differences Biofortified and non-biofortified beans were not a hindrance to consumer acceptance. Additionally, a farmer feedback study carried out among over 300 iron bean farmers showed that about 80% of the farmers were still willing to plant the iron bean varieties in the next season, with 85% desiring to increase their farmland for iron beans (Murekezi, Birol, Asare-Marfo, & Katsvairo, 2013).

Congo

Beans are prominent in the diets of the people of DRC. The biofortification of beans in the Democratic Republic of Congo (DRC) has been in effect since 2008 to date with 10 first wave (100% iron target) and second-wave (60-100% iron target) varieties being released. The breeding strategy combines high iron with other species of desirable agronomic features. The breeding strategy has been based on concept studies. Evaluation studies on the effectiveness of biofortified beans in addressing iron deficiency have been carried out. A study conducted by Petry et al. (2013) on the bioavailability of biofortified beans among young women showed that participants absorbed substantial amounts of iron from the Biofortified beans than the normal beans. Sustainability of fortified beans in Congo is promising because there are increasing market presence and high-volume seed sales. Moreover, there are multiple stakeholders with HarvestPlus such as DRC national agricultural research organization (INERA), farmers' associations/CBOs, and several NGOs (Bouis, Low, McEwan, & Tanumihardjo, 2013).

India

The biofortification of Pearl millet in India has been undertaken by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) which is responsible for breeding research in partnership with NARES and non-governmental organizations (Bouis, 2014). The conventional open-pollinated variety (OPV) was enhanced to develop the initial biofortified breed, and many more have been released up to date. Pearl millet is a staple crop in most of the

Indian states. Studies have demonstrated pearl millet to be effective in improving iron status in teenagers in a six-month study carried out in Maharashtra, India. There was a significant improvement in total iron body level with a 64% chance of resolving iron deficiency among the participants within six months (Finkelstein et al., 2015). The existence of multiple partnerships, high acceptance levels among farmers and consumers, and a high volume of seed sales are proof of sustainability of the biofortification of pearl millet in India.

Pro-Vitamin A Biofortification programs

Uganda

Biofortification in Uganda was first experimented on the traditionally bred orange sweet potato (OSP) by the HarvestPlus, the International Potato Center (CIP), among others. Breeding research has been conducted in Uganda by The National Crops Resources Research Institute (NaCRRI) with the help of CIP. As a result, plant breeders have generated multiple OSP varieties containing provitamin A content of approximately 30-100ppm; which is above the expected level of 32ppm. The entire breeding line comprises of both conventionally developed germplasm and some additionals from CIP. A variety of biofortified candidates are tested by the National Agricultural Research Systems (NARS) in addition to the provision of technical assistance to seed systems. While the provitamin A trait is introduced and maintained in the breeding populations, continuous OSP breeding concentrates on biotic and abiotic stress while improving/sustaining the levels of provitamin A.

The effectiveness of OSP in Uganda was assessed using a randomized control trial. 24,000 households were reached in Uganda from 2006 to 2009 with over 60% rate of adoption (Hotz et al., 2012). The introduction of OSP in rural Uganda led to a high intake of vitamin A among women and children by decreasing the incidence of low serum retinol by 9% (Hotz et al., 2012).

Kenya

The Mama SASHA action research project in Western Kenya was aimed at improving the intake of vitamin A among expectant women and their infants (Low, 2015). The outcomes showed that only those children of pregnant women who had participated in the program had substantial improvements in their vitamin A status. Additionally, the study by Kaguongo, Ortmann, Wale, Darroch, and Low (2012) on the acceptance of orange flesh sweet potato varieties in Western provinces of Kenya found out that there was an increased likelihood of adoption by the farmers.

Nigeria

Biofortification crop delivery program for provitamin A cassava in Nigeria in 2011 began with the stem multiplication in ten local government areas (LGA). The program expanded in 2012 to over 60 villages in four states. The International Center for Tropical Agriculture (CIAT) uses rapid cycling in pre-breeding and generates in-vitro clones and seed populations to Nigeria for local adaptive breeding. Genotype-by-environment (GxE) testing is used to ensure that the varieties produced are best adapted to multiple environments across the country (Maroya, Kulakow, Dixon, Maziya-Dixon, & Bakare, 2012). Provitamin A cassava varieties with 6-8 ppm

(50% target) and up to 10 ppm (66% target) were released in 2011 and 2014 respectively. Biofortification has received significant acceptance with the 'gari' variety being supplied the most accounting for 58% of the overall sales in 2015 (Pfeiffer et al., 2018). De Moura et al. (2015) carried out a cluster-randomized cross-sectional survey in Nigeria to ascertain the consumption level of cassava and vitamin A intake among women and children. The authors found out that there were deficiencies of vitamin A with children being the most affected (60.4%). The infection of malarial parasites lowers serum retinol thus increasing the incidence of vitamin A deficiency. However, a randomized community-based trial is being conducted in Nigeria to ascertain the efficacy of biofortified cassava in enhancing the Vitamin A status of children (Haskell et al., 2017).

Zambia

Provitamin A maize breeding programs in Zambia began in 2007 being initiated by Zambia Agriculture Research Institute (ZARI), International Maize and Wheat Improvement Center (CIMMYT), and IITA. The breeding pipeline comprises of materials from the two leading organizations namely CIMMYT (tropical mid-altitude) and IITA (tropical lowlands) in addition to conventional germplasm (Simpungwe et al., 2017). The initial breeding crosses for the hybrids in 2004 consisted of the best white-grained inbred lines maize without provitamin A and the temperate yellow lines containing provitamin A concentrations (Pixley, Rojas, Babu, Mutale, Surles, & Simpungwe, 2013). Subsequently, the breeding work has wholly been founded on the phenotypic selection using high-performance liquid chromatography (HPLC) to quantify carotenoids. Gannon et al. (2014) conducted an efficacy trial among 5-7-year old in the Eastern

Province of Zambia. The findings indicated that three months of the consumption of orange maize significantly increased the total body stores of vitamin A compared to the control group. Another efficacy study carried out in Zambia among children aged 4-8 years found out that the consumption of orange maize in six months led to high serum beta-carotene (Palmer et al., 2016). The program for orange maize in Zambia is sustainable because of the high rating of preference by the farmers and consumers based on consumer acceptance studies. Moreover, the studies showed that orange maize has the potential to compete with white maize even when they were not cognizant of the nutritional benefits. Consumers are also willing to pay a premium price for the varieties of orange maize than white maize once they are aware of its nutritional advantages (Meenakshi et al., 2012).

Conclusion

Biofortification of micronutrients (i.e. zinc, iron, and vitamin A) have been implemented in different countries in Asia and Africa. Efficacy of Biofortification studies across the countries has reported high success rates both in terms of addressing the existing nutritional deficiencies and receiving high rates of acceptance among farmers and consumers. As a result of Biofortification, the health of citizens from developing countries has improved because the strategy is cost-effective and one-time. Moreover, Biofortification has led to a significant increase in the micronutrient of staple crops thus reducing the effects of deficiencies. Consumer and farmers' acceptance of new varieties has also contributed to the increased demand and market for the biofortified varieties. Additionally, Biofortification has received multiple partnerships that are critical in its sustainability. Partnerships provide sufficient resources for advanced research in breeding leading to varieties with quality combinations and thus high yields. Based on the adequate supply of zinc, vitamin A and iron, Biofortification is the way to go in addressing deficiencies of micronutrients of public health relevance.

Recommendations

There is a need for the establishment of policies to support the National implementation of Biofortification at all levels to ensure that it is much more cost-effective. There is also the need for making improved mineral and vitamin content of the new varieties of crops at research centers besides increasing production alongside other agronomic features. The developed varieties should also be shared across regions for potential benefits. The existing efficacy studies are not adequate with other countries lacking any evidence of the effectiveness of Biofortification. Thus, further evaluation studies are needed to specifically examine the nutritional status of the populations consuming the Biofortified varieties. The Biofortification strategy should also be integrated into some main international frameworks that substantially affect national governments. This paper also recommends the identification of opportunities to assimilate BF in the existing funding processes and frameworks such as the Global Alliance for Improved Nutrition (GAIN) among others.

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