Review of Bio Fortification Challenges Limitations and Opportunities in Crops in Ethiopia

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ABSTRACT

Bio fortification is the process of increasing micronutrient density in staple crops. Bio-fortified crops offer significant benefits for enhancing rural food systems in low-income and middle-income countries. Micronutrient deficiencies are a significant global public health challenge, affecting over 2 billion individuals worldwide, with pregnant women, lactating women, and young children being the most vulnerable groups. Crop bio fortification can be achieved through breeding, agronomy, and genetic modification, with fertilization-based and biotechnological approaches being the main methods. Bio fortified crops, such as pulses, show promise for addressing malnutrition challenges and improving overall health. Malnutrition is a significant issue in Ethiopia, emphasizing the importance of enhancing nutrient intake and dietary diversity to combat deficiencies. Research on bio fortification has primarily focused on zinc, iron, and provitaminA crops, with efforts to develop multi-nutrient bio fortified maize. Monitoring changes in micronutrient status and health outcomes in randomized trials is crucial for evaluating the nutritional effectiveness of bio-fortified crops. While positive effects have been observed on children's health, further research is needed to fully understand the impact of bio-fortification on different populations.

Keywords: bio-fortification, micronutrients, staple crops, rural food systems, malnutrition, genetic modification, agronomy, nutrient intake, dietary diversity, zinc, iron, provitamin a, multi-nutrient, health outcomes, randomized trials

INTRODUCTION

Bio-fortification is determined from two dialects; Greek word 'Bios' implies 'Life' and Latin word 'Fortification' implies 'make strong.' Typically, a word coined to allude to expanding the bioavailable micronutrient substance of nourished crops through hereditary choice by means of plant breeding (Nestle et al., 2006; Hotz and McClafferty, 2007). Bio-fortification implies moving forward the dietary quality of nourishments through hereditary design and plant breeding. The objective of the proposed program is to improve the well-being of destitute individuals by breeding staple nourished crops that are rich in micronutrients. The Bio fortification Challenge Program looks for bringing the total potential of rural and nourishment science to bear on the tireless issue of micronutrient ailments. A micronutrient lack of healthy sustenance, essentially the result of diets destitute in bioavailable vitamins and minerals, influences more than half of the world's population, particularly in women and preschool children.

Bio-fortification, the method of breeding supplements into nourished crops, provides a comparatively cost-effective, maintainable, and long-term means of conveying more micronutrients. This approach, not as it, will lower the number of extremely malnourished individuals who require treatment by co-elementary intercessions, but will offer assistance to keep up with progressive dietary status. Besides, the bio-fortification methodology looks for the micronutrient-dense characteristic in those assortments that, as of now, have favored agronomic and utilization characteristics, such as tall abdicate. Promoted surpluses of these crops may make their way into retail outlets, coming to buyers in first provincial and after those urban zones, in differentiation to complementary intercessions, such as fortification and supplementation that start in urban centers. Bio-fortified staple nourishments cannot provide as high a level of minerals and vitamins per day as supplements or mechanically fortified nourishments, but they can offer assistance by expanding the everyday ampleness of micronutrient immaterial among people throughout their life cycle (Bouis et al. 2011).

Bio-fortification is the process of increasing the density of micronutrients in staple crops through conventional plant breeding, agronomic practices, or genetic modification. Bio-fortification efforts have focused primarily on addressing vitamin A, iron, and zinc deficiencies, which collectively account for the greatest unaddressed burden of disease associated with “hidden hunger” in low- and middle-income countries (LMICs).

Bio-fortified crops offer significant benefits for enhancing rural food systems in LMICs, where farming families rely heavily on locally grown staple crops. Deficiencies in vitamin A, iron, and zinc are common in these areas, and alternative nutritional interventions are often inaccessible or expensive. Bio-fortification is particularly important for young children, adolescent girls, and women, who have higher micronutrient requirements due to growth, development, and menstruation. Research has shown that the daily consumption of iron-bio-fortified crops can improve iron levels and cognitive function across different age groups and regions. This impact is most pronounced in individuals with a poor iron status, highlighting the importance of targeting those with the greatest need.

Recent studies have demonstrated that bio-fortified beans and pearl millet, when consumed as staple foods, have a higher absorption rate of iron than conventional varieties. In fact, they can fulfill between 75-90 percent of the daily average physiological iron requirement for women and children. This finding highlights the potential of nutrient-rich crops to address hidden hunger, a prevalent issue affecting one in three individuals worldwide. While modern agriculture has successfully addressed energy needs, there is now a growing emphasis on producing food that is not only calorically sufficient, but also rich in essential nutrients. This shift in focus is crucial for combating the negative health consequences associated with hidden hunger caused by mineral and vitamin deficiencies in diets (Kennedy et al., 2003).

Bio-fortification is a cost-effective and sustainable method to enhance the nutritional value of food crops by breeding essential nutrients. This approach offers a long-term solution to address malnutrition, as it not only reduces the number of severely malnourished individuals requiring additional interventions, but also helps improve their overall nutritional status. Additionally, Bio-fortification is particularly beneficial for reaching malnourished rural populations, who may have limited access to commercially fortified foods and supplements.

Bio-fortification focuses on incorporating micronutrient-rich traits into crop varieties that already possess desirable agronomic and consumption characteristics, such as high yield. By doing so, surplus crops with enhanced nutritional content can be made available in retail outlets, initially in rural areas and subsequently in urban centers. This differs from other interventions such as fortification and supplementation, which typically begin in urban areas.

Although bio-fortified staple foods may not provide the same level of minerals and vitamins per day as supplements or industrially fortified foods, they play a crucial role in increasing the daily intake of micronutrients among individuals at all stages of life. This contributes to improving the overall nutritional adequacy (Bouis et al. 2011).In contrast to the ongoing financial expenses for supplementation and commercial fortification initiatives, a single investment in plant breeding has the potential to provide farmers with nutrient-rich planting materials that can be cultivated for many years. The varieties developed for a specific country can be assessed for their performance in different regions and adjusted accordingly, thereby amplifying the advantages of initial investment. The nutritionally enhanced varieties are cultivated and consumed annually.

Micro-nutrient deficiency

Micronutrient deficiencies pose a significant global public health challenge, affecting over two billion individuals worldwide. These deficiencies primarily involve key vitamins and minerals such as vitamin A, iodine, iron, and zinc (UNICEF, 2009).
Most affected individuals reside in low-income countries and often suffer from multiple micronutrient deficiencies. Lack of access to nutrient-rich foods, including fruits, vegetables, animal products, and fortified foods, is a common cause of these deficiencies, often due to their high cost or unavailability. Consequently, micronutrient deficiencies increase the risk of contracting infections and succumb to diseases such as diarrhea, measles, malaria, and pneumonia, which are among the top ten causes of illness globally (Berdanier, 2002).

Moreover, micronutrient deficiencies can significantly increase overall mortality risk and lead to various detrimental health consequences. These consequences include impaired intellectual development and cognition, weakened immune function, and a reduced work capacity. The impact of micronutrient deficiencies is particularly severe among children, pregnant women, and developing fetuses. Approximately 30% of the world's population is unable to reach their full mental and physical potential owing to these deficiencies (UNICEF, 2004).

The groups most vulnerable to micronutrient deficiencies included pregnant and lactating women as well as young children. These individuals have higher requirements for vitamins and minerals and are more prone to the negative effects of deficiencies. Pregnant women face a heightened risk of maternal mortality and give birth to underweight or mentally impaired children. Meanwhile, a lactating mother's micronutrient status directly impacts the health and growth of her breastfed infant, especially in the first six months of life. In young children, micronutrient deficiencies increase the likelihood of mortality from infectious diseases and hinder physical and cognitive development. Micronutrient deficiencies can arise swiftly in emergency situations or exacerbate existing deficiencies due to factors such as loss of livelihoods and crops, disruptions in food supplies, outbreaks of diarrheal diseases leading to nutrient mala-absorption, and infectious diseases suppressing appetite, while increasing the need for micronutrients to combat illness.

Overview of Bio fortification in crops

Crop bio fortification involves enriching plant seeds with essential nutrients to address malnutrition challenges. Methods include breeding, agronomy, and genetic modification, with breeding showing higher success rates. Prominent bio fortified crops include maize, sweet potato, soybean, and others, providing micronutrients to targeted populations. Fertilization-based approaches involve direct nutrient application to enhance plant growth, while biotechnological approaches use molecular biology techniques. Bio-stimulants and symbiotic microorganisms can improve nutrient uptake and biomass production. Biotechnological approaches utilize genetic engineering and marker-assisted selection to modify metabolic pathways for increased nutrient content. Marker-assisted selection is reliable for breeding programs, while identifying traits for remobilization of nutrients is crucial for seed enrichment. Overall, bio fortified crops hold promise in addressing malnutrition challenges through various methods of enrichment.

Bio fortification of pulse crops

Pulses are the plants belonging to family Fabaceae and recognized as the second most important food source after cereals which play an important role due to their nutritional and health-related benefits. Pulses are the dried edible seeds of certain plants in the legume family. Pulses are very high in protein and fiber and are low

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in fat. Pulses are nitrogen fixing crops that improve the environmental sustainability of annual cropping systems. Pulses come in a variety of shapes, sizes, and colors, and can be consumed in many forms, including whole or split, ground into flour, or separated into fractions such as protein, fiber, and starch. Other foods in the legume family, such as fresh beans and peas, are not considered pulses; the term “pulse” only refers to dried seeds. Soybeans and peanuts are also not considered pulses because they have much higher fat content, whereas pulses contain virtually no fat. The most important pulses include chickpea (Cicerarietinum), broad bean (Viciafaba), pigeon pea (Cajanuscajan), mungbean (Vignaradiata), urdbean (Vignamungo), cowpea (V. unguiculata), lentil (Lens culinaris ssp. culinaris), lathyrus (Lathyrussativus L.), etc. (Singh et al. 2015).bio-fortification of pulses by breeding, agronomy, microbiology, and genetic modification-based approaches. There are some accomplishments by traditional breeding approaches, mutation breeding, and foliar/root application of respective fertilizers in pulses. However, research on marker development and its utilization in marker-assisted breeding is still in the initial stages. Pulses are primarily non-staple legumes; therefore, they have received little attention from the scientific community. However, considering their richness in protein content and dietary fiber, they have the potential to be nutritional foods. Therefore, Bio-fortification of pulses with increased nutritional quality is expected to gain attention in the future.

The World agricultural practices aim to provide sufficient food energy and nutrients for human well-being and health. Over time, agricultural development has been one of humankind’s greatest achievements. Green Revolution has expanded the global production of staple food crops, especially cereals. The major concern of the green revolution was to increase crop yield, and minimum effort was made to improve the quality of these food products. This has led to the displacement of traditional food crops, providing greater levels of essential micronutrients with less nutritious but high-yielding crops. Micronutrient malnutrition affects more than half of the world’s population and is considered to be one of the most serious global challenges to humankind. Similar to cereals, pulses have a long history of cultivation and have been a significant constituent in human diets since approximately 10,000 BC (Fuller and Harvey 2006).

Although several positive effects have been associated with pulse composition, further improvement is required in terms of major and minor nutrients. The development of micronutrient-enriched staple food crops may be an effective and sustainable means of increasing micronutrient intake to support human health. Bio-fortification is the process of increasing the nutrient density in a crop. It is a feasible, upcoming, and cost-effective technique that includes various strategies such as classical breeding, population mapping, and genetic selection to obtain superior lines of pulse crops, as shown in . Therefore, Bio-fortification of various pulses including lentils (Lens culinaris L.), field pea (Pisumsativum L.), and chickpea (Cicerarietinum L.) with highly bioavailable Fe, Zn, Se, and I is urgently required to tackle with chronic diseases linked to micronutrient malnutrition around the world. Recently, the genetic potential for Bio-fortification of bioavailable Fe, Zn, and provitamin A has been reported for the edible portions of several staple food crops, including rice (Oryza sativa L.), wheat (Triticum sp.), maize (Zea mays L.), common bean (Phaseolus vulgaris L.), sweet potato (Ipomoea batatas L.), and cassava (Manihotesculenta C.).

Until now, our agricultural system has not been designed to promote human health; instead, it concentrates only on increasing grain yield and crop productivity. This approach has led to an increase in micronutrient deficiencies in legumes, thereby increasing micronutrient malnutrition among consumers. Currently, agriculture is shifting from producing a greater quantity of food crops to producing nutrient-rich food crops in sufficient quantities to improve the nutritional quality of various foods (Singh et al. 2015). Bio-fortified pulses have huge potential to combat hidden hunger, as the edible portions are denser in bioavailable micronutrients, minerals, and vitamins. Thus, Bio-fortification will emerge as a cheaper agricultural-based strategy for mitigating nutritional needs.

When consumed regularly, bio-fortified staple crops will generate measurable improvements in human health and nutrition. This will facilitate the fight against “hidden hunger” or “micronutrient malnutrition,” particularly in poor and developing countries (Garg et al. 2018).

Malnutrition (Micronutrient deficiency) and Bio fortification

Malnutrition, in all forms, and diet-related non-communicable diseases (NCDs) have a significant impact on the health and well-being of individuals. This results in reduced learning abilities and productivity, and increased rates of morbidity, disability, and mortality, creating substantial social and economic burdens on individuals, families, communities, and nations. Additionally, malnutrition is often inaccurately measured and reported. Malnutrition violates people's right to sufficient food and represents an unacceptable financial strain. The total annual cost of malnutrition was estimated at US$3.5 trillion for the global economy in 2010, equivalent to 4-5 percent of global GDP, or US$400-500 per person. This cost encompasses the expenses associated with under-nutrition (approximately US$2.1 trillion) and NCDs related to over-nutrition (around US$1.4 trillion).

Micronutrient malnutrition, also known as hidden hunger, which involves inadequate intake of essential vitamins and minerals, has adverse effects on human health. Hidden hunger affects over two billion individuals worldwide, with the highest prevalence observed in Africa and South Asia. Children and women of reproductive age are particularly susceptible to malnutrition, resulting in impaired growth, health issues, and complications during childbirth. While human diets often lack seven minerals (iron, zinc, copper, calcium, magnesium, selenium, and iodine) and various vitamins, deficiencies in iron, zinc, vitamin A, and vitamin B9 (foliate) are among the most severe. Bio-fortification, which involves enhancing the levels of micronutrients in food crops through agricultural methods, is recommended as a crucial strategy to combat micronutrient malnutrition. Impressive progress has been made in bio fortification of mainly single micronutrients across an array of primary staple food crops. Bio fortified crops have been developed via conventional breeding or genetic engineering, although the latter have yet to receive full approval for release to farmers. Bio fortification via genetic engineering can enable high level accumulation of micronutrients and is not constrained by variation in available germplasm. Bio fortification strategies can combine conventional breeding with genetic engineering. Genetic engineering enables the simultaneous augmentation of multiple micronutrients, along with improving the post-harvest stability of vitamins, while also including ergonomically important traits, such as enhanced yield and stress resilience.

In the last few years, the cost-effectiveness and feasibility of implementing Bio-fortification using conventional breeding techniques have been established as key interventions for reducing mineral and vitamin deficiencies in developing countries. Consequently, a recent World Bank report assumed that bio-fortified cereal crops should be the norm rather than the exception.

Insufficient energy intake and inability to reconstruct body tissues as consuming less than the required amount of any nutrient is called undernourishment. Today, more than 820 million people worldwide are hungry, two billion people suffer from micronutrient deficiencies, and two billion people are overweight or obese (FAO 2018; UNEP 2021). Nutritional and micronutrient deficiencies contribute substantially to the global burden of disease; people have micronutrient deficiencies for at least one including iron (Fe), zinc (Zn), iodine (I), selenium (Se), calcium (Ca), and vitamins such as foliate and vitamin A (Beal et al. 2017; FAO 2020a, b; Kumssa et al. 2015; World Health Organization (WHO) and UNICEF 2017) .Fe deficiency is seen in 20–25% of the world population and Zn deficiency is seen in 17.3% (Cooper et al. 2012). Fe and Zn are two important nutrients in human nutrition and they are among the most common micronutrient deficiencies in the world. Zn deficiency is a serious health problem and is common in South Asian and sub-Saharan African countries (Shahzad et al. 2014; Shekari et al. 2015). Furthermore, 2 billion people suffer from I deficiency (Horton et al. 2008), and 254 million pre-school children have vitamin A deficiency. It was reported that symptoms of night blindness were detected in 5.2 million pre-school children and low serum retinol concentrations were detected in 190 million children due to vitamin A deficiency (Sherwin et al. 2012). Vitamin A and I deficiencies are most common in South Asian and sub-Saharan African countries

(Stevens et al. 2015; Australia, mildly (Zimmermann, 2009). I deficiency leads to stillbirth, cretinism, goiter, thyroid inflammation, and impaired cognitive development (Landini et al. 2011).

Ethiopia Nutrition Profile

Malnutrition during childhood and pregnancy has numerous negative consequences on the survival and long-term well-being of children. Additionally, it has wide-ranging effects on human capital, economic productivity, and national development. The implications of malnutrition are of great concern to policymakers in Ethiopia. According to the most recent Mini-Demographic and Health Survey (DHS) 2019 conducted by the EPHI and ICF International, 7 percent of children under the age of five in Ethiopia suffer from acute malnutrition or wasting, while 37 percent are stunted. Ethiopia, with a population of 109.2 million as of 2019 (UNICEF). Ethiopia is the second most populous country in Africa. It is projected to be among the eight countries in the world with the highest population growth between 2017 and 2050, with an estimated population of 205.4 million (Population Reference Bureau, 2019). Currently, Ethiopia ranks 135th out of 162 countries in terms of progress towards achieving Sustainable Development Goals (SDGs) (Sachs et al. 2019). The most recent DHS in 2016 revealed that 25 percent of female deaths were related to pregnancy or childbirth, 77 percent of married women were at risk of high-risk births, and the under-five mortality rate was 55 deaths per 1,000 live births (EPHI and ICF 2019).

Ethiopia remains one of the poorest countries in the region, although growth in its agricultural sector has contributed to poverty reduction. While agriculture continues to be a significant part of the economy, especially in rural areas where 55 percent of women and 83 percent of men are engaged in agricultural work (CSA and ICF International 2016; World Bank 2019), subsistence agriculture plays a major role in the economy and livelihoods of rural populations. This type of agriculture is characterized by weak markets and limited access to improved technologies, making the country particularly vulnerable to climate-related shocks. Conflict and climate change also pose additional challenges to Ethiopia's development.

Micronutrient deficiencies remain a significant issue in Ethiopia. Child anemia rose from 44 percent in 2011 to 57 percent in 2016. More than a third of children, 35 percent, suffer from zinc deficiency. Maternal anemia also increased from 17 percent in 2011 to 24 percent in 2016, with 34 percent of women being zinc deficient. In contrast, men had a 15 percent anemia rate in 2016. Globally, it is estimated that half of anemia cases are due to iron deficiency, but the specific contribution in Ethiopia is uncertain. Only 34 percent of women received iron supplementation during pregnancy, and a mere 5 percent consumed them for the recommended 90+ days. Calcium supplementation and multiple micronutrient supplements are not included in the health services package. Various other factors also play a role in poor nutrition outcomes in Ethiopia. Early childbearing is common, with 27.7 percent of adolescent girls starting childbearing by age 19 in 2016, a slight decrease from 33.6 percent in 2011. Adolescent girls are more likely to be malnourished and have low birth weight babies, who are at higher risk of illness and death compared to those born to older mothers. Exclusive breastfeeding among children under six months has increased from 49 percent in 2005 to 59 percent in 2019, although 6 percent of children in this age group are not breastfed at all. The percentage of underweight children decreased from 33 percent in 2005 to 21 percent in 2019, but 6 percent of all children in Ethiopia are severely underweight. The prevalence of underweight children decreases with higher levels of mother's education and wealth quintile. Additionally, access to sanitation services in Ethiopia is very low, with only 7 percent of households utilizing them.

Micronutrient deficiencies and bio fortification in Ethiopia

Micronutrient deficiencies, such as vitamin A and related nutrients, play a crucial role in protecting against various conditions associated with oxidative stress, including aging, cancer, cardiovascular disease, cataracts, diabetes mellitus, and infection (Laquatra 2003). Inadequate iodine intake can result in thyroid enlargement (goiter), hypothyroidism, and mental retardation in infants and children whose mothers were iodine deficient during pregnancy (Association 2014). In fact, in 2007, more than 6 million women in Ethiopia were affected by goiter (Abuye&Berhane 2007). Iron is also essential as it is a component of hemoglobin, which enables red blood cells to transport oxygen throughout the body. Additionally, iron is crucial for the proper production and breakdown of several neurotransmitters, and it plays a vital role in normal neurodevelopment during fetal and early childhood (Edistein 2011). It is involved in the catalytic activity of approximately 100 enzymes and contributes to immune function, protein synthesis, wound healing, DNA synthesis, and cell division. Zinc is another micronutrient that supports normal growth and development during pregnancy, childhood, and adolescence. It is necessary for the proper functioning of taste and smell senses. Since the body does not have a specialized zinc storage system, a daily intake of zinc is necessary to maintain a steady state (King 2013).

Both adults and children require foliate or folic acid for overall health, including the prevention of anemia, the production of healthy red blood cells, proper energy metabolism, and neurological health and development (NIH 2009). Deficiencies in foliate and vitamin B12 can lead to megaloblastic anemia when combined. Vitamin B12 is crucial for nerve function and the production of DNA and RNA in cells. In Ethiopia, ensuring food security and optimizing human capital are the dual challenges for nutrition and economic policies. Despite being one of the largest recipients of food aid globally, Ethiopia is also considered one of the top-performing countries in addressing these challenges.

Malnutrition undermines the basis of economic progress by weakening individuals' vitality, vigor, innovative and critical thinking abilities, as well as their drive for initiative and entrepreneurship. The widespread prevalence of poor health, reduced cognitive abilities, decreased physical performance, and lower productivity impose a significant obstacle to the advancement of national economic growth. Alleviating this economic challenge and maximizing Ethiopia's human and economic capabilities could significantly improve the chances of attaining the GTP's ambitious objective for economic advancement. As per NNP, micronutrient deficiencies have a profound impact on the physical and mental health of individuals. Deficiencies in vitamins and minerals pose a serious public health concern, with over half of children and a quarter of adult women suffering from anemia, and nearly 40% of children experiencing vitamin A deficiency.

Dietary diversification

There is compelling evidence in low- and middle-income countries (LMICs) indicating that diets primarily centered on starchy staples with limited intake of fruits, vegetables, and animal-based products are linked to insufficient intake of essential nutrients (Ruel, 2003). A recent study synthesized the connection between dietary diversity and nutritional adequacy in adolescents and adults (Verger et al., 2021). Fifty research studies revealed that greater dietary diversity was consistently associated with improved nutritional adequacy in most instances, regardless of the economic setting. Moreover, multiple studies conducted in LMICs demonstrated that higher dietary diversity was correlated with a decreased risk of micronutrient deficiencies: lower likelihood of vitamin A insufficiency due to the consumption of meat, poultry, fish, fruits, and vegetables among Kenyan women of reproductive age (Fujita et al., 2012). Similarly, lower chances of zinc deficiency were observed as a result of consuming animal-derived foods among Ethiopian women of reproductive age (Gebremedhin et al., 2011); and reduced likelihood of inadequate zinc status was linked to the consumption of meat, poultry, and fish among Mozambican adolescents (Korkalo et al., 2016). However, the evidence regarding the protective effect of dietary diversity against anemia in women of reproductive age in LMICs is conflicting: while seven studies reported a connection between higher dietary diversity and reduced odds of anemia, five studies found no association (Limburg et al., 2006).

While there is consistent evidence supporting the role of higher dietary diversity in preventing undernourishment in LMICs, as evidenced in Burkina Faso (Lourme-Ruiz et al., 2021), the relationship between greater dietary diversity and body weight (either insufficient or excessive), or the risk of non-communicable diseases, was found to be inconsistent in both adolescents and adults (Verger et al., 2021). Nevertheless, evidence does exist for the protective impact of dietary diversity against certain health outcomes (e.g., cardiovascular diseases) but not for others (e.g., type 2 diabetes; Mozaffari et al., 2021, 2022).

Bio fortification, micronutrient intakes and status, impacts on health

The majority of research on the potential of Bio-fortification to address micronutrient deficiencies has primarily focused on three key micronutrients: zinc, iron, and provitamin A (Ofori et al., 2022). Studies suggest that Bio-fortification could enhance the coverage of the estimated average requirement by 25% for zinc crops, 35% for iron crops, and over 85% for provitaminA crops (Van Der Straeten et al., 2020). Recent efforts have been directed towards developing multi-nutrient bio-fortified maize to increase the chances of meeting recommended intakes of both macro- and micronutrients, thereby reducing multiple deficiencies (Goredema-Matongera et al., 2021; Van Der Straeten et al., 2020). Evaluating the nutritional effectiveness of bio-fortified crops requires monitoring changes in micronutrient status and health outcomes of individuals participating in randomized trials conducted under controlled conditions. The literature presents varying results among children, women, and the general population (Table. 1). Bio-fortification seems to enhance the micronutrient status of children (Palmer et al., 2016a, b; Scott et al., 2018) and demonstrate positive effects on eye health (Palmer et al., 2016a), cognitive function (Scott et al., 2018), and diarrhea (Jones & De Brauw, 2015). However, no significant improvements have been observed in the zinc or iron status and anemia among women (Murray-Kolb et al., 2017; Sazawal et al., 2018). Despite the lack of enhancement in micronutrient status, some health benefits have been noted in terms of cognitive performance (Murray-Kolb et al., 2017), morbidity, and a reduction in the duration of illnesses such as pneumonia, vomiting, and fever (Sazawal et al., 2018). A systematic review and meta-analysis by Finkelstein et al. (2019) based on only three randomized efficacy trials confirmed that the consumption of iron-bio-fortified crops can enhance cognitive function, particularly attention and memory. The significance of biological indicators is often a subject of debate in public health.

Bio fortification of Staple Crops in Ethiopia

This section looks at CSA crop output and area data that is used to determine the value of six bio fortifiable products in Ethiopian agriculture. In the meher crop season of 2014–2015–2018–2019, maize made up more than 15% of the total crop area, ranking second in significance only to teff. The combined area of millet, sweet potatoes, and rice is greater than that of all the vegetable and fruit categories. 12% of the major crop area was made up of wheat. The significance of these crops for global bio fortifiable is emphasized.

Harvest Plus is an organization that develops and promotes bio-fortified food crops with the goal of improving public health and nutrition. It has released 12 crops in 37 African, 15 Asian, and 11 Latin American and Caribbean countries that contain micronutrients like iron, zinc, and pro-vitamin A carotenoids. Trial stages are being conducted in Ethiopia for iron bean, zinc wheat, vitamin A cassava, vitamin A maize, iron/zinc potato, and iron/zinc lentil varieties. Additional information about the creation and distribution of bio fortified varieties can be found in policy documents cited by the Federal Democratic Republic of Ethiopia (GFDRE) government. The goal of the study is to increase Ethiopians' consumption of non-bio fortified crops NIPN, (2022).

One affordable strategy to address micronutrient deficiencies in rural populations and lower socioeconomic groups is bio fortification. Ethiopia must overcome several obstacles before it can expand, including a lack of funding and a specialized organization to oversee bio fortifiable initiatives. The low adoption of bio fortified crops can be attributed to two factors: a poor seed supply system and limited availability of improved seeds. The Ethiopian seed system value chain needs to be improved in order to increase access to bio-fortified seeds. It is also essential to target bio fortified crops according to current food consumption patterns and to carry out the bio fortifiable initiatives listed in the National Food and Nutrition Strategy. Over the past 20 years, Ethiopia has made strides toward decreasing malnutrition; however, malnutrition is still pervasive and micronutrient intake is insufficient. With fewer sources of nutrients, Ethiopians have one of the least varied diets in sub-Saharan Africa Bachewe, et,al (2023).

This diet is low in nutrient-dense foods such as fruits, vegetables, and animal source foods (ASF) and high in starchy staples. This has been connected to impaired immunity, delayed child development, and poor cognitive outcomes. The economic success of developing countries depends on labor productivity and human capital, both of which are reliant on access to adequate nutrition. Although voluntary guidelines and supplementation programs are currently in place for wheat and edible oil fortification, their implementation is limited because of the consumption patterns of urban residents. Orange-fleshed sweet potatoes, for example, are examples of bio fortification that may increase intakes of micronutrients and lessen deficiencies. To prove these interventions' efficacy and effectiveness, more data is nevertheless required Bachewe, et,al (2023).

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Bio fortifiable is a cost-effective intervention

Although supplementation is an effective short-term intervention to address micronutrient deficiencies, it is expensive and coverage remains relatively low in Ethiopia. Bio fortifiable can be used to complement supplementation and fortification as it has the potential to reach populations with limited access to existing interventions[1]. Potentially bio-fortifiable crops are already the main contributors to the dietary in- takes of Ethiopians. Maize and wheat accounted for nearly 30% of the food consumed in 2016.1. Despite the significant economic potential of food fortification, various obstacles hinder the establishment of a supportive environment for the global expansion of food fortification. These challenges encompass inadequate private-public partnerships and the absence of national regulations regarding food fortification. A recent comprehensive review examined the difficulties faced by LSFF programs in LMICs, as well as the efficacy of food fortification programs NIPN, (2022). Despite the considerable advantages of food fortification strategies on nutritional well-being, certain studies have reported conflicting outcomes, indicating no significant impact of food fortification programs and the assurance of safe upper limits. For instance, a study involving Brazilian children under six years old revealed no discernible effect of iron-fortified flour on the prevalence of anemia. This study, comprising four population-based surveys conducted over a four-year period, assessed dietary intake and hemoglobin levels. Surprisingly, the results indicated a rise in anemia among children. Despite the study detecting an average consumption of fortified flour at 100 grams per day, the poor dietary quality of children with low iron bioavailability compromised the benefits of fortified flour. Bio fortification, a cost-effective approach to addressing micronutrient deficiencies, has a lasting impact on food security and farmers' livelihoods. With an estimated return on investment of 15 to 20 people per dollar spent, it represents a one-time investment that can yield significant health and economic advantages. High-yielding crops tailored to local growing conditions are bio fortified, enhancing agricultural productivity and food availability. Moreover, they improve nutritional status, enabling individuals to lead active and productive lives while enhancing food utilization. Farmers who cultivate bio fortified crops can achieve increased yields and enhanced crop qualities, such as disease resistance, leading to improved income and livelihood security.

BIO FORTIFICATION INAGRI- CULTURAL AND FOOD SYSTEMS

Bio fortifiable is an economical method of enhancing the nutritional value of food crops and promoting public health. It addresses the global issue of micronutrient malnutrition and enhances food security. Farmers especially benefit from bio fortification because it can be incorporated into current agricultural systems without requiring extra care or money. It also contributes to the accomplishment of the Sustainable Development Goals of the UN, which include promoting sustainable agriculture and putting an end to hunger.

Bio fortification policy in Ethiopia

Aiming to support the development of bio fortified crops and vegetables, increase farmers' access to them, establish a bio fortifiable center, distribute bio fortified seeds, and enable remote production and consumption of bio fortified pulses and vegetables, the National Nutrition Program (NNP) of Ethiopia: 2016-2020 makes five mentions of bio fortifiable . Nevertheless, bio fortifiable is not included in the accountability and results matrix for implementation of the NNP. Through the use of tools and materials for Social and Behavioral Change Communication (SBCC), the National Nutrition Sensitive Agriculture Strategy seeks to promote bio fortified crops and increase year-round availability, access, and consumption of a diverse range of safe and nutritious foods. Three of the 13 strategic objectives and six of the strategic initiatives of the National Food and Nutrition Strategy highlight bio fortification; however, the main focus is Ethiopia's bio fortifiable policy is becoming more and more well-known, although opinions on it at the moment are divided. In order to boost the production and consumption of micronutrients in staple crops, key informants recommend a precise set of guidelines. Currently, the Ministry of Agriculture concentrates its interventions on cereals, ignoring root crops, which are given less attention when there is a drought. Stronger public-private partnerships are required, along with extensive campaigns of awareness and promotion. It is suggested to offer incentives for private investments in food processing, bio fortifiable and related fields. Policies, including produce labeling, should lower bureaucratic barriers for new enterprises and incentivize farmers to cultivate bio-fortified seeds Huertas, et, al **(2022).**

Seed system and policy In Ethiopia

Ethiopian seed producers have difficulty coordinating with seed developers and analysts of seed demand, which results in a lack of knowledge about next-generation seeds and a risk-averse approach to developing new varieties until demand is determined. The adoption of bio fortified varieties and the performance of seed developers are adversely affected by this lack of coordination. According to a study, 12% of wheat growers used non-bio fortified varieties, compared to nearly 40% of maize growers who used improved varieties. Nonetheless, the percentage of farmers utilizing improved seeds is low, and less than 2% of haricot bean growers employed improved varieties. This shows that the percentage of farmers adopting improved seeds is too low for a bio fortifiable intervention to be effective and that policymakers and those working in the field need to give increasing the adoption of modern inputs top priority.

The KII participants draw attention to the significant obstacles Ethiopia faces in creating micronutrient-enriched varieties, especially with regard to the seed system. Reproduction, transportation, and farmer adoption are all necessary for the propagation of seeds. A seed release code and a regulatory body at the MoA oversee the comparatively well-functioning seed certification process, which takes place twice a year. The authority to assess new variety seeds and compare them to existing varieties rests with the Ethiopian Institute of Agriculture. The quantity of seed producers, prompt delivery, and motivation are obstacles, though. The cooperation of producers, demand analysts, and seed developers is also lacking. To decentralize or expand the number of seed producers, interventions are required.

Despite being a relatively new field, bio fortifiable in Ethiopia lacks a dedicated organization to oversee related activities. Supervising and organizing research on bio fortified varieties, efficacy, affordability, and marketing requires an establishment. Support is provided in part by specialists at the MoA's Food and Nutrition Coordination office. Better engagement in bio fortifiable requires increased collaboration between central government agencies and regional governments.

Challenges of Bio fortification in Ethiopia

According to the study, there are four main obstacles to bio-fortification in Ethiopia: insufficient funding, a lack of attention to policy, and poorly equipped laboratories. Some institutions reallocate funds from other areas to fund research specifically for bio-fortified varieties as a result of insufficient funding. Furthermore, virus-free planting materials and micro propagation require well-equipped labs, and the measurement of nutrient content in bio fortified crops lacks near-infrared spectroscopy.

Conclusions and Policy Implications

The process of bio fortifiable involves adding micronutrients, specifically zinc, iron, and vitamin A, to staple crops in order to improve long-term health problems in women and children. Bio fortifiable plays a critical role in enhancing public health in Ethiopia, especially in regions where these deficiencies are common. Policymakers must prioritize demand-side management, locally developed bio fortified seed varieties, a coordinating body, clearer policy documents, effective seed production and distribution systems, and bio fortification. Seed companies can be encouraged to create bio fortified varieties through the use of policy tools and subsidies. Adoption of bio fortified seeds is influenced by a number of factors, such as knowledge about nutrition, social networks, household education, growing bio fortified varieties, and access to complementary inputs. Researchers ought to give priority to nutrient- and crop-efficient

CONCLUSION AND RECOMMENDATIONS

Bio-fortification is a process aimed at increasing the nutrient content of staple crops to combat malnutrition, especially in low- and middle-income countries. It targets deficiencies in key nutrients like vitamin A, iron, and zinc. Research has shown that bio-fortified crops have higher iron absorption rates, contributing significantly to meeting daily iron requirements for women and children. While not as potent as supplements, bio-fortified staple foods play a crucial role in increasing essential nutrient intake, particularly for vulnerable populations.

Bio-fortification focuses on incorporating nutrient-rich traits into crop varieties with desirable characteristics like high yield. By making these crops available in retail outlets, Bio-fortification can reach a wider population, offering a cost-effective and sustainable solution to malnutrition. Micronutrient deficiencies are a significant global public health challenge, affecting over 2 billion individuals worldwide, with pregnant women, lactating women, and young children being the most vulnerable groups.

Crop Bio-fortification can be achieved through breeding, agronomy, and genetic modification, with fertilization-based and biotechnological approaches being the main methods. Bio-fortified crops, such as pulses, show promise in addressing malnutrition challenges and improving overall health. In Ethiopia, malnutrition is a significant issue, emphasizing the importance of enhancing nutrient intake and dietary diversity to combat deficiencies.

Research on Bio-fortification primarily focuses on zinc, iron, and provitamin A crops, with efforts to develop multi-nutrient bio-fortified maize. Monitoring changes in micronutrient status and health outcomes in randomized trials is crucial to evaluate the nutritional effectiveness of bio-fortified crops. While positive effects have been observed in children's health, further research is needed to fully understand the impact of Bio-fortification on different populations.

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