Available online at www.ijpab.com

DOI: http://dx.doi.org/10.18782/2582-2845.9035

ISSN: 2582 – 2845

Ind. J. Pure App. Biosci. (2023) *11*(6), 53-67

Indian Journal of Pure & Applied Biosciences

Peer-Reviewed, Refereed, Open Access Journal

Review Article

Biofortification for Enhancement of Micronutrient Contents in Cereals

Muhammad Zaib[1*], Hassan Zubair[2], Abdul Hannan Afzal[3], Muskan Naseem[3], Duha Maryam[3], Seema Batool[4], Shafqat Raza[5], Muhammad Umar[5], Aiza Marium[2], Hussain Umair Tariq[6]

[1]Department of Soil and Environmental Science, [2]Department of Agronomy, [3]Department of Plant Breeding and Genetics, [6]Department of Animal Science, University of Sargodha, Sargodha 40100, Pakistan

[4]Department of Development and Environmental Studies, Arctic Studies, University of Paris Saclay, France

[5]Department of Agronomy, University of Layyah, Layyah 31200, Pakistan

*Corresponding Author E-mail: zaibch767@gmail.com

Received: 3.10.2023 | Revised: 27.11.2023 | Accepted: 6.12.2023

ABSTRACT

Micronutrient deficiencies present a global public health threat, particularly in regions reliant on staple crops like maize, rice, and wheat. This review delves into the intricate relationship between boron, zinc, and iron deficiencies and these essential crops. Boron, vital for both plant growth and human health, influences physiological processes beyond agriculture. Similarly, zinc and iron play crucial roles in enzymatic activities and overall well-being. Deficiencies in these micronutrients can lead to severe health consequences, affecting millions worldwide. The review addresses challenges in implementing fertilizer-based solutions, tackling economic constraints, technological limitations, and environmental concerns. Economic barriers, especially for smallholder farmers, stem from the high costs of micronutrient-enriched fertilizers. Governments, international organizations, and public-private partnerships are crucial for subsidizing and incentivizing fertilizers. Technological limitations involve formulating efficient fertilizers, with ongoing research in nanotechnology and precision agriculture holding promise. Environmental concerns necessitate promoting sustainable farming practices, with precision agriculture and organic alternatives emerging. The article concludes by discussing potential avenues for future research and innovation in fertilizer technologies, emphasizing sustainability and scalability for ongoing progress in agricultural practices.

Keywords: *Global public health, plant nutrition, biofortification, staple crops, micronutrients, health issues, environmental concerns*

Cite this article: Zaib, M., Zubair, H., Afzal, A.H., Naseem, M., Maryam, D., Batool, S., Raza, S., Umar, M., Marium, A., Tariq, H.U. (2023). Biofortification for Enhancement of Micronutrient Contents in Cereals, *Ind. J. Pure App. Biosci. 11*(6), 53-67. doi: http://dx.doi.org/10.18782/2582-2845.9035

INTRODUCTION

With the world population projected to soar between 9 to 10 billion by the end of 2050, the global community faces an unprecedented challenge. Meeting the food demands of this alarming population surge poses a critical dilemma for researchers and policymakers. Innovative and sustainable agricultural practices and strategic policy frameworks become imperative to ensure food security for the expanding global populace. The urgency to address this challenge highlights the need for collaborative efforts on a global scale to navigate the complexities of feeding an ever-growing world. Micronutrient deficiencies threaten global public health, affecting a substantial portion of the population, particularly in regions where staple crops such as maize, rice, and wheat form the backbone of daily diets. Among the critical micronutrients, boron, zinc, and iron stand out due to their indispensable roles in human health. The insufficiency of these micronutrients in the diet can lead to severe health consequences, ranging from anemia to impaired immune function, affecting millions worldwide Plants require eight essential micronutrients for optimal growth and development: zinc (Zn), iron (Fe), copper (Cu), manganese (Mn), molybdenum (Mo), boron (B), nickel (Ni), and chlorine (Cl). The term "micronutrients" is commonly used to denote crucial plant components necessary in smaller quantities. Despite their lower concentrations in soils and plants, these micronutrients are equally important to primary and secondary plant nutrients. Micronutrients are vital for various physiological processes, influencing enzyme activation, photosynthesis, and overall plant health. Although present in minute amounts, the scarcity of these elements can significantly impact plant growth (Zaib et al., 2023a; 2023b).

Zinc is crucial for enzyme function, iron is essential for chlorophyll synthesis, and boron is involved in cell wall formation. These micronutrients collectively contribute to the plant's ability to resist diseases, produce seeds, and adapt to environmental stresses. Recognizing the importance of micronutrients in sustaining plant life is integral for agricultural practices. Proper soil management and fertilization strategies are essential to ensure the availability of these micronutrients, fostering healthy and productive crops. In addressing the delicate balance of micronutrient levels, agricultural practices can optimize plant nutrition and enhance overall crop resilience. Iron (Fe), zinc (Zn), copper (Cu), manganese (Mn), boron (B), molybdenum (Mo), and nickel (Ni), are essential for plant growth and development. They serve as cofactors in various enzymatic reactions and are crucial for processes such as photosynthesis, respiration, and nitrogen fixation (Zaib et al., 2023b; 2023c; 2023d).

As a micronutrient essential for plant growth and human health, Boron plays a pivotal role in bone health, brain functions, and wound healing. Its significance extends beyond the realm of agriculture, influencing physiological processes crucial for human well-being (Hunt, 1998). Similarly, zinc is a vital micronutrient involved in various enzymatic activities and holds a key position in immune function, wound healing, and DNA synthesis. In many regions, zinc deficiency poses a global health challenge that warrants attention and strategic interventions (Prasad, 2008). Iron, another critical micronutrient, plays a fundamental role in oxygen transport, energy production, and immune function. Iron deficiency remains a leading cause of anemia worldwide, impacting both physical and cognitive development, especially in vulnerable populations (Zimmermann and Hurrell, 2008).

This comprehensive review aims to address the intricate connection between micronutrient deficiencies, with a specific focus on boron, zinc, and iron, and staple crops such as maize, rice, and wheat. By examining the current status of micronutrient deficiencies in regions heavily dependent on these crops, the review seeks to shed light on the urgency of implementing strategies to bridge the micronutrient gap and improve human health outcomes (Welch and Graham, 2004; Chakmak, 2008). Also, wastewater application poses a dual threat to both human health and staple crop growth. Contaminants in wastewater, such as heavy metals and pathogens, can jeopardize the safety of water supplies for communities. Additionally, when used for irrigation, wastewater may introduce harmful pollutants to the soil, impacting the growth and quality of staple crops and posing potential risks to food safety. Managing wastewater in agriculture is vital to safeguard both human well-being and sustainable crop production (Zaib et al., 2023e).

Micronutrient deficiencies in cereals

Global Distribution of Micronutrient Deficiencies

Micronutrient deficiencies remain a global public health challenge, disproportionately affecting certain regions due to dietary patterns and staple crop consumption. Regions such as sub-Saharan Africa, South Asia, and Southeast Asia have been identified as particularly vulnerable to deficiencies in essential micronutrients like iron, zinc, and vitamin A. The prevalence of these deficiencies is closely linked to the dependence on staple crops as dietary staples in these areas. In sub-Saharan Africa, a substantial portion of the population relies heavily on staple crops such as maize, cassava, and millet (Ali et al., 2021; Bouis and Saltzman, 2017). While serving as dietary staples, these crops often lack sufficient levels of critical micronutrients, contributing to widespread deficiencies. Iron deficiency, for example, is prevalent in regions where maize is a dietary staple, as maize typically contains lower bioavailable iron compared to other cereals (Ali et al. 2022a; De-Regil et al., 2013)

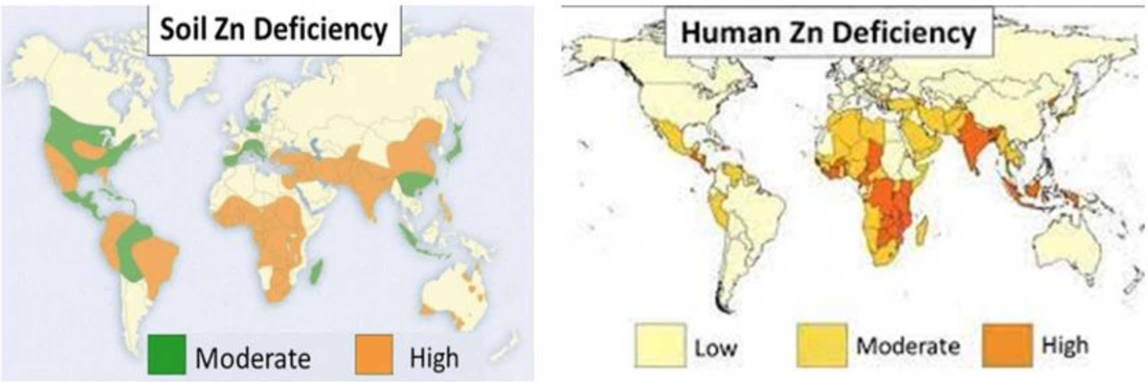

Figure 1: Geographical overlap of human Zn deficiency and soil Zn deficiency

Dehydration, a severe issue in plants, significantly impacts the absorption of essential nutrients by roots and their subsequent transport from roots to shoots, resulting in reduced uptake of crucial elements like iron, calcium, magnesium, sodium, etc., thereby necessitating interventions in nutrient intake and exclusion procedures, ultimately contributing to a diminished rate of the plant transpiration process (Ali et al., 2022b; Zaib et al., 2023f). The milling process that produces polished rice removes the outer layers, where many of the key nutrients are concentrated, leading to nutritional gaps in the diet. Southeast Asia encounters similar issues, with rice being a primary staple. The consumption of predominantly polished rice contributes to deficiencies in iron and zinc (Saltzman et al., 2013). These deficiencies have far-reaching implications for public health, as iron deficiency, for instance, can lead to anemia, especially among women and children.

The correlation between staple crop consumption and micronutrient deficiencies underscores the importance of addressing agricultural and dietary practices to enhance nutritional outcomes. Biofortification, a process of enhancing the nutrient content of crops through breeding or agronomic practices, has emerged as a promising strategy to tackle micronutrient deficiencies associated with staple crops (Ali et al., 2022c; Smith, 2020). Initiatives promoting the cultivation and consumption of biofortified crops, enriched with essential micronutrients, aim to improve overall nutritional status and health outcomes, particularly in regions where staple crops play a central role in daily diets.

Factors Contributing to Micronutrient Deficiencies in Staple Crops

Low micronutrient content in staple crops is influenced by a multitude of factors, presenting challenges for global food security and human nutrition. One significant contributor to micronutrient deficiency is the quality of the soil in which crops are cultivated. Soil composition, nutrient availability, and pH levels play pivotal roles in determining plants' uptake of essential micronutrients. Studies have shown that poor soil quality, characterized by nutrient composition imbalances, can decrease micronutrient concentrations in crops (Brown, 2018). Additionally, factors such as soil erosion and depletion contribute to diminished soil fertility, further exacerbating the issue of low micronutrient levels in staple crops (Cakmak, 2008). Agricultural practices also significantly impact the micronutrient content of staple crops. The use of certain fertilizers, irrigation methods, and crop rotation practices can either enhance or hinder the absorption of micronutrients by plants. Unbalanced fertilizer application, for example, may lead to deficiencies or imbalances in micronutrient uptake (Ali et al., 2022d; Balk and Paul, 2003; Zaib etal., 2023g). Furthermore, irrigation practices that do not consider the micronutrient needs of crops can contribute to inadequate nutrient supply, affecting the final nutritional profile of the harvested produce (White and Broadley, 2009).

Genetic factors inherent in crop varieties can determine their ability to accumulate and store micronutrients. The selection and breeding of crops for high yield and resistance to pests or diseases may inadvertently lead to reduced micronutrient content. This is particularly relevant in modern agriculture, where crop breeding has often prioritized traits other than nutritional content (Bouis, 2011). Genetic modifications aimed at improving crop resilience and productivity may unintentionally result in lower concentrations of essential micronutrients (Cakmak et al., 2010)

Addressing the challenge of low micronutrient content in staple crops requires a comprehensive understanding of these factors and the development of targeted intervention strategies. Sustainable agricultural practices, including precision farming, organic fertilization, and soil conservation, can contribute to improving soil quality and nutrient availability. Additionally, promoting the cultivation of crop varieties with inherent resistance to micronutrient deficiencies or employing biofortification techniques through breeding programs can enhance the nutritional quality of staple crops (Riaz et al., 2022c; Zaib et al., 2023h). Biochar, a carbon-rich material produced through the pyrolysis of organic matter, serves as an effective soil amendment. When incorporated into the soil, biochar enhances nutrient retention, promoting increased availability of essential elements for plant growth. Its porous structure and high cation exchange capacity contribute to improved soil fertility, making biochar a valuable tool for sustainable agriculture (Zaib et al. 2023i).

Table: 1. Factors Contributing to Micronutrient Deficiencies in Staple Crops

Key Factor	Description
Soil Quality	i. Soil composition, nutrient availability, and pH levels affect micronutrient uptake by plants. ii. Poor soil quality, characterized by nutrient imbalances, leads to decreased micronutrient concentrations in crops
Soil Erosion and Depletion	i. Soil erosion and depletion contribute to diminished soil fertility, exacerbating low micronutrient levels in crops
Agricultural Practices	i. Fertilizer use, irrigation methods, and crop rotation impact micronutrient absorption by plants ii. Unbalanced fertilizer application may lead to deficiencies or imbalances in micronutrient uptake iii. Inadequate irrigation practices can result in insufficient nutrient supply, affecting the nutritional profile of harvested produce

Role of Fertilizers in Enhancing Micronutrient Content

Boron, Zinc, and Iron Fertilizers

Various types of fertilizers have been specifically designed to provide targeted supplementation in addressing micronutrient deficiencies in crops, particularly in boron, zinc, and iron. Boron, zinc, and iron are essential micronutrients that play crucial roles in plant growth and development, and their deficiency can significantly impact crop yields and quality. In one more study, Inorganic fertilizers for micronutrients, such as iron (Fe), zinc (Zn), manganese (Mn), and copper (Cu), typically contain water-soluble forms of these elements. These fertilizers can address specific micronutrient deficiencies in crops, such as zinc and iron biofortification in cereals (Brown et al., 2002; Riaz et al., 2022b). Arsenic disrupts the concentration of zinc in soil, creating challenges for plant nutrient uptake. This interference may lead to altered zinc availability in the soil, potentially impacting crops' overall health and nutritional quality. Addressing this dynamic relationship is essential for sustainable agriculture and maintaining optimal zinc levels in the soil-plant system (Zubair et al., 2023).

Firstly, boron deficiencies can be mitigated through the application of boron-containing fertilizers. Boron is essential for plant cell elongation, pollen tube growth, and carbohydrate metabolism (Shorrocks 1997). Common boron fertilizers include borax and boric acid, which can be applied through soil incorporation or foliar spraying. Research indicates that careful management of boron application is necessary, as excessive levels can lead to toxicity and environmental concerns (Alloway, 2008). Secondly, zinc deficiencies are often tackled with zinc-containing fertilizers. Zinc is a key component in enzyme systems and is crucial for various physiological processes in plants (Broadly et al., 2007). Zinc sulfate and zinc oxide are commonly used fertilizers for addressing zinc deficiencies. These fertilizers can be applied through soil amendments or foliar application, with the choice of method depending on the specific crops and soil conditions. It is essential to consider the soil pH, as it can influence the availability of zinc to plants (Ali et al., 2023). Thirdly, iron deficiencies can be addressed through iron-containing fertilizers. Iron is vital for chlorophyll synthesis and electron transport in photosynthesis (Riaz et al., 2022a). Climate change disrupts photosynthesis, a vital process for plant growth, by altering environmental conditions such as temperature, precipitation, and carbon dioxide levels. These changes can negatively impact the efficiency of photosynthetic reactions, affecting plant productivity and overall ecosystem health. Increased temperatures and extreme weather events pose challenges to the delicate balance required for optimal photosynthesis. Understanding these disruptions is crucial for addressing the broader implications of climate change on global ecosystems (Zaib et al., 2023j). Iron chelates, iron sulfate, and iron oxides are commonly used as fertilizers to alleviate iron deficiencies. These fertilizers can be applied through soil incorporation or foliar spraying. However, the effectiveness of different iron fertilizers may vary depending on soil conditions, pH, and the specific crops being cultivated (Cakmak, 2008). Despite the positive impact of micronutrient fertilizers on crop productivity, it is crucial to consider potential environmental implications. The excessive application of boron, zinc, or iron fertilizers can lead to runoff, affecting water quality and potentially causing harm to aquatic ecosystems. Therefore, it is imperative to adopt precision application methods and adhere to recommended dosage guidelines to minimize environmental risks (Schepers and Pampolino, 2008).

Fertilizer Management Practices

In the realm of agricultural practices, an exploration of best practices in fertilizer management is essential for optimizing crop production and enhancing the nutritional quality of crops. One fundamental aspect of effective fertilizer management involves soil testing. Soil testing provides crucial insights into the nutrient levels present in the soil, enabling farmers to make informed decisions regarding the types and amounts of fertilizers required for specific crops. The significance of soil testing in fertilizer management is well-established (Raza et al., 2023). By tailoring fertilizer application to the soil's specific needs, farmers can address nutrient deficiencies and promote optimal plant growth.

Precision agriculture (PA) represents a sophisticated farming methodology that leverages modern technologies and data-driven techniques to optimize crop production. The primary objective of precision agriculture is to enhance productivity, efficiency, and sustainability by tailoring interventions to specific areas of a field, accounting for variations in soil, climate, and crop conditions. In contrast to traditional uniform application methods, which distribute inputs evenly across a field, often resulting in inefficiencies and waste, precision agriculture customizes interventions to maximize resource use.

Key components of precision agriculture include advanced tools like Geographic Information Systems (GIS), the Global Positioning System (GPS), remote sensing, sensor technologies, data analytics, and machine learning. These technologies empower farmers to generate detailed maps of their fields, closely monitor crop health and growth, and precisely apply inputs where they are most needed. By integrating these innovative tools, precision agriculture ensures a more targeted and resource-efficient approach, contributing to improved yields, reduced environmental impact, and overall sustainability in agricultural practices (Schepers and Francis, 2005; Irfan et al., 2023). This targeted approach contributes to cost-effectiveness and mitigates environmental concerns associated with excessive fertilizer use (Alteri, 1995). The integration of precision agriculture techniques into fertilizer management strategies demonstrates a commitment to sustainable and resource-efficient farming practices.

Sustainable farming techniques constitute a pivotal element in the discourse on best practices in fertilizer management. Organic farming and agroecology practices prioritize ecological balance and reduce environmental impact. These approaches emphasize the use of natural fertilizers, cover cropping, and crop rotation to maintain soil fertility and enhance micronutrient availability (Pretty, 2008). Adopting sustainable farming techniques contributes to improved micronutrient content in crops and long-term soil health and biodiversity conservation (Pandey et al., 2017: Zaheer et al., 2023).

Furthermore, the relationship between proper fertilizer management and enhanced micronutrient content in crops is underscored by scientific research. Studies have demonstrated that judicious fertilizer application, based on soil nutrient assessments and sustainable practices, positively influences the micronutrient composition of crops (Alloway, 2008). For example, adequate soil boron, zinc, and iron levels, achieved through optimal fertilizer management, directly impact the nutritional quality of staple crops such as maize, rice, and wheat (Penland, 1998). These findings reinforce the imperative of integrating scientific insights into on-the-ground fertilizer management practices.

Impact on Human Health

Enhanced Micronutrient Content and Human Nutrition

Micronutrient deficiencies pose a significant global health challenge, affecting millions of individuals and leading to a range of health issues. Boron, zinc, and iron are essential micronutrients that play crucial roles in human health, and their adequate intake is vital for maintaining overall well-being. This section delves into the potential health benefits of consuming crops enriched with elevated levels of boron, zinc, and iron. By exploring how improved crop nutrient content can contribute to reducing micronutrient deficiencies, we aim to shed light on the potential impact on global health. Boron is known to support bone health by aiding in the metabolism of calcium and magnesium, essential minerals for bone strength (Penland, 1998). Emerging research suggests that boron may play a role in cognitive function and brain health (Prasad, 2008). Zinc is a key player in immune function, contributing to the development and function of immune cells (Lansdown, 2007). The micronutrient is essential for wound healing processes, promoting tissue repair and regeneration (Koury and Ponka, 2004). Iron is a critical component of hemoglobin, the protein responsible for transporting oxygen in the blood (Beard, 2001). Iron is involved in energy production and metabolism, supporting overall vitality (Sterens et al. 2013). Micronutrient deficiencies, often referred to as hidden hunger, affect a significant portion of the global population, particularly in developing countries (Bouis and Saltzman, 2017). These deficiencies can lead to a range of health issues, including anemia, impaired immune function, and cognitive deficits. Addressing these deficiencies is a crucial step towards improving public health on a global scale. Biofortification, the process of enhancing the nutritional content of crops, presents a sustainable solution to combat micronutrient deficiencies (Hunt, 1998). Cultivating crops with elevated levels of boron, zinc, and iron can address these hidden hunger challenges.

Consuming boron-enriched crops can contribute to better bone health, potentially reducing the risk of bone-related disorders (Penland, 1994). Preliminary studies suggest that increased boron intake may positively impact cognitive function, providing a new avenue for addressing neurological health concerns (Wessels et al., 2017). Incorporating zinc-enriched crops into diets can enhance immune function, offering protection against infections and diseases (Lansdown, 2002). The increased intake of zinc through crops may facilitate faster wound healing and tissue regeneration (Zimmermann and Hurrell, 2007). Iron deficiency is a leading cause of anemia worldwide. Consuming iron-enriched crops can be a valuable strategy in combating this prevalent health issue (Beard, 2008). Adequate iron intake supports energy metabolism, contributing to sustained energy levels and overall vitality (HarvestPlus, 2023a). Several global initiatives have successfully implemented biofortification strategies to enhance crop nutrient content. For example, the Harvest Plus program has focused on developing zinc-enriched varieties of staple crops like rice and wheat, with positive outcomes in combatting zinc deficiencies (HarvestPlus, 2023b).

Economic and Social Implications

Bridging the micronutrient gap in staple crops holds substantial promise for enhancing human health, and this review will explore the economic and social implications of such initiatives, drawing on relevant literature. Micronutrient deficiencies, including those of boron, zinc, and iron, have been a persistent concern, particularly in regions where staple crops form the dietary backbone (Penland, 1998). By augmenting the content of these essential micronutrients in crops like maize, rice, and wheat, we not only address nutritional deficiencies but also unlock a cascade of economic and social benefits.

Improved human health resulting from enhanced micronutrient intake can have profound effects on overall productivity. Malnutrition, often associated with micronutrient deficiencies, can lead to decreased physical and cognitive abilities, hampering work capacity and productivity (Zimmermann and Hurrell, 2007). By addressing these deficiencies, individuals can experience improved health and vitality, contributing to increased productivity in both agricultural and non-agricultural sectors. Studies have shown that adequate intake of micronutrients positively correlates with cognitive function, which is crucial for learning and work performance. Thus, biofortification of staple crops can catalyze a healthier and more productive workforce.

Reducing healthcare costs is another compelling economic advantage of bridging the micronutrient gap. Micronutrient deficiencies are often linked to a range of health issues, including anemia, impaired immune function, and developmental disorders (Bouis and Saltzman, 2017). If left unaddressed, these health conditions can result in increased healthcare expenditures for individuals and governments. By proactively tackling micronutrient deficiencies through biofortification, the incidence of nutrition-related health problems can be reduced, decreasing healthcare costs. This, in turn, contributes to the economic well-being of individuals and frees up resources for other critical healthcare needs. Beyond individual health benefits, the economic implications extend to broader societal development. A population with improved overall health is better positioned to contribute effectively to economic activities and participate in societal advancement. The potential economic gains from a healthier population are manifold and can lead to increased national productivity, economic growth, and a more robust workforce.

Moreover, addressing the micronutrient gap aligns with global initiatives for sustainable development. The United Nations' Sustainable Development Goals (SDGs) emphasize the importance of eradicating hunger, ensuring good health and well-being, and promoting sustainable agriculture. Biofortification directly aligns with these goals, offering a sustainable solution to improve nutrition and health outcomes (UNICEF, 2013). As nations work towards achieving these SDGs, investments in biofortification programs become crucial for long-term social and economic development.

Challenges and Future Directions

Micronutrient deficiencies pose a significant threat to global food security and human health (Welch and Graham, 2002). In response to this challenge, fertilizer-based solutions have emerged as promising strategies to enhance the micronutrient content in crops (White and Broadly, 2005; Gruissem, 2015). However, the successful implementation of these solutions is not without challenges, particularly regarding economic constraints, technological limitations, and potential environmental concerns. One of the primary challenges associated with implementing fertilizer-based solutions for enhancing micronutrient content is the economic barrier faced by farmers, especially those in resource-limited regions (Stein and Podriguez, 2009). Smallholder farmers may find it challenging to afford micronutrient-enriched fertilizers, given the prohibitive costs associated with these specialized formulations, often containing essential micronutrients such as boron, zinc, and iron (Zou, 2012; Bouis and Welch, 2010).

Economic constraints further extend to the availability of funds for research and development to create affordable, micronutrient-enriched fertilizer formulations (Rashid and Minot, 2010). Addressing these economic constraints requires a multi-faceted approach.

Governments and international organizations can play a crucial role in addressing economic constraints by subsidizing or incentivizing the production and distribution of micronutrient-enriched fertilizers (Fan, 2008). Public-private partnerships are essential for fostering collaboration between agricultural enterprises and research institutions to develop cost-effective formulations (Haug, 2009). Additionally, farmer education programs on the long-term economic benefits of improved crop yields through enhanced nutrient content may stimulate greater adoption (Hidrobo, 2014). The effectiveness of fertilizer-based solutions heavily relies on the development of appropriate technologies for micronutrient delivery to crops (Cordell, 2009; VanLauwe, 2011). Challenges include formulating fertilizers with optimal micronutrient concentrations, ensuring their efficient uptake by plants, and preventing nutrient leaching or runoff (Sutton, 2011). Technological limitations may also encompass inadequate infrastructure for fertilizer production and distribution, particularly in remote or rural areas (Cakmak, 2009; Giller, 2015).

To overcome technological limitations, ongoing research is crucial to develop advanced fertilizer formulations with enhanced micronutrient bioavailability. Nanotechnology and precision agriculture techniques can contribute to the targeted delivery of micronutrients to crops, minimizing wastage and maximizing effectiveness. Investments in infrastructure development, such as improved distribution networks, can facilitate the widespread availability of micronutrient-enriched fertilizers (White and Broadley, 2009). While fertilizers play a crucial role in improving crop yields and nutrient content, there are environmental concerns associated with their use (Alloway, 2008). Excessive fertilizer application can lead to nutrient imbalances, soil degradation, and water pollution (Graham and Welch 1996). Moreover, if not applied judiciously, certain micronutrients may have detrimental effects on ecosystems and human health (Graham and Rengel, 1993). To address environmental concerns, sustainable farming practices, such as precision agriculture and integrated nutrient management, should be promoted (DeRosa, 2010). Precision agriculture enables targeted and controlled application of fertilizers, minimizing environmental impacts (Regel, 2015). Additionally, promoting organic and bio-fertilizers can offer environmentally friendly alternatives (Bǖnemann, 2018). Stringent regulations, guidelines on fertilizer use, and farmer education on responsible application are essential components of mitigating potential environmental concerns (Ali et al., 2021).

CONCLUSION

In conclusion, micronutrient deficiencies, particularly in boron, zinc, and iron, pose a substantial threat to global public health, affecting populations reliant on staple crops like maize, rice, and wheat and leading to consequences such as anemia and impaired immune function. This review emphasizes the interconnectedness of agricultural practices and nutritional outcomes, advocating for a multifaceted approach that integrates biofortification strategies, sustainable agricultural practices, and targeted fertilizer management. The global distribution of micronutrient deficiencies highlights the link between staple crop consumption and nutritional gaps, necessitating the adoption of biofortification to address deficiencies at the source. While specialized fertilizers containing micronutrients are effective, environmental considerations call for precision application methods. The impact on human health underscores the positive correlation between enhanced micronutrient intake and improved health outcomes, aligning with global sustainable development goals. Overcoming challenges in implementing fertilizer-based solutions requires collaborative efforts to address economic constraints, technological limitations, and environmental concerns through subsidies, research and development initiatives, and farmer education programs. In essence, addressing micronutrient deficiencies demands a holistic approach involving agricultural, nutritional, economic, and environmental considerations, with collaborative efforts crucial for creating sustainable and effective solutions to enhance the nutritional quality of staple crops and improve global public health.

Acknowledgement:
This creative scientific literature, an Acknowledgement, is an expression of gratitude for assistance in creating original work.

Funding:
No Funding for this paper

Conflict of Interest:
There is no conflict of interest between authors.

Author's Contribution:
All authors are contributed equally, and equal response is observed from all authors.

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