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Agronomic Biofortification with Micronutrients: A Pathway to Achieving Sustainable Development Goal-3

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Micronutrient malnutrition, often referred to as hidden hunger, affects billions of people worldwide. While global efforts largely emphasize increasing food quantity, the quality of food remains a major concern. Agronomic biofortification offers an effective and sustainable approach to enhance the micronutrient content of staple crops such as cereals, pulses, and oilseeds. Through various agronomic approaches like soil application, seed treatment with beneficial microbes, and foliar feeding, the micronutrient levels in grains can be substantially increased, for example, iron by 5–57% and zinc by 10–95%. By improving the nutritional value of crops, agronomic biofortification directly contributes to achieving SDG-3 (Good Health and Well-Being). In the near future, it holds significant potential to reduce malnutrition and improve human health globally.

Keywords: Malnutrition, Good health, Micronutrition, SDG-3

In many developing countries, cereals are the most common staple foods. Although they help in meeting basic hunger needs, their nutritional and micronutrient content is often very low. According to the WHO, nearly 2 billion people suffer from micronutrient deficiencies, particularly iron (Fe) and zinc (Zn). Modern high-yielding field crops have significantly boosted food production, but a major drawback is their low micronutrient concentration, which contributes to widespread hidden hunger. Even though the human body requires micronutrients in very small amounts, their deficiency can lead to severe health disorders and, in extreme cases, even death. Adequate intake of Fe and Zn is crucial; zinc activates more than 300 enzymes, while iron plays a vital role in metabolic functions and oxygen transport. The average zinc concentration in wheat, rice, and maize is 31.84 mg kg^{-1}, 16 mg kg^{-1}, and 15 mg kg^{-1}, respectively, which is much lower than the levels required to meet human nutritional needs 45 mg kg^{-1} for wheat, 28 mg kg^{-1} for rice, and 38 mg kg^{-1} for maize. Moreover, the bioavailability of zinc is often poor due to high phosphorus levels in soil, which reduce its absorption.

The Fe concentration in cereals such as wheat and maize is 45.4 mg kg^{-1} and 16 mg kg^{-1}, respectively. Iron content in grains also declines significantly during milling and processing. The micronutrient concentration in grains largely depends on its availability in the soil; for example, soils with DTPA-extractable Zn below 0.5 mg kg^{-1} and for Fe below 4.5 mg kg^{-1} are considered deficient for optimal plant growth. In India, around 35% of soils are zinc-deficient, and about 11% are iron-deficient.

Biofortification offers a dual advantage by improving both the micronutrient content and its bioavailability in grains. This makes it a highly feasible and cost-effective solution for low-income populations who rely heavily on staple cereals for daily nutrition.

Role of Zinc and Iron in Various Physiological Processes

Zinc (Zn): Zinc plays a vital role in maintaining healthy cellular functioning. It is essential for DNA and RNA synthesis, transcription, cell division and differentiation, growth and development, and normal reproductive health. Because of its presence in synaptic vesicles, zinc is also crucial for learning and memory processes. Recent studies suggest that zinc supplementation may help reduce inflammation and protect against brain damage. During chemotherapy, zinc levels in the body often decline, and dietary supplementation can support recovery and improve treatment tolerance.

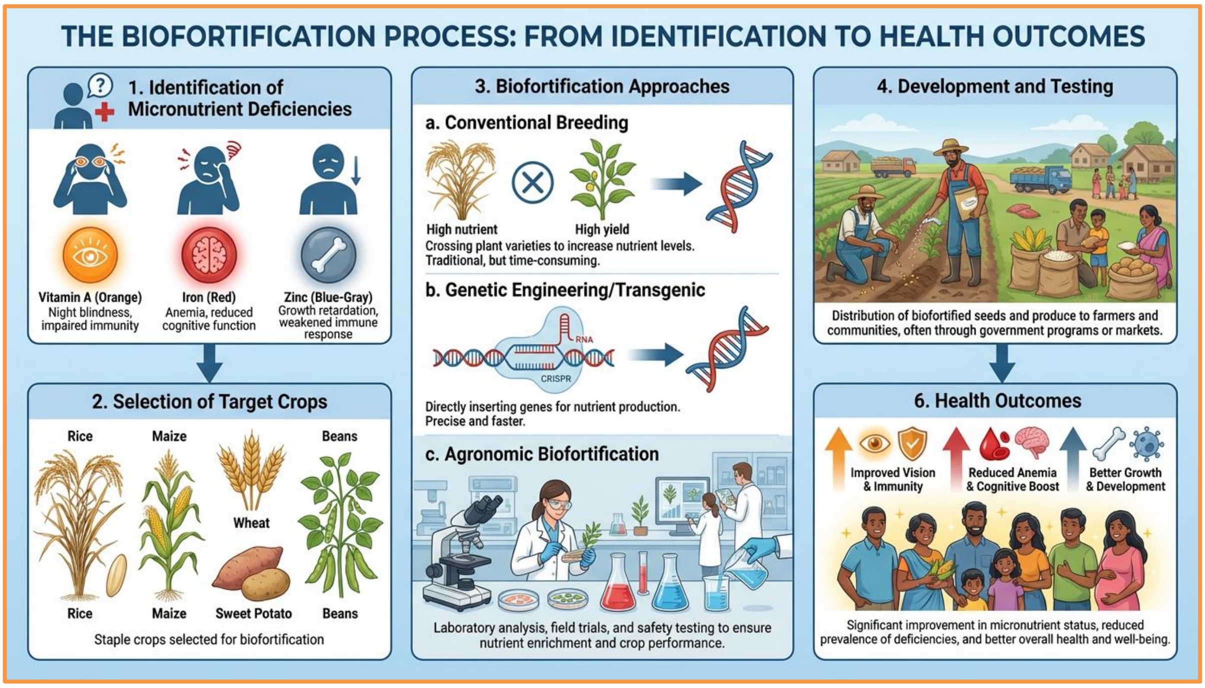

Fig. Biofortification process from identification to health outcomes.

Iron (Fe): For maintaining biological activities, iron plays a vital role. It helps in the transport of O_2, DNA synthesis, haem synthesis, electron transport, and cellular respiration. Nearly 70% of the body's iron is present in haemoglobin.

The recommended intake of iron for children, adolescents, and adults is 7–11 mg, 13 mg, and 18 mg, respectively. For zinc (Zn), the recommended intake is 7 mg for children and 11 mg for adolescents and adults. However, the actual intake in many populations is much lower than these recommendations. Due to this, several health problems occur, such as weakened immunity and increased vulnerability to infections. Zn deficiency leads to reduced growth, impaired immunity, and parakeratosis, a skin disorder characterized by abnormal keratinization. Fe deficiency also causes poor immune function, lethargy, and reduced thermoregulation, especially in young animals. Worldwide, about 17% of people have inadequate zinc intake, while 40% of pregnant women and 42% of children are anaemic, caused by iron deficiency.

Agronomic Biofortification Techniques

Agronomic biofortification can be achieved through several methods, but the most common approaches are seed treatment, soil application, and foliar application using fertilizers, biofertilizers, or nano fertilizers. Applying zinc and iron through these methods enhances their concentration in grains and in different seed components such as the aleurone layer, embryo, and endosperm.

Soil Application: Soil application of micronutrient fertilizers, particularly zinc sulphate heptahydrate ($ZnSO_4 \cdot 7H_2O$ @ 5–25 kg/ha), is the most common method used to enhance plant growth and improve grain zinc content. Other zinc sources and their Zn content

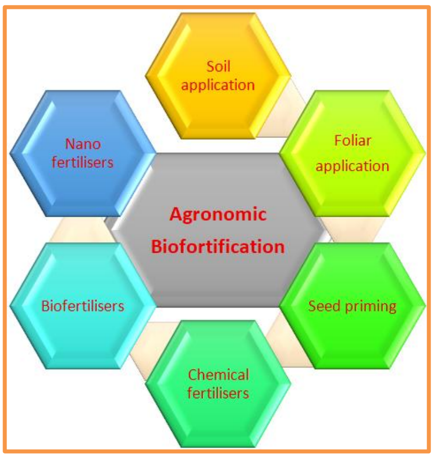

Fig. Approaches for Agronomic Biofortification

include $ZnSO_4 \cdot H_2O$ (33–35%), ZnO (78%), $ZnCO_3$ (52%), zinc chelate (12–14%), and Zn-EDTA (12.5%). However, despite its wide adoption, this approach has relatively low micronutrient use efficiency, making it less cost-effective. Continuous use can also lead to the accumulation of unused micronutrients in the soil, contributing to long-term soil pollution compared to more targeted and efficient technologies.

Foliar application: Compared to soil application, Foliar spraying requires less fertilizer and delivers nutrients more quickly. Nutrients applied on the leaf surface enter the plant either through stomatal openings or by cuticular penetration and are then rapidly transported to other plant parts via plasmodesmata. Several factors influence the efficiency of foliar application, including leaf type, wind velocity, fluid pH, and the growth stage at which the spray is applied. In wheat, the booting and milking stages are considered the most responsive for foliar zinc application. A 0.5% $ZnSO_4$ solution is commonly recommended for zinc foliar application. Zn is applied as a foliar spray for pulses at the pre-flowering and pod-formation stages, and for wheat at the flag-leaf and grain-filling stages. Iron (Fe), usually applied as $FeSO_4$, is also more effective through foliar application because soil-applied Fe often forms insoluble compounds."

Seed priming: Seed priming refers to soaking seeds in a nutrient-enriched solution before sowing to activate physiological processes that support better germination and early growth. This technique enhances plants' ability to overcome abiotic stresses and improves overall nutritional quality. This technique also promotes the leaching of antinutritional compounds such as phytic acid. For nutrient priming, microgreens are particularly effective because nutrients move rapidly from the seed to the emerging greens, which are consumed at the early seedling stage when their nutrient density is highest.

Chemical Fertiliser: Nitrogen fertilization is an essential agronomic technique for improving protein content in crops. The application of N also enhances grain Fe and Zn levels because it supports the remobilization of these micronutrients, thereby increasing their bioavailability. Several studies show that even without Zn supplementation, applying N fertilizer can still improve the Zn content of cereals and pulses. Foliar spraying with 1.0% urea has been reported to increase both Zn and Fe concentrations in grains.

Biofertilizers: Microorganisms such as plant growth–promoting rhizobacteria (PGPR), arbuscular mycorrhizal fungi (AMF), and zinc-solubilizing bacteria (ZSB) play a direct role in enhancing the nutritional quality of crops through nutrient mineralization. The organic acids released by these microbes improve the mineralization and solubility of nutrients. In addition, the Phyto siderophores secreted by microbes help increase the uptake of Fe and Zn by plants.

Nano fertilizers: Nanoparticles typically range in size from 1 to 100 nm. These active, encapsulated nutrient carriers have a very high surface area due to their extremely small size, which enhances the interaction between nutrients and plant tissues. ZnO nanoparticles (around 25 nm) are widely used to increase plant growth and improve micronutrient uptake. Nano-fertilizers support the principle of applying the right fertilizer, at the right place, and at the right time, and this precision is effectively achieved through advancements in nanotechnology.

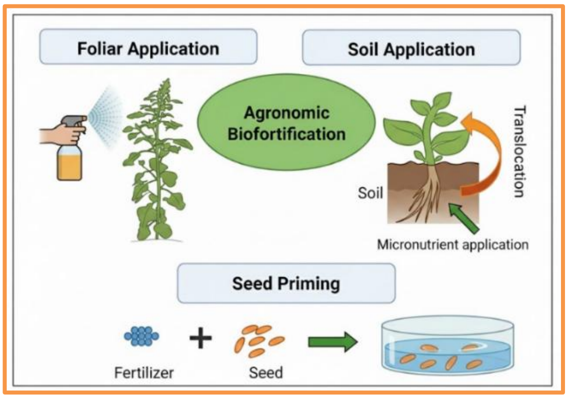

Fig. Agronomic Biofortification: Soil and Foliar Application, and Seed Priming

Case Study

A field study conducted at the ICAR–National Dairy Research Institute (NDRI), Karnal, demonstrated the effectiveness of agronomic biofortification in a wheat–baby corn cropping system under zero tillage. The study addressed widespread zinc and iron deficiencies affecting crop productivity and nutritional quality. The practice involved seed priming with

$ZnSO_4$ @ 0.5% along with foliar application of $ZnSO_4$ and $FeSO_4$ @ 0.5% recorded highest nutrient uptake, grain and fodder yields. This integrated micronutrient management resulted in better crop growth, improved yield, and enhanced quality of food and fodder, along with improved soil health and higher economic returns. The evidence highlights how simple agronomic interventions can improve micronutrient availability in crops, contributing to nutritional security and human health, thereby supporting Sustainable Development Goals.

Advantages and Limitations of agronomic biofortification

Advantages

- Rapid and practical: Zinc application through seed treatment, soil application, or foliar spraying can improve grain zinc concentration within a single cropping season.
- Cost-effective: It can provide nutritional benefits without requiring the development and release of new crop varieties.
- Easy adoption: Farmers can apply biofortification practices to existing, well-adapted and high-yielding cultivars.
- Flexible: Agronomic biofortification can be integrated into different cropping systems and production environments.
- Wide applicability: Zinc fertilization can be effective across diverse soils, crops, and growing conditions.
- Immediate nutritional benefits: It provides a relatively quick approach to addressing micronutrient deficiencies while genetic biofortification programs continue.

Limitations

- High fertilizer cost: The increasing price of micronutrient fertilizers can discourage farmers, particularly those with limited resources.
- Affordability concerns: Biofortified food products may sometimes command premium prices, limiting access among poorer populations.
- Risk of improper application: Excessive or poorly timed fertilizer application can adversely affect soil health, beneficial microorganisms, and crop productivity.
- Environmental concerns: Unbalanced fertilization may contribute to nutrient losses and environmental degradation.
- Soil and microbial sensitivity: Soil pH and fertilization practices strongly influence microbial activity and nutrient availability, making proper nutrient management essential.
- Economic uncertainty: Farmers are less likely to adopt biofortification when it does not increase yield, profitability, or overall economic returns.
- Need for balanced fertilization: Agronomic biofortification is most sustainable when micronutrient application is combined with balanced and site-specific nutrient management.

Summary

To determine the best fertilizer combinations for achieving higher grain Fe and Zn, the 4R strategy using the right source, at the right rate, at the right time, and in the right place, must be followed. Future research should focus on improving the mobility of minerals in soil, their uptake by plants, bioavailability and absorption in the human body. Maintaining long-term soil health agronomic biofortification is essential and can be achieved through balanced fertilizer application. The **HarvestPlus** program serves as a prime example of successful collaboration among international organizations, governments, NGOs, academic institutions, and agricultural bodies. Strong partnerships and effective knowledge-sharing are crucial to ensuring that biofortified crops reach a wider community and benefit populations at risk of micronutrient malnutrition.