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Review Article

Micronutrient deficiency in food crops and humans in Bangladesh and strategies for mitigation

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ABSTRACT

Micronutrients are substances required in trace amounts for the growth and metabolism of living organisms. In human nutrition, micronutrients include both vitamins and minerals, whereas in plant science, the term generally refers only to minerals. Thus, from a nutritional perspective, micronutrient deficiency denotes a lack of essential vitamins and minerals in the diet. Micronutrient deficiency is a major global health concern, affecting over two billion people worldwide, particularly children under five years of age and pregnant and lactating women. The most common deficiencies involve iron (leading to anaemia), zinc, vitamin A, and vitamin D. These deficiencies contribute to stunted growth, weakened immunity, cognitive impairment, and increased susceptibility to disease. This article aims to review the status of micronutrient deficiencies in both food crops and human populations in Bangladesh, and to advocate strategies for their mitigation. For normal growth and development, humans require 10 essential trace elements (minerals) and 14 vitamins. The trace elements include iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), iodine (I), selenium (Se), molybdenum (Mo), chromium (Cr), fluorine (F), and silicon (Si). Vitamins are classified into two groups: (a) water-soluble vitamins (e.g., ascorbic acid, biotin, cobalamin, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamin), and (b) fat-soluble vitamins (e.g., retinoic acid, calciferol, tocopherol, phylloquinone, and menaquinone). In plants, the essential micronutrients include iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), molybdenum (Mo), chlorine (Cl), and nickel (Ni). The health impacts of micronutrient deficiencies are often not immediately visible; hence, they are commonly referred to as “hidden hunger.” In many rural areas, cereal-based diets—while providing the majority of caloric intake—are relatively low in essential vitamins and minerals, contributing to this condition. Poverty further exacerbates the problem by limiting access to nutrient-rich foods such as meat, milk, fish, fruits, and vegetables. Addressing human micronutrient deficiencies requires a multifaceted approach, including supplementation, food fortification, biofortification, and dietary diversification. Additionally, homestead gardening (for fruits and vegetables) and nutrition education programs can play a crucial role in achieving long-term nutritional resilience. Future research should explore diverse and integrated strategies, particularly in fortification, biofortification, and public awareness, to effectively combat micronutrient deficiencies.

Introduction

Micronutrient deficiency is a global health concern. The present establishes a clear dichotomy between food security (caloric intake) and nutritional security (micronutrient adequacy). While the global agricultural system has succeeded in producing adequate carbohydrates through cereal crops, it fails

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to meet the physiological demands for trace elements and vitamins (FAO et al., 2023; Ahmed et al., 2021). This discrepancy is particularly acute for vulnerable demographics—children under five and pregnant women—whose developmental stages create a heightened biological "demand" for minerals like iron (Fe) and zinc (Zn).

The synthesis of data regarding Bangladesh reveals a population of 177 million (as of 2026) caught in a nutritional transition. Despite ranking 8th globally in population, the country struggles with a diet heavily reliant on rice, which is naturally low in Zinc (15-16 $\mu g\ g^{-1}$). The text identifies two primary barriers to nutritional health: Economic barriers**:** High prices for pulses, fruits, and vegetables render a "healthy diet" unaffordable for 66% of the population, and Biological barriers: The presence of antinutrients like phytic acid in cereal grains actively inhibits the absorption of minerals in the human gut (White and Broadley, 2009). Access to food is not enough; access to nutritious food is important for a healthy nation. The RDA (recommended daily allowance) of different minerals for humans is: Fe 8.0-18.0, Zn 8.0-11.0, Mn 1.8-2.3, Cu 0.9, I150, Se 55, Mo 45, Cr 25-35, and F 3-4 mg (White and Broadley, 2009).

There is a notable tension between the country's "significant progress" and its remaining challenges. On one hand, stunting levels dropped from 42% in 2013 to 28% in 2019 (Hossain, 2022). On the other hand, the 2019-20 National Micronutrient Survey paints a sobering picture. Anaemia has affected 40-50% of women and children, and vitamin deficiencies have affected 21-23% of preschool children, who suffer from Vitamin A and D deficiencies. Recent research by Nguyen et al. (2025) highlights that while adequacy is improving, significant inequities persist, particularly among children aged 2 to 5.

The text moves beyond identifying problems to suggesting dietary and agricultural shifts. It highlights the untapped potential of indigenous biodiversity, noting that small fish species like *mola* and *dhela* contain 50 to 100 times the micronutrient content of larger commercial fish (Hossain, 2022). Furthermore, it contrasts the Recommended Daily Allowance (RDA) for humans with the suboptimal levels currently found in crops, suggesting a need to shift agricultural priorities from "yield-only" to "nutrient-sensitive" farming. The argument implies that meeting the UN Sustainable Development Goals (SDGs) by 2030 will require bridging the "knowledge gap" between soil health, crop nutrient density, and human intake.

Although in the recent past many initiatives have been taken to address micronutrient deficiencies in food crops and humans in Bangladesh, some knowledge gaps remain, which this article addresses. Thus, this article aims to review the status of micronutrient deficiencies in food crops and humans in Bangladesh and advocate effective strategies for their mitigation.

Concept of micronutrients

Malnutrition can arise in three forms (Ritchie and Roser, 2020): (a) hunger and under nourishment, (b) obesity or over nourishment, and (c) micronutrient deficiencies. In this article, micronutrient deficiency has been addressed. Micronutrient refers to a substance that is essential in trace amounts for the growth and metabolism of a living organism.To a human nutritionist micronutrient could be a vitamin or a mineral,while plant scientists mean it only minerals. So, nutritionally micronutrient deficiency is a dietary deficiency of minerals and vitamins.

Essential micronutrients

Humans need 10 trace elements (minerals) and 14 vitamins for their normal growth and development. The trace elements include Fe, Zn, Mn, Cu, I, Se, Mo, Cr, F, and Si. The vitamins are of two types: (a) water-soluble vitamins, *viz*., ascorbic acid, biotin, cobalamin, folic acid, niacin, pantothenic acid, pyridoxine, riboflavin, and thiamin, and (b) fat-soluble vitamins, *viz*., retinoic acid, calciferol, tocopherol, phylloquinone, and menaquinone (Graham et al., 2001).

Unlike humans, both animals and plants require eight essential trace elements, but not all the same. The essential trace elements for animals are Co, Cu, Fe, Mn, Zn, I, Se, & Si, and those for plants are Fe, Mn, Zn, Cu, B, Mo, Cl, and Ni. Four micronutrients, viz. Fe, Mn, Zn, and Cu are common in humans, animals, and plants. Nutrient Mo is common for humans & plants and Se & Si are common for humans and animals. Other nutrients such as B, Cl, and Ni are essential only to plants. A list of minerals required by humans, livestock and crops is shown in Table 1 and the human requirement are presented in Table 2.

Table 1. Essential micronutrients for humans, livestock and crops.

Life	Micronutrients
Humans	Fe, Zn, Mn, Cu, I, Se, Mo, Cr, F, Si
Livestock	Fe, Zn, Mn, Cu, Co, I, Se, Si
Plants	Fe, Zn, Mn, Cu, B, Mo, Cl, Ni

Source: Bell and Dell, 2008.

Table 2. Amount of essential micronutrients required for humans

Element	RDA	RNI	UL	SUL
Fe (mg)	8.0-18.0	11.4	45.0	17.0
Zn (mg)	8.0-11.0	9.5	40.0	25.0
Mn (mg)	1.8-2.3	>1.4	11.0	4.0
Cu (mg)	0.9	1.2	10.0	10.0
I (µg)	150	140	1100	500
Se (µg)	55	75	400	450
Mo (µg)	45	50-400	2000	NS
Cr (µg)	25-35	>25	NS	NS
F (mg)	3-4	NS	10.0	NS
Si (mg)	NS	NS	NS	1500

Source: White and Broadley, 2009. NS=Non specified; RDA=Recommended daily allowance (US recommendation); RNI=Reference nutrient intake (UK recommendation) (Amount enough for atleast 97% in a group); UL=Upper intake level (US recommendation); SUL=Safe upper level (UK recommendation).

Of the essential micronutrients, the most frequently reported deficiencies for human health are Fe, Zn, I and vitamin A (Welch and Graham, 2004), the reason can be attributed to the smaller amount of micronutrients in cereal grains (Garg et al., 2018) which the people usually more consume and the higher amount of antinutrient substances e.g. phytic acid (Whiteand Broadley, 2009), a substance that inhibits the ab- sorption of mineral elements by the gut.

Functions of micronutrients

Each mineral nutrient has a definite role in humans, animals and plants (Tables 3 and 4; Fig. 1).

Hidden hunger

Hidden hunger is a form of malnutrition in which individuals consume enough calories but lack essential vitamins and minerals (micronutrients) like iron, zinc, iodine, and Vitamin A. The health impact of micronutrient deficiency is not always visible; it is therefore called ‘hidden hunger’. Swaminathan (2014) states, ‘Hidden hunger is one form of hunger which arises from lack of micronutrients’. Poor diet is a major cause of hidden hunger. Cereal-based diets, the primary source of energy (calories) for rural people, are relatively low in vitamins and minerals, leading to hidden hunger. In addition, poverty is a major factor limiting access to nutritious foods, such as meat, milk, fish, fruits, and vegetables (Bouis et al., 2011a). About 800 million people worldwide are chronically hungry (calorie deficiencies) (FAO et al., 2017) and more than 2 billion people are affected by hidden hunger (micronutrient deficiencies), the vast majority from developing countries (WHO, 2006; McGuire, 2015; Hodge, 2016). Based on Disability-Adjusted Life Years (DALYs) data, Gödecke et al. (2018) observed that all country-level determinants have a larger effects on the burden of chronic hunger (calorie deficiencies) than on the burden of hidden hunger (micronutrient deficiencies), and complementary micro-level interventions are required to end hidden hunger. The Hidden Hunger Index (HHI) for countries in South Asia and Southeast Asia is shown in Table 5.

Table 3. Functions of micronutrients in plants.

Micronutrients	Key functions
Iron	Component of cytochromes, ferrodoxins and leghaemoglobin; involved in the nitrogenase and nitrate reductase enzymatic reactions, associated with chlorophyll formation, protein synthesis.
Manganese	Involved in the oxidation-reduction processes of photosynthetic electron transfer system, acts as a bridge for ATP and enzyme complex (phosphokinase), activates IAA oxidases.
Zinc	Synthesis of tryptophane needed for the production of auxins; activation of dehydrogenase and carbonic anhydrase enzymes; helps in protein synthesis, high P interferes with Zn uptake by plants.
Copper	Acts as an electron carrier in photosynthesis and respiration; part of enzymes e.g. cytochrome oxidase; involved in protein and carbohydrate metabolism and N_2 fixation, helps in pollination and seed set, involved in the desaturation and hydroxylation of fatty acids.
Boron	Regulates carbohydrate metabolism; involved in protein synthesis; helps in transport of photosynthetic sugars to meristematic (growing) tissues; good role in pollen viability and seed formation.
Molybdenum	Constituent of nitrate reductase and nitrogenase enzymes; role in Fe absorption and translocation in plants.
Chlorine	Involved in the evolution of O_2 in photosynthesis; increases cell osmotic pressure, stomatal regulation, increases hydration of plant tissues.
Nickel	Works as a co-factor to enable urease to catalyze the conversion of urea into the ammonium ion, which plants can use as a source of N.

Source: BARC, 2024.

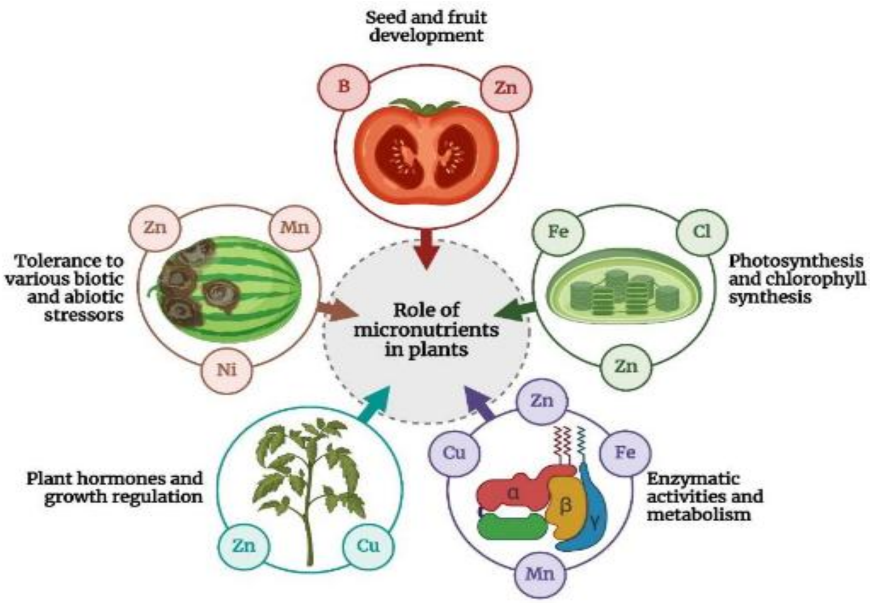

Fig. 1. Role of micronutrients in plants (Behera et al., 2025).

Table 4. Functions of micronutrients for humans and their food sources.

Micronutrient	Key functions	Key food sources
Vitamin A (Retinoids/Carotenoids)	Vision, immune system, cellular communication, skin health	Liver, fish, eggs, carrots, spinach, sweet potatoes, cantaloupe
Vitamin B1 (Thiamine)	Glucose breakdown, energy metabolism	Whole grains, nuts, seeds, legumes, pork, fortified foods
Vitamin B2 (Riboflavin)	Cell function, growth, development, metabolism	Liver, dairy products, eggs, meat, leafy greens
Vitamin B3 (Niacin)	Converts food into energy, DNA repair	Meat, fish, poultry, legumes, peanuts
Vitamin B6 (Pyridoxine)	Metabolism, brain development, immune function	Fish, poultry, legumes, nuts, whole grains
Vitamin B9 (Folate/Folic Acid)	Cell division, DNA production, nerve function	Leafy greens, beans, asparagus, peanuts, fortified grains
Vitamin B12 (Cobalamin)	Red blood cell formation, neurological function, DNA synthesis	Meat, fish, eggs, dairy, shellfish
Vitamin C (Ascorbic Acid)	Antioxidant, collagen production, immune support	Citrus fruits, berries, peppers, broccoli, tomatoes
Vitamin D	Calcium absorption, bone health, immune function	Fatty fish, egg yolks, fortified milk, sunlight exposure
Vitamin E	Antioxidant, protects cells from free radicals	Vegetable oils, nuts, seeds, spinach
Vitamin K	Blood clotting, bone metabolism	Leafy greens (kale, spinach), broccoli, vegetable oils
Calcium (Mineral)	Bone structure, muscle contraction, nerve transmission	Dairy (milk, cheese, yogurt), leafy greens, fish with bones
Iron (Mineral)	Oxygen transport, energy metabolism	Red meat, lentils, beans, spinach, fortified cereals
Zinc (Mineral)	Immune function, wound healing, protein synthesis	Shellfish, beef, pumpkin seeds, nuts, whole grains
Iodine (Mineral)	Thyroid hormone production, brain development	Iodized salt, seafood, dairy products
Magnesium (Mineral)	Bone health, over 300 metabolic reactions, nerve function	Nuts, spinach, legumes, whole grains
Selenium (Mineral)	Thyroid health, antioxidant protection	Brazil nuts, seafood, eggs, meat

Source: Gombart et al., 2020.

Table 5. Hidden Hunger Index (HHI) and micronutrient deficiencies in South Asia and Southeast Asia.

Region	Country	Deficiency prevalence (%)			
		HHI score	Zn[1]	Fe[2]	Vitamin[3]
South Asia	Afghanistan	47.7	59.3	19.0	64.5
	India	48.3	47.9	34.7	62.0
	Pakistan	26.7	42.0	25.5	12.5
	Bangladesh	29.3	43.0	23.5	21.7
	SriLanka	22.3	19.2	12.6	35.3
	Nepal	35.3	49.3	24.2	32.3
	Bhuttan	33.3	37.5	40.3	22.0
	Maldives	30.0	31.9	48.9	9.4
Southeast Asia	Indonesia	27.3	40.1	22.3	19.6
	Thailand	14.7	15.7	12.6	15.7
	Philippines	30.7	33.8	18.2	40.1
	Malaysia	11.7	15.6	16.2	3.5
	Singapore	NA	4.4	11.3	NA
	Vietnam	24.0	43.3	17.1	12.0
	Myanmar	36.3	40.6	31.6	36.7
	Cambodia	31.0	39.5	31.0	22.3
	Laos	38.7	47.6	24.1	44.7
	Brunei	NA	11.6	14.5	NA
	Timor-Leste	39.0	55.7	15.8	45.8

Source: Muthayya et al., 2013. NA=Data not available, HHI score= [Stunting (%) + Anaemia (%) + Low serum retinol (%)]/3, three components equally weighted; [1]Stunting as proxy for Zn; [2]Anemia as proxy for Fe; [3]Low serum retinol, <0.7 μmol L^{-1}

The situation of Fe and Zn deficiency is worse in South and southeast Asia, where a high proportion of cereal crops, such as rice and wheat, are consumed as a staple food (Cakmak, 2008; Stein, 2009). Cereals contribute about 60% for Zn and 55% for Fe to the daily intake of these minerals by Bangladeshi people (Islam et al., 2014). Ahmed et al.(2016) reviewed micronutrient deficiencies among children and women in Bangladesh. Their view states that, as per the National Micronutrients Status Survey report (2011-2012), among the preschool-age children, 20.5% are deficient in vitamin A, 44·5% in Zn and 10.7% in Fe. About 57% of non- pregnant and non-lactating women are anemic, and 25% women are Fe deficient, and nearly 50% pregnant and lactating women are anaemic, induced by Fe deficiency.

Soil as a source of micronutrients

A link exists between the health of soil and the health of people who consume foods produced on soils (Friedrichsen et al., 2018). Healthy soils continuously provide ecosystem services, such as sustaining plant and animal productivity, increasing biodiversity, and maintaining or enhancing the qualities of air and water, thereby supporting human health (Anonymous, 2018). Plants depend on soil for nutrients, and both humans and animals depend on plants for food. So, soil can be regarded as the basis of life. Jahiruddin (2020a) has reviewed how soil health affects human health. When soil is healthy, plants grown on healthy soil are healthy, reviewed how soil health affects human health. When soil is healthy, plants grown on healthy soil are healthy, and consequently, man eating plant food is healthy. As reported by Hasan et al. (2020), 55-60% soils of Bangladesh are deficient in two micronutrients, viz., zinc & boron, and farmers are advised to apply zinc sulphate and boric acid fertilizers. We do not fully understand the complex interactions among soil, crops and human health. For a thorough understanding of safe and nutritious food production grown on soil and its broadly impact on human health, a multidisciplinary approach is needed. Contributions from experts in agriculture, human nutrition and social sciences are important for addressing micronutrient deficiencies in food crops and human health issues.

Biofortification

Biofortification is a biological process of adding micronutrients to food crops through breeding or an agronomic approach. It is recognized as a good means of improving the diet of the malnourished rural population (Bouis, 2013; Garg et al., 2018). A number of studies have been done and are in progress regarding biofortification of cereals, such as in rice (Behura et al., 2011; Mubarak et al., 2015; Jahiruddin and Islam, 2018), wheat (Cakmak et al., 2010; Guzmán et al., 2014; Jahiruddin and Islam, 2018), and maize (Qin et al., 2012; Šimic´ et al., 2011).

Breeding approach includes conventional breeding and genetic engineering (transgenic). The agronomic approach covers fertilizer management, variety screening and crop diversification. The HarvestPlus Challenge Programme on 'Biofortified Crops for Improved Human Nutrition' was initiated in 2004 with the objective of developing cultivars of staple food crops that are rich in Fe, Zn, and vitamin A (β-carotene). The target crops include 7 food crops: rice, wheat, maize, cassava, pearl millet, beans and sweet potato. Those crops have been chosen based on the observation that those foods are consumed as staple foods by the world's poor. The HarvestPlus programme is carried on in south Asia for rice Zn (target 28 μg g^{-1}) in Bangladesh and India, for wheat Zn (target 28 μg g^{-1}) (& Fe secondary) in India and Pakistan, and for lentil Fe (target 70 mg g^{-1}) (& Zn secondary) in Bangladesh, Nepal and India (HarvestPlus, 2014).

The success of biofortification programme depends on three factors, as outlined by Bouis et al. (2011b). The factors are: (i) the biofortified crop must be high yielding and profitable to the farmer, (ii) the biofortified crop must be as efficacious and effective in reducing micronutrient malnutrition of humans, and (iii) the biofortified crop must be acceptable to both farmers and consumers in the regions where people are afflicted by micronutrient deficiency. For example, BRRI dhan62 (Zn-enriched rice variety) has not been popularized among the farmers in Bangladesh due to low yield potential (4.0-4.5 tha^{-1}). However, the later varieties, notably BRRI dhan74, 84, 100, and 102 have addressed this problem with high yield potential and high Zn content. These bio-fortified, non-GMO varieties offer high zinc content (ranging from 22.8–27.6 μg g^{-1} Zn content) (Table 6).

Table 6. Zinc enriched BRRI rice varieties.

Variety	Season	Zinc content (μg g^{-1})	Yield potential (t ha^{-1})	Key feature
BRRI dhan102	Boro	25.5	8.1	Long slender grain
BRRI dhan100	Boro	25.7	7.7	Slender, non-sticky
BRRI dhan84	Boro	27.6	6.5	Red-colored grain
BRRI dhan74	Boro	24.2	7.1	Coarse grain, high yield
BRRI dhan72	Aman	22.8	6.0	Tidal flood tolerant
BRRI dhan64	Boro	24.0	6.5	Mediumcoarse grain
BRRI dhan62	Aman	19.0	4.5	Shortest duration (100 days)

BRRI, 2025.

Recently, Jahiruddin (2020b) has comprehensively reviewed biofortification of food crops, with greater emphasis on micronutrient malnutrition in South Asia. Apart from the breeding approach of biofortification, the fertilization strategy (agronomic method) is a rapid way to achieve micronutrient-dense foods without incurring yield loss. An increment of 4-8 μg g^{-1} Zn in wheat grain and 2-4 μg g^{-1} Zn in rice grain is possible through Zn fertilization (Jahiruddin and Islam, 2018). Farmers of South Asian countries commonly use N, P and K fertilizers; use of micronutrient fertilizers is limited (Jahiruddin, 2019). Efficient management of N and Zn fertilizers would help enhance the grain Fe and Zn concentrations, as evidenced by positive correlation of seed Fe and Zn with N contents in several crops (Cakmak et al., 2010; Kutman et al., 2010). Siddika (2019) observed a synergistic relationship between N and Zn concentrations of rice. However, the success rate and acceptability of the genetic engineering technique (transgenic) appear to be much lower compared to conventional breeding. Furthermore, the globally introduction of GMO food crops is a subject of debate, and in fact, their consumption is very low. In breeding programs, breaking the negative relationship between grain yield and Zn or Fe concentration is a challenging for enhanced micronutrient density in cereal grains (Zhao and McGrath, 2009; Bouis and Welch, 2010; Waters and Sankaran, 2011). Processing of food grain is also important in the context of the biofortification strategy. Minerals such as iron, zinc, and copper, which are highest in rice bran, are lost during milling and polishing. This is not a problem for Se and S, since they reach maximum levels in the embryo (Gregorio et al., 2000). In the past, nutrient supplementation, food fortification, and dietary diversification were widely used to reduce micronutrient deficiency (Casey et al., 2009; Eneroth et al., 2010; Ritchie and Roser, 2020). However, these approaches had limited success (Ssemakula and Pfeiffer, 2011). Child mortality from diarrhoea and pneumonia was reduced significantly in Bangladesh with the use of the‘baby zinc’ tablet developed by ICDDR,B (Baqui, 2002; Brooks et al., 2005). However, fortification and supplementation programs could complement biofortification for better use by urban people, not by rural people.

Mitigation of micronutrient deficiencies in Bangladesh is primarily driven by the National Strategy on Prevention and Control of Micronutrient Deficiencies (2015-2024), which employs a multi-sectoral approach combining food fortification, supplementation, and food-based dietary diversification. These strategies aim to address high rates of deficiencies (iron, vitamin A, zinc, iodine) by focusing on vulnerable groups, including children, women of reproductive age, and pregnant women.

When a soil is critically deficient in micronutrients, the benefits of biofortified varieties cannot be achieved. Thus, biofortification should be considered as an integrated approach in which both breeding and agronomic approaches are equally important for the question of sustainability (Mubarak et al., 2015). In cultivation of micronutrient biofortified varieties, the application of micronutrient fertilizers can be regarded as a sustainable strategy to boost the crop

Strategies for micronutrient deficiency mitigation

There are four possible ways to address mitigation of micronutrient deficiency in humans.

➢ Supplementation	Use of concentrated micronutrients in pill, powder or liquid form
➢ Food fortification:	Addition of micronutrients to food products during processing such as ri milling, wheat flours
➢ Biofortification:	Addition of micronutrients to food crops by breeding or agronomic method.
➢ Diet diversification:	Consumption of micronutrient rich diet, e.g. fruits, vegetables, pulses.

Ritchie and Roser, 2020.

yield with higher mineral concentrations in edible parts (White and Broadley, 2005; Graham et al., 2007; Pfeiffer and McClafferty, 2007). Concurrently, it is also needed to enhance the concentrations of 'promoter'substances such as ascorbate (vitamin C), which stimulates the absorption of mineral elements by the gut, and to lower the concentrations of 'antinutrients', such as phytate, which interferes with their absorption (White and Broadley, 2009). Agronomic biofortification complements the breeding approach. Thus, neither breeding nor an agronomic approach alone can adequately and sustainably solve the problem of micronutrient malnutrition. For an effective and sustainable strategy, agronomic biofortification needs to be complemented by breeding for micronutrient enrichment of food crops.

Agricultural and community-based nutrition programs in Bangladesh

These programs focus on enhancing food security through homestead food production (HFP), dietary diversification, and nutrition education to combat micronutrient deficiencies, particularly benefiting women and children. There are several programs and models aligned with the community-based nutrition and Homestead Food Production (HFP) programs to increase micronutrient-rich food consumption among vulnerable households. There is ample evidence that the HFP program in Bangladesh has improved food security for more than 5 million vulnerable people across diverse agro-ecological zones (Ahmed and Chowdhury, 2016). Rahman et al. (2025) advocate promoting nutrient-dense crop production and homestead gardening with green leafy vegetables & fruits and awareness programs to change dietary behaviors in order to attain long-term nutritional resilience in Bangladesh.

Helen Keller International (HKI) HFP Program: The foundational model introduced over two decades ago to combat vitamin A deficiency by promoting year-round production of nutrient-rich fruits and vegetables.

BARI "Palima" Model: Initiated in 1998 by the On-Farm Research Division (OFRD) of the Bangladesh Agricultural Research Institute (BARI), focusing on homestead vegetable and fruit production based on local ecological niches.

SI-MFS (Sustainable Intensification of Mixed Farming Systems): Since 2022, this initiative has supported over 9,000 farmers in northern/southern Bangladesh, often using the "Saidpur Model" for year-round intensive vegetable, fruit, and small livestock production.

Floating Garden (Baira) Agriculture: FAO-supported initiatives that use traditional hydroponic techniques in waterlogged areas to produce vegetables like okra, brinjal, and gourds.

Community-Based Initiatives: Programs like those in Rangpur and Nilfamari (JANO initiative) teach climate-smart agriculture and nutrition education.

Rohingya Camp Homestead Gardening: A specialized program in Cox's Bazar utilizing cash-based transfers to motivate participation in gardening activities.

Key research gaps

Widespread vitamin D and B12 deficiencies: There is a huge gap in knowledge regarding Vitamin D and Vitamin B12 deficiencies, with limited intervention strategies targeting these deficiencies.

Evaluation of fortification compliance: There is a lack of data on consumer compliance, actual nutrient intake, and the bioavailability of these fortified foods in rural, low-income settings.

Climate change and nutritional security: There is a critical need to understand how climate change (flooding, salinity, heat) impacts nutrient-dense food production.

Impact of infectious disease and sanitation: Research is needed on how diarrhoeal diseases and parasitic infections in slum areas affect nutrient absorption and on the effectiveness of supplementation programs.

Urban vs. rural disparities: There is a limited study tracking the shifting prevalence of hidden hunger in urban slum dwellers compared to rural, coastal, and haor-affected populations.

Thus, these knowledge gaps need to be addressed through productive research and interventions.

Conclusion

Micronutrient deficiency is a global health problem affecting over 2 billion people, particularly children and pregnant women, causing several health consequences like stunted growth, cognitive impairment, and weakened immunity. Common deficiencies are iron, zinc, vitamin A, and vitamin D, which results mainly from a cereal (rice) based diet of poor people living in rural areas. Young children (under five) and pregnant and lactating women are at particular risk of micronutrient deficiencies. Key strategies to combat this problem include food fortification (e.g., iodization of salt), biofortification, dietary diversification, and nutrient supplementation. Homestead food production programs encouraging small-scale, nutrient-dense gardening (fruits/vegetables) could be introduced to improve dietary diversity. Biofortification, such as the introduction of zinc-enriched rice (e.g., BRRI dhan 84, 100 & 102) and Golden Rice (Vitamin A), can increase the nutrient density of crops. This chapter provides an excellent foundation by establishing the Economic Barrier (the price of pulses/vegetables) and the Biological Barrier (phytic acid), making a compelling case that "access to food is not enough." Future research should explore diverse avenues to effectively address micronutrient deficiency through fortification, biofortification, and awareness programs. Contributions of experts from agriculture, human nutrition and social science fields are important to address the micronutrient deficiency of food crops and human health issues in this country.

Conflict of interest

Regarding the publication of this paper, the author has no conflict of interest.

References

Ahmed F, Prendiville N and Narayan A. Micronutrient deficiencies among children and women in Bangladesh: progress and challenges. *J. Nutr. Sci.*,2016; 5: e46.

Ahmed M and Chowdhury MAT. Homestead food production (HFP) in Bangladesh: An Approach to improve diet quality and enhance micronutrients-rich sustainable food security. *OIDAInt. J. Sustain. Dev.* 2016; 9(10): 51-57.

Ahmed F, Khosravi-Boroujeni H, Khan MR, Roy AK and Raqib R. Prevalence and predictors of vitamin D deficiency and insufficiency among pregnant rural women in Bangladesh, 2021; 13(2): 449.

Anonymous. *Conference on Connections between Soil Health and Human Health*. October 16-17, 2018. Silver Spring, Maryl and USA.

Baqui AH. Effect of zinc supplementation started during diarrhoea on morbidity and mortality in Bangladeshi children: community randomized trial. *Br. Med. J.* 2002; 325: 1059-1059.

BARC. *Fertilizer Recommendation Guide-2024*. Bangladesh Agricultural Research Council (BARC), Farmgate, Dhaka, 2024.

Behera SR, Bhatt M, Gairola A, Rana S, Mohapatra A. Joshi D and Tripathy A. A comprehensive review of micronutrients and their implications on vegetable quality. *J. Adv. Biol. Biotechnol.* 2025; 28(5): 284-299.

Behura N, Sen P and Kar MK. Introgression of yellow stem borer (Scirpophaga incertulus) resistance genes into cultivated rice (Oryza sp.) from wild species. *Indian J. Agric. Sci.,* 2011; 81: 359-362.

Bell RW and Dell B. *Micronutrients for Sustainable Food, Feed, Fibre and Bioenergy Production*. International Fertilizer Industry Association (IFA), Paris, France, 2008.

Bouis HE, Hotz C, McClafferty B, Meenakshi JV and Pfeiffer WH. Biofortification: A new tool to reduce micronutrient malnutrition. *Food Nutr. Bull*. 2011; 32(1 Suppl): S31-40.

Bouis HE and Welch RM. Biofortification – A sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Sci.* 2010; 50: S20-S32.

Bouis HE, Eozenou P and Rahman A. Food prices, household income, and resource allocation: Socioeconomic perspectives on their effects on dietary quality and nutritional status. *Food Nutr Bull.* 2011a; 32: S14-S23.

Bouis HE, Hotz C, McClafferty B, Meenakshi JV and Pfeiffer WH. Biofortification: A new tool to reduce micronutrient malnutrition. *Food Nutr. Bull.* 2011b; 32: S31-S40.

Broadley MR, White PJ, Hammond JP, Zelko I and Lux A. Zinc in plants. *New Phytologist,* 2007; 173: 677-702.

Brooks WA, Santosham M, Naheed A, Goswami D, Wahed MA, Diener-West M, Faruque ASG and Black RE. Effect of weekly zinc supplements on incidence of pneumonia and diarrhoea in children younger than 2 years in an urban, low-income population in Bangladesh: Randomised controlled trial. *The Lancet,* 2005; 366:999-1004.

BRRI (Bangladesh Rice Research Institute). Modern Rice Cultivation, 25th Edition, 2025; p 128.

Cakmak I, Pfeiffer WH and McClafferty B. Biofortification of durum wheat with zinc and iron. *Cereal Chem.*, 2010; 87: 10-20.

Cakmak I. Enrichment of cereal grains with zinc: Agronomic or genetic biofortification? *Plant Soil,* 2008; 302: 1-17.

Casey GJ, Phuc TQ, MacGregor L, Montresor A, Mihr- shahi S, Thach TD, Tien NT and Biggs BA. A free weekly iron-folic acid supplementation and regular deworming program is associated with improved hemoglobin and iron status indicators in Vietnamese women. *BMC Public Health,* 2009; 9:261.

Eneroth H, Arifeen S, Persson LA, Lonnerdal B, Hossain MB, Stephensen CB and Ekstrom EC. Maternal multiple micronutrient supplementation has limited impact on micronu trient status of Bangladeshi infants compared with standard iron and folic acid supplementation. *J. Nutr.* 2010; 140: 618-624.

FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2023: *Urbanization, agrifood systems transformation, and healthy dietsacross the rural-urban continuum*. Rome, Italy, 2023.

FAO, IFAD, UNICEF, WFP, WHO. The State of Food Security and Nutrition in the World 2017: *Building resilience for peace and food security. World Food Programme*, FAO, Rome, Italy, 2017.

Friedrichsen CN, Daroub SH, Monroe MC, Stepp JR and Wani SP. Mental models of soil management for food security in peri-urban india. *Urban Agric. Region. Food Syst.,* 2018; 3(1):170002.

Garg M, Sharma N, Sharma S, Kapoor P, Kumar A, Chunduri V and Arora P. Biofortified crops generated by breeding, agronomy, and trans- genic approaches are improving lives of millions of people around the world. *Front. Nutr.* 2018; 5: 12.

Gödecke T, Stein AJ and Qaim M. The global burden of chronic and hidden hunger: Trends and determinants.*Glob. Food Secur.* 2018; 17: 21-29.

Gombart AF, Pierre A and Maggini S. A review of micronutrients and the immune system-working in harmony to reduce the risk of infection. *Nutr.* 2020; 16; 12(1): 236.

Graham RD, Welch RM and Bouis HE. Addressing micronutrient malnutrition through enhancing the nutritional quality of staple foods: Principles, perspectives and knowledge gaps. *Adv. Agron.* 2001; 70: 77-142.

Graham RD, Welch RM, Saunders DA, Ortiz-Monasterio I, Bouis HE, Bonierbale M, deHaan S, Burgos G, Thiele G, Liria R, Meisner CA, Beebe SE, Potts MJ, Kadian M, Hobbs PR, Gupta R and Twomlow S. Nutritious subsistence foodsystems. *Adv. Agron.* 2007; 92: 1-74.

Gregorio GB, Senadhira D, Htut H and Graham RD. Breeding for trace mineral density in rice. *Food Nutr. Bull.* 2000; 21: 382-386.

Guzmán C, Medina-Larqué AS, Velu G, González-Santoyo H, Singh RP, Huerta-Espino J, Ortiz-Monasterio I and Peña RJ. Use of wheat genetic resources to develop biofortified wheat with enhanced grain zinc and iron con centrations and desirable processing quality. *J. Cereal Sci.* 2014; 60: 617-622.

HarvestPlus. Better Crop. Better Nutrition. HarvestPlus, Washington, DC, USA. 2014.

Hasan MN, Bari MA and Lutfar MR. Soil fertility trends in Bangladesh 2010 to 2020. *SRSRF project*. Soil Resource Development Institute, Ministry of Agriculture. The Government of the People's Republic of Bangladesh. 2020; pp 84.

Hodge J. Hidden hunger: Approaches to tack- ling micronutrient deficiencies. In: *Gillespie S, Hodge J, Yosef S, Pandya-Lorch R (Eds)*, Nourishing Millions: Stories of Change in Nutrition. International Food Policy Research Institute (IFPRI), Washington DC, USA, 2016.

Hossain M. Fighting malnutrition and food insecurity in Bangladesh with micronutrient-rich small fish. In: Grow Further, www.growfurther.org. 2022.

Islam M, Jahiruddin M, Islam M, Alim M and Akhtaruzzaman M. Consumption of unsafe foods: Evidence from heavy metal, mineral and trace element contamination. *FAO Project Completion Report*, Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh, 2014.

Jahiruddin M and Islam MR. Biofortification of zinc and iron in cereals by fertilizer use and variety selection. Funded by BAS-USDA, *Project Completion Report.* of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh, 2018.

Jahiruddin M. Research and development on natural resource management in south Asia. In: *Shrestha RB, Bokhtiar SM, Khetarpal R and Thapa YB (Eds)*, Agricultural Policy and Program Framework: Priority Areas for research and Development in South Asia. SAC, Dhaka, Bangladesh, 2019.

Jahiruddin M. Soil health and human well-being: areview. *Fundam. Appl. Agric.* 2020a; 5(4): 443-452.

Jahiruddin M. Biofortification of food crops: A novel strategy for reducing micronutrient malnutrition. *Fundam. Appl. Agric.* 2020b; 9: 10.

Kutman UB, Yildiz B, Ozturk L and Cakmak I. Biofortification of durum wheat with zinc through soil and foliar applications of nitrogen. *Cereal Chem. J.* 2010; 87: 1-9.

McGuire S. FAO, IFAD, and WFP. the state of food insecurity in the world 2015: Meeting the 2015 international hunger targets: Taking stock of uneven progress. *Adv. Nutr.*, 2015; 6: 623-624.

Mubarak T, Sheikh FA and Bangroo SA. Role of rice in tackling hidden hunger: The biofortification approach. *Res. J. Agric. Sci.*, 2015; 6: 1-7.

Muthayya S, Rah JH, Sugimoto JD, Roos FF, Kraemer K and Black RE. The global hidden hunger indices and maps: An advocacy tool for action. *PLoS ONE*,2013; 8: e67860.

Nguyen PH, Ali M, Ghostlaw J, Tran LM, Parvin A, Bakhtiar MM and Ahmed AU. Trends and inequities in adequacy of micronutrient intakes in rural Bangladesh. *J. Nutr.* 2025; 155(2): 492-508.

Pfeiffer WH and McClafferty B. HarvestPlus: Breeding crops for better nutrition. *Crop Sci.* 2007; 47: S88-S105.

Qin H, Cai Y, Liu Z, Wang G, Wang J, Guo Y and Wang H. Identification of QTL for zinc and iron concentration in maize kernel and cob. *Euphytica*, 2012; 187: 345-358.

Rahman MZ, Amjath-Babu TS, Robbani M, Rashid MM, Dipok, Choudhury K and Hasan MF. Mitigating micro-nutrient deficiencies in the diets of rural farm households on the south-central coast of Bangladesh: What roles do the markets and homestead play? *J. Agri. Food Res.*2025; 23: 102193.

Ritchie H and Roser M. Micronutrient Deficiency. Our World in Data, 2020.

Siddika A. Biofortification of zinc in ricegrain through nitrogen and zinc fertilizer ap- plication. MS Thesis, Department of Soil Science, Bangladesh Agricultural University, Mymensingh, 2019.

Šimic´ D, Drinic´ SM, Zdunic´ Z, Jambrovic´ A, Ledencˇan T, Brkic´ J, Brkic´ A and Brkic´ I. Quantita- tive trait loci for biofortification traits in maize grain. *J. Here.,* 2011; 103: 47-54.

Ssemakula G and Pfeiffer W. Considerations for implementation of biofortification in develop-ing countries: The case of Sub-Saharan Africa. Symposia Brief: Progress, Challenges, and the Way Forward in Breeding and Gene Discovery: Vitamin A. *First Global Conference on Biofortification*. November 9-11, 2011. Washington DC, USA.

Stein AJ. Global impacts of human mineral malnutrition. *Plant Soil,* 2009; 335: 133-154.

Swaminathan MS. Bring more women farmers on board to eliminate hunger. The Times of India, November 6, 2014.

Waters BM and Sankaran RP. Moving micronu-trients from the soil to the seeds: Genes and physiological processes from a biofortification perspective. *Plant Sci.,* 2011; 180: 562-574.

Welch RM and Graham RD. Breeding for micronu-trients in staple food crops from a human nutri-tion perspective. *J. Exp. Bot.* 2004; 55: 353-364.

White P and Broadley M. Biofortifying crops with essential mineral elements. *Trends Plant Sci.,* 2005; 10: 586-593..

White PJ and Broadley MR. Biofortification of crops with seven mineral elements often lacking in human diets - iron, zinc, copper, calcium, magnesium, selenium and iodine. *New Phy.* 2009; 182: 49-84.

WHO. Guidelines on Food Fortification with Micronutrients. Allen L, de Benoist B, Dary O, Hurrell R, eds., World Health Organization, Geneva, Switzerl and; 2006.

Zhao FJ and McGrath SP. Biofortification and phytoremediation. *Curr. Opin. Plant Biol.,* 2009; 12: 373-380.