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Micronutrients and Its Emerging Effects from Soil to Plants and Animal/Human Health: A Review

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Abstract:
Micronutrients play a key role in growth and development of plants, animals and humans. The three systems are interlinked with each other. Micronutrients namely, zinc (Zn), copper (Cu), iron (Fe), manganese (Mn), boron (B), molybdenum (Mo), chlorine (Cl), nickel (Ni), cobalt (Co) are essential for both plants and animals. Iodine (I), selenium (Si), fluorine (F) and chromium (Cr) are essential for human but not for plants, but absorbed by plant from soil and water and enter into the animals and humans through food chain. Micronutrient application has not only contributed in enhancing the food grain production but also helped in sustaining soil health and fortifying the country's nutritional security. Food and fodder produced on the soils having poor trace element concentration, causes micronutrient malnutrition in animals and humans. Even though the levels of trace elements like Cu, Zn, Mn, Fe, Mo, Se and Co in crops are sometimes sufficient for optimum yields but they are sub-optimal to meet the needs of livestock leading to their widespread deficiencies. Widespread nutritional deficiencies of vitamin A, Fe, Zn, and iodine affecting human health, disproportionately especially women and young children, have been reported. Soil-related deficiencies of trace elements such as Se, Cu, Fe and Zn are also implicated as casual factors for anaemia, zinc deficiency, etc. For correcting micronutrient malnutrition in animal and human, the strategies of micronutrient management should focus on enrichment of these elements in edible plant parts and making them bioavailable without compromising on the sustenance of crop production. Holistic approach is required to develop sustainable technologies to reduce micronutrient malnutrition by launching a mission mode programme on micronutrient research in soil-plant/animal/human continuum mode.

Keywords: Micronutrients, biofortification, genetic fortification, monocropping, Dietary diversification.

1. INTRODUCTION

Micronutrients are the essential trace elements that is required by plants and animals in small quantities but in critical concentrations for optimal growth, development, and health. These includes the vitamins like vitamin A, vitamin C, etc., and minerals like iron (Fe), zinc (Zn), etc[1]. There is a deep interconnection between soil, food, and health and it helps in the formation of a sustainable and healthy ecosystem. Soil is the main source of all nutrients and hence nutrient rich soil produces more nutritious crops. Soil fertility determines the quantity and quality of food that can be grown on a given area of land, and agricultural productivity is directly tied to the soil structure, its fertility and this quality of the food indirectly affects human health. When there is a low quantity of micronutrients present in soil, deficiencies can occur due to insufficient dietary intake, as occurs in malnutrition, and here it indicates the need for taking initiatives to prevent the inadequate supply of micronutrients in plant foods that includes the combination of two or more foods to ensure a complete and balanced intake of essential nutrients which is commonly practiced in food industries[1,2].

In normal, humans require below 100 milligrams of micronutrients per day in comparison to macronutrients which are required in gram amount daily. The minerals for human and animals include 13 elements such as Ca, Fe, Zn etc., which originate from the Earth's soil and cannot be synthesized by living organisms. For human micronutrient requirements also include vitamins, which are the organic compounds required in micrograms or milligrams. These essential nutrients either cannot be synthesized at all or may be in insufficient amounts, and therefore it must be obtained by the diet. They perform a range of functions, including enabling the body to produce enzymes, hormones and other substances needed for normal growth and development. In plants only a small quantity of micronutrients is required, but they are essential for vital cell functions. Some of the critical micronutrients for plant growth and development includes iron (Fe), boron (B), manganese (Mn), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl), and nickel (Ni)[1,2,3].

Despite the importance of micronutrients, its deficiencies are widespread affecting soil health, crop productivity, and human well-being. Moreover, their impact on a body's health is critical, and deficiency in any of them can cause severe and even life-threatening conditions. Deficiency of micronutrient in soil and plants is a global nutritional problem and is prevalent in many countries worldwide with different magnitude of severity. To be mentioned, the most common severe micronutrient deficiencies are Fe deficiency, vitamin A deficiency, zinc deficiency and Iodine deficiency[4]. The World Health Organization (WHO) considers that more than 2 billion people worldwide suffer from vitamin and mineral deficiencies, primarily iodine, iron, vitamin A and zinc, with important health consequences[4,5]. In order to improve the nutritional quality of the food supply and provide public health benefit with minimal health risk, food fortification is introduced as defined by WHO it is the practice of deliberately increasing the content of one or more micronutrients (i.e., vitamins and minerals) in a food or condiment[5].

1.1.MICRONUTRIENTS IN SOIL

Micronutrients such as Zn, Fe, Mn, Cu and so on are very crucial for life. Since soil is the main source of nutrients hence when the concentrations of micronutrients in soil are excessively low, their supply becomes insufficient to meet the needs of organisms. Conversely, when their concentrations in soil are excessively high, they can have toxic effects. In most soils, the total content of micronutrients, such as Mn and Fe, is high; however, Mn and Fe deficiency in soils has occurred worldwide. Today, there is a reduction in the crop yield and quality of agricultural products has deteriorated as more than 50% of soil lacks micronutrients[6,7,8]. More than 2 billion people in the world are in a state of malnutrition, and the lack of micronutrients has had an adverse impact on human health. Thus, research on the availability of micronutrients in soil has become a major focus in the fields of agriculture and environmental science[9].

Micronutrient content in soil is dependent on several factors[10] such as:

1. Geochemical composition (total micronutrient contents of the soil parent material)
2. Soil type (clay mineralogy, particle size distribution, soil horizon, soil age, soil formation processes)
3. Intrinsic soil properties like pH, redox potential (Eh), soluble salt concentration (EC)
4. Quality and quantity of soil organic matter and calcium carbonate content

5. Inputs of trace elements which are supplied through atmospheric deposition, pesticides, manures, fertilizers
6. Available content of macronutrients
7. Micronutrient interactions and vegetation.

In different bio-climatic zones of the world, micronutrients deficiencies in crops can be found on many types of soils. Some of the widely occurring types of soil which are most frequently associated with micronutrient deficiencies are: Calcareous soils, Organic soils, Sandy soils, Saline and Sodic (salt-affected) soils, Vertisols and Gleysols (poorly drained/waterlogged soils).

The main contributors to the global burden of diseases are currently the micronutrient deficiencies which nearly hits half of the world's population with its insidious effects. Reports say that more than 2 billion people suffer from one or more micronutrient deficiency diseases. Worldwide more than 800 million people, mostly women and children, do not have access to food that meets their basic energy needs, and nearly one-third of these live in India. It is seen that micronutrient deficiencies are highly prevalent in places where cereals with low nutritional quality are the main component of the diet. In order to explain the adverse effects of deficiencies and toxicities and avoid suboptimal concentrations that limit the attainment of optimum economical yield of crops along with productivity and welfare of animal and human well-being, a greater attention must be paid for increasing awareness to the role of micronutrients in soil, plant, animal, and human nutrition. Deficiencies of minerals essential for the health of animals and humans exist in many soils around the world, while other soils have accumulated toxic elements for example cadmium (Cd) and arsenic (As). These toxic elements contaminate the soil and produce phytotoxic effects by entering the food chain and also deteriorates the surface water and ground water. Some of the common global soil micronutrient deficiencies (MND) includes the deficiency of zinc. It is stated that 50% of the cereal-cultivated soils globally have low amounts of plant available Zn. This calls out for an urgent need for increasing concentrations of Zn in cereal-based foods. According to model studies, enrichment of cereal-based foods with Zn effectively saves the lives of about 50,000 children annually[8]. Other common global soil micronutrient deficiencies are I, Fe etc. Iodine is a trace mineral, and its primary function is in the synthesis of thyroid hormone.

The iodine content of many foods is dependent upon soil concentration of the element and fertilization and irrigation practices. Globally, $\sim$ 2 billion are estimated to have inadequate iodine status. As many as half of the European population (52%, 459.7 million people) is estimated to have inadequate iodine status and more than 500 million individuals are affected in Southeast Asia. Fe is the most abundant element in the earth's crust and is essential for plant growth. Two forms of iron exist, namely heme and non-heme. Heme iron is found in animal sources, whereas non-heme iron is found in plants and used in fortification. Neither form of iron is highly bioavailable; heme iron bio availability is estimated to be 12–25%, and non-heme iron is <5% bioavailable. Fe deficiency is the most common MND in the world, affecting more than 30% of the world's population, an estimated 2 billion people[11].

Intensification of agriculture through advances in agricultural technology and increasing food demand for an ever-growing population have put our soils under pressure, leading to nutrient depletion, physical degradation, and reduction in biodiversity[8].

Low total concentrations of micronutrients (and most non-essential trace elements) are often found on sandy textured soils (e.g., Podzols) and/or on heavily weathered tropical soils (e.g., Ferralsols) and can give rise to single and/or multi element deficiencies. High soil pH values (>7.0) such as are found on calcareous, heavily limed or saline soils are likely to cause deficiencies of B, Cu, Fe, Mn, Ni and Zn.

Multi-element deficiencies are also highly likely on these soils. In contrast, Mo is likely to be highly available in high pH soils, but can be deficient in acid soils. Organic matter-rich soils, such as peats (Histosols), muck soils and heavily manured mineral soils are likely to have low available concentrations of B, Cu, Mn, Se and Zn[11,12].

However low organic matter contents can also predispose to deficiencies of B, Cu and Zn. Clay-rich soils which usually have relatively high adsorptive capacities and tend to be imperfectly to poorly drained can be deficient in Cu, Mn and Zn. Paddy soils used for wetland rice production are prone to Zn deficiency, but can have toxic Fe concentrations due to the reduction of insoluble Fe oxides.

Hence, this micronutrient deficiencies in crops and herbage, tend to be reflected in low intakes in animal and human diets. However, in the case of grazing livestock the soil-plant-animal pathway maybe passed by direct (usually accidental) ingestion of soil and so the amount of metal(loid)s ingested by the animals may not be affected by soil-plant barriers. However, the presence of adsorbent minerals and antagonistic elements in the animal GI tract can modify the availability of the micronutrient to the animal[13].

Thus, the deficiencies in the soil further affects the plant, animal and human health as mentioned below.

1.2.MICRONUTRIENTS IN PLANTS

Essential nutrients (macro and micro) are required by plants for its appropriate functioning and development. Micronutrients comprise less than 1% of the dry weight of most plants and are vital for their growth. They are essential to maintain the stability of proteins, cellular structures and through their interactions with other physiologically active molecules and enzymes, micronutrients help in the biosynthesis of nucleic acids, proteins, cofactors, carbohydrate metabolism, lipid metabolism, chlorophyll maintenance, electron transport, anti-oxidative systems and much more[14].

There are eight micronutrients required by higher plants and these are: B, Cl, Cu, Fe, Mn, Mo, Ni and Zn. In addition, Co is essential for the bacterial fixation of N in nodules on the roots of legumes. It is very important that the micronutrient requirements of crops are met as well as their macronutrient needs (e.g., N, P and K) if they are to yield satisfactorily and bear products, such as grains, fruits, vegetable leaves or storage roots, of acceptable quality[12].

The mineral composition of fruits, vegetables, and food crops is dependent on the genetic make-up of the crop species, climatic circumstances, soil qualities including microbe diversity, management practices, and the extent of ripeness of the plant at harvesting. The principal causes of the nutrient decline are the degradation of the soil in which crops are grown; developing new high-yield varieties; agronomic factors associated with the commercialization of agriculture; the use of synthetic fertilizers, pesticides, and herbicides to boost food production; improvements in irrigation and the advent of affordable technologies; the introduction of genetically modified food; enhanced air and water pollution; global warming; thinning of the ozone layer; and elevated CO_2 concentration. The global environmental disaster, including current farming methods with a sole focus on crop yields, has resulted in a decline in crops' nutrient quality from the baseline values. Modern farming methods are also associated with declines in soil quality, soil microbial diversity, soil water contamination, and the exhaustion of soil nutrients. There is evidence that the soil quality, the forms and levels of applied nutrients, and the farming system affect the yield and the phytochemical and nutritional composition of produce. An additional consideration is that warming air temperatures and increased solar radiation may lead to higher soil temperatures, resulting in more microbial activity, higher soil respiration rates, and potential limitations in soil nutrient availability [15,16].

Micronutrient depletion develops in the soil as a result of farming techniques, such as intensive farming, monocultures, and acid soil liming, which affect the plants in various ways. When nutrient demand exceeds the rate of supply, the plant frequently switches to alternative metabolic pathways, which are often dependent on limiting micronutrients. A decrease in one micronutrient content might reduce the bioavailability of other nutrients in the soil[17].

Ideal concentrations of micronutrients in plants are 100, 100, 50, 20, 20, 6, 0.1 and 0.1 mg kg1 of dry matter for Cl, Fe, Mn, B, Zn, Cu, Mo and Ni respectively. Plants show deficiency symptoms or enter into the hidden hunger condition when the concentrations of micronutrients fall below their respective critical concentrations. Visual diagnosis of micronutrient disorders is a powerful tool for rapid identification of plant health linked to fertility, micronutrient availability, uptake and verification of soil or foliar test results[10].

In general, there are 4 stages in the development of micronutrients deficiency in plant[10]:

Stage 1: Depletion of micronutrients stored in the body – diminishing degree of saturation of the carriers and enzymes

Stage 2: Impairment of micro nutrients dependent biochemical functions

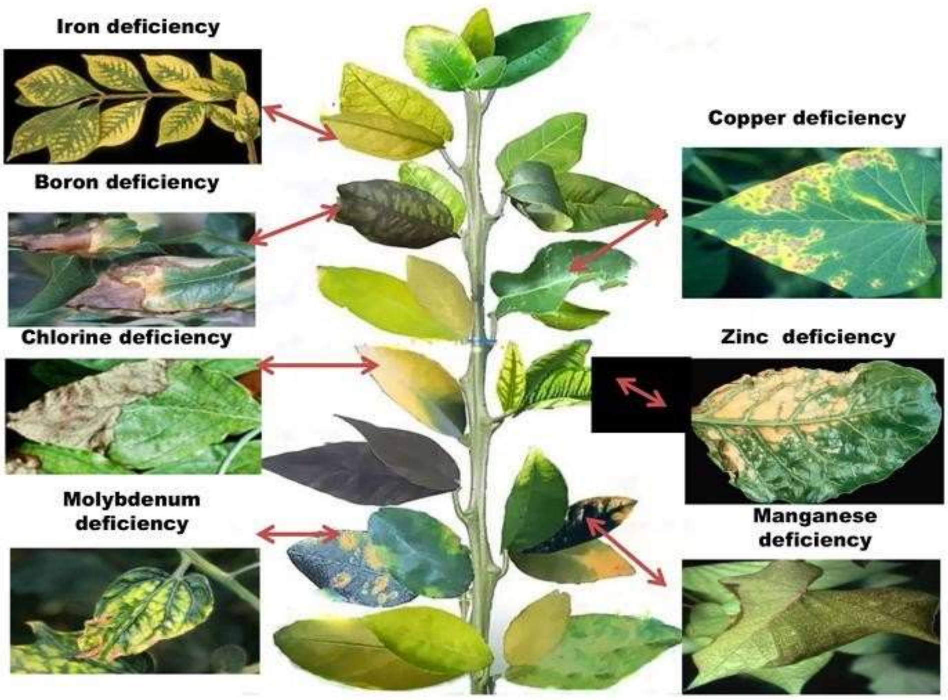
Stage 3: Measurable changes in cellular and physiological functions and

Stage 4: Appearance of structural and functional lesions

The deficiency of micronutrient in plants leads to its impairment of biological and physiological functions (up to stage 3) and at the stage 4 it shows deficiency as lesions or clinical symptoms (stage 4). The first three stages cause significant loss in plant growth and development and ultimately leads to the reduction in yield.

The bioavailability of micronutrients in plants is heavily influenced by climatic factors like drought, severe rain, waterlogging or salinity. The ideal concentration of each micronutrient in the crop is influenced by chemical and physical features of the soil, such as soil pH, nutrient availability, clay minerals, microbial activity, amount of organic matter in the soil, quantity of other nutrients etc.[14]

Identifying metal-tolerant genes and/or proteins is the first step in deciphering the pathways linked with micronutrient stress tolerance[18].



Source- Proteomic and Genomic Studies of Micronutrient Deficiency and Toxicity in Plants[14]

2. Resulting impact of micronutrient deficiencies in plants/food

One of the increasing problems of modern agrochemistry is the lack of available forms of micronutrients in the soil for wheat, as for any cereal crop, and their impacts on the crop yield. However, in recent years, the production of wheat grain has increased globally, but its quality has not improved, which can have a negative impact on animal and human health. Wheat is presently the most widely grown crop in the world, grown on 217 million hectares per year with a total world production exceeding 700 million tons, due to its many favourable qualities for human nutrition[7].

Important commercial high-yielding fruits such as apples, oranges, mango, guava, banana, and vegetables such as tomato and potato have lost their nutritional density by up to 25–50% or more during the last 50 to 70 years due to environmental, genetic, and field soil dilution factors[16].

Some common visible micronutrient deficiencies in crops[19,20,21,22]

Element	Symptoms	Sensitive crops
Copper	Wilting, melanism, white twisted tips, reduction in panicle formation, disturbance of lignification and of the development and fertility of pollen	Cereals, sunflower, spinach, onions, carrots and alfalfa
Iron	Interveinal chlorosis of young leaves	Fruit trees (citrus), grapes, peanut, soya bean, sorghum and calcifuge species
Manganese	Chlorotic spots and necrosis of young leaves and reduced turgor. Necrotic spots on cotyledons of peas	Cereals, legumes and fruit trees (apples, cherries and citrus)
Molybdenum	Chlorosis of leaf margins, "Whiptail" of leaves and distorted curving of cauliflower; "fired" margin and deformation of leaves due to NO_3 excess and destruction of embryonic tissues	Brassicae and legumes
Nickel	Leaf tip necrosis (legumes), chlorosis and patchy necrosis (*Gramineae*)	Wheat, potato, bean, soya bean
Zinc	Interveinal chlorosis (mainly in monocotyledons), stunted growth, "little leaf", rosetting of trees and violet-red points on leaves	Cereals (especially maize and rice), grasses, flax/linseed and fruit trees (citrus)

When the supply of a micronutrient to plants is either deficient or excessive, in addition to crop yields and quality being affected, visible symptoms of physiological stress are often observed, especially in cases of severe deficiency or toxicity[23]. In most cases, severe deficiencies will cause stunted growth, discoloration and, in some cases, necrotic spots on leaves. The discoloration will usually commence as chlorosis when, instead of the normal green colour of chlorophyll, either all or part of the leaves turn yellow, or even white, but they can also turn brown. Deficiency symptoms can also include smaller or twisted leaves, and loss of turgour. Leaf symptoms are usually seen only on old leaves in the case of Mo, on new leaves with Fe, Mn and Cu, on both young and old leaves with Zn, and in terminal buds with B deficiency. Green veins are seen on new leaves with Fe and Mn deficiency and yellow veins with Cu deficiency[24].

3. Agricultural Practices and Micronutrient Cycling

3.1. Monocropping and chemical inputs leading to nutrient depletion: Mono cropping has led to soil erosion, poor soil fertility and finally decline in crop productivity. It leaves the same nutrients from the earth and leaves soil weak and unable to support healthy plant growth. This may farmers are forced to use chemical fertilizers to encourage plant growth and fruit production. These fertilizers, in turn, disrupt the natural makeup of the soil and contribute further to nutrient depletion. Mono crops also provide a friendly home for pests that happen to like that crop, since it shows up reliably, every spring. Organic Farming, the Alternative Approach Monoculture problems can be avoided altogether if organic farming methods are employed. Crop rotation, even if it's just the two crops, is one-way farmers of commodity crops are balancing the need to keep their farms healthy with the need to grow the plants they can sell. There is evidence of positive and economic benefits from crop–animal interactions that promote sustainable agriculture and environmental protection. Under the stress of intensive agriculture, environmental degradation has been reported in many economically developed countries from excessive use of high energy inputs such as fertilizers and pesticides. Use and recycling of locally available inputs and integrating them with the minimum needed quantities of external inputs would enhance the sustainability of the farming process[25].

3.2. The Significance of Micronutrient Fertilizers, Their Interactions, and Application Techniques in Wheat Cultivation:

The micronutrient fertilizers Zn, Mn, B, Fe, Cu, and Mo are the six most essential for increasing productivity in wheat farming[26,27]. Though they account for a smaller amount, their importance in promoting the yield and yield parameters should not be ignored. Their contributions to plant nutrition and soil productivity render them more significant. Moreover, micronutrient fertilizers not only play pivotal roles in plant nutrition, the better development of grains, the improvement of physiological traits and yield parameters, and in ameliorating nutrient deficiency in wheat[28], but humans and animals also require them for their well-being[27,29]. According to researchers, the application of micronutrient fertilizers such as (Fe + Zn) in combination with N and K is the best option for achieving a higher grain yield and quality of wheat[30,31]. The use of micronutrient fertilizers (B, Cu) positively affected the wheat parameters and increased the grain yield considerably[32]. Micronutrients also play pivotal roles in chlorophyll and nucleic acid formation, protein synthesis, metabolism, and several enzymatic activities of photosynthesis, as well as respiration[33,34]. Research has shown that small amounts of foliar-applied micronutrients (singly or combined with other essential elements) can increase the yield and its components, thus enhancing wheat growth and quality.

3.3. Role of organic farming and crop rotation: Organic farming is increasingly popular worldwide. The organic cropping system is associated with the strict adherence to the principle that synthetic mineral fertilizers and crop protection chemicals should not be used. This guarantees better qualitative soil parameters and better quality of agricultural produce[35,36]. Such agricultural practices allow healthy and safe food to be produced, while at the same time respecting the natural environment because nutrient-rich and healthy soil is the "starting point" for food safety[37]. The organic farming system caused a significant increase in soil B and Cu content (respectively by 8 and 4%) relative to the conventional system. The soil content of the analysed micronutrients was also dependent on the plant species in the crop rotation. The cultivation of potato and field bean promoted significantly the highest B accumulation in the soil in comparison with the soil under winter wheat. Potato and field bean also contributed to a higher Cu content in the soil relative to both cereal crops. The organic cropping system contributed to a significantly higher soil content of magnesium and micronutrients (B, Cu, Mn, Zn). The cultivation of potato and field bean also promoted higher micronutrient availability in the soil than cereal cropping. The soil content of micronutrients (Zn, Cu, Fe, Mn, B, and Mo) largely depends on soil pH and soil organic matter content as well as on microbial activity[37]. A large amount of organic matter in the soil promotes lower reduction potential and contributes to higher availability of micronutrient cations in the soil. Organic matter is also a source of organic C in the soil. It increases water-soluble and exchangeable forms of micronutrients[38,39]. Adding organic matter to the soil resulted in the increased occurrence of complex forms of micronutrients. Moreover, organic matter accumulated in the soil had an effect on transformations of the adsorbed fractions into micronutrient forms more available to plants. Apart from that, soil organic matter has a direct and indirect impact on nutrient transformations and favoured the binding of micronutrients such as B, Cu, Zn, and Mo, in particular[38,40]. Hence, it is confirmed that organic farming (associated with a larger amount of organic matter in the soil) resulted in higher soil micronutrient availability.

4. Micronutrients and Human Health

Micronutrients (vitamins and minerals) have numerous health benefits including tissue maintenance, bone and teeth formation and health, serving as cofactors and coenzymes to enzyme various enzyme systems, aiding the regulation and coordination of most body functions, and other biochemical and physiological functions in the body. Micronutrients are essentially required by human and other organisms in varying amounts throughout life to coordinate various physiological functions to maintain health. Micronutrients are essential for healthy living, and should augmented with proper hygiene, including adequate body management and waste disposal. Micronutrient requirements are in amounts generally below 100 mg/day, while macronutrients are required in grams per day. Micronutrient requirements for human also include vitamins; organic compounds required in microgram (μm) or milligram (mg) amounts. Micronutrient deficiency is not sufficient amount of one or more of micronutrients required for optimal health. In humans and in other animals they include both deficiencies of vitamins and minerals[3].

There is a famous diction that good human health is linked with healthy soils, which produce variety of food. In fact, an integral link between soil and human health was recognized several thousand years ago[10]. While the required amounts of micronutrients are very small, micronutrient deficiency (MND) can have wide-range negative health impacts that will ultimately result in death if untreated. MNDs are common, affecting an estimated 2 billion people worldwide[42]. The most common deficiencies exist for vitamin A, folate, iron, io dine, and zinc; however, several other MND disorders exist. Coexistence of multiple MNDs frequently occurs. MNDs often occur as part of a cycle of malnutrition and may be coupled with protein or energy malnutrition. Pregnant women and their children 5 years of age and younger are the most vulnerable population subgroups[11].

5. Micronutrient Malnutrition (Hidden Hunger)

MND's are only one form of undernutrition. MND's are often referred to as hidden hunger. At the most basic level, MND's like all forms of undernutrition, occur due to insufficient intake or sufficient intakes combined with impaired absorption due to infection, disease, or inflammation. The basic root cause of most undernutrition is poverty. Iron, vitamin A and iodine deficiencies are the three micronutrient deficiencies of greatest public health significance in the developing world[6,11].

Iron: Iron is a mineral that is an essential component of haemoglobin, myoglobin, enzymes, and cytochromes and is necessary for oxygen transport and cellular respiration [41,42,43]. Iron also is critical for optimal growth and cognitive function. Two forms of iron exist, namely heme and non-heme. Iron deficiency is the most common MND in the world, affecting more than 30% of the world's population, an estimated 2 billion people[16]. Iron deficiency causes anaemia and disrupts optimal function of both the endocrine and immune systems. Iron deficiency is particularly common during pregnancy because of increased requirements for fetal growth and development. Maternal iron deficiency is associated with low birth weight, pre mature delivery, and a host of perinatal complications, especially haemorrhage. Anaemia is estimated to contribute to 20% of maternal deaths[44]. Iron deficiency may also be associated with enhanced absorption of environmental metal toxins such as cadmium. Fortification programs with iron exist in several countries with the food vehicles of choice ranging from flours, dairy products, condiments, sugar, and salt to infant formulas. Fortification and supplementation may be appropriate for areas with high concentrations of vegetarians[11]. People living in environments prone to infection from malaria and hookworm, and whose habitual diet is high in phytate with iron, iodine and vitamin A are the most widespread forms of micronutrient malnutrition with public health consequences[6].

Prevention methods: Usual Solid Foods- Measures to prevent ID after the age of 4-6 months include a sufficient intake of iron-rich complementary foods such as eggs, chicken's liver, duck, mutton, chicken, salmon, wheat germ, sorghum etc., but most complementary foods are low in iron unless they are fortified with iron[44,45,46].

Nonheme Iron- Inorganic iron, which is mainly found in products of plant origin, accounts for more than 80% of the iron in a standard diet, but its bioavailability is low (1–12%)

Sources of Heme Iron- Owing to their heme iron content, which is higher for beef than pork and poultry, meats are highly valued sources of iron, with an absorption of approximatively 25%, which is not affected by dietary factors, except calcium. Moreover, the presence of heme iron in a meal enhances the non-heme iron absorption from foods consumed at the same time via an unclear mechanism. In young children, the association between red meat consumption and iron status has rarely been found to be significant, except in cases of a high-meat diet. Red meat, however, helps to prevent ID, but it is only sparingly consumed by infants and young children. On the other hand, processed and cooked meat when boiled, braised, or roasted has decreased heme iron content, with an average loss of 17% from the first few minutes of heating at 60˚C and of 50% after 60 min at 95˚C.

Fortified Foods- Addition of Iron to Staple Foods- Several studies have shown that, especially in low-income countries, iron food fortification, referring to the addition of iron alone or with other micronutrients during food processing, was a safe and costeffective way of preventing ID despite some technical difficulties related to undesirable changes in the food, such as alterations in appearance and taste. Thus, various commonly consumed foods have been fortified in addition to formula, mainly cereals, but also wheat flour, maize flour, rice, soy sauce or fish sauce, salt, and candies. Such strategies may, however, have a limited impact in infants and young toddlers due to their relatively low staple food consumption and even lower seasoning and condiment intake.

Iodine: Iodine is a trace mineral, and its primary function is in the synthesis of thyroid hormone. Approximately 60% of the total body pool of iodine is stored in the thyroid gland[45]. Thyroid hormone is necessary for regulation of human growth and development. Iodine in foods and dietary supplements is generally either in a salt or organic form[46]. The iodine content of many foods is dependent upon soil concentration of the element and fertilization and irrigation practices[47]. Iodine stores in vivo during a sufficient state are estimated at 60 µg, and during deficiency, stores are much lower in the 10- to 20 µg range[45]. Hypothyroidism can occur in individuals when dietary intakes are lower than 10–20 µg daily, and it is frequently accompanied by goitre[47]. Maternal iodine deficiency, particularly when it occurs during early pregnancy, can lead to irreversible neurological complications and mental retardation in the offspring referred to as iodine deficiency disorder (IDD)[48]. Pregnant females and infants (<24 months of age) are the population groups at highest risk of iodine deficiency. Exclusively breastfed infants may also be at risk if not provided iodine in complementary foods49. While iodine is found in breast milk[47], its concentration is dependent on maternal intake and status. Globally, ~ 2 billion are estimated to have inadequate iodine status. As many as half of the European population (52%, 459.7 million people) is estimated to have inadequate iodine status and more than 500 million individuals are affected in Southeast Asia. While the group of highest concern is pregnant females, we have no global estimation of the burden of iodine deficiency in this group. Approximately 30% (241 million) of the world's school-aged children have insufficient iodine intakes. Many countries of the world (~ 120 countries) have fortified table salt with iodine because iodine is found naturally in very few foods. Salt is traditionally the food vehicle chosen for iodization because it is universally consumed at a relatively consistent intake level; the process of adding iodine to salt is very cheap at less than 5 cents per person per year. Global estimates from the UNICEF indicate that 68% of households have adequate table salt iodine. Universal salt iodization refers to all salts used within a country, regardless if iodine is in table salt or in salt used by the food industry. Very few countries in the world have achieved universal salt iodization, and often, the food industry does not use iodized salt in food production. Iodine can also be found in dietary supplements. Universal salt iodization is the most practical strategy to reduce iodine deficiency globally iodine deficiency does have some health risks for certain populations in terms of thyroid function and should be considered within the context of each country separately[11].

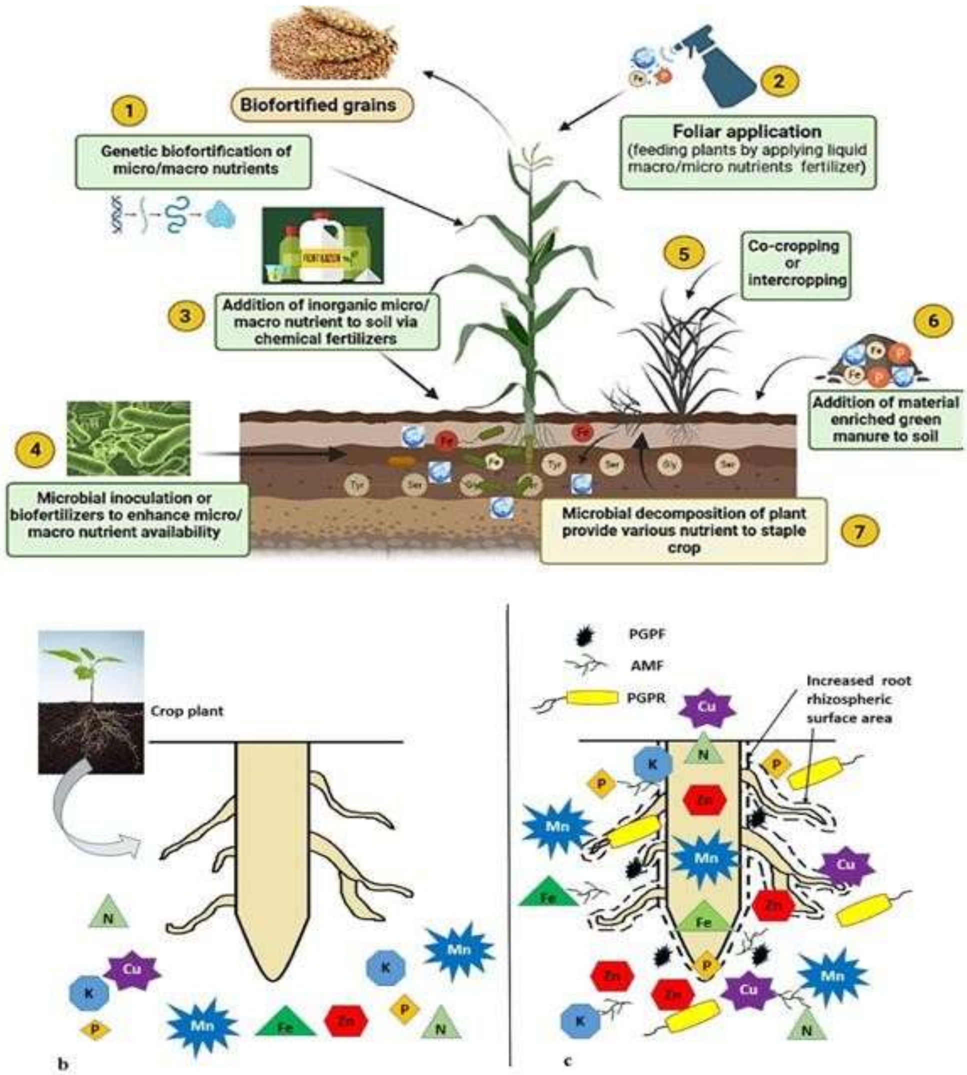
Vitamin A: Vitamin A is a fat-soluble vitamin that has multiple roles in the body including vision, cell differentiation, immune function, reproduction, and organ and bone formation and growth. Vitamin A comes from animal sources in the diet preformed as retinol or retinyl esters, or from provitamin A carotenoids found in plant sources. Provitamin A carotenoids, which exhibit differential vitamin A activity, are converted to the active forms of the vitamin (retinal and retinoic acid) for use by the body. Vitamin A deficiency (VAD) has been associated with increased rates and severity of infections and is a primary cause of childhood morbidity and mortality in the developing world, particularly in Africa and Southeast Asia[48,49,50]. VAD is the leading cause of preventable blindness in children. VAD causes xerophthalmia, a series of ocular manifestations like night blindness, Bitot's spots, and corneal ulcerations and lesions[51]. The WHO estimates that 250–500 million children are blind because of VAD, and half of these children will die within a year of vision loss. VAD is also common in pregnancy in lower-income countries with estimates ranging from 10 to 20%. Very little is known about older children and adults with regard to vitamin A status; however, because VAD tends to cluster in families, communities, and regions, we can assume that vitamin A status is low in areas with child and pregnancy burden. Subclinical VAD affects far greater numbers of individuals, particularly in Africa and Asia [11].

Zinc: Zinc is an essential mineral that is involved in multiple aspects of cellular metabolism. Zinc is required for the activity of more than 200 enzymes, and it is critical for immune system function, cell division, and protein and DNA synthesis. Zinc is also required for normal growth and development from in utero until puberty. The human body has no long-term storage system for zinc, so consistent dietary intake is needed to sustain all of these functions and maintain the relatively small exchangeable zinc pool. Zinc is primarily found in animal products and seafood. Similar to iron, zinc absorption is impaired by phytates, fibre, and lignin's, all of which impair the bioavailability from non-animal sources of zinc. Calcium and casein may reduce the bioavailability of zinc from cow's milk. Zinc is present in human breast milk. Zinc status has been associated with reduced incidence, severity, and mortality due to diarrhoea and respiratory and malarial infection. Infection is known to compromise dietary intake and micronutrient absorption, and diarrhoea can contribute to losses in key micronutrients. Deficiency in zinc is thought to be one of the primary causes of morbidity in developing countries and, yet, surprisingly little is known about the status of the world. Globally, it is estimated that 17.3% of the population has inadequate zinc intakes, with the highest estimates in Africa (23.9%) and Asia (19.4%). Pregnant females and their young children are the highest-risk groups for zinc deficiency. A specific disorder resulting from zinc deficiency in animals is parakeratosis – a disorder of the epidermal layer of the skin occurring in calves, sheep, goats and piglets. Phytate (inositol hexaphosphate): Zn ratio plays an important role in influencing the Zn bioavailability in animal body. Dietary zinc dependence in infants is greatest when the prenatal liver stores get exhausted and subsequent transient zinc deficiency can occur as mother's milk has an exceptionally low concentration of zinc. By and large, dietary Zn intake consisting mainly of rice and wheat in the poor people of the country is far below the normal levels and is imbalanced being low in Zn and high in phytate, resulting in low Znbioavailability because phytate: Zn molar ratio in diets more than 15 causes significant reduction in Zn absorption and it results in Zn deficiency in humans. Supplementation of Zn-rich recipes improved plasma Zn status, cognitive performance and taste acuity signifying the need to adopt dietary Zn intake for normal health[10].

Source- Micronutrients in Soils, Plants, Animals and Humans[10]

6. Preventive measures for decreasing the micronutrient deficiencies

6.1. Biofortification-The vast majority of studies on the potential of biofortification to reduce micronutrient deficiencies have focused on three main micronutrients: Zn, Fe and provitamin A. It has been estimated that biofortification has the potential to improve coverage of the estimated average requirement by 25% for zinc crops, 35% for iron crops, and > 85% for provitamin A crops. Recent challenges concern the development of multinutrient biofortified maize to increase the likelihood of meeting recommended intakes of macro- and micronutrients thereby reducing multiple deficiencies. Examples of biofortification projects include iron biofortification[51,52,53] of rice, beans, maize and sweet potato; zinc biofortification of wheat, rice, beans, sweet potato and corn; and Vitamin A biofortification of sweet potatoes, corn and cassava. Research on biofortification has identified the advantages of this approach, specifically it targets poor families living in remote rural areas with no or limited access to industrially fortified foods. These families often rely on subsistence farming and can grow, consume and sell their own fortified crops. Additionally, when targeted correctly, biofortification can enable food systems to deliver more nutritious foods cost-effectively. Nutrient poor diets based on staple crops (tubers and cereals) typically lead to multiple micronutrient deficiencies, but biofortification can increase a crop's nutritional value using traditional breeding and agronomic biofortification techniques. However, biofortification via genetic engineering—which allows for simultaneous introduction of multiple micronutrients in a single crop could support increased levels of multiple micronutrients in a single food crop and high-level accumulation of micronutrients.



Source-Biofortification as a solution for addressing nutrient deficiencies and malnutrition[25]

6.2. Food fortification- Industrial or large-scale food fortification (LSFF) is the addition of micronutrients during processing to commonly consumed foods such as salt, flours, oil, sugar and condiments. LSFF programs can be categorized as either mandatory meaning they are initiated and regulated by the government or voluntary where food processors add nutrients to their foods on their own volition but is still governed by regulatory limits. Mandatory fortification programs are increasingly common, especially when it comes to fortified flour and iodized salt. Edible oils are an increasingly common vehicle for fortification[52,53], and thus far 27 countries have mandated oil fortification with Vitamin A; and 14 countries have mandated milk fortification, 11 countries fortify milk with both Vitamin A and D, one country (Costa Rica) is additionally fortifying with iron and folic acid, and two countries (China and Canada) are adding calcium, in addition to Vitamin A and D.

6.3. Food supplementation-Food supplementation involves the intake of additional nutrients in the form of capsules, syrups or tablets to add to the nutrients that are obtained from the consumption of foods to meet the RDA requirement. Food supplements include vitamins, amino acids and proteins, essential fatty acids, mineral, fiber, and calorie supplements. In most developing countries, vitamin supplements are most commonly used in combating hidden hunger whilst mineral supplements such as Zn, Fe, and amino acid supplements are less common. Food supplements are usually targeted to small populations with acute nutrient deficiencies in developing countries. Food supplementation is also a short-term, direct and controllable strategy, and can be tailored to meet the specific needs of a targeted population. It yields positive results rapidly and is cost-effective as compared to other interventions such as dietary diversification. vitamin A supplementation had positive effects on child development; indicating food supplementation can be used to improve the nutritional status of a population with micronutrient deficiencies. Zinc supplementation at infancy increases specific growth outcomes, especially after age 2. Nevertheless, identifying those at risk of Zn deficiency is challenging due to the lack of a reliable diagnostic tool. Another challenge can be reaching rural population as it needs continuous distribution of the supplements. Other disadvantages of food supplementation include its reliance on the compliance of the targeted population, require well-defined structures to successfully implement in targeted populations and is highly unsustainable, especially in developing countries[54,55]. Food supplementation may also cause toxicity, which has severe effects on the health of targeted populations.

6.4. Dietary diversification- Micronutrients such as Fe, Zn, I, and vitamins are limited in most staples but can be found in certain types of foods. Therefore, consuming a narrow range of foods and more staples with insufficient quantities of micronutrient rich foods may result in hidden hunger. This makes dietary diversification a vital strategy that can be used in curbing malnutrition and hidden hunger. Dietary diversification helps alleviate all forms of deficiencies, aids in boosting the immune system, and is culturally acceptable, and sustainable as compared to other interventions used in alleviating malnutrition and hidden hunger. The major disadvantages of dietary diversification as a strategy of alleviating malnutrition and hidden hunger include the obligation of nutrition education, change in dietary patterns, the need for accurate food data and presence of anti-nutrients in foods consumed, which impact nutrient absorption. Another disadvantage of dietary diversification is the need of financial commitment involved in purchasing and producing high-quality varieties of foods. Therefore, dietary diversification is very difficult to implement in developing countries; hence other interventions such as food supplementation, food fortification and biofortification are preferred in developing countries.

Providing sufficient funds and human resources for under taking research addressing micro-nutrient problems of soil, plant, animal and human health.

Identification of soils/areas deficient or toxic in micronutrients and assessment of impact on agricultural productivity, nutritional quality and animal and human health.

Genetic biofortification is a seed-based approach where the germ plasm is enriched with specific nutrients: micronutrients, protein, amino acids etc. It can be done by conventional breeding, marker driven molecular breeding, or genetic engineering. Zn- and Fe- rich rice, wheat and maize. Golden rice rich in beta-carotene, high Fe rice (high ferritin gene from mangroves) are examples of genetic engineering for biofortification.

Data availability, complex statistical modeling of MND's: Without population-level assessments of the micronutrient deficiencies, we will remain uncertain about their public health impact and thus fail to address and prevent potential deficiencies and associated health consequences. Thus, assessing biomarkers of more micronutrients in nationally or regionally representative surveys is urgently needed to shed light on the extent of the problem.

7. CONCLUSION

Micronutrients play a vital role in sustaining the health of soil, plants, and ultimately, humans and animals. These trace elements, though required in small amounts, are essential for crucial physiological and biochemical processes in plants, such as enzyme activation, chlorophyll synthesis, and disease resistance.

Micronutrient deficiencies in soils and crops adversely affect animal and human health and their productivity. The causes of MND's in soil are due to soil pH, soil concentration of the element, fertilization and irrigation practices, high uses of modern agricultural fertilizers, environmental conditions, type of the soil etc. Healthy soils rich in balanced micronutrients support the plant growth and leads to higher nutritional quality in crops. In turn, this directly impacts human health and animal health by ensuring the adequate dietary intake of essential elements like Fe, Zn, Cu etc. Hence, any micronutrient deficiency or presence of excess amount of micronutrients in soil disrupts the delicate chain, leading to poor crop yields and nutritional imbalance in humans leading to many health issues. Since, soil is the primary source of micronutrients, it all starts from the soil, the plant productivity and human/animal health. The greatly increasing problem of hidden hunger affects the half of the world with zinc deficiency, iron deficiency etc. Many preventive measures were adopted for replenishment of nutrients in the soil like using organic cropping, food fortification, nanofertilizers, etc as mentioned above. Many public awareness drives are also adopted for increasing awareness among people and in the poverty strike area people are provided with proper medication and food supplements etc. Thus, ensuring adequate micronutrient levels in soil and food is the key to achieve the food security and human well-being as a whole.

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