16 Micronutrient Deficiencies in Humans and Animals: Strategies for Their Improvement

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Abstract

Among the trace minerals, the most important for humans and animals comprised of Fe, Zn, Mn, Cu, B, and Mo which are physiologically and metabolically essential. In developing countries like India, amelioration of deficiency of iron and zinc in humans occupies prime priority as it results in malnutrition, while in animals Zn, Mn, and Cu need attention. Iron deficiency usually shows its effect in the form of anemia, fatigueness, reduction in intelligence, and work efficiency, while zinc deficiency is more prominent in the form of indigestion, respiratory infections, and growth retardation in both humans and animals. In order to combat against these deficiencies, nutritional intervention in the form of nutraceutical/mineral mixture and biofortification is required. Nutraceutical approach includes pharmaceutical or dietary Fe/Zn supplementation or diet diversification, while biofortification of cereal grains or other foods requires the role of nutritionist, biotechnologists, plant breeders, and agronomists. Global projects have focused on genetic biofortification of food and fodder crops like rice, wheat, maize, and pearl millet, etc., but still the gap is there as so far only two cultivars have become available for cultivation. Crops grown on above-listed micronutrient-deficient soil are treated with micronutrient fertilizer during agronomic biofortification. Success has been achieved in India for the biofortification of Zn in wheat, rice, oats, and chickpea which can help in eliminating malnutrition. Combined efforts are being needed involving agricultural scientists, physicians, planners, managers, and

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nutritionists (crops, animals, and human) for amelioration of micronutrient deficiencies in humans and animals.

Keywords
Animals • Biofortification • Deficiencies • Humans • Micronutrients • Symptoms

16.1 Introduction

Humans and animals require microelements such as Fe, I, Zn, Mn, Cu, Se, Mo, Cr, F, B, Ni, Si, V, As, Li, Sn, and Co and macroelement, that is, Cl (Welch 2005), while in plant microelements, namely, Fe, Mn, Zn, Cu, B, Mo, Cl, and Ni have been considered to be essential for normal growth and development (Prasad and Power 1997). Research indicates that elements like Ni (Dixon et al. 1975; Brown et al. 1987; Malavolta and Moraes 2007), Va (Lyalikova and Yurokova 1989; Guo 1987), and Co (Ahmed and Evans 1960) are also needed by plants. Mostly these elements are called micronutrients as required in very small quantity for nourishment. These are used in the form of chemical element, ion, compound, or molecule in plants, while in case of humans and animals, the plant and animal origin food products and their by-products serve as source of these micronutrients. Worldwide in human and animal nutrition, the term micronutrient refers to combined vitamins and minerals, and their deficiencies have been referred to as hidden hunger because the sufferer is unable to detect the deficiency of the micronutrients in primitive stage, which shows its effect only in the long run. This book chapter describes various essential micronutrients for humans and animals (Nielsen 1999) and the effect of biofortification in amelioration of their deficiency consequences.

16.2 Deficiency Symptoms and Recommended Daily Allowance

16.2.1 Iron

On an average human body contains 2.38 g iron in women and 3.8 g iron in men. Iron is present in all human cells. Hemoglobin (Hgb) makes up 96 % of the red blood cells on dry matter basis (Weed et al. 1963). Hgb is the iron containing oxygen transport metalloprotein in red blood cells of humans and most other vertebrates. This element has prime importance in humans and animals as it is involved in carrying oxygen throughout the body in the form of hemoglobin. Nearly about 85 % of the Fe in human body is present in two heme proteins, namely, hemoglobin and myoglobin, which are responsible for the transport and storage of oxygen in different body parts (Bell and Dell 2008). Some Fe in the form of nonheme proteins, such as ferritin and transferritin, is mainly responsible for storage and transport of Fe in the form of metalloflavoproteins, ferredoxins, or Fe–S proteins (Yip and Dallman 1996). Iron from animal food sources with exception of eggs is better absorbed than iron from plant sources. The poor availability of iron from egg yolk is due to the presence of phosphor-protein, phosvitin. Iron from hemoglobin is more available to human than nonheme iron. Iron from green vegetables is less available than the iron from bean, chick peas, and okra.

Survey data indicates that in developing countries, Fe-deficiency anemia is prevalent in around two billion people (Stolzfus and Dreyfuss 1998). Mostly sufferers are persons with fast growth like infants, toddlers, and pregnant women who have higher Fe requirement than normal. The deficiency appears in the form of pallor, fatigueness, reduced intelligence, and work efficiency (Lynch 2003). Once diagnosed iron supplementation has to be carefully monitored, because there is no mechanism of iron excretion from human body. Only 1–2 mg day^{-1} is lost as a result of sloughing of dead cells. In women about 0.006 mg iron kg^{-1} day^{-1} could be lost during menstruation (Schmeier and Petruzelli 2008). High amounts of iron could lead to iron poisoning especially in young children (Tenenbein 2005). Pain in the stomach, nausea, and vomiting including blood in the vomiting are the common symptoms of iron poisoning. Since green fodders are rich source of iron, farm animals rarely suffer from Fe deficiency (Underwood and Suttle 1999).

16.2.1.1 Recommended Dietary Allowance (RDA)

RDA (per day) for iron is as follows: infants 0–6 months 0.27 mg (average intake); infants 7–12 months 11 mg; children 1–3 years 7 mg, 4–8 years 10 mg, and 9–13 years 8 mg; adolescents 14–18 years 11 mg (males) and 15 mg (females); adults 19–50 years 8 mg (males) and 18 mg (females); pregnancy 27 mg; and lactating 14–18 years 10 mg and 19–50 years 9 mg (FNB 2001). The tolerable upper limit for iron is 45 mg day^{-1}. Heme iron content in some foods is as follows: mg 100 g^{-1}, clam (28.0), pork lever (18.0), lamb kidney and cooked oyster (12.0), beef lever (6.5), raw yellow beans (7.0), toasted sesame seeds (14.7), and spinach (3.5). Iron from meat being heme is more readily absorbed than from grains and vegetables, which is more non-heme. Phytates in cereal grains decrease the iron absorption, and low bioavailability of iron in the diet in developing countries is the primary cause of iron deficiency anemia in those countries (Berger and Dillon 2002; Yip and Ramakrishnan 2002). Efforts are underway to develop GM cereals with iron-rich grains, such as golden rice (Potrykus et al. 1996; Murray-Kolb et al. 2002).

16.2.2 Zinc

There is 2–4 g zinc in the human body (Rink and Gabriel 2000). Most zinc is present in the brain, muscles, bones, kidney, liver, prostate, and some parts of the eye (Wapnir 1990); the latter two body parts have the highest concentration. Semen is particularly rich in zinc, which is responsible for prostate function and reproductive organ growth (Berdnier et al. 2007). Zn is important for many metabolic processes in the body. As related with protein metabolism, Zn is responsible for repairment of wear and tear of body tissues, RNA synthesis, and DNA transcription (Shukla et al. 2009) and healing of wounds, blood formation, immunity, and overall growth (Walker and Black 2004). Zn is also involved in functioning of insulin hormone (Miccici 2000). There is some evidence that Zn helps in combating cancer (Ho 2004). Thymidine kinase enzyme is most sensitive to Zn depletion. Meat and other animal sources of protein are most reliable sources of zinc in the diet.

Zinc deficiency is widespread in the world and Prasad (1984) brought it to the focus, when he reported that zinc deficiency was the cause of dwarfism and hypogonadism among adolescents from the lowest social classes of Egypt and Iran. Dwarfism has also been reported in about 61 million children aged 0–5 years (Ringstad et al. 1990). The deficiency symptoms of Zn in children mainly include gastrointestinal disturbances and respiratory problems (Fischer Walker et al. 2009). According to USFNB, RDA for children (4–8 years) and adult males and females is 5, 11, and 8 mg day^{-1}, respectively. A survey in Haryana state in India showed that 65 % of the 258 pregnant women sampled had Zn deficiency (Pathak et al. 2008), which is a matter of concern in India. Stein et al. (2007) using disability adjusted life years (DALYs) observed that Zn deficiency in India is a highly relevant health problem and reported a loss of 2.8 million DALYs per year.

In animals the deficiency symptoms appear in the form of parakeratosis, dermatitis, hair loss, deformed limbs, stiff joints, reduced growth due to fall in appetite and reproductive problems, and swollen feet with open scaly lesions and impaired reproduction (Spears 1995; McDowell 2003; Miller and Miller 1962).

16.2.3 Manganese

Total Mn content of a 70 kg man is about 12–20 mg (Watts 1990). Manganese is distributed in tissue throughout the body with the highest concentrations in the liver, thyroid, pituitary, pancreas, kidney, and bones. In tissue Mn is largely located in mitochondria. Manganese is essential for the activity of several enzymes involved in mucopolysaccharide synthesis. In case of humans and animals, manganese is required in sufficient concentration for optimum growth, development, and reproduction. It is related with functioning of various enzymes like Mn-superoxide dismutase, pyruvate carboxylase, arginase, glycotransferases, glutamine synthetase, prolidase, etc. (Keen and Zidenberg-Cheor 1999). Usually Mn deficiency is uncommon in humans (Bell and Dell 2008) because requirement is easily met out by daily food items. However UNFNB (2001) has recommended 2.1–2.3 and 1.6–1.8 mg day^{-1} requirement for men and women, respectively. The largest content is in blueberries, wheat bran, nuts, and cocoa. Coffee and tea are also rich source of manganese. Calcium, phosphate, and iron interfere with absorption of manganese. Chelating agents like EDTA increase the excretion of manganese into the urine.

Manganese deficiency symptoms include hypocholesterolemia, impaired growth, weight loss, transient dermatitis, intermittent nausea (Watts 1990), bone demineralization (Norose et al. 1992), skin rash (Friedman et al. 1987), osteoporosis in women (Freeland-Graves and Llanes 1994), epilepsy (Carl and Gallagher 1994), and change of hair color (Doisy 1973). Manganese concentration in human hair has been reported to be related to certain diseases; lower levels have been found in Down's syndrome, epilepsy, and schizophrenia, while elevated levels were associated with multiple sclerosis, learning disabilities, and Parkinson's disease (Chatt and Katz 1988; Ashton 1980). For more information on the results of clinical trials on Mn, reference may be made to Drake (2015).

In livestock Mn deficiency appears in the form of reproductive disorders, skeletal deformation, and short tendons in newborn young ones (McDowell 2003).

16.2.3.1 Recommended Adequate Intake (AI) for Humans

There is no RDA for Mn in humans. The recommended adequate intake levels (mg day^{-1}) for Mn are as follows: infants 0–6 months 0.003 mg and 7–12 months 0.6 mg; children 1–3 years 1.2 mg, 4–8 years 1.5 mg, and 9–13 years 1.9 mg (males) and 1.6 mg (females); adolescents 14–18 years 2.2 mg (males) and 1.6 mg (females); adults 19+ years 2.3 mg (males) and 1.8 mg (females); pregnancy 2.0 mg; and breast-feeding 2.6 mg (FNB 2001).

16.2.4 Copper

Copper content in human adults varies from 50 to 120 mg (average 80 mg), with the highest concentrations being in the liver (3.6–5.1μgg^{-1}) and brain (3.3–6.3 μg g^{-1}) (WHO 1996; Uauy et al. 1998; Lech and Sadik 2007). Human hair is particularly rich in Cu and may contain 22.9–46.6 μg g^{-1} Cu (Angelova et al. 2011). Copper has a role to play in oxidation-reduction reactions and enzyme functions like Cu-superoxide dismutase, dopamine betahydroxylase and monoamine oxidase, Cu-metalloenzymes, cytochrome oxidase functioning of central nervous system, and genes regulated by Cu-dependent transcription factors (Uauy et al. 2008). Ferroxidase II is responsible for catalyzing the oxidation of Fe(II) to Fe(III), which facilitates its transport to sites of red blood cell formation (Bell and Dell 2008). Copper is necessary for iron absorption. Among the animal products, rich sources of copper include the liver, lobster, and oyster, while milk and eggs are poor.

Copper deficiency in humans is rarely found except in infants dependent on cow's milk (Turnlund 1999). USFNB (2001) has recommended RDA of 440 μg day^{-1} for children and 900 μg day^{-1} for adults. On the contrary Cu deficiency symptoms are widely noticeable in farm animals in the form of uncoordinated gait in lambs, hair around eyes of cattle, crimpled wool in sheep, and heart failure leading to death in cattle (McDowell 2003).

16.2.5 Boron

In the human body, the highest concentrations of boron are in the heart (28 mg kg^{-1}), followed by the ribs (10 mg kg^{-1}), spleen (2.6 mg kg^{-1}), and liver (2.3 mg kg^{-1}) (Devirian and Volpe 2003). A boron concentration in blood is 0.06 mg kg^{-1}, in plasma 0.02 mg kg^{-1}, in urine 0.75 mg kg^{-1}, and in bones, nails, and hair between 4.3 and 17.9 mg kg^{-1} (Hunt 2003, 2010). The boron content in the same tissue can differ depending on the health of the individual. For example, the concentration of boron was 3 mg kg^{-1} in arthritic bones compared to 56 mg kg^{-1} in the healthy bones (Scorei and Popa 2010). In human tissues and body fluids, most boron is present as boric acid (98.4 %), while the rest is as borate anion (1.6 %). Boron is mainly responsible for improving immune system (Hunt 2003) and in functioning of steroids, hormones, minerals, and vitamins in human and animal body system (Devirian and Volpe 2003). It is involved in binding process with the cell membrane (Verstaeten et al. 2005). Boron may have a role in immune function (Hunt 2003) and in the metabolism of steroids, hormones, some mineral nutrients, and vitamins (Devirian and Volpe 2003). Further research is needed for justifying the role of boron in metabolic reactions (Bell and Dell 2008). Some recent studies in Geochemistry point out the role of B in the synthesis of RNA (Periur 2001; Scorei and Cimpoiasu 2006; Saladino et al. 2011). It has been reported that ingested boron through diet helps in strengthening bone in case of animals like rats, chicken, and pigs (Armstrong and Spears 2001). No specific symptoms of B deficiency have been observed in animals and humans and no recommended dietary allowance (RDA) is recommended.

16.2.5.1 RDA for Boron

There is no RDA for B and the safe intake limit is 1–10 mg day^{-1}. Boron concentrations (mg kg^{-1}/mg L^{-1}) in some foods are as follows: raw avocado 14.3, peanut butter 5.87, salted dry roasted peanuts 5.83, dry roasted pecans 2.64 ppm, prune juice 5.64, grape juice 3.42, sweetened chocolate powder 4.29 ppm, and table wine (12.2 % alcohol) 3.64 (Hunt 2010). Boron concentrations are low in meat, poultry, or fish (Hunt 2010). Generally, the intake of boron is between 1 and 3 mg daily depending upon amounts and kind of foods (Dinca and Scorei 2013). Borax given the number E285 is also used as a food additive in some countries, such as, China, mainly for improving the texture of noodles.

16.2.6 Molybdenum

Molybdenum is now recognized as an essential micro-mineral in human nutrition (Rajagopalan 1988). Molybdenum is a cofactor present in the active site in four enzymes in humans (Coughlan 1983; Cohen et al. 1971), which are known as molybdoenzymes. These are sulfite oxidase, aldehyde oxidase, xanthine oxidase, and mitochondrial amidoxime reducing component (mARC). Sulfite oxidase catalyzes the transformation of sulfite to sulfate in the metabolism of sulfur-containing amino acids methionine and cysteine. This enzyme is known to be crucial for human health. Aldehyde oxidase and xanthine oxidase catalyze hydroxylation reactions that involve a number of different molecules with similar chemical structures. Xanthine oxidase catalyzes the breakdown of nucleotides (precursors to DNA and RNA) to form uric acid, which contributes to the plasma antioxidant capacity of the blood. The functions of mARC are not yet well understood.

No natural case of Mo deficiency in humans has been reported, although a case of diet-induced deficiency of Mo was reported by Abumrad et al. (1981). For more details on clinical aspects, reference may be made to Delage et al. (2015).

There are a number of enzymes other than those mentioned for humans with which Mo is associated in animals (Hille 1999). In ruminants, excess Mo in diet causes Cu deficiency due to the formation of insoluble complex in rumen which can be rectified by supplementation of sulfate; otherwise molybdenosis can occur in animals.

Excess dietary molybdenum has been found to result in copper deficiency in grazing animals. In the digestive tract of ruminants, the formation of compounds containing sulfur and molybdenum, known as thiomolybdates, prevents the absorption of copper and can cause fatal copper-dependent disorder (Suttle 2012).

16.3 Amelioration of Micronutrient Deficiencies in Humans and Animals

Amelioration of micronutrient deficiencies can be broadly grouped under two categories, namely, nutraceutical/mineral mixture and biofortification of cereals and other staple food crops.

16.3.1 Nutraceutical/Mineral Mixture

Nutraceutical/mineral mixture intervention of a micronutrient deficiency can be approached in three ways, namely, pharmaceutical supplementation, dietary supplementation, and dietary diversification.

16.3.2 Pharmaceutical Supplementation

India has made considerable success in pharmaceutical supplementation, and a variety of tablets, capsules, syrups, and tonics containing Fe are available off the shelf. Recently some Zn formulations have also entered the Indian market. However, more public awareness about these has to be created. Also people need to be advised that these supplements must be taken only under medical supervision, because dietary Fe overload can cause Fe poisoning, since the human body has no adjustable Fe excretory mechanism (Lynch 2003). There are also reports that Zn supplements over 100 mg day^{-1} taken over 10 years may increase the risk of prostate cancer (Litzman 2003).

16.3.3 Dietary Supplementation

Dietary supplementation can either be at industrial level or at home. Examples of industrial supplementation are iodized salt, vitamin A supplemented edible oils, Fe-enriched corn flakes, etc., which are already in the Indian market. Home supplementation with micronutrients is more difficult to achieve, because it involves training, specially housewives in making micronutrient supplemented foods. However, some success stories with Fe enrichment of foods such as khichri (rice cooked with a pulse) and laddoos (a popular Indian sweet) are available (Kanani and Poojara 2000; Sood and Sharda 2002; Varma et al. 2007).

16.3.4 Dietary Diversification

This involves adding or increasing the content of food articles rich in Fe, Zn, and other micronutrients. Animal products such as meat, fish, and poultry are rich sources of Fe and Zn, but per capita consumption of these in India is only 1.6, 1.9 and 1.28 kg year^{-1}, respectively, as against 5.9, 8.3 and 35.5 kg year^{-1} in China and 42.6, 45.4, and 29.7 kg year^{-1} in the USA. What to say of animal products, even the availability of pulses, which are richer in Fe and Zn, has declined from 68 g capita^{-1} day^{-1} in 1961 to 35 g capita^{-1} day^{-1} in 2006–2007 (Anonymous 2009). Thus, diversification of common man's diet in India is a difficult task.

Cereal grains such as rice and wheat, which are staple food in India, are low in Fe and Zn. For example, polished rice may contain only 5 mg Fe and 13 mg Zn per kg grain (Welch 2005). Wheat grains may contain 45–51 mg Fe and 30–43 mg Zn per kg grain (Dhaliwal et al. 2009). Further, cereal grains contain phytates, which reduce the bioavailability of Fe and Zn. A phytate to Zn ratio of 15 or less is considered good for zinc bioavailability (Gibson 2005). Some simple practices such as soaking the grains overnight or sprouting them can easily reduce phytate content and make Fe and Zn more bioavailable. Some green and fresh vegetables, such as cluster beans, French beans, ladies finger, green peas, carrots, okra, cabbage, etc., are rich in Fe (Jaggi 2007) and can help in meeting Fe needs. Beans are also rich in Zn.

All nutraceutical approaches require a well-organized infrastructure and trained staff to create the need awareness of micronutrients and continued funding, which is difficult to get. Further such programs, most of the time, would remain restricted to urban population, which is easy to reach and is more receptive due to a high level of women's education. People in rural areas, especially those difficult to reach by road or rail, thus remain deprived of benefits from the nutraceutical approach.

16.4 Biofortification of Cereal Grains/Straw and Other Foods with Micronutrients

16.4.1 Genetic Strategies

In an attempt to attain higher and higher yields, the concentration of micronutrients in grains has generally been overlooked. White et al. (2009) reported that increased yields in modern potato cultivars are often associated with reduced concentration of minerals. Similarly Cakmak et al. (2000) found higher Fe and Zn concentration in primitive wheat cultivars than in modern varieties. Efforts are therefore being made to breed food crop cultivars with higher micronutrient concentration (Graham et al. 2001; Bouis 2003).

16.4.2 Role of Biotechnology and Plant Genetic Diversity to Enhance Mineral Composition

Biotechnology refers to a set of medical, agricultural, and industrial techniques that use living organisms to create new, or to improve existing, products and processes. In particular, the use of the process of genetic modification is a very important aspect for increased density of the minerals in the economic produce of the crops. The capacity of genetic modification to produce plants with useful traits such as decreased pest resistance, reduced post-harvest losses, increased yield, reduced labor requirements, or enhanced content of particular desirable constituents is readily apparent (Tripp 2001). In the latter case, pure naturally occurring molecules can be produced economically and efficiently for use as pharmaceuticals, pesticides, or other purposes. Likewise efficient production of ingredients with specific qualities such as edible oils (Voelker 1997), pigments, and flavor ingredients supports the food industry in developed countries. Epidemiological, in-vitro, and clinical data affirm the positive relationship of a diversity of dietary components to good health. The biotechnology is already used to introduce, isolate, and enhance specific nutritional and functional properties in food, motivated by either consumer demand or entrepreneurial innovation (Bouis et al. 2003; Tucker 2003).

The use of biotechnology to create genetically modified organisms (GMOs) has the potential to design foods with specific attributes. Enhanced nutritional quality of crops may be achieved by enabling the capacity of the plant to synthesize vitamins, to take up minerals with greater efficiency, or by reducing anti-nutrient factors such as phytates or tannins that can make nutrients unavailable as well as lower food palatability (Raboy 2002; Bouis et al. 2003; Tucker 2003). Crops with enhanced qualities such as high β-carotene and lycopene tomatoes or oats with enhanced β-glucans that are available as whole foods can attract consumers to pay premium prices (Hasler 2002). Such products are demand driven in relation to their perceived benefit. However, futuristic scenarios of using genomics to match diets with individual genotypes (Kaput and Rodriguez 2004) bear little relevance to economic reality of developing country populations.

Forage crops show particular potential of nutritional enhancement with positive impact on livestock nutrition and productivity (Casler 2001; Cherney and Cherney 2002). Because animal-source foods generally provide more available iron, vitamin A, and protein than plants (Allen and Gillespie 2001; Allen 2003; Murphy and Allen 2003), even small increases in intake offer real benefits to the majority of the world's malnourished. In nutritional terms, considerable benefit will come from increasing animal productivity and consequently animal-source foods in the diet. However, animal-source foods are more expensive than plant foods and increased production can have negative environmental impact. Nonetheless, for poor households, keeping livestock is an important economic and dietary asset. Increasing consumption of animal-source foods in poor communities using improved fodders and other innovative means contributes to the economic benefits of animal ownership in poor communities and is a positive example of programs that have increased local production and consumption (Allen 2003).

While the technical achievements of nutritional enhancement of human foods and animal fodders may be analogous, the impacts on nutrition and health are not. The objectives of each exercise differ, as do the measures of health. In the case of animal fodder, the diet is consumed under controlled situations with no or little choice offered. Moreover, nutritional physiology and behavior of omnivorous humans are considerably more complex than herbivorous and provisioned animals.

For human populations, the benefits of consuming phytochemically enhanced foods (other than in terms of quantity of fruits and vegetables) for individual or public health have not been demonstrated. Neither will the long-term epidemiological studies required to show their impacts be soon forthcoming. Interventions with nutrient-enhanced foods in undernourished populations would have shorter-term impact but demonstrating the effectiveness and long-term sustainability of these interventions will also be challenging (Allen and Gillespie 2001; King 2002; Bouis et al. 2003). A less ambitious use of biotechnology is the marker-assisted selection for quality trait identification (Naylor et al. 2004). While accessions screened for markers of nutrient or phytochemical quality could be used in traditional breeding or biotechnology efforts, they can also be promoted directly to consumers as nutritionally valuable crop varieties.

A number of global projects on genetic biofortification of food crops are underway (Stein 2009). Some of these are listed below. In addition, there are several small projects on other crops (Stein 2009).

- *HarvestPlus, a Global Challenge Program* of the Consultative Group of the International Agricultural Research (CGIAR) focuses on breeding for higher levels of Fe, Zn, and beta-carotene in the major staple crops of the developing countries, namely, rice, wheat, maize, cassava, sweet potato, and beans.
- *The Golden Rice Project* focuses on genetic engineering approach to biofortify rice with beta-carotene, Fe, Zn, Vitamin E, and protein under the "Great Challenges in Global Health" scheme funded by Bill & Melinda Gate Foundation.
- African Biofortified Sorghum Project funded by Bill & Melinda Gates Foundation focuses to fortify sorghum with Fe, Zn, Vitamin A, and Vitamin E.
- Bio-Cassava Plus targets to increase Fe, Zn, vitamin A, vitamin E, and protein in cassava.
- Biofortification of bananas with Fe, pro-vitamin A, and vitamin E.

Genetic biofortification of food crops is beset with several problems. Biofortification is the process of generating genetically improved food crops that are rich in bioavailable micronutrients, either through conventional breeding or genetic modification. Some of these are:

- Initial genetic research requires heavy funding (Qaim et al. 2007), which at the moment has fortunately come from some philanthropic organizations, such as Bill and Melinda Gates Foundation. But such funds may not be available in the future.
- Genetic research needs time, may extend to several years.
- The cultivars fortified with micronutrients developed may not be as high yielding as the

present cultivars and may face problems in acceptance by the farmers.

- The newly developed cultivars fortified with micronutrients may differ in quality and the consumers may not accept these, at least initially (De Groote and Chege Kimenju 2008).
- Cultivars fortified with micronutrients using genetic engineering are still not accepted by a number of countries (Cohen and Pearlboy 2002; Conko and Miller 2002; Neilson et al. 2001).
- Even if a nation accepts genetically modified (GM) crop cultivars, it may not be possible to export the produce to other countries (Isaac 2002), which do not allow the consumption of GM foods.

Despite the enormous research activities, so far, only two biofortified crop cultivars have been successfully developed. So far no micronutrient-rich cultivar has been released in any food crop. It is generally opined that developing countries in Asia and Africa, where micronutrient problems are widespread, stand to gain from biofortified food crop cultivation.

16.4.3 Agronomic Strategies

Agronomic biofortification or ferti-fortification (Cakmak et al. 1999) of food crops with micronutrients involves application of micronutrient fertilizers to crops and is restricted to micronutrients that are essential for plant growth. Also it is applicable only to areas with soils deficient in micronutrients. It is worth mentioning that Zn-deficient soil areas are also the regions from where Zn malnutrition is most reported (Prasad 2009).

Shivay et al. (2008a) from New Delhi reported that an application of 5.2 kg Zn ha^{-1} as 2 % Zn (as zinc sulfate or zinc oxide) coated urea increased Zn content in rice grain from 30.2 to 47.7 mg kg^{-1}. Similarly an application of 2.6 kg Zn ha^{-1} as 2 % Zn (as zinc sulfate or zinc oxide) coated urea increased Zn content in wheat grain from 39.9 to 51.1 mg kg^{-1} (Shivay et al. 2008b). This increase in Zn content in rice or wheat grain was also associated with an increase in grain yield.

The major advantages of agronomic biofortification include the following:

1. It is done on crop cultivars already being cultivated by the farmers and the produce is acceptable to the consumers.
2. Farmer is saved from the investment on new seeds.
3. Gain in the micronutrient concentration in grain or other food products is obtained in the same year.
4. Application rates of mineral micro-nutrients (MMNs) are much smaller when these are applied to foliage.
5. Agronomic biofortification or ferti-fortification is thus a win–win approach for developing countries.

16.5 Conclusion

Iron and zinc deficiencies are widespread in India and the world. Since these are hidden hungers, creation of public awareness about the ill effects of Fe and Zn malnutrition is important. Research on micro-mineral nutrition in medical and other institutions needs to be encouraged. Agronomic biofortification of food crops is the fastest and safest way for the intervention of Fe and Zn deficiency. An integrated approach involving human and animal nutrition experts and agricultural scientists is suggested for ameliorating of micronutrients deficiencies in humans and animals.

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