Biofortification: Pathway Ahead and Future Challenges

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Abstract

A large share of global population is affected by mineral and vitamin deficiency, particularly in the developing countries. Recent estimates exposed the problem will be more disappointing in the near future. Biofortification is emerging as a potential crop-based approach to deal with the mineral malnutrition problem by enriching the density of bioavailable micronutrients and vitamins in food products. In recent years, significant advancement has been made in the fundamental understanding of micronutrient acquisition and translocation in soil-plant system. However, the current knowledge base in this area needs significant advancement to accelerate the pace of biofortification programme. Apart from the conventional breeding techniques, possible transgenic and agronomic approaches have also been identified for increasing the zinc, iron, selenium and iodine concentrations in the edible parts of food crops. Although these approaches are useful to address the mineral malnutrition problems worldwide, the effectiveness of the biofortification programme essentially relies on the farmers' and consumers' acceptance and future policy interventions. Therefore, strategic research and appropriate policy can lead to biofortification's grand success in the near future. In this chapter, we discussed the current knowledge and future prospects of crop biofortification.

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34.1 Introduction

Despite significant advances in alleviating the hunger and malnutrition in some countries, global nutritional security is far from the reality, particularly in the developing world (Stein et al. 2008). Worldwide, billions of individuals are suffering from continuous insufficient intake of micronutrients because of the widespread dietary mineral deficiency in commonly eaten staple food crops (White and Broadley 2005; Thavarajah and Thavarajah 2012; Graham et al. 2007). Recent estimates have suggested that nearly 850 million individuals experience the ill effects of some kind of undernourishment in this planet (United Nations Millennium Development Goals Report 2006a, b). Insufficient intake of micronutrient and vitamins is extensive among the world's population who are dependent on vegetarian diet, consisting of few staple crops (Connolly 2008). Traditionally, to address this issue, we basically depend on mineral supplementation, dietary diversification and food fortification interventions, and their positive impact has already been assessed in different parts of the world (Welch and Graham 2004a; White and Broadley 2005). However, fortification and supplementation programmes largely target the urban population. Further, these types of programmes call for huge amount of fund, which is practically difficult to invest for most of the governments of low-income countries (Meenakshi et al. 2010). In addition, this programme does not include the 'food-based approach' which favours consumption of locally available plant and animal species from diverse origin (Shrimpton 2002). In this situation, a crop-based technique has been developed, in which the edible parts (grain, straw, root and tubers) of food crops are enriched with micronutrients through appropriate breeding methods. This approach is named as 'biofortification' (Bouis et al. 2000; Bouis 2002; CIAT/IFPRI 2004). Worldwide, the technique is progressively becoming popular as a potential strategy to minimise the micronutrient-related unhealthiness (Meenakshi et al. 2010). In fact, the poor people are mostly affected by micronutrient deficiency as they cannot afford micronutrient-rich foods like fruits, vegetables, pulses and animal products. Therefore, micronutrient fortification in common staple food crops can improve their nutrition and health status. Hence, as an alternative low-cost approach, 'biofortification' can play a vital role in mitigating the micronutrient malnutrition and ensure quality of life worldwide (Waters and Sankaran 2011).

34.2 Extent of Deficiency and Its Impact

Mineral and vitamin deficiency affect a major share of the world's population, mostly in the developing world (Stein 2010). Among the minerals that are essential for human health, zinc and iron deficiencies are widespread. Besides this, iodine, selenium and cobalt deficiencies are also observed in different parts of the world. Basically, the deficiency is due to low concentration of these minerals in their day-to-day diets (Fageria et al. 2012). Based on United Nations' estimates, almost one billion individuals are suffering from a kind of trace element deficiency. The problem is more common for women and children, especially in the countries like Africa, Asia and South America (Fageria et al. 2012). Globally, vitamin deficiency is another challenging problem, particularly vitamin A deficiency. Vitamin A deficiency is responsible for early deaths of young children. Every year, almost one million young children die under the age of five due to vitamin A deficiency. Recent estimate also documented that almost 3 % mortality of young children may be directly related to vitamin A deficiency, and besides this all night blindness disorder is attributed to vitamin A deficiency. According to the reports of the World Health Organization (WHO), approximately 250 million pre-school children are deficient in vitamin A. Apart from this, substantial proportion of pregnant women is also suffering from vitamin A deficiency especially in the underdeveloped world. Deficiency of iodine is also widespread in humans. Almost 20 % of the developing world's population is suffering from iodine deficiency disorders. Iodine is very important for pregnant women and iodine deficiency during pregnancy is causing nearly 20 million babies to be born mentally impaired. According to WHO, globally 1.6 billion people are in serious risk of iodine deficiency as some regions are identified under low soil native iodine category (Bruno et al. 2008; Hetzel et al. 2004).

Worldwide, deficiency of iron in human increases the risk of disability as well as death (Boccio and Iyengar 2003). The World Health Organization estimated that out of 3.7 billion iron-deficient individuals, 2 billion people are severely affected and considered as anaemic (Yang et al. 2007). Subsequently, it has been documented that 5 % of all types of maternal mortality is directly associated with iron deficiency (Meenakshi et al. 2010), and every year 50,000 young women are dying during pregnancy/or childbirth due to severe iron deficiency. Likewise, deficiency of zinc also leads to serious health problems and almost one third of the world's population are now deficient in zinc (Welch and Graham 2004b; Hotz and Brown 2004; Muller and Krawinkle 2005). Zinc deficiency in humans is designated as the fifth important cause of diseases and deaths in the developing countries (White and Broadley 2009; WHO 2002) (Fig. 34.1).

The role of selenium is also vital and has a unique value in mammalian nutrition (Diwadkar-Navsariwala et al. 2006). The bioavailability of selenium is usually low in soils of China, United Kingdom, East Europe, Africa and Australia. Therefore, crop plants have lower density of selenium in these regions (Smkolji et al. 2005; Pedrero et al. 2006; Genc et al. 2005). Continuous intake of low-selenium content food causes complicated health-related problems like epilepsy, oxidative stress-related conditions, infertility, immune deficiency, etc. (Rayman 2012; Whanger 2004; Zeng and Combs 2008). Hence, the global statistics of the problem of micronutrient deficiency is really upsetting and needs immediate attention.

34.3 Biofortification: Importance and Relevance

Food fortification, supplementation and dietary diversification programmes have effectively addressed the micronutrient malnutrition in several countries (Khush et al. 2012). However, biofortification has some added benefit over other interventions, i.e. it is a low-cost sustainable technique and virtually addresses the economically backward households and subsistence farmers (Nestel et al. 2006). Apart from this, 'investment is only required at the research and development stage, and thereafter they would become entirely sustainable' (Gomez-Galera et al. 2010; Bouis 1996; Graham et al. 2001; Welch and Graham 1999, 2002, 2004a; Welch 2002). In different parts of the world, food crops are usually deficient in micronutrient because of low native soil micronutrient concentration, cultivation of high-yielding varieties that demands higher quantity of micronutrients and in the long run depletes the soil micronutrient level, liming practices in acidic soils (Fageria and Baligar 2008), unfavourable soil reaction in sandy and calcareous soil for micronutrient availability, continuous application of high analysis fertilizer that contains very negligible amount of micronutrient and minimal use of organic amendments (Fageria et al. 2002). Hence, increasing micronutrient density as well as improving the bioavailability of these trace elements in major food crops is a promising strategy to combat the micronutrient malnutrition problem. In this

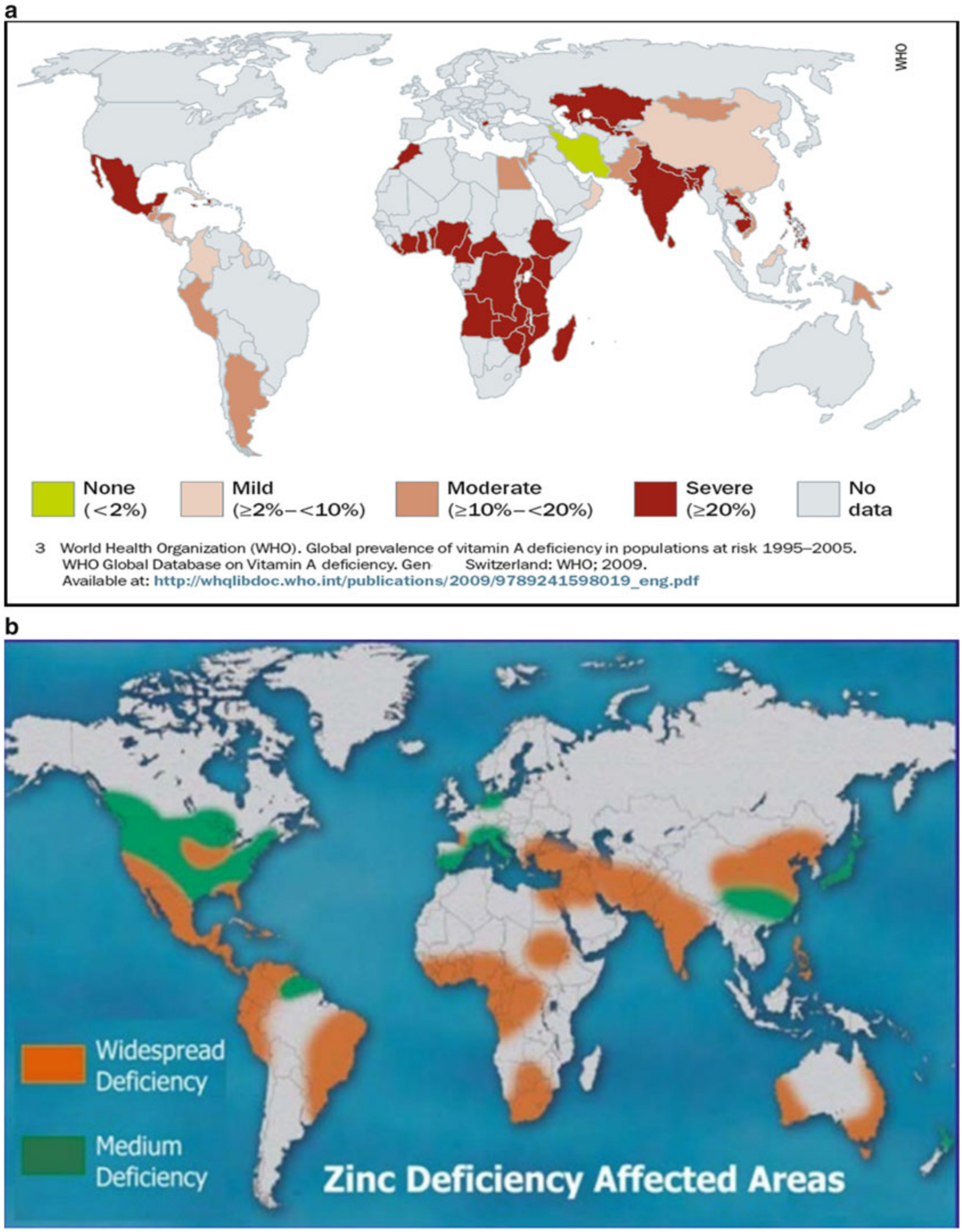

Fig. 34.1 Distribution of global area with variable degree of vitamin A deficiency (**a**) and zinc deficiency (**b**) (Alloway 2004)

programme, the basic target is to improve the levels of important micronutrients of staple food (e.g. rice, potato, etc.), which are widely consumed by a large share of the world's population. Therefore, even very little enhancement in bioavailable micronutrient level in targeted food crops may have considerable impact on alleviating the malnutrition problem, particularly in the developing countries (Sperotto et al. 2012). Additionally, an improved soil-plant system will ensure nutrient cycling and ecologically viable environment (Yang et al. 2007). In the long run, 'biofortification' approach is expected to be more important as a strategy that also has a lower dependency in infrastructure and compliance (Gomez-Galera et al. 2010).

34.4 Research Advances

34.4.1 Understanding the Physiological Basis of Micronutrient Delivery in Soil-Plant System

Understanding the mechanisms of soil-plant nutrient system is essential for successful biofortification method. Lately, a significant progress has been noticed in explaining the plant adaptation mechanisms to micronutrient stress (Ghandilyan et al. 2006) and the complicated transport pathway of micronutrient (iron and zinc) from soil to plant system (Khush et al. 2012). The uptake and translocation procedure of important metals are understood more clearly with physiological and genetic processes.

Research results have been documented that the rice genotype with rich in iron have higher translocation rate of iron from root to the shoot and grain when compared with noniron rich rice genotypes. At the same time, iron-rich rice genotypes have higher accumulation of iron and zinc in endosperm tissues of rice grain (Hao et al. 2005). Scientists have explained this mechanism genetically and confirmed that the expression of specific genes in the phloem cell and grains is basically responsible for the above process. Likewise, the enhanced micronutrient content in transgenic *indica* rice grain is due to expression of the gene 'ferritin' that results in not only higher iron and zinc in whole rice but also in polished rice. Detailed knowledge of physiological and molecular basis of micronutrient translocation and accumulation in plant is crucial for need-based manipulation of the plant system (Vasconcelos et al. 2003). Significant advancement in the understanding of the molecular mechanisms has been observed since the last two decades. The processes of zinc acquisition from soil to plant system have been described by molecular genetics in grain crops like rice, wheat and rye (Yang and Romheld 1999). In the same line, molecular process of detailed transport pathways, distribution pattern and chelating mechanisms of copper, iron and zinc have been explained by Grotz and Guerinot (2006). Based on comparative assessment of phytosiderophore production of different cereals, Romheld and Marschner (1990) confirmed that among the cereals, barley crop has the highest production of phytosiderophore and its associated iron acquisition from soil to plant system. Scientists have identified a metal chelator, nicotianamine (NA), which is responsible for metal transports and homeostasis (Douchkov et al. 2005). Hence, the clear understanding of the pathways of metal transport in plant system enables us to strategically improve the micronutrient mobilisation and transportation to the edible plant parts.

Enhancing bioavailability of micronutrients is also an important challenge under biofortification programme. Scientists proposed that not the absolute density of micronutrients in the edible plant parts but the bioavailability of micronutrient is more important. In fact, phytic acid, which fixes the micronutrients like iron and zinc in the plant system, reduces the bioavailability of micronutrient. Consumption of higher phytic acid content food products is difficult to digest and greatly restricts the absorption of micronutrients. Therefore, attempts have been made to reduce the level of phytic acid in the food crops. Degradation of phytic acid through enhanced activity of phytase enzyme as well as minimising the level of phytin can improve the bioavailability of micronutrients in the human digestive system (Raboy 2002). In this context, the phytate-to-zinc molar ratios or the phytate and calcium-to-zinc ratio are important indicator of micronutrient availability. A greater variability among the species and genotypes has been noticed for phytic acid content and can be used for developing the variety with desired traits (Cakmak et al. 1999). However, as a major plant metabolite the anti-nutrients (e.g. phytic acid) also take part in plant metabolism, stress resistance and pest and pathogen resistance (Yang et al. 2007). The role of phytin in early seedling vigour has been well established, and reduced phytin level greatly hampers the seedling vitality particularly in low fertile soils as it serves energy and is an important source of mineral and phosphorus. Additionally, some anti-nutrients (e.g. polyphenols and phytate) are also important for human health and can reduce the risk of heart disease and diabetes, and also these are potential anticarcinogens (Shamsuddin 1999). Therefore, manipulation of anti-nutrient concentration in edible food crops through breeding approaches should essentially consider the negative consequences on health (Welch and Graham 2004a). Therefore, for successful biofortification, comprehensive knowledge on the physiological process of uptake from the rhizosphere, phloem sap loading, translocation and unloading rates within the reproductive organs, and remobilisation mechanisms are very important (Welch and Graham 2004a; Welch 1986; Sperotto et al. 2012) (Fig. 34.2).

34.4.2 Breeding Approach

Sizeable genotypic variation exists in micronutrient density in different crop species (Yang et al. 2007). Substantial genotypic variation in grain micronutrient concentration of rice, maize and wheat has been documented (Bouis 1996; Graham et al. 2007; Welch and Graham 1999, 2004b). Plant breeder mainly targets to use this existing genotypic diversity for developing micronutrient-enriched crop varieties (Zapata-Caldas et al. 2009). At present, a number of research programmes have been initiated to develop the desired crop varieties with higher micronutrient density (iron and zinc), vitamin A, tryptophan and lysine at the global level. These programmes mainly concentrate on few staple food crops like rice, wheat, cassava, potato, bean, etc. (Pfeiffer and McClafferty 2007). An integrated effort of the Consultative Group on International Agricultural Research (CGIAR) centres on the programme 'HarvestPlus' aiming to breed for increasing concentration and bioavailable zinc and iron in seeds of major stable food crops (Bouis 2002; Pfeiffer and McClafferty 2007). Likewise, in search of potential donors, IRRI (International Rice Research Institute) started a programme in collaboration with the Department of Plant Science, University of Adelaide, Australia. In this programme almost 7000 entries were screened for both iron and zinc contents in the rice grain. Afterwards, a higher variation in iron and zinc level in rice grain has been documented from the study (Khush et al. 2012). In the same line, reports show that the entries of rice, wheat, maize, bean, cassava and yam differ greatly in iron concentration (Frossard et al. 2000; Welch 2001; Genc et al. 2005; Haas et al. 2005; Nestel et al. 2006). The variation in iron content in rice, wheat and maize was noted to be 6–22, 10–160 and 15–360 mg kg^{-1}, respectively (White and Broadley 2005). Therefore, selective breeding might be a potential tool to develop micronutrient-rich staple food crops (Tiwari et al. 2009). An improved breeding line from India has been identified, i.e. IR 68144-3B-2-2-3 (IR72$\times$ Zawa Bonday), which is rich in iron level (21 mg kg^{-1} unmilled brown rice), concurrently a good yielder also. Likewise, some emmer wheat accessions were found tolerant to zinc deficiency in soil and maintained a very high level of zinc (up to 139 mg kg^{-1}), iron (up to 88 mg kg^{-1}) and protein (up to 380 g kg^{-1}) in grains (Peleg et al. 2008). Subsequently, latest research also suggests that 'synthetic wheat derived from *Aegilops tauschii* has also a high genetic potential for increasing grain zinc density of cultivated wheat' (Calderini and Ortiz-Monasterio 2003). Recently, some genotypes with low phytic acid content have been identified in rice, maize and barley (Raboy 2000). Hence, from the above points, it is clear that micronutrient concentration in food grain can be increased substantially through adoption of appropriate breeding techniques. As a low-cost and relatively easy strategy, breeding techniques always

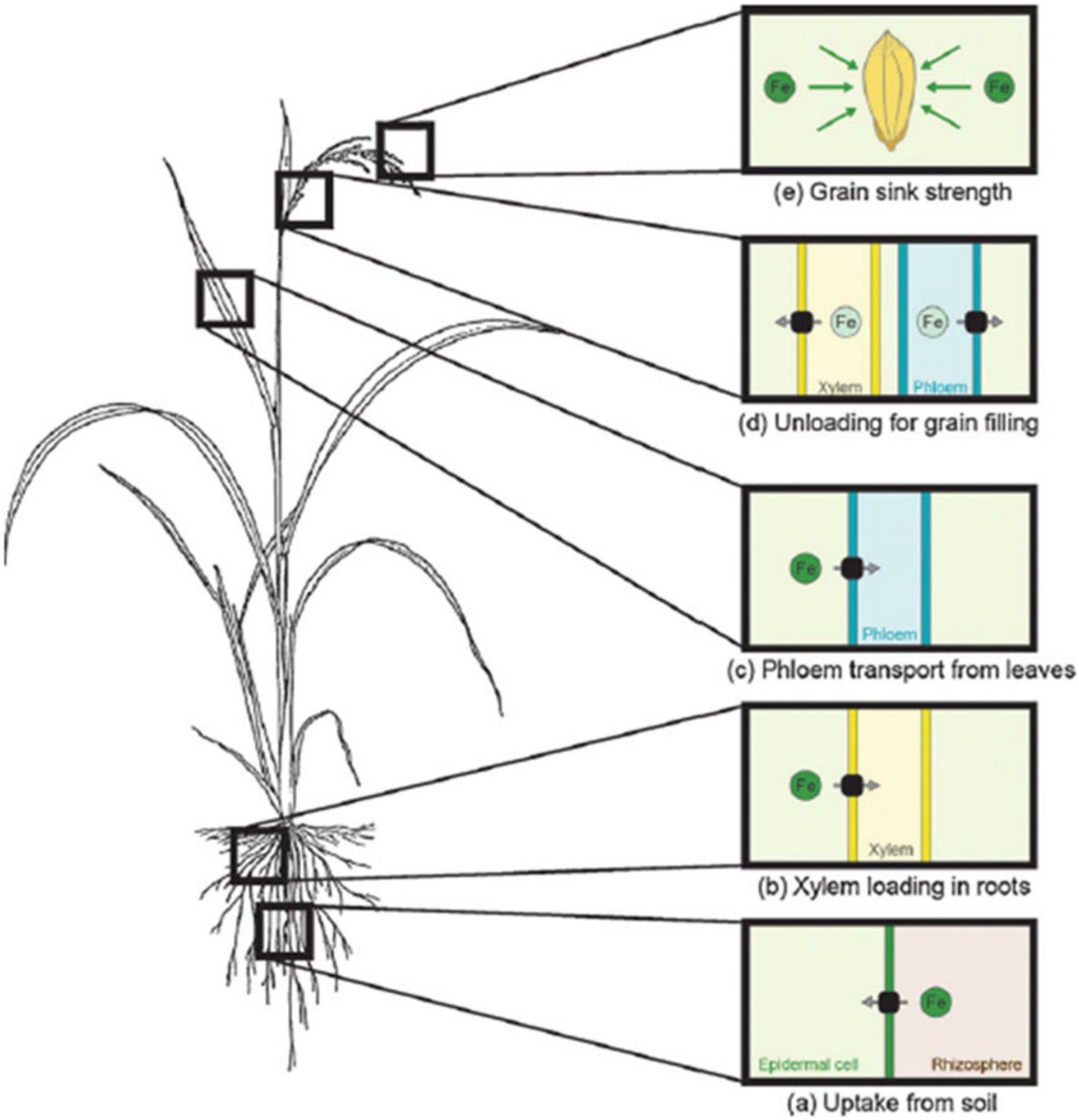

Fig. 34.2 Rate-limiting process of iron transportation from soil to seed (Sperotto et al. 2012)

consider the best biofortification tool to overcome the micronutrient malnutrition problem. However, the availability of micronutrient in soil greatly influences the success of this technique. Meanwhile, continuous cultivation of HYVs of cereal crops aggravated the micronutrient deficiency in soils. Therefore, there is an every need to balance the soil micronutrient pool to get the long-term benefit from these biofortified crops.

34.4.3 Agronomic Approach

Compared to breeding approach, agronomic biofortification represents a short-term solution to the problem. In fact, with introduction of high-yielding exhaustive crop varieties, the soil native micronutrient level has depleted to a large extent (Cakmak 2008). Globally, the extensive deficiency of micronutrient in soil is mainly responsible for low micronutrient density in food crops and associated malnutrition problems. Therefore, crop plants show higher response to micronutrient fertilisation in soil micronutrient-deficient areas. Hence, there is a need to improve the soil chemical and biological system for facilitating the optimum acquisition of micronutrients by the crop plants. With adoption of appropriate fertilisation practice, significant improvement in grain micronutrient concentration has been reported by many researchers. Agronomic approach is therefore very important as short-term and sustainable technique of biofortification (Cakmak 2008). Application of zinc fertilisers in wheat (Hu et al. 2003), rice (Li et al. 2003), pea and cowpea (Fawzi et al. 1993) not only improves the micronutrient density in grains but productivity also. The application method of micronutrient fertilisers greatly influences the efficacy in increasing concentration of micronutrients in edible plant parts. Based on field experimentation, it has been confirmed that the foliar application of zinc spray in wheat at early dough or milk stage crop is more effective than soil application (Cakmak et al. 2010a). Basically, at field situation, foliar or foliar + soil application is found more promising. Research evidences have also suggested that foliar application of zinc in wheat improved the zinc concentration of wheat grain by almost 2–3 folds under different regimes of soil zinc availability (Cakmak et al. 2010b; Cakmak 2008). Likewise, zinc concentration in white rice can be improved extensively with spraying zinc at heading stage. More importantly, application of zinc-based fertilisers reduces the overloading of phosphorus in grain, thereby reducing the phytic acid concentration. Minimising the phytic acid concentration helps to increase the bioavailability of zinc or other micronutrients when consumed (Cakmak et al. 2010b; Erdal et al. 2002). Additionally, micronutrient-enriched seeds have higher germination and vigour and are considered potentially more tolerant to micronutrient stress in soil.

The low availability and mobility of iron in soil also restrict its uptake from soil to plant system. Furthermore, upon application of iron fertiliser in the form of $FeSO_4$, rapidly converts to to Fe (III) form, and become unavailable for plant (Frossard et al. 2000). Meanwhile, iron availability in calcareous soil is one of the challenging problems and effectiveness of iron fertilisers is also noticeably poor. Therefore, rapid conversion of iron to unavailable form and reduced mobility in plant system (phloem) collectively results the lower effectiveness of soil and foliar application of iron-based fertilizers, particularly for cereal crops in calcareous soil (Rengel et al. 1999; Cakmak 2008; Fawzi et al. 1993). In this situation, some researchers emphasised on organic Fe fertilisers to solve the problem. The nutritional quality as well as grain yield of peanut (Xiao et al. 2000), wheat (Hu et al. 2003) and green pea (Zhang et al. 2006) was substantially improved with application of organic Fe fertiliser. Besides this, various cheated compounds (Fe-EDTA, Fe-DTPA, Fe-EDDHA, Fe-citrate and Fe-IDHA, etc.) also can be used to correct the severe Fe chlorosis in crop plants. Interestingly, the transportation mechanism of nitrogen and iron in vegetative part of the plant system is regulated by a common genetic process (Waters et al. 2009), and a positive relationship between grain nitrogen and iron has been confirmed by many researchers. Therefore, integrated or mix foliar application of urea and Fe fertilisers had synergistic effect on grain iron concentration as nitrogen helps to penetrate iron into the leaf tissues (Swietlik and Faust 1984; Rodriguez-Lucena et al. 2010b). Hence, to facilitate iron biofortification of food crops, nitrogen nutrition is also very crucial and needs special attention. Recently, several researchers reported that iron and zinc nutrition can be improved with suitable interspecific root interactions. Intercropping of cereal (*graminaceous* species) with dicot plant, e.g. maize + peanut, chickpea + wheat, guava + sorghum or maize, improves iron and zinc uptake because of interspecific root interactions (Huang et al. 2012; Kamal et al. 2000; Zuo et al. 2004; Inal et al. 2007). Therefore, intercropping with appropriate component crops may be a key approach for improving the micronutrient concentration in the targeted crop by increasing the soil availability of micronutrients. Similarly, agronomic approaches to increase the selenium concentration in food crops are becoming increasingly popular. Foliar applications of selenium fertilisers (Na_2SeO_4 and K_2SeO_4) are very effective and have immediate effect on plant selenium concentration, while some less soluble selenium fertiliser ($BaSeO_4$) and selenite are known to have delayed effect but last for a long time (Broadley et al. 2010). However, agronomic biofortification has several limitations, e.g. a grater variability of micronutrients in soil system, soil chemical reactions that reduce the availability of applied micronutrient fertilisers, non-efficient transportation foliar application that results in micronutrient deficiency in roots, etc. (Yang et al. 2007). Hence, strategic fertilisation strategy needs to be developed at the same time and soil properties should be improved to ensure micronutrient availability. Furthermore, the success of genetic biofortification also largely depends on strategic soil and fertiliser management (Cakmak 2008), and thus agronomic biofortification is basically complementary to breeding biofortification approach.

34.4.4 Biotechnological Approach

Genetic engineering is also a potential tool to enhance the micronutrient content in food grains. Plant genetic makeup may be modified for higher synthesis of vitamins and higher acquisition of minerals and reduce synthesis rate of antinutrient compounds (phytic acid, tannins, etc.) (Bouis et al. 2003; Raboy 2002; Tucker 2003). Presently, significant advances have been achieved in the field of developing transgenic plant with higher micronutrient density. The ferritin (iron storage protein gene) has been successfully transferred from soybean/French bean to rice crop (var. Kitaake) through *Agrobacterium*-mediated transformation (Goto et al. 1999; Lucca et al. 2001) that results in almost threefold increase in rice grain iron concentration over control rice variety (Vasconcelos et al. 2003). Similarly, an attempt has been made to evaluate the expression of two transgenes NAS (AtNAS1) from *Arabidopsis thaliana* and ferritin (Pvferritin) from *Phaseolus vulgaris* in rice crop, which results in a synergistic effect on uptake and storage of iron concentration in grain endosperm (sixfold Fe overcontrol). In the same line, barley grain zinc concentration was improved by incorporating zinc-transporter protein genes from *A. thaliana*. Transgenic approach has been adopted in rice to manipulate the phytosiderophore biosynthetic pathway by introducing the gene for nicotianamine aminotransferase. The transgenic rice crops are resistant to iron-deficient conditions of calcareous soil and produce four times higher yield than the control rice plants (Takahashi et al. 2001). Lactoferrin, a human iron-binding protein present in milk, has been expressed in rice (Nandi et al. 2002) and potato (Chong and Langridge 2000) crops that results in increased availability of iron in plant residues. 'Transgenic approaches to biofortification rely on improving the phytoavailability of mineral elements in the soil, their uptake from the rhizosphere, translocation to the shoot and accumulation in edible tissues. Besides this, transgenic approaches may be used to reduce the concentrations of antinutrients and increase the concentrations of promoter substances' (White and Broadley 2005; Puig et al. 2007).

34.5 The Impact of Biofortification Research and Key Factors

The success of biofortification largely depends on several factors including farmer's acceptance of biofortified varieties and consumption of biofortified food products by the undernourished target population. Hence, cultivation of biofortified varieties and its consumption are the key factors that decide the impact of this programme. Till now, biofortification is in preliminary stage (research phase) in most of the developing countries. Meenakshi et al. (2010) stated that 'The impact of any food-based intervention depends on the dose–response to increased nutrient intakes. Ideally, this would entail determining a biological relationship between enhanced micronutrient intakes and nutritional outcomes'.

Till date, many success stories of biofortification programmes have been documented worldwide. Upon consumption of biofortified cassava, the vitamin A deficiency of northeast Brazil population has been reduced by almost 20 %. Likewise the biofortified maize and sweet potato reduce the occurrence of vitamin A deficiency to an extent of 32 and 64 %, respectively. The biofortification intervention was found highly cost-effective in northeast Brazil and Ethiopia. The consumption of biofortified bean even at very low quantity (45–55 g per day) was found promising and trimmed down the burden of iron deficiency up to 22 and 36 %, respectively (Fig. 34.3).

Under HarvestPlus programme in Mozambique and Uganda during 2007–2009, approximately 24,000 households had been supplied with orange sweet potato rich in provitamin A to reduce the occurrence of vitamin A deficiency. At the end of the project, the adoption rate of provitamin A-rich sweet potato increased up to 61–68 % and almost two thirds of the total women and children are consuming sweet potato for vitamin A (Hotz et al. 2012). Data also reported that the incidence of zinc deficiency reduced by 3–20 % in Latin America with consumption of biofortified beans. Interestingly, the magnitude of reduction of zinc deficiency with biofortified rice and wheat was much higher in Asian countries. Introduction of biofortifed rice in Bangladesh decreased the zinc deficiency by 17– 33 %, while 5–33 % decrease was noticed with high-zinc wheat in Pakistan. Hence, it is apparent that biofortification could have greater impact on mitigating micronutrient malnutrition worldwide.

34.6 Future Prospects

Currently, biofortification intervention is a promising crop-based strategy for eliminating micronutrient malnutrition. Still, substantial exploration hole exists in current biofortification methodology and presently it is a challenging endeavour. The detailed understanding of the mechanisms of mineral translocation from soil to seed are lacking in most of the food crops. Hence, advanced knowledge in the basic understanding of the rate limiting steps of micronutrient acquisition and translocation in soil-plant system should be generated. In addition the safety issues of biofortified crops have to be analysed in detail before making them available to the consumers. Comprehensive knowledge gap also exists in bioavailability of micronutrients in food grain and mineral distribution pattern in plant system. The loss of micronutrient during processing on selective removal of outer tissues is also not analysed for most of the crops and needs to be explored. In the near future, few most recent advances can assume a colossal part in the improvement methodology and can play an enormous role in the enrichment process of plant edible parts. Some of the important strategies would be transferring genes for higher iron and zinc content through molecular cytogenetics, minimising the loss of micronutrients during postharvest processing by uniform allocation of minerals in the grain, manipulation of phytic acid level to enhance the bioavailability, etc. Recently, fertiliser products of nanoscale level are viewed as a potential agro-input for precise micronutrient management even at very low application rate. Consequently, strategic utilisation of these nano-based micronutrient fertilisers may help in biofortification process. Till now, the biofortification technique is confined to some major crops and some crops with local relevance. In the same line, there is a need to explore all the crops that are directly or indirectly associated with micronutrient deficiencies. Thus, an integrated approach of biofortification strategies can improve human health through consumption of micronutrient-fortified food products. However, before we use this tool effectively for mitigating micronutrient malnutrition, some questions are always be there on its scientific feasibility, adoption probability at farmers and consumer level, economic viability and production stability (Nestel et al. 2006). In this background, the success of biofortification programme is directly associated with improved policies including nutrition education, marketing, agricultural policy and finally public

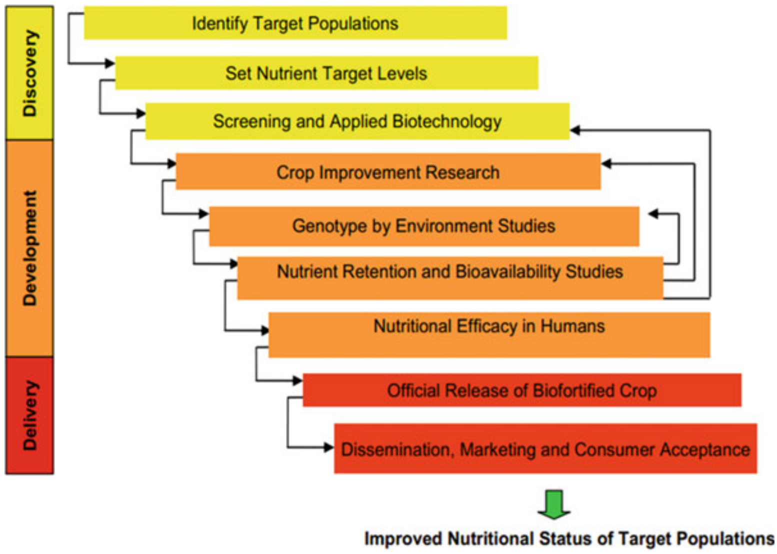

Fig. 34.3 HarvestPlus pathway (Bouis et al. 2011)

awareness. Interdisciplinary research team including human nutrition scientists and crop scientist would essentially work together for developing the final end products with desired nutritional properties. Sometimes, enrichment of micronutrient and vitamins has negative effect on colour and taste of the end product and usually not liked by the consumers. Therefore, biofortified crops will have to have acceptable sensory and cooking qualities for greater adoption. Furthermore, the desired yield level and resistant to biotic and abiotic stresses of these biofortified crop varieties should also be guaranteed. Therefore, in the future more systematic steps towards developing biofortified crops along with suitable agronomic management options are needed to eliminate the micronutrient malnutrition in human and ensure food and nutritional security.

34.7 Conclusion

In the future world, mineral and vitamin deficiency are expected to be more threatening, and biofortification strategy is appearing as a potential tool for addressing the problem. Given a low-cost, easy and crop-based approach, biofortification technique holds a great promise for mitigating the micronutrient malnutrition problem in the developing world. Significant progress has been made in this line, and future strategic research and appropriate policy could lead to biofortification's great success in the coming years.

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