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Biofortification of Food with Microelements

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Abstract: Problem statement: Recently a particular attention was paid to the issue of microelement hunger, also termed hidden hunger. The problem was of global significance, since was related with the public health and concerns over 2 billion people. **Approach:** The study discusses the state of the art in the research on food biofortification as the sustainable solution to cope with micronutrient deficiencies. Enrichment of food with microelements seems to be the rational method of preventive, not interventionist character. Consuming such food should reduce the intake of mineral supplements containing inorganic salts, whereby microelements posses low bioavailability. Different methods of increasing the density of microelements in food of plant and animal origin (agronomic and biotechnological) are discussed. **Results and Conclusion:** Using microelements introduced with either fertilizers or feeds in the form which is highly bioavailable should yield plant and animal products containing higher levels of these constituents. Introducing microelements bound to a biomass which serves as a biological carrier is possible by means of the process of biosorption. The method is widely discussed in the literature as wastewater treatment process in which metal cations are removed from effluents and bound with the biomass by postulated ion exchange mechanism. The same process can be used to enrich the biomass with metal cations of nutritional significance. Studies on laying hens fed with new feed additives produced by biosorption yielded higher densities of Fe, Zn, Mn and Cu in eggs content, as compared with the control group which was fed with diet containing inorganic form of microelements.

Key words: Micronutrients, microelement malnutrition, biofortification, supplementation, nutritional quality

INTRODUCTION

The problem of essential elements hunger: It is estimated that by the year 2050, human population will reach 9 billion people (Connolly, 2008; Ghaly *et al.*, 2010 and Girgis *et al.*, 2010). A challenge for global food and nutrition security society is to feed the world population with nourishing food (Welch and Graham, 2004; Hirschi, 2008; Quasem *et al.*, 2009; Ghaly, 2009). On the other hand, expectations for higher grain productivity in the past, caused decreased content of minerals in grains (Zhao and McGrath, 2009; Zhao and Shewry, 2011). In the future, an impact on the production of high quality food would be laid on, which is understood as food which contains the required level of nutrients, not only the required portion of energy (Pijls *et al.*, 2009; Ghaly and Alkoaik, 2010; Roukos *et al.*, 2010).

The issue of microelement deficiency is related with food security (Meenakshi *et al.*, 2010; Ghaly *et al.*, 2010; Zadeh and Begum, 2011). Micronutrient deficiencies are difficult to diagnose and consequently the problem is termed ‘hidden hunger’ (Stein *et al.*, 2008). It is estimated that affects more than a half of the global population (Zhao and McGrath, 2009). Deficiency concerns the following essential elements: Fe, Zn, Se, I, Cu, Ca and Mg (Zhao and McGrath, 2009), but mainly Fe and Zn (Rosado *et al.*, 2009). It is assessed that 5 billion people suffers from deficiency of iron (Meenakshi *et al.*, 2010).

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Table 1: The methods to increase intake of microelements

Fortification	Addition of micronutrients to food during processing (Meenakshi *et al*., 2010)
Supplementation	Intake of micronutrient supplements, eg. in the form of pills. The problems related with supplementation include adverse side effects, inadequate supply, the need to hold a daily regime and the costs (Stein *et al*., 2008)
Biofortification	Food-based intervention to enhance the content of micronutrients mainly in staple foods (White and Broadley, 2009)
Agronomic biofortification	The use of micronutrient fertilizers (Zhao and McGrath, 2009; Galinha *et al*., 2011)

The adverse effects related with hidden hunger include higher susceptibility to infectious diseases, impaired physical and cognitive development and mortality rates (Stein *et al*., 2008). The mostly endangered are women and children (Arsenault *et al*., 2010; White and Broadley, 2005). In particular, deficiency of Fe causes impaired physical activity, cognitive development and maternal mortality (Stein *et al*., 2008).

The content and bioavailability of minerals (Fe, Zn, I, Se) are lower in plant than in animal derived foods (Waters and Sankaran, 2011). The latter type of food is expensive hence the diet of poor people bases mainly on staple foods which supply low doses of bioavailable microelements (Nestel *et al*., 2006; Fairweather-Tait and Hurrell, 1996). Consequently, a correlation between hidden hunger and poverty was found (Stein *et al*., 2008; Johns and Eyzaguirre, 2007).

The mostly sustainable solution to the problem of malnutrition of essential elements is diversified diet (Graham *et al*., 2001; Welch, 2002; Naylor *et al*., 2004). Public health interventions include: fortification, supplementation or biofortification (Meenakshi *et al*., 2010). Biofortification approach is designated to increase micronutrient concentrations in the edible parts of plants through plant breeding or the use of biotechnology, the most commonly through agricultural practices (Cakmak, 2008; DellaPenna, 2007). Industrial fortification of food, pharmaceutical supplementation or the promotion of dietary diversification are the methods undertaken in many countries to alleviate the problem of micronutrient hunger (Hart *et al*., 2011; Stein *et al*., 2008). Benefit-cost ratios of those interventions were proved (Stein *et al*., 2008). Table 1 presents different approaches towards the increase of microelements intake.

MATERIALS AND METHODS

The concept of biofortification: Biofortification recently gained increased international attention as an alternative to fortification and supplementation programs, since enables to substitute supplements or fortificants with biofortified food. (Stein *et al*., 2008). It is advocated economically and environmentally friendly strategy (Dayod *et al*., 2010). In biofortification, the content of bioavailable forms of essential elements is increased in edible parts of crops by agricultural methods or by genetic selection (Blasco *et al*., 2010; Graham *et al*., 1999; Paarlberg, 2002). Biofortificationaims to develop plants with increased content of bioavailable essential elements in edible parts (Jeong and Guerinot, 2008; Stomph *et al*., 2009). Another concept is to decrease the content of elements in inedible parts of plants (e.g., roots) (Palmgren *et al*., 2008). It is expected that biofortified plants would not have decreased productivities, inferior taste nor require any additional inputs (Dayod *et al*., 2010). Enhancement of bioavailability of micronutrients can also be achieved by changing the level of pronutrient or antinutrient components in foods (Barber, 1995; Zhao and McGrath, 2009). The latter includes phytate which could be reduced by transgenic expression of phytase (Zhao and McGrath, 2009). The problem of low bioavailability of microelements in soil can be alleviated by the increase of production of compounds which complex metal ions (phytosiderophores), modification of soil conditions (pH), increased micronutrient fertilization, using synthetic metal chelators (Zhao and McGrath, 2009).Rhizosphere organisms participating in decomposition processes, cycling of trace elements and mineral weathering influence bioavailbility of essential elements to plants (Barcelo and Poschenrieder, 2011). Another approach towards biofortificationis the use ofhyperaccumulating plants (Barcelo and Poschenrieder, 2011).

Plant varieties with high level of micronutrients are crossed with high-yielding varieties to obtain plants which are highly productive and give nutritious grain (Dickinson *et al*., 2009). New varieties of plants are more efficient in taking up microelements from soil. This would require more extensive micronutrient fertilization to complement the part taken by plants (Dickinson *et al*., 2009). It is important that farmers accept new crop varieties. It would be possible only if productivity would be similar (Dickinson *et al*., 2009).

RESULTS

Mechanisms of plants biofortification: Grains of good quality should contain the required level of micronutrients (Fe, Zn and Cu) (Waters and Sankaran, 2011). By using certain techniques it is possible to produce biofortified grains (Waters and Sankaran, 2011). Biofortification of plants with microelements can be achieved by transgenic modification or plants breeding (Bouis, 2003). There were some attempts to increase the level of micronutrients in transgenic plants, however in many cases the adverse effects on plant functioning were observed (Dawson *et al*., 2009). It is postulated that in order to elaborate new, efficient plant varieties, it is essential to understand the mechanism of storage and transportation of microelements in plants (Dayod *et al*., 2010). The density of minerals in plant foods depends on uptake from rhizosphere to roots, translocation to shoots in xylem and then transport to leaves and seeds (Waters and Sankaran, 2011). Seeds can be biofortified by increasing uptake of micronutrients (Waters and Sankaran, 2011). In plants, micronutrients are transported by chelators (Waters and Sankaran, 2011). Plants accumulate excess of microelements in root vacuoles (Palmgren *et al*., 2008). To develop plants with higher density of micronutrients in leaves and grains it is essential to improve root to shoot transfer (Palmgren *et al*., 2008).

The bottleneck for microelements accumulation in grains is transport from xylem to phloem and in cereals filling of grain with microelements (Palmgren *et al*., 2008). Bhat *et al*. (2010) investigated the availability of essential minerals in plants. The information was used in the elaboration of new value-added foods and in biofortification (Bhat *et al*., 2010).

Biofortification programs: At present, there are several research programs undertaken, eg. HarvestPlus (www.harvestplus.org) which aimed to increase Fe content in bran and millet and to increase Zn in wheat and rice.

Biofortification of foods in Se is the intervention undertaken in some countries (Barcelo and Poschenrieder, 2011). The strategies included agronomic biofortification with Se-fertilizers, introduction of Se with irrigation water or genotype selection of plants which accumulate Se excessively in edible parts (Barcelo and Poschenrieder, 2011).

Clinical studies: It is necessary to prove that the consumption of biofortified foods leads to enhanced absorption of microelements in mammals (Connolly, 2008). There were few clinical studies which showed that biofortification is an efficient method to fight with microelement hunger. It was shown that the consumption of rice with 2.6 mg kg^{-1} higher content of iron improved Fe body burden of Fe-deficient women (Haas *et al*., 2005).

Also other studies demonstrated that biofortified foods supply bioavailable form of microelements. Literature reports that the consumption of carrots fortified with Ca caused increased absorption of this element in mice and human (Connolly, 2008). It was also reported that iodine biofortification of plant derived foods improved the status of this element in humans (King, 2002; Blasco *et al*., 2010).

DISCUSSION

Using biosorption in biofortification of food: The density of microelements in edible parts of plants and animals can be also increased by the supplementation of microelements in the form with higher bioavailability (Zielinska *et al.*, 2009; Michalak *et al.*, 2009). It is well documented that microelements supplemented in the form of chelates posses good bioavailability. The most frequently used carrier of microelements are amino acids whereby nutritive cations are bound with carboxyl groups. A drawback of these preparations is high price. The cost of feed or fertilizer supplementation is 10 times higher as compared with the mineral salts.

Another possibility is the use of the biomass instead of organic molecules as the carrier of microelements. The presence of carboxyl functional groups on the surface of various types of the biomass assures the similar chemism of binding as in the chelates. The advantage of such a solution is lower cost of the biomass as compared with organic molecules. Zootechnical studies on laying hens and swine confirmed high bioavailability of microeelements from the biomass preparations and showed the possibility of biofortification of eggs and meat.

CONCLUSION

Future prospects: The implementation of biofortification depends on degree by which biofortified foods would be adopted by farmers and accepted by consumers. Important will be cost-effectiveness (Meenakshi *et al*., 2010). So far, biofortified products have not been released to the market (Stein *et al*., 2008).

Microelements are not only important in development of organism of animals, but also plants (Dickinson *et al*., 2009). Therefore farmers should observe higher yields in cultivation of plants and animals breeding if microelements are not deficient.

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