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RICE GENOTYPES (*ORYZA SATIVA*) FOR HIGH ZINC CONTENT IN GRAINS : A REVIEW

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Abstract

Zinc (Zn) is one of the most essential micronutrients for both crop growth and human nutrition. In rice production, yields are often reduced and Zn concentration in grains is often low when Zn is in short supply to the crop. This may result in malnutrition of people dependent on a rice based diet. A thorough characterization of genotype and environmental interactions are essential to identify key environmental factors influencing Zn in grains. A combination of genetic and agronomic biofortification may be more effective strategies to enhance Zn content in rice grains. A holistic breeding approach for rice involving high Zn trait development, high Zn product development, product testing and release, including bioavailability studies are essential for successful Zn biofortification.

Key words: Rice, grain, biofortification, high zinc

Introduction

Rice is the major staple food and source of energy for more than half of the world's population, but the presently grown popular high yielding rice varieties are a poor source of essential micronutrients such as Zn in their polished (white) form (Kennedy *et al.,* 2002). The biofortification of rice with enhanced levels of Zn in its polished form may be a cost-effective and sustainable solution to assist in combating Zn malnutrition.

Zn deficiency is a global threat that affects both crop production and human nutrition. In humans, Zn deficiency-induced malnutrition adversely affects overall growth, leading to stunting in children, susceptibility to infectious diseases, iron deficiency anaemia and poor birth outcome in pregnant women (Graham *et al.,* 2012). Zinc deficiency is mostly affected to children that caused growth stunting. Soil with poor of bioavailability of Zn resulting the Zinc deficiency in rice plant and thus become one of the major constraints toward Zn bio-fortification in rice grain. According to Dobermann and Fairhurst (2000), rice is categorized as highly sensitive crop toward the Zinc deficiency that will resulted in reduction in yield. In addition, the result also shows that zinc mass concentration often low due short supply of Zn application. The application of Zinc fertilizer, $ZnSO_4$ is important in keeping adequate amount of zinc transport to the seeds during reproductive growth stage, enriching the amount of Zinc in soil solution and increase the yield performance. Foliar or combined soil + foliar application of Zn fertilizers under field conditions are highly effective and very practical way to maximize uptake and Zn accumulation in grains (Cakmak 2008).

Zinc deficiency in rice

The lack of diversity in the diet and poor-quality foods with routine consumption of cereal-based staples are the main causes of Zn deficiency in humans (Pfeiffer and McClafferty, 2007). In rice, low plant-available Zn in soil causes leaf bronzing and poor tillering at the early growth stages, leading to delayed maturity and significant yield loss (Dobermann and Fairhurst, 2000). The main cause of deficiency of plant available Zn in soil is the precipitation or adsorption of Zn with various soil components, depending on the pH and redox potential (Impa and Johnson-Beebout, 2012). One of the interventions that have been proposed to overcome Zn deficiency in humans

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is the biofortification of staple foods with Zn during their natural growth cycle, through either Grain Zn accumulation mechanisms in rice plants can be grouped into two categories according to the predominant sources of Zn loading: as continued root uptake during the grain-filling stage (Jiang *et al.,* 2007) and remobilization of Zn from shoots or roots (Wu *et al.,* 2010).

High Zinc content in rice

Genotypes differ significantly for Zn efficiency and grain Zn content. Rice genotypes are extensively sorted for Zn efficiency. There is also no relation between Zn efficiency and Zn content in grain. Zinc efficient genotypes absorb more Zn from soils, produce more dry matter and grain yield but do not necessarily have the highest Zn content in shoot or grain (Kalayci *et al.,* 1999). High grain Zn content is not only an agronomic trait but it also appears to be under genetic control and should be selected independently.

High Zn concentration in grain may be a feasible parameters for Zn biofortification (Rengel *et al.,* 1999). However, grain yield also needs to be considered for economical outcome from agricultural farms. Giving equal weight to concentration and yield, indexing for grain yield and grain Zn concentration seems most feasible. Newly developed high yielding genotypes with higher Zn bioavailability in grains will have higher acceptability among farming communities (Welch and Graham, 2004). As yield is reduced at low Zn supply, genotypes that respond best to Zn application for grain yield and grain Zn concentration should be recommended for breeding and cultivation.

Genotypes differ in Zn bioavailability based on Zn and phytate contents in food (Ficco *et al.,* 2009). Scientists have presented a mathematical model of Zn absorption as dependent on various dietary components, including Zn, phytate and Zn ratio. Trivariate model of Zn absorption as a function of dietary Zn and phytate is a simplistic expression (Hambidge *et al.,* 2010) that the breeders can use. Therefore, genotypes can more precisely be screened for higher Zn bioavailability in grains and higher grain yields. In most of the developing countries, however, little or no data is available about Zn bioavailability in the grains of cultivated wheat genotypes. There is a strong need to screen wheat genotypes for high Zn bioavailability in grains before recommending for general cultivation.

Zinc Fertilizer effect on Rice

About 50% yield increase during 20th century can be attributed to application of inorganic fertilizers to nutrient deficient soils (Fageria, 2008). Balanced and integrated use of plant nutrients still has a large potential to increase the grain yield. Poor farmers in developing countries do not apply Zn to rice paddy. Lack of awareness, economical constrains and product unavailability are the reasons for slow adoptability of small poor farmers to Zn application (Bell and Dell, 2008). Field demonstrations are valid programs to impart awareness in farmers about beneficial effects of micronutrients on crop yield. Sillanpää (1990) reported universal rice response to Zn application in most of the countries investigated under FAO field trails. Numerous studies have shown pronounced increase in shoot dry matter production (11 to 109%), grain yield (9 to 256%) and grain Zn concentration (9 to 912%) of rice with application of Zn to Zn deficient soils (Anonymous, 1998; Rengel *et al.,* 1999; Yilmaz *et al.,* 1997). Zinc efficient rice cultivars (genotypes that can grow and produce well on Zn deficient soils) also response to Zn application for grain yield and Zn concentration. Therefore, Zn application to Zn deficit soil is of great importance for increasing yield and grain Zn concentration.

The critical soil DTPA-extractable Zn for rice is about 0.75 mg Zn kg^{-1} soil (Bansal *et al.,* 1990). However, genotypes differ significantly for optimum soil Zn levels. Soil Zn level required for optimum grain Zn concentration may be higher than Zn required for optimum plant growth. In a pot study conducted at different soil Zn levels, yield reduction was not observed up to 7 mg Zn kg^{-1} soil, but plant Zn concentration was increased (Takkar and Mann, 1978).

Green Revolution is possible due to introduction of fertilizer responsive-dwarf genotypes that produced higher grain yields. Therefore, vigorous shoot growth does not ensure highest grain yield. Quality and quantity of wheat grain are the only attributes that can influence our inputs. Current food crises demand optimum Zn concentration in grain without any losses in yield. Although concentration in grain increases with Zn addition, recommendations of Zn application rates are generally reported for 90 to 95% relative yield on marginal return basis (Rengel *et al.,* 1999). Recommendations for 95 to 100% relative grain yield will ensure higher grain Zn concentration with optimum yield levels. Such Zn application rates may be possible if government ensures the supply of Zn enriched macronutrient fertilizers to farmers (Cakmak, 2000; 2008). However, researchers should carefully determine critical grain Zn concentrations for a specific genotype-environment combination and high rates of Zn should be recommended considering both human Zn requirements and plant Zn toxicity.

Genetic variability in Grains Zinc Content

Genotypic variation for the accumulation for micronutrient accumulation in grain have been reported in staple crops such as rice (Graham *et al.,* 1999; Gregorio *et al.,* 2000; Zhang *et al.,* 2004), wheat (Ortiz-Monasterio and Graham, 2000; Balint *et al.,* 2001) and maize (Arnold and Bauman, 1976; 2000), soybean (Raboy *et al.,* 1984), bean (Moraghan and Grafton, 1999).

There is a large genetic variation for grain Zn content in rice germplam accessions and this variation can be exploited in breeding programs to enhance Zn content in the grains (Graham *et al.,* 1999; Welch and Graham, 2004). Qui *et al.,* (1995) reported a higher variability in mineral contents in some rice cultivars and the level of iron content varied from 15.41 mg kg^{-1} to 162.37 mg kg^{-1} and zinc content ranged from 23.92 mg kg^{-1} to 145.78 mg kg^{-1}. Graham *et al.,* (1999) noticed higher iron content trait is expressed in all rice environments tested such as dry season in normal and saline soils, in acid and neutral soils.

Liu *et al.,* (1998) found higher variability in mineral contents like Fe, Zn, Mn and P in black rice than white rice genotypes. Wang *et al.,* (1997) reported the range for zinc content in grains of rice ranged from 0.79-5.89 mg/100 g with an average of 3.34 mg/100 g in a study done among 57 rice varieties. Graham *et al.,* (1999) reported the presence of genetic variation for grain Zn concentration among 1000 rice genotypes grown and screened in International Rice Research Institute (IRRI) farm, Los Banos, Philippines, where its concentration in the brown rice ranged from 15.3 to 58.4 ppm while Fe concentration ranged from 6.3 to 24.4 ppm. A trait for high iron and zinc has been linked to aromatic varieties such as jasmine and basmati (Graham *et al.,* 2002).

One of the best rice lines developed by IRRI, designated IR68144- 3B-2-2-3, contains 21 ppm of iron and 34 ppm of zinc was obtained from a cross between a high yielding variety (IR72) and a tall, traditional variety (Zawa Bonday) from India. This elite line has good grain quality, high yielding and preliminary studies show that it improves human nutrition (Bouis, 2001). Ortiz-Monasterio *et al.,* (2000) at International Maize and Wheat Improvement Center (CIMMYT) reported a significant genotype X environment interactions for Fe and Zn grain concentrations in wheat where there is a strong genetic component for Fe and Zn accumulation in the grain. Venuprasad *et al.,* (2002) reported high phenotypic and genotypic coefficient of variation for number of tillers per plant, grain yield per plant, total biomass per plant, harvest index. Kennedy and Burlingame (2003) studied on nutrient composition of rice varieties. They have reported that Standardization of data to 100 g samples of unpolished rice (dry matter basis), showed intra-varietal ranges of; 9 g protein, 5.65 mg iron, 3.34 mg zinc, 1.6 mg thiamin, 0.392 mg riboflavin and 7.2mg niacin. Finally they have concluded that there is a wealth of genetic diversity in rice with a largely untapped potential.

Nine genotypes of rice were evaluated for iron and zinc content in rice grain at IRRI by Martinez et al. (2006), found a range of 8.8 to 21.0 ppm, 14.0 to 40.0 ppm for iron and zinc respectively. Total variability of a trait is divided into genotypic variability and phenotypic variability. The estimate of variability suggests the variation in heritable portion of a trait that could be transferred from parent to offspring in response to selection (Hallauer and Carena, 2009; Lakshmana *et al.,* 2009). Grain Zn concentration is substantially higher in certain landraces of Southeast Asia than in commonly grown high yielding rice varieties (Zozali *et al.,* 2006). Singh *et al.,* (2010) reported Zn content in grains of rice ranges from 30 ppm in Selection New 2 to 64 ppm in Dular among 25 rice genotypes taken for the study. Nagarathna *et al.,* (2010) reported the presence of wide genetic variability in rice Zn content from 0.84 to 5.00 mg/100g dry weight. Martínez *et al.,* (2010) evaluated 11, 400 rice samples collected in local stores and supermarkets in Colombia, Bolivia, Nicaragua and the Dominican Republic for iron and zinc content during 2006-2009 in brown and milled rice samples found 2-3 ppm for iron and 16-17 ppm for zinc in milled rice, whereas values for brown rice were 10-11 ppm for iron and 20-25 ppm for zinc. A breeding program to develop Zn rich genotypes can be initiated by screening of available germplasm accessions to identify the genetic variation for the trait that could serve as donors.

Then high zinc containing genotypes can be crossed with high yield potential, tolerance to biotic and abiotic stresses and good grain quality genotypes (Martínez *et al.,* 2010). The contents of Fe and Zn in grains of traditional rice genotypes were significantly higher than those of improved cultivars (Anandan *et al.,* 2011). On the basis of grain zinc content, rice genotypes could be grouped into three categories, low (less than 14 ppm), moderate (14 ppm–24 ppm) and high (greater than 25 ppm). Kibanda and Luzi-kihupi (2007) reported absence of environmental influence on grain length and grain size (length/width) but observed higher genetic variance for these traits. Bisne *et al.,* (2009) found high genotypic and phenotypic coefficient of variations for harvest index and 100 grain weight; high heritability coupled with high genetic advance for harvest index, grain yield per plant from a trial with four CMS lines, eight testers and thirty-two hybrids evaluated. Samak *et al.,* (2011) reported high genotypic and phenotypic coefficient of variations for grain

Zn content in grains of rice. They have reported the early fixation the genotypes for homozygosity for the concerned traits. It is found that the estimates of heritability and genetic advance of F5 progenies for grain zinc and manganese content in rice showed subtle increase as compared to the F4 progenies.

Chemical attributes

The most important quality criterion based on chemical characteristics are moisture, crude protein, crude fat, crude fiber and ash contents are an. The moisture content during storage showed changes with the length of storage and the temperature of storage (Gooding and Davies, 1997). The moisture content is also important aspect because all grains have to be stored for a certain period before their end use. The grains having high moisture content are difficult to store safely because these are more susceptible to attack a pests and diseases. (Gooding and Davies, 1997). The moisture content varies from 7 to 11% (Awan, 1996). Rice protein is more nutritious because of its higher lysine content than any other cereal proteins. Chemical compositions of cereals are characterized by protein content (Lasztity, 1999). Micro-kjeldahl analysis and different methods are used to determine the protein content in rice. The protein content is affected by environmental conditions, such as soil and applicability of nitrogen fertilizer. Protein in cereals is mainly present in bran and periphery of the endosperm. Rice protein contains most of the essential amino acids which provides the well balanced proportion for humans. It is evident that the amount of protein in rice is not very high but the quality of rice protein is far better than other cereals because it is more nutritious (about 4-5%) lysine which is higher than wheat, corn and sorghum (James and McCaskill, 1983; Janick, 2002). Araullo *et al.,* (1976) stated that the edible portion of brown rough rice consists of about 8% protein and milled rice contains 7% protein. The protein content ranged from 43% to 18.2% in IRRI's world collection rice has been reported (Gomez, 1979). The protein content ranged from 7.38 to 8.13% in different Pakistani rice varieties also reported by Awan (1996).

References

Anandan, A., G. Rajiv, R. Eswaran and M. Prakash (2011). Genotypic variation and relationships between quality traits and trace elements in traditional and improved rice (*Oryza sativa* L.) genotypes. *Journal of food science*, **76(4)**, H122-H130.

Anonymous (1998). Micronutrients in Agriculture: Pakistani Perspective. National Fertilizer Development Center, Islamabad, Pakistan.

Araullo, E.V., D.B. De Padua and M. Graham (1976). *Rice: postharvest technology*. Intr. Develop. Res. Cen. Ottawa Canada. 113-118.

Arnold, J.M. and L.F. Bauman (1976). Inheritance of and Interrelationships among Maize Kernel Traits and Elemental Contents 1. *Crop Science*, **16(3):** 439-440.

Awan, I.A. (1996). Physical and biochemical char acterization of some of the Pakistani rice varieties. *M. Sc.(Hons.) Thesis. Dept. of Food Tech., Univ. Agric. Fsd*, 163.

Bálint, A.F., G. Kovács, L. Erdei and J. Sutka (2001). Comparison of the Cu, Zn, Fe, Ca and Mg contents of the grains of wild, ancient and cultivated wheat species. *Cereal Research Communications*, **29:** 375-382.

Bansal, K.C., J.F. Viret, J. Haley, B.M. Khan, R. Schantz and L. Bogorad (1992). Transient expression from cab-m1 and rbcS-m3 promoter sequences is different in mesophyll and bundle sheath cells in maize leaves. *Proceedings of the National Academy of Sciences*, ***89*(8)**, 3654-3658.

Bell, R. and B. Dell (2008). Micronutrients for sustainable food, feed, fibre and bioenergy production. International Fertilizer Industry Association, Paris.

Bisne, R., A.K. Sarawgi and S.B. Verulkar (2009). Study of heritability, genetic advance and variability for yield contributing characters in rice. *Bangladesh Journal of Agricultural Research*, **34(2):** 175-179.

Bouis, H.E. and R.M. Welch (2010). Biofortification - a sustainable agricultural strategy for reducing micronutrient malnutrition in the global south. *Crop Science*, **50:** S20-S32.

Cakmak, I. (2000). Possible Roles of Zinc in Protecting Plant Cells from Damage by Reactive Oxygen Species. *New Phytology,* **146:** 185-205.

Cakmak, I. (2008). Enrichment of cereal grains with zinc: agronomic or genetic biofortification. *Plant and soil*, **302(1-2):** 1-17.

Dobermann, A. and T. Fairhurst (2000). Rice: nutrient disorders and nutrient management. Potash and Phosphate Institute, Potash and Phosphate Institute of Canada and International Rice Research Institute.

Fageria, N.K. (2008). The use of nutrients in crop plants. Boca Raton, CRC Press, 430p.

Ficco, D.B.M., C. Riefolo, G. Nicastro, V. De Simone, A.M. Di Gesu, R. Beleggia and P. De Vita (2009). Phytate and mineral elements concentration in a collection of Italian durum wheat cultivars. *Field Crops Research*, **111(3):** 235-242.

Gomez, K.A. (1979). Effect of environment on protein and amylose content of rice. In *Proceedings of the workshop on chemical aspects of rice grain quality* (pp. 59-68). International Rice Research Institute Los Baños, Laguna, Philippines.

Gooding, M.J. and W.P. Davies (1997). *Wheat production and utilization: systems, quality and the environment*. CAB international, Wallingford.

Graham, R.D., M. Knez and R.M. Welch (2012). How much nutritional iron deficiency in humans globally is due to an underlying zinc deficiency? *Advances in Agronomy,* **115:** 1–40.

Graham, R. (2002). *A proposal for IRRI to establish a grain quality and nutrition research cente:* IRRI discussion paper series No. 44, International Rice Research Institute, Los Banos, Philippines (No. 2169-2019-1615).

Graham, R., D. Senadhira, S. Beebe, C. Iglesias and I. Monasterio (1999). Breeding for micronutrient density in edible portions of staple food crops: conventional approaches. *Field Crops Research*, **60(1-2):** 57-80.

Gregorio, G.B., D. Senadhira, H. Htut and R.D. Graham (2000). Breeding for trace mineral density in rice. *Food and Nutrition Bulletin*, **21(4):** 382-386.

Hallauer, A.R. and M.J. Carena (2009). Maize. In *Cereals* (pp. 3-98). Springer, New York, NY.

Hambidge, K.M., L.V. Miller, J.E. Westcott and N.F. Krebs (2008). Modeling zinc (Zn) absorption (AZ) from single test meals (SM) as a function of dietary zinc (DZ) and phytate (DP).

James, C. and D. McCaskill (1983). Rice in the American diet. *Cereal Foods World (USA)*. **28(11):** 667-669.

Janick, J. (2002). Rice: the natural history of rice. *Tropical Horticulture*, 20-2.

Jiang, S.L., J.G. Wu, Y. Feng, X.E. Yang and C.H. Shi (2007). Correlation analysis of mineral element contents and quality traits in milled rice (*Oryza sativa* L.). *J. Agric. Food Chem.,* **55:** 9608–9613.

Kalayci, M., B. Torun, S. Eker, M. Aydin, L. Ozturk and I. Cakmak (1999). Grain yield, zinc efficiency and zinc concentration of wheat cultivars grown in a zinc-deficient calcareous soil in field and greenhouse. *Field Crops Research*, **63(1):** 87-98.

Impa, S.M. and S.E. Johnson-Beebout (2012). Mitigating zinc deficiency and achieving high grain Zn in rice through integration of soil chemistry and plant physiology research. *Plant and Soil,* **361:** 3–41.

Kennedy, G., B. Burlingame and V.N. Nguyen (2002). Nutritional contribution of rice and impact of biotechnology and biodiversity in rice-consuming countries, 20th International Rice Comission Bankok Thailand 23–26 July 2002.

Kibanda, J.N. and A. Luzi-Kihupi (2007). Influence of genetic and genotype x environment interaction on quality of rice grain. *African Crop Science Journal*, **15(4):** 173–182.

Lakshmana, D., B.D. Biradar and R.L. Ravi kumar (2009). Genetic variability studies for quantitative traits in a pool of restorers and maintainers lines of pearl millet (*Pennisetum glaucum* L.). *Karnataka Journal of Agricultural Sciences*, **22(4):** 881-882.

Lasztity, R. (1999). Cereal chemistry. Hungary: Akademiai Kiado.

Liu, H.Y., V. Badarinarayana, D.C. Audino, J. Rappsilber, M. Mann and C.L. Denis (1998). The NOT proteins are part of the CCR4 transcriptional complex and affect gene expression both positively and negatively. *The EMBO journal*, **17(4):** 1096-1106.

Martínez, C., J. Borrero, R. Taboada, J.L. Viana, P. Neves, L. Narvaez, P.A. Adames and A. Vargas (2010). Rice cultivars with enhanced iron and zinc content to improve human nutrition. In *28th International rice research conference*. 8-12 November 2010, Hanoi, Vietnam.

Martinez-Herrera, J., P. Siddhuraju, G. Francis, G. Davila-Ortiz and K. Becker (2006). Chemical composition, toxic/ antimetabolic constituents and effects of different treatments on their levels, in four provenances of *Jatropha curcas* L. from Mexico. *Food chemistry*, **96(1):** 80-89.

Moraghan, J.T. and K. Grafton (1999). Seed-zinc concentration and the zinc-efficiency trait in navy bean. *Soil Sci. Soc. Am. J.,* **63:** 918–922.

Nagarathna, T.K., A.G. Shankar and M. Udayakumar (2010). Assessment of genetic variation in zinc acquisition and transport to seed in diversified germplasm lines of rice (*Oryza sativa* L.). *J. Agric. Tech*, **6:** 171-8.

Ortiz-Monasterio, J.L. and R.D. Graham (2000). Breeding for trace minerals in wheat. *Food & Nutrition Bulletin,* **21:** 392-396.

Pfeiffer, W.H. and B. McClafferty (2007). Biofortification: breeding micronutrient-dense crops. In: M.S. Kang, P.M. Priyadarshan (eds) Breeding major food staples. Blackwell Publishing Ltd, Oxford, pp 61–91.

Prasad, A.S. (2004). Zinc deficiency: its characterization and treatment. *Met. Ions Biol. Syst.,* **41:** 103–37.

Roohani, N., R. Hurrell, R. Kelishadi and R. Schulin (2013). Zinc and its importance for human health: An integrative review. *J. Res. Med. Sci.,* **18:** 144–157.

Qiu, L.C., J. Pan and B.W. Duan (1993). The mineral nutrient component and characteristics of color and white brown rice. *Chinese Journal of Rice Science*, **7(2):** 95-100.

Raboy, V., D.B. Dickinson and F.E. Below (1984). Variation in Seed Total Phosphorus, Phytic Acid, Zinc, Calcium, Magnesium and Protein among Lines of *Glycine max* and *G. soja* L. *Crop Science*, **24(3):** 431-434.

Rana, M.K. and K.V. Bhat (2004). A comparison of AFLP and RAPD markers for genetic diversity and cultivar identification in cotton. *Journal of Plant Biochemistry and Biotechnology*, **13(1):** 19-24.

Rengel, Z., G.D. Batten and D.D. Crowley (1999). Agronomic approaches for improving the micronutrient density in edible portions of field crops. *Field crops research*, **60(1-2):** 27-40.

Resurreccion, A.P., T. Hara, B.O. Juliano and S. Yoshida (1977). Effect of temperature during ripening on grain quality of rice. *Soil science and plant nutrition*, **23(1):** 109-112.

Samak, N.A., S. Hittalmani, N. Shashidhar and H. Biradar (2011). Exploratory studies on genetic variability and genetic control for protein and micronutrient content in F4 and F5 generation of rice (*Oryza sativa* L.). *Asian Journal of Plant Sciences*, **10(7):** 376-379.

Sillanpaa, M. and M. Sillanpää (1990). *Micronutrient assessment at the country level: an international study* (No. 63). Food and Agriculture Organization of the United Nations. 10.1186/s12889-016-2765-y.

Singh, S., S. Mishra and K. Kalpana (2010). Phenotypic diversity in grain yield and nutritional traits of rice (*Oryza sativa* L.). *Int. Rice Res. Notes,* **35:** 1-4.

Takkar, P.N. and M.S. Mann (1978). Toxic levels of soil and plant zinc for maize and wheat. *Plant and Soil*, **49(3):** 667-669.

Torun, B., P.W. Davies, M.E. Livingstone, M. Paolisso and R. Sackett (1996). Energy requirements and dietary energy recommendations for children and adolescents 1 to 18 years old. Discussion. *European journal of clinical nutrition*, **50:** S37-S81.

Venuprasad, R., M.E. Bool, L. Quiatchon, M.S. Cruz, M. Amante and G.N. Atlin (2012). A large-effect QTL for rice grain yield under upland drought stress on chromosome 1. *Molecular Breeding*, **30(1):** 535-547.

Wang, Y., Y. Jiang, M. Meyering-Voss, M. Sprinzl and P.B. Sigler (1997). Crystal structure of the EF-Tu EF-Ts complex from *Thermus thermophilus*. *Nature structural biology*, **4(8):** 650-656.

Welch, R.M. and R.D. Graham (2004). Breeding for micronutrients in staple food crops from a human nutrition perspective. *Journal of experimental botany*, **55(396):** 353-364.

Wu, C.Y., L.L. Lu, X.E. Yang, Y. Geng, Y.Y. Wei, H.L. Hao, P.J. Stoffella and Z.L. He (2010). Uptake translocation and remobilization Zinc absorbed at different growth stages by rice genotypes of different Zn densities. *J. Agric. Food Chem.,* **58:** 6767–6773.

Yilmaz, A., H. Ekiz, B. Torun, I. Gultekin, S. Karanlik, S.A. Bagci and I. Cakmak (1997). Effect of different zinc application methods on grain yield and zinc concentration in wheat cultivars grown on zinc deficient calcareous soils. *Journal of plant nutrition*, **20(4-5):** 461-471.

Zazoli, M.A., M. Shokrzadeh, E. Bazerafshan, M. Hazrati and A. Tavakkouli (2006). Investigation of zinc content in Iranian rice (*Oryza sativa*) and its weekly intake. *American-Eurasian Journal of Agricultural and Environmental Science*, **1(2):** 156-159.

Zhang, Y., Y.H. Xu, H.Y. Yi and J.M. Gong (2012). Vacuolar membrane transporters OsVIT1 and OsVIT2 modulate iron translocation between flag leaves and seeds in rice. *The Plant Journal*, **72(3):** 400-410.