

Iron for plants and humans

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The essentiality of iron (Fe) for plant growth was established by E. Gris as early as 1843; this was some 50 years earlier than the discovery of other trace elements such as Mn and Zn as plant essential micro-nutrients. The earlier discovery might be attributed to two reasons: the easily visible symptoms of Fe-deficiency characterized by yellow color (chlorosis) on the young leaves, and the globally widespread distribution of Fe-deficient soils. Although Fe is abundant in soil, plants often suffer from Fe-deficiency due to its low solubility especially in alkaline calcareous soils. Both the production and quality of crops and fruits are reduced as a result of Fe-deficiency in about 30% of the world's land.

However, some plant species have developed efficient strategies for acquiring and taking up Fe from low-

solubility sources. Two distinct strategies have been identified (Römheld 1987). Strategy I is found in dicotyledonous and non-graminaceous monocotyledonous species, whereas Strategy II is found only in graminaceous species. They differ in the way to solubilize and transport Fe. The Strategy I plants are characterized by release of proton (H^+) and reductants/chelators, such as electron (e^-), organic acids, and phenolics, into the rhizosphere, thereby increasing Fe solubility, by enhanced reduction and uptake for ferrous iron. By contrast, Fe-acquisition by the Strategy II plants is characterized by secretion of hexadentate Fe^{3+} -chelating substances (phytosiderophores, mugineic acids) and by their specific uptake system (Ma 2005). During the last decade, great achievements have been made in the identification of key genes involved in Fe acquisition, uptake, translocation, homeostasis, distribution etc. Some of the most noteworthy examples include the identification of *FRO2* and *IRT1* genes, which encode Fe^{3+} -chelate reductase and Fe^{2+} -transporter, respectively, in *Arabidopsis thaliana* (Robinson et al. 1999; Eide et al. 1996); these discoveries shed light on the molecular mechanisms underlying Fe uptake in strategy I plants. More recently, many genes involved in the biosynthesis of phytosiderophores and uptake of Fe(III)-phytosiderophore transporter (YS1) have also been identified by Nishizawa's group and Curie et al. (2001), respectively. The homologs of these genes have been isolated and characterized in different plant species. Recently, a citrate transporter required for

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efficient translocation of Fe from roots to shoots has also been identified in *Arabidopsis* and rice (Durrett et al. 2007; Yokosho et al. 2009). Furthermore, transcription factors regulating Fe-deficiency signaling pathway have been identified, such as FER/FIT, BHLH38/39 in the Strategy I plants (Ling et al. 2002; Colangelo and Gueriot 2004; Yuan et al. 2005, 2008), and IRO2, IDEF1 and IDEF2 in the Strategy II plants (Ogo et al. 2007, 2008; Kobayashi et al. 2007). Based on these findings, attempts on transgenic plants with enhanced tolerance to Fe deficiency have been made (Takahashi et al. 2001). However, some unidentified transporters involved in iron transport in different tissues and cells and their regulatory mechanisms remain to be examined in the future.

Iron is also an essential element for humans. Iron deficiency is a major malnutrition in human health (<http://www.harvestplus.org/iron.html>). Crops provide a direct or indirect source of iron for humans; therefore, increasing iron density in staple foods is considered to be the most effective and economic method to alleviate the problem of Fe deficiency in humans. Manipulations of genes involved in uptake, inter-cellular transport, distribution and storage of Fe have resulted in Fe biofortification in several plant species (e.g. Masuda et al. 2008; Wirth et al. 2009). On the other hand, this objective could be also achieved with new environmentally friendly agronomic practices which increase the soil-available fraction of the micronutrient; the development of such practices requires, however, an ever deeper understanding of the processes occurring in the rhizosphere that influence Fe acquisition by crop plants.

Recognizing the importance of Fe for both plants and humans, an international symposium on iron nutrition and interactions in plants (ISINIP) has been held every 2 years since 1981. The latest one (14th ISINIP) organized by Prof. Hong-Qing Ling, was held in Beijing, from October 11 to 16, 2008, jointed with the Annual Meeting of HarvestPlus-China. More than 200 scientists from this research field participated in the symposium and communicated their new findings. The topics of the symposium covers several levels from field to genes, including remediation of iron deficiency, iron fertilizers, physiological responses to iron deficiency, isolation and characterization of genes involved in iron nutrition, iron biofortification, etc. In this special issue, we have selected eight papers from the symposium. Two are review articles dealing with the role of frataxin in

mitochondrial iron metabolism (see Murgia et al. 2009, this issue) and distribution and transport of iron in barley and wheat (see Borg et al. 2009, this issue). The work by Tomasi et al. 2009 (this issue) reports the mechanism of iron acquisition operating in the leaves, which could affect the use efficiency of Fe from natural sources. Takahashi et al. 2009 (this issue) show that the expression of the metal transporter ZIP genes and distribution of iron as well as other micronutrients changed during the course of seed germination. Two papers from Lucena's group examined the availability of Fe-lignosulfonate complexes and HJB (N, N'-Bis(2-hydroxy-5-methylbenzyl)ethylenediamine-N, N'-diacetic acid) as Fe-sources for plants (see Rodrigues-Lucena et al. 2009, this issue, and Nadal et al. 2009, this issue). The last two papers report on heavy metals (Cd and Zn) (see Wu et al. 2009, this issue; Ogawa et al. 2009, this issue); these are included because these heavy metals may share the same transporters for Fe.

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