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ROLE OF PHYTOSIDEROPHORES IN IRON UPTAKE BY PLANTS

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ABSTRACT

Phytosiderophores are various organic chelating molecules secreted by the roots of different species of the grass family (including oat, barley, wheat, and rice). The iron (Fe)-phytosiderophore complex enters the roots through an iron transporter in the plasma membrane and attributed mainly to the efficiency of acquisition of Fe under conditions of low soil Fe availability rather than to its utilization or re-translocation within a plant. A higher Fe acquisition efficiency may be due to either or all of the following: an efficient ionic uptake system, better root architecture, higher synthesis and release of Fe mobilizing phytosiderophores by the roots and uptake of phytosiderophores complex.

Keywords: Crop uptake, Iron, Phytosiderophores.

Iron is the most important micronutrient in crop production. Deficiency of iron has been observed in north Bihar, Andhra Pradesh, Gujarat, Rajasthan, Uttar Pradesh, Haryana, Karnataka, Maharashtra, Tamil Nadu, and Punjab. Iron deficiency is generally noticed in calcareous and alkaline soils but its percent deficiency is varying region wise (Singh, 2008). The release of phytosiderophores is one of the most important mechanisms which enhance the mobilization of Fe in soil and their uptake by crop. Fe deficiency chlorosis in crop plants is a widespread nutrient problem particularly on calcareous soils in arid and semiarid regions, which often results in significant yield losses (Mortvedt, 1991). Such reductions have been reported in many crops, such as upland rice, maize and sorghum (Jolley *et al.*, 1996). Repeated grazing by livestock's induced Fe-deficiency in Fe deficiency areas, chlorosis in wheat was also reported (Berg, 1993). Soil amendments and foliar sprays of Fe are common methods to correct Fe deficiency. However, these methods are expensive, time-consuming and may be effective only for one cropping season.

Alternatively, breeding of plant genotypes with higher efficiency in acquisition of Fe from soil is a realistic approach. Selection for resistance, however, is difficult because of heterogeneous soil and highly variable environmental conditions that affect expression of Fe-deficiency chlorosis in the field. A lack of understanding the factors influencing chlorosis expression has also impeded the development of reliable screening methods in laboratory, controlled greenhouse, or environmental-chamber environment (Jolley et al.,1996). So the development of reliable Fe-deficiency chlorosis screening criterion is a necessary prerequisite for significant improvement of Fe-deficiency chlorosis resistance.

Recently, many studies suggested that phytosiderophores (non-proteinogenic amino acids) release has been linked to the ability of species and genotypes to resist Fe- deficiency chlorosis (Hansen *et al.*, 1996; Schmidt, 2003). Therefore, phytosiderophores release has been suggested as a selection criterion for Fe efficient graminaceous monocots.

Characteristics of Phytosiderophores

These are molecules with a high affinity for Fe^{3+} remove from minerals by chemical or biological weathering and contribute towards their dissolution in soil solution.

These Fe-chelates are highly soluble and are stable over a wide pH range.

They are of crucial importance for the iron and zinc transport in soils and iron supply to plants.

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Chemical structure of phytosiderophores

Mugineic acid and its derivatives (commonly called mugineic acids or MAs) are hexadentate ligands with aminocarboxylate and hydroxycarboxylate functional groups (Figure 1). The ligands are synthesized by hydroxylation of the parent compound nicotianamine (Ma and Nomoto, 1996; Mori, (1987). Their molecular weight ranges from 278 (DDA-A) to 336 (HMA, epi-HMA).

Concentrations of phytosiderophores in the rhizosphere

In hydroponics culture studies; overall phytosiderophores release rates area function of the nutritional status of the plant. The nutritional status is not only a function of the free iron activity in solution but also of plant age (Gries, *et al.* 1995). The observed release rates of phytosiderophores under strong iron deficiency greatly exceed iron-uptake rates required for normal growth. Phytosiderophore exudation by plant roots is highly restricted in time and space. Diurnal exudation for only a few hours during the light period is commonly observed (Marschner, *et al.* 1986a).

The release of siderophores varies along the root and is most pronounced in apical root zones. These restrictions along with known exudation rates and estimated microbial degradation rates have been used as parameters of a radial diffusion model to estimate the local distribution of phytosiderophores in the rhizosphere (Romheld, 1991). The model predicts a strong gradient of phytosiderophores concentrations away from the root surface with average concentrations of 1 mM within the first 0.25 mM during the period of maximum exudation rates.

TABLE 1: Conditions for phytosiderophore analysis with HPLC.

Parameters	Descriptions
Column	AA-pak Li-type (6.0 mm I.D. X 200mm)
Column temperature	40°C
Buffer	0.15 N Li^+, pH 2.75(adjustment by 60% $HClO_4$)
Buffer flow	0.5 ml/min
Reagent	Hypo solution, pH 10.5; OPA solution pH 10.5
Reagent temperature	50°C
Reagent flow	0.4 ml/min for OPA solution and 0.4 ml for Hypo solution
Wave length	345 nm for excitation and 455 nm for emission

Extracted phytosiderophore from the rhizosphere of iron stressed barley after several days of growth in calcareous soil and found it average concentrations in the low micro - molar range (Shi *et al*, 1988).

Isolation of Phytosiderophores

Isolation of phytosiderophores is an important for its study (Figure 2). There is the process for phytosiderophores isolation. The uprooted plant roots is first washed properly with the help of water then kept in Fe–deficient media, then amount and nature of released phytosiderophores is studied with the help of High-performance liquid chromatography (HPLC) (Mori *et al.*, 1991). Some important conditions for analysis of phytosiderophores secreted from plant roots with the help of HPLC (Table 1).

Reactions of Phytosiderophores in soil

In the apoplastic space and the rhizosphere, phytosiderophores can scavenge iron from a range of iron bearing compounds including iron oxides (Figure 3). The iron deficiency induced synthesis and exudation of phytosiderophores, and the subsequent uptake of iron–siderophore complexes has been described as the ''strategy II'' iron acquisition mechanism (Marschner et al., 1986b). This strategy resembles bacterial and fungal iron acquisition systems involving microbial siderophores. A large body of work has been devoted to the regulation and molecular level understanding of the plant physiological responses to iron deficiency (Curie and Briat, 2003; Tagliavini et al., 2000).

Factors Affecting Release of Phytosiderophores

Amount and composition of phytosiderophores are affected by light, crop varieties and micronutrient status and day time (Cakmak *et al.*, 1994). The rate of phytosiderophores release differs between species, and is positively correlated with the plant resistance to Fe deficiency chlorosis. Affinity of mugineic acids for heavy metal cations decreases in the order: $Cu^{2+} > Fe^{3+} >> Zn^{2+} >> Mn^{2+}$. Its biosynthesis is also a Zn-dependent process, it is affected by plant species and age; soil type, properties and nutrient status; nutritional status of the plant; temperature and light intensity and duration. The uptake rate of different Fe-phytosiderophores was varied between species. These differences between species appear to be related to difference in root morphology. The highest uptake rates per unit root dry weight were found in Fe deficient rice and sorghum which are

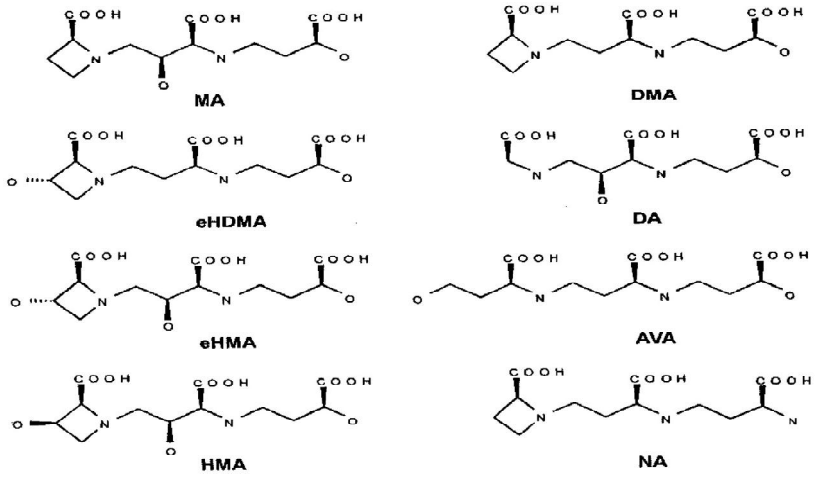

FIG. 1: Structure of mugineic acid derivatives and nicotianamine.

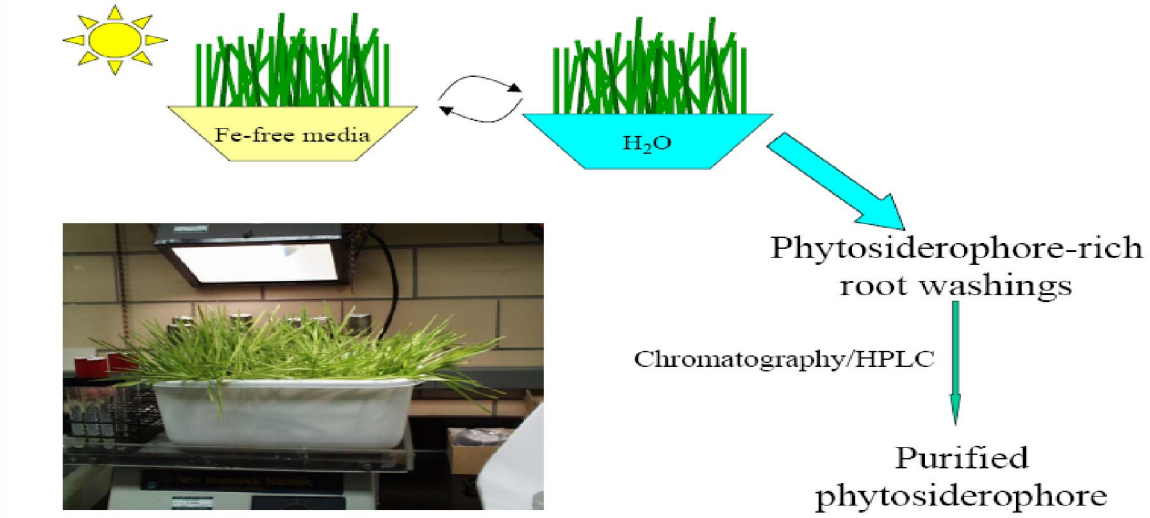

FIG. 2: Isolation of Phytosiderophores.

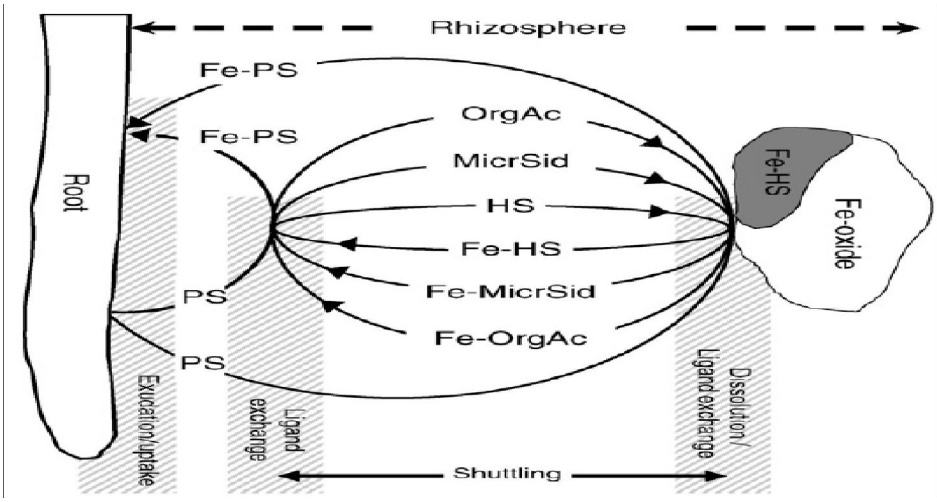

FIG. 3: Schematic representations of important processes in strategy II iron acquisition.

characterized by a fine highly branched root system. The lowest uptake rates were found in maize which has relatively thick roots (Romheld and Marschner, 1990).

CONCLUSION

Phytosiderophores production is a general response of plants in iron and zinc deficiency in particular. It acts as a life saving mechanism in plants. Uptake rate of phytosiderophore-chelated Fe and Zn is 100 and 5 to 10 times higher than that of free Fe and Zn, respectively. With the help of biotechnological tools and techniques, we can insert the phytosiderophores secretion responsible gene into field crops. It will increase the crop uptake in nutrient deficient conditions and indirectly crop yield.

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