ROLE OF DIFFERENT FORMS OF SIDEROPHORES IN ENVIRONMENTAL REMEDIATION

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INTRODUCTION

Siderophores are organic compounds with low molecular weight that are produced by plants and microorganisms which is growing under low iron conditions. The primary function of these compounds is to chelate the ferric iron (Fe^{3+}) from different terrestrial and aquatic ecosystem and thereby make it available to the microbial and plant cells. Siderophores have received much attention in recent years because of their potential roles and applications in various areas of environmental research. Their significance in these applications is because siderophores have the ability to bind a different metal in addition to iron, and they have a wide range of chemical structures and specific properties. The siderophores also function as biocontrol's, biosensors, bioremediation and chelation agents, in addition to their important role in weathering soil minerals and enhancing plant growth. The siderophores are two major types based on the source where it originates *viz.,* Phyto siderophore and microbial siderophore.

Phyto siderophores

Phyto siderophores (PS) are organic substances like nicotinamine, mugineic acids and avenic acid etc. produced by plants under iron-deficient conditions, which can form organic complexes with Fe^{3+}, and increase the movement of iron in soil. It is non proteineous, low molecular weight acids released by the graminaceous species under the iron and Zn deficiency stress. In deficient condition this mobilizes micronutrients like iron, zinc, manganese and copper from the soils to plant.

Characteristics of phytosiderophores-

1. They have very high attraction towards Fe^{3+}, and chelate the Fe^{3+} from minerals and make them in available form to plants.
2. These iron-chelates are highly soluble and stable over a wide pH range.
3. They are of crucial importance for the zinc and iron transport in soils and its supply to plants.
4. Zn-PS have similar structural confirmations as Fe-PS and a similar regulatory mechanism for the biosynthesis and/or release of PS under both Zn and Fe deficiencies.
5. A plant releases PS at higher amounts about a few hours to the onset of the light period. Under continuous darkness or continuous light, the rate of release of PS is lower.
6. There has been observed a sharp rise in PS production three hours after onset of the light period, which gradually declines thereafter microorganisms produce a wide range of siderophores.

Microbial Siderophores

Bacterial siderophores

They are catecholates and some are carboxylates and hydroxamates. The most common fungal siderophores is hydroxamates belonging to the ferrochrome family which is further divided into five groups, depending on the side chain of the hydroxamate functional group. Microorganisms use different siderophore-mediated iron transport systems. For bacteria, the transport systems vary between gram-positive bacteria and gram-negative bacteria. In gram-negative bacteria (e.g., *Escherichia sp.*) outer membrane receptors that recognize the Fe (III)–siderophore complexes at the cell surface. In contrast, in gram-positive bacteria (e.g., *Bacillus sp.*), which lack the outer membrane, the outer membrane receptors are completely absent. Therefore, the Fe (III)–siderophore complexes are bound by periplasmic siderophore binding proteins that are anchored to the cell membrane because of the lack of a periplasmic space.

Fungal siderophores

Fungi have four different mechanisms for siderophore mediated Fe transport systems

(i) Shuttle mechanism, the Fe(III)–siderophore complex is transported across the cell membrane, where the Fe(III) is released from the ligand and reduced by the reductive enzymes, whereas the free siderophore is then recycled. This mechanism is, used by *Ustilago maydis*.

(ii) Taxicab mechanism, the Fe(III) from the extracellular siderophore is transferred across the cell membrane to intracellular ligands. This mechanism is used by *Rhodotorula* species.

(iii) Hydrolytic mechanism, the whole Fe(III)– siderophore complex is transported into the cell and is subjected to several reductive and degradative processes to release the Fe(III). This mechanism is used by *Mycelia sterilia*.

(iv) Reductive mechanism, the Fe(III)–siderophore complex is not transported across the cell membrane. The reduction of Fe(III) to Fe(II) occurs at the cell membrane. This mechanism is used by *Ustilago sphaerogena.*

Siderophores in environmental application

Metal remediation

Metals play a vital role in the development of human civilizations (Jonhson *et al*., 2002), but the manufacturing industry, sludge applications, nuclear power stations and mining have led to metal pollution (Wasi *et al*., 2013). Siderophores are extremely effective in solubilizing and increasing the mobility of a wide range of metals such as Cd, Cu, Ni, Pb, Zn, and the actinides Th(IV), U(IV) and Pu(IV). This ability of siderophores mainly depends on their ligand functionalities, by which means siderophores may have a strong affinity or selectivity for a particular metal other than Fe with regards to the stability constants of this metal–siderophore complex. Thereby, siderophores become a useful tool in bioremediation, which is a cost-effective and environmentally friendly technique.

Hydrocarbon removal

Petroleum hydrocarbons in marine ecosystems are one of the major environmental problems. Microorganisms could play an important role in the remediation of petroleum hydrocarbons from the marine environment. Microbial siderophores participate in the biodegradation of petroleum hydrocarbons through an indirect mechanism, by facilitating the Fe acquisition for the degraded microorganisms under Fe-limiting conditions.

Biosensors

A biosensor is a biomolecule coupled to an electrical device such as a transducer, amplifier or noise filter in order to increase the signal to noise ratio that allows detection of various types of responses through specifically engineered systems. The siderophore with an exceptional Fe(III)-binding constant would be an ideal choice for the molecular recognition element of the sensor that could be applied in the determination of Fe bioavailability in oceanic water or soils. The concentration of Fe present in the ocean has been determined by using a siderophore as a biosensor.

Green pulping

The pulp and paper industry is a primary source of many environmental problems including global warming, human toxicity, ecotoxicity, photochemical oxidation, acidification, nitrification and solid wastes. The main problem of pulp and paper manufacturing results from the bleaching processes. Some pollutants are emitted into the air, while others are discharged in wastewater. Siderophores are considered as effective agents in pulp treatment, where they can reduce 70% of the chemicals needed to bleach Kraft pulp, and that makes siderophores environment-friendly alternatives.

Conclusion

Presently, it has become clear that siderophores represent central organic compounds in Fe uptake in many microorganisms and plants. The chemical structures of different siderophores and the membrane receptors involved in Fe uptake has opened new areas for research. The importance of siderophores is obvious, and they play a significant role in the environmental applications, even if there are many questions remaining to be answered. The relationship between siderophores and microbial structure, in environments with low Fe bioavailability, i.e., oceans and some soil conditions, are still not clearly known. Combining metagenomics with detailed chemical analysis will reveal important information that could be used to improve the current environmental applications and develop new applications for siderophores.