Chapter 8

MICROBIAL SIDEROPHORES IN THE PLANT RHIZOSPHERE

DAVID E. CROWLEY

Department of Environmental Sciences, University of California, Riverside, CA 92521, USA.
Email: crowley@ucr.edu

Abstract: Siderophores are iron chelating agents that are produced by almost all microorganisms in response to iron deficiency. Due to the requirement of iron for cell growth and metabolism, siderophore mediated acquisition of iron plays a central role in determining the ability of different microorganisms to colonize plant roots and contributes to microbial interactions in the plant rhizosphere. There are now approximately 500 known siderophores, some of which are widely used by a variety of microorganisms, whereas others are used only by the same microbial species and strains that produce them. Siderophores also have been examined for their potential importance in plant iron nutrition and for their ability to mobilize heavy metals. There has been considerable debate over their relative importance for plant iron nutrition that has centered around their ability to release iron by means of chelate reductases that function in Strategy I plants and to exchange iron with phytosiderophores in Strategy II grasses. A key question concerning the relevance of siderophores in plant nutrition has been whether siderophores are produced in sufficient quantities by microorganisms to supply physiologically relevant quantities of iron to plants. Siderophores are generally detected in low concentrations in soil extracts. Molecular methods using reporter genes further show that siderophore production is limited to sites of high microbial activity. There is now general recognition that siderophores have a fundamental role in determining the bioavailability of iron to microorganisms that colonize the rhizosphere and are required for rhizosphere competence in microorganisms that are being developed for biocontrol of plant diseases and plant growth promotion.

Key words: chelate; disease suppression; iron; microbial ecology; plant growth promoting bacteria

1. INTRODUCTION

Iron is one of the most commonly limiting trace elements in nature but is essential for the growth and metabolism of almost all living organisms. Deficiencies of iron are primarily due to the poor solubility of this trace element with increasing pH such that above pH 4, almost all microorganisms have evolved highly specific systems that employ iron chelating substances, called siderophores, that are secreted into the environment to dissolve iron minerals and hold it in a soluble form that can move by diffusion and deliver iron to the cell surface. Due to the wide array of mechanisms and iron chelating agents that are used by microorganisms for acquiring iron, competition for this element can occur between different species of microorganisms that coexist in the rhizosphere. This has important ramifications in the rhizosphere where the ability to acquire iron can influence both the species composition of the rhizosphere microbial community and availability of trace metals to plant roots. There is now a large body of primary literature on the role of siderophores in various aspects of soil chemistry, microbiology and plant nutrition. Earlier reviews have integrated this knowledge into conceptual models of how siderophores function in the plant rhizosphere (Crowley et al., 1991; Buyer et al., 1994). These models are now being born out by studies exploring microsite phenomena using molecular methods with reporter genes to examine microbial iron stress responses. Siderophores appear to be particularly important for contributing to rhizosphere competence of plant growth promoting and disease suppressive bacteria. These compounds are also now being examined in relation to other aspects of the rhizosphere including heavy metal uptake and bioremediation of soil pollutants. This chapter provides an overview of the general role of microbial siderophores in rhizosphere microbial ecology and recent studies that contribute to our understanding of the role of siderophores in the rhizosphere.

2. MOBILIZATION OF IRON BY SIDEROPHORES

2.1 Iron availability in the plant rhizosphere

Iron availability in the plant rhizosphere is limited by the extreme insolubility of inorganic iron minerals that dissolve at much slower rates than are required to support plant and microbial growth (Lindsay, 1995). The solubility of inorganic iron is controlled both by the pH and redox of the soil solution and involves a series of iron hydrolysis species that are in equilibrium with iron bearing minerals that have different solubilities that