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Review

Beneficial role of bacterial endophytes in heavy metal phytoremediation

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ABSTRACT

Phytoremediation is an emerging technology that uses plants and their associated microbes to clean up pollutants from the soil, water and air. In recent years, phytoremediation assisted by bacterial endophytes has been highly recommended for cleaning up of metal polluted soils since endophytic bacteria can alleviate metal toxicity in plant through their own metal resistance system and facilitate plant growth under metal stress. Endophytic bacteria improve plant growth in metal polluted soils in two different ways: 1) directly by producing plant growth beneficial substances including solubilization/transformation of mineral nutrients (phosphate, nitrogen and potassium), production of phytohormones, siderophores and specific enzymes; and 2) indirectly through controlling plant pathogens or by inducing a systemic resistance of plants against pathogens. Besides, they also alter metal accumulation capacity in plants by excreting metal immobilizing extracellular polymeric substances, as well as metal mobilizing organic acids and biosurfactants. The present work aims to review the progress of recent research on the isolation, identification and diversity of metal resistant endophytic bacteria and illustrate various mechanisms responsible for plant growth promotion and heavy metal detoxification/phytoaccumulation/translocation in plants.

Contents

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1. Introduction

Rapid urbanization, industrialization and intensive agriculture are main causes of heavy metals pollution on a global scale. Heavy metals are non-degradable and without intervention they persist in soil for centuries. The persistence of heavy metals may adversely affect the ecosystem, not only agricultural product and water quality, but also soil microorganisms and human health (Kidd et al., 2012). Most of the physiochemical remediation methods are very costly and also destructive to soil ecosystem (Hooda, 2007). Phytoremediation, employs plants to remove or stabilize heavy metals or render them less toxic *in situ* in an efficient and cost effective manner, has received increasing attention in the last decades (Glick, 2010). In general, soils normally contain low background levels of heavy metals. However, accumulation of heavy metals in soils is attributed to rapid industrialization, which would pose toxicity to plants, impairing their metabolism, biomass production and yield (Weyens et al., 2009). Although some of hyperaccumulators, such as *Alyssum serpyllifolium*, *Arabidopsis halleri*, *Phytolacca americana*, *Thlaspi caerulescens*, *Solanum nigrum* and *Sedum plumbizincicola*, are known to take up high concentrations of heavy metals (Ma et al., 2011a, 2015a; Chen et al., 2014; Wei et al., 2014), most of them are not suitable for heavy metal phytoremediation because of their very low biomass production, slow growth rates and preference for selected metal (Braud et al., 2006; Abhilash et al., 2012). Therefore, it is very important to develop suitable phytoremediation strategies for remediating multi-metal polluted field soils.

To enhance phytoremediation efficiency, many researchers have studied the close interactions among plants-microorganisms-heavy metals in rhizosphere soils (Glick, 2010; Dharni et al., 2014; Ma et al., 2015b). Recently, inoculation of plants with selected and acclimatized microbes (bioaugmentation) has attained prominence for phytoremediation of metal polluted soils (Lebeau et al., 2008; Glick, 2010; Ma et al., 2011b). Some studies have found that, plant growth promoting rhizobacteria (PGPR) have the capacity to alleviate metal induced phytotoxicity and enhance biomass production of plants when grown in metal contaminated soils. Although the role of PGPR on plant growth and heavy metal phytoremediation potential in polluted soils has been studied extensively (Dharni et al., 2014; Ma et al., 2015b), still little is known on plant–endophytic bacteria interactions and their potential role in phytoremediation of metal contaminated soils (He et al., 2013; Chen et al., 2014; Babu et al., 2015; Ma et al., 2015a). Therefore, the objectives of this review were to summarize and discuss the methods of isolation, screening and identification of endophytic bacteria and the diversity of metal resistant endophytic bacteria associated with plants growing in metal polluted soils. Moreover, attention was particularly given to the mechanisms by which endophytic bacteria promote plant growth and influence metal detoxification/accumulation/translocation in plants. Finally we discussed the prospects of the use of metal resistant endophytic bacteria in phytoremediation of metal contaminated soils.

2. Endophytic bacteria

Endophytic bacteria resides in plant tissues beneath the epidermal cell layers, where they can colonize the internal tissues and form a range of different lifestyles with their host including symbiotic, mutualistic, commensalistic and trophobiotic (Schulz and Boyle, 2006). They are ubiquitous in a large diversity of plant species and can colonize a particular host with highest densities in root and decline from stems to leaves (Porteous-Moore et al., 2006). In general, most endophytes originate from the epiphytic bacterial communities in the rhizosphere or phyllosphere or other plant parts; however, some may be transmitted through the seed or damaged foliar tissues (Bacon and Hinton, 2006).

The long term co-evolution of plants and endophytic bacteria resulted in an intimate ecosystem, which help plants to adapt/survive in both biotic and abiotic stress conditions (e.g. pathogen infection, drought, salinity and contaminants) and enhance the ecological balance of natural system (Ryan et al., 2008). Particularly, in order to circumvent the metal stress, endophytic bacteria have evolved several types of mechanisms, through which they alleviate the toxicity of metal ions. These mechanisms include the efflux of metal ions exterior to the cell, transformation of metal ions to less toxic forms, sequestration of metals on the cell surface or in intracellular polymers, and precipitation, adsorption/desorption or biomethylation (Rajkumar et al., 2013). Recent experiments with hyperaccumulator plants revealed that the inoculation of soils/seeds/seedlings with metal resistant endophytic bacteria improved plant growth and accelerated phytoremediation process in naturally and/or artificially metal-contaminated soil by enhancing nutrient acquisition, cell elongation, metal accumulation or stabilization, and alleviation of metal stress in plants (Luo et al., 2011a,b; Shin et al., 2012; Babu et al., 2013; Chen et al., 2014; Wei et al., 2014; Zhu et al., 2014; Ma et al., 2015a). Similarly, the colonization and propagation of plant growth promoting endophytic bacteria (PGPE) are also well known for their role in the enhancement of soil fertility and stimulation of host plant development by providing a plethora of growth regulators (Phetcharat and Duangpaeng, 2012) and assimilable essential nutrients (Doty, 2008), or by synthesizing 1-aminocyclopropane-1-carboxylic acid (ACC) deaminase (Zhang et al., 2011a), as well as by reducing disease severity through suppressing pathogens (Aravind et al., 2010). Further, bioaugmentation with such endophytic bacteria possessing multiple plant growth promoting traits including metal resistance/detoxification/accumulation/transformation/sequestration can diminish the metal phytotoxicity and alter the phytoavailability of heavy metals in contaminated soils, making them a perfect choice for microbial assisted phytoremediation studies (Rajkumar et al., 2009; Weyens et al., 2009; Ma et al., 2011b).

3. Analysis of endophytic bacterial communities

Numerous studies have demonstrated the adverse effect of different heavy metals on microbial diversity and their interaction with plants in polluted soils (Glick, 2010). Similarly, for successful functioning of introduced endophytes and their role in plant growth and heavy metal phytoremediation, exhaustive efforts have been made to explore the diversity, survival, distribution, colonization and behavior of endophytic bacteria in plant hosts (Fig. 1).

3.1. Culture-dependent diversity analysis

Methods used to isolate and characterize endophytic bacteria