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Review

Endophytic bacteria: Prospects and applications for the phytoremediation of organic pollutants

Muhammad Afzal [a,*], Qaiser M. Khan [a], Angela Sessitsch [b]

[a] National Institute for Biotechnology and Genetic Engineering (NIBGE), P.O. Box 577, Jhang Road, Faisalabad, Pakistan
[b] AIT Austrian Institute of Technology GmbH, Bioresources Unit, 3430 Tulln, Austria

HIGHLIGHTS

- Plant–endophyte partnership is promising approach to remediate contaminated soil.
- Endophytic bacteria can enhance phytoremediation of organic pollutants.
- Endophytic bacteria diminish toxicity and evapotranspiration of organic pollutants.
- It protects the food chain by decreasing agrochemical residues in food crops.

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ABSTRACT

Recently, there has been an increased effort to enhance the efficacy of phytoremediation of contaminated environments by exploiting plant–microbe interactions. The combined use of plants and endophytic bacteria is an emerging approach for the clean-up of soil and water polluted with organic compounds. In plant–endophyte partnerships, plants provide the habitat as well as nutrients to their associated endophytic bacteria. In response, endophytic bacteria with appropriate degradation pathways and metabolic activities enhance degradation of organic pollutants, and diminish phytotoxicity and evapotranspiration of organic pollutants. Moreover, endophytic bacteria possessing plant growth-promoting activities enhance the plant's adaptation and growth in soil and water contaminated with organic pollutants. Overall, the application of endophytic bacteria gives new insights into novel protocols to improve phytoremediation efficiency. However, successful application of plant–endophyte partnerships for the clean-up of an environment contaminated with organic compounds depends on the abundance and activity of the degrading endophyte in different plant compartments. Although many endophytic bacteria have the potential to degrade organic pollutants and improve plant growth, their contribution to enhance phytoremediation efficiency is still underestimated. A better knowledge of plant–endophyte interactions could be utilized to increase the remediation of polluted soil environments and to protect the foodstuff by decreasing agrochemical residues in food crops.

Contents

* Corresponding author. Tel.: +92 41 2651475; fax: +92 41 2651472.
E-mail addresses: afzal@nibge.org, manibge@yahoo.com (M. Afzal).

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1. Introduction

Organic compounds, released in the environment by various human activities, are posing serious threat to the environment due to their toxicity, hydrophobic nature and persistence in the environment for a longer period of time. The presence of organic compounds in soil, such as hydrocarbons, polyaromatic hydrocarbons, polychlorinated biphenyls, phenols, chlorophenols, toluene, trinitrotoluene, benzene, herbicides and pesticides, inhibits growth and metabolic activities of soil-associated microbes, even at very low concentrations (Oleszczuk, 2006; Porteous Moore et al., 2006; MacKinnon and Duncan, 2013; Sun et al., 2013). Furthermore, organic compounds can enter the food chain, and due to their toxic nature they can cause mutagenicity and carcinogenicity in animals and humans (Mahanty et al., 2011; Guo et al., 2012; Havelcová et al., 2014). Therefore, the removal of these organic compounds from soil and water is one of the main issues in the field of environmental sciences and engineering (Cameselle et al., 2013; Chigbo et al., 2013; Wei et al., 2014; Zhu et al., 2014).

Traditional physical and chemical methods for the clean-up of soil and water polluted with organic compounds are often costly and environmentally destructive (Gerhardt et al., 2009; Pandey et al., 2009; Marques et al., 2011). Phytoremediation, i.e. the application of plants for the clean-up of polluted soil and water, is an efficient, cost effective and environmental friendly 21st century technology (Xia, 2004; Pilon-Smits, 2005; Schwitzguébel et al., 2009; Phillips et al., 2012). Moreover, plants utilized for phytoremediation purposes may be used for biomass/biofuel production and carbon sequestration (Batty and Dolan, 2011; Abhilash et al., 2012; Ali et al., 2013). Although plants suitable for phytoremediation have to be adapted to the polluted environment, the presence of organic pollutants in soil generally reduces plant development and eventually phytoremediation efficacy (Escalante-Espinosa et al., 2005; Kirk et al., 2005; Peng et al., 2009; Thion et al., 2013). The exploitation of plant–bacteria partnership may overcome these limitations whereby plants are used in combination with pollutant-degrading, plant growth-promoting microorganisms, or both, for the clean-up of polluted soil and water (Weyens et al., 2009a; Glick, 2010; Yousaf et al., 2011; Khan et al., 2013a). When using plants and microbes in combination, the plant provides the habitat as well as nutrients to the associated rhizosphere and endophytic bacteria. In return, the bacteria enhance the stress tolerance of the plant or improve plant growth and detoxify the plant environment by degrading the pollutant.

There are complex and varied interactions between plants and their associated microbes and these interactions have been extensively studied and used to increase soil fertility, plant development and phytoremediation of polluted soil and water. Rhizobacteria colonize the close vicinity of roots, whereas endophytic bacteria colonize the plant interior without causing pathogenicity to their host plant. Rhizobacteria have been investigated for their plant growth-promoting capacity and in the last decade the use of such bacteria to enhance phytoremediation efficiency has been reported (He et al., 2005; Liste and Prutz, 2006; Biryukova et al., 2007; Gerhardt et al., 2009). Endophytic bacteria have also received considerable attention as many of them have an intimate relationship with the plant and are prominent plant growth promoters (Ryan et al., 2008; Compant et al., 2010; Mitter et al., 2013a). However, the concept of using endophytic bacteria to improve phytoremediation efficiency has been proposed relatively recently (Andria et al., 2009; Weyens et al., 2009b; Yousaf et al., 2011; Andreolli et al., 2013). Endophytic bacteria equipped with pollutant degradation pathways and metabolic activities can diminish both phytotoxicity and evapotranspiration of volatile organic compounds (Weyens et al., 2009c; Shehzadi et al., 2014). Moreover, the application of endophytic bacteria possessing plant growth-promoting activities may enhance the plant's adaptation and growth in polluted soil. As endophytic bacteria colonize the plant interior they can interact more closely with their host plant as compared to rhizobacteria (Sessitsch et al., 2004; Germaine et al., 2009).

Recently, many endophytic bacteria have been isolated from different plants and many of them showed pollutant-degrading as well as plant growth-promoting activities (Phillips et al., 2008; Yousaf et al., 2010a; Oliveira et al., 2014). Soil inoculation of these endophytic bacteria exhibited higher levels of colonization in the rhizo- and endosphere of different plants as compared to rhizobacteria. Moreover, their inoculation improved both plant growth and degradation of organic pollutants (Germaine et al., 2009; Yousaf et al., 2011). Recently, several studies demonstrated that the expression of pollutant-degrading genes of endophytic bacteria in the rhizosphere and endosphere of a plant may show a significant role in the mineralization of organic contaminants (Andria et al., 2009; Afzal et al., 2011; Yousaf et al., 2011). Owing to pollutant-degrading and plant growth-promoting activities, endophytic bacteria are therefore highly promising for certain phytoremediation methods (Glick, 2010; Yousaf et al., 2011; Khan et al., 2013a).

The importance of plant–endophyte synergisms for the removal of pollutants from soil and water is still underestimated. As many endophytic bacteria exhibit pollutant-degrading, plant-growth promoting activities or both, a better knowledge of mechanisms of these activities of endophytes can be exploited to improve the phytoremediation of organic pollutants present in soil and water. Although the role of endophytic bacteria to increase phytoremediation of heavy metal contaminated soil has been reviewed in several recent review articles (Rajkumar et al., 2009; Ma et al., 2011; Sessitsch et al., 2013), the role of endophytic bacteria to enhance the phytoremediation of organic pollutants has been rarely addressed. Therefore, this review describes the ecology of pollutant-degrading endophytic bacteria, their role in the degradation of pollutants present in environment, factors affecting the abundance and expression of pollutant-degrading genes in different plant components and interactions between plants and pollutant-degrading endophytic bacteria. It also exploits the prospects of using of endophytic bacteria to increase organic pollutant degradation in soil and water and thus the efficacy of phytoremediation. Three particular mechanisms of how endophytic bacteria may enhance phytoremediation of organic pollutant have been proposed: they may enhance (1) plant growth and biomass production, (2) organic pollutant bioavailability, and (3) population size and activity of indigenous bacteria to degrade organic pollutants through horizontal gene transfer. Further, enhanced plant biomass production can reduce the ratio of organic pollutant to the quantity of plant tissue, lessening plant stress. Finally, we will highlight the potential of genetically modified endophytic bacteria, horizontal gene transfer and metagenomic studies to improve plant–endophyte partnerships for the clean-up of polluted soil and water.