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Review

Cadmium minimization in food crops by cadmium resistant plant growth promoting rhizobacteria

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ABSTRACT

Heavy metal contamination of agricultural soils leads to diverse environmental and ecological problems including microbial community shift, plant growth and yield reduction, deterioration of soil and entry of metal in the food chain. Cadmium (Cd) pollution has become a major agricultural concern and a common practice of phytoremediation is to develop plant systems that hyperaccumulate the metal in plant parts. This process may be enhanced by inoculating the plants with specific metal resistant bacteria that promote plant growth and assist metal accumulation in plant tissues. On the other hand, many recent reports describe the application of Cd resistant plant growth promoting rhizobacteria to enhance agricultural yields without accumulation of metal in plant tissues. Plant scientists are welcoming the selection of the microorganisms capable of promoting plant growth in Cd-polluted environments, with minimum or no accumulation of Cd in edible parts. This review provides information about the traits and mechanisms possessed by certain Cd resistant rhizobacteria that ameliorate Cd stress to plants, and provides several examples of their use in Cd polluted agricultural soils. A central aspect of the review deals with possible mechanisms how Cd accumulation may be reduced by microbial inoculants.

Contents

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1. Introduction

Various human activities leading to metal pollution of land, ground water and atmosphere include mining, smelting and atmospheric emissions from metallurgical industries and vehicles along with dumping of wastes from several industries such as tanneries, electroplating, textile etc. These anthropogenic activities along with the disposal of municipal wastes and sewage are the main sources of pollution of agricultural soils with heavy metals. Unlike organic pollutants which can be degraded by microorganisms, heavy metals usually tend to persist and accumulate in the soils (Xu et al., 2012). Cadmium (Cd) occurs in most zinc ores and is a by-product of zinc production. It is used in batteries, electroplating and electronic devices. Cd is a non-essential, toxic heavy metal which can be readily taken up by plants and transported to the aerial parts (Sterckeman et al., 2015). High Cd levels cause several adverse morphological, physiological, biochemical and structural changes in plants, such as growth inhibition, water imbalance, inhibition of seed germination and result in severe agricultural loss (Tran and Popova, 2013).

In addition to the adverse effect on crop yield, Cd accumulation in edible plant parts including fruits and seeds, leads to its entry in to the food chain (Chaney et al., 2004; Chavez et al., 2015). Cd is efficiently retained in human kidneys and shows a long biological half-life of about 10–30 years, resulting in a cumulative increase in body with age. Thus, a serious health threat can potentially arise even from low-level chronic Cd exposure. Cd is classified as a group 1 carcinogen. A variety of serious health risks related to Cd, including renal dysfunction, osteoporosis, cancer, and cardiovascular disease, have been reviewed recently (Clemens et al., 2013). Cd is regarded as the only metal that might pose human or animal health risks at plant tissue concentrations that are not generally phytotoxic (Peijnenburg et al., 2000).

Multiple problems caused by Cd in agricultural soils include (a) reduced crop yield, (b) Cd contamination of edible plant parts and (c) human intake of Cd through food crops. Thus, it is imperative to develop a multi-faceted strategy to overcome these problems. Understanding the mechanisms responsible for Cd accumulation and transport in plants, development of specific varieties of crop plants that show reduced uptake, and agronomic practices to reduce Cd availability have been well described (Clemens et al., 2013). Different aspects of exposure and biological toxicity of Cd, its contamination in soils & fertilisers, chemistry & reactivity in soils, effect on plants, entry into the food chain, and effect on mammalian systems have been well explained (Sigel et al., 2013). A number of recent reviews deal with new developments in Cd-plant interactions such as biochemical and molecular basis of Cd stress in plants (Azevedo et al., 2012) and its regulation (Gallego et al., 2012), root responses to Cd (Lux et al., 2011), mechanism of transport of Cd to edible plant parts (Clemens et al., 2013), Cd signalling pathways (Chmielowska-Bąk et al., 2014), mechanisms of tolerance to Cd (Choppala et al., 2014), proteomics of plant response to Cd (Villiers et al., 2011), role of mineral nutrients in alleviation of Cd toxicity and accumulation (Nazar et al., 2012) and strategies for Cd minimization in plants and grains (Sebastian and Prasad, 2014; Uraguchi and Fujiwara, 2012).

Accumulation of Cd in plant is controlled by several factors that include plant species, its genotype, soil characteristics, environmental factors, presence of other minerals and nutrients (Quezada-Hinojosa et al., 2015; Volpe et al., 2015). An important factor that is relatively less studied is the role of microorganisms in controlling the availability of Cd to plants and their role as determinants of plant growth and yields in Cd polluted soils. Plant-associated microorganisms are known to play a vital role in promoting plant growth by various mechanisms (Kim et al., 2011); particular attention has been paid to a group of bacteria known as plant growth promoting rhizobacteria (PGPR) (Lugtenberg and Kamilova, 2009). Besides their role in enhancing plant growth and crop yield, plant-associated microorganisms have several other applications including remediation of soils from organic and metal pollutants. Many reviews deal with the role of PGPR in mobilization and phytoextraction of heavy metals from soil (Ma et al., 2011; Sessitsch et al., 2013; Wu et al., 2006) and in particular strategies for Cd removal from soils by phytostabilization and hyper-accumulation (Li et al., 2012). The plant growth promoting (PGP) bacteria that promote phytoextraction of metals are usually metal tolerant, increase Cd bioavailability and enhance accumulation of the metal in plant; so that the metal may be effectively removed from the soils. These bacteria efficiently increase the mobilization of Cd by solubilising metal phosphates, enhance root surface area for Cd uptake, and promote root to shoot translocation of Cd. However, such organisms may enhance metal content in edible plant parts. In recent times, there is growing literature on plant-associated microorganisms that promote plant growth in metal polluted soils but prevent or reduce the accumulation of the metal in edible plants. Many Cd resistant PGPR show a number of responses to metal ions e.g. metal biosorption, metal precipitation, enzymatic metal transformation and rendering them unavailable; thereby reducing the metal ion toxicity towards the plant. Thus, PGPR may increase or decrease the metal bioavailability in different plants-microbial associations. The factors responsible for the outcome of plant-microbial interaction on metal accumulation are not clearly understood. This review provides consolidated information available on the microorganisms-mediated reduction of Cd in plants. The article describes some of the basic information on Cd resistant PGP bacteria, mechanisms employed by the bacteria to overcome Cd toxicity, and traits involved inplant growth promotion. The possible effects of the PGP traits on Cd accumulation vis-a-vis Cd minimization in plant tissues are discussed.

2. Cadmium resistant plant growth promoting rhizobacteria

Microorganisms may develop resistance towards Cd and dominate the metal polluted rhizospheric soil. Bacteria which are resistant to high concentration of Cd and possess the ability to promote plant growth under Cd stress condition may be termed as Cd resistant PGPR. In order to protect the plants from Cd stress, these bacteria must be (1) resistant to Cd, (2) capable of binding free Cd^{2+}, (3) actively colonizing root surface and/or rhizosphere, (4) possess some PGPR traits (Pishchik et al., 2002). Cd resistant PGPR may reduce the metal uptake by plants and its translocation to aerial parts. In some cases PGPR may reduce the Cd^{2+} availability to plant by accumulating Cd inside the bacterial cells (Kumar et al., 2011). On the other hand, some PGPR do not deal directly with Cd sequestration but reduce the plant stress based on their plant growth promoting traits. Rhizospheres of tolerant and hyper-accumulator wild plants growing in Cd-contaminated sites may be regarded as valuable source of cadmium resistant PGPR. These PGPR may eventually be used as inoculants under agricultural