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Review

A critical review on effects, tolerance mechanisms and management of cadmium in vegetables

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HIGHLIGHTS

- Cd-contaminated vegetables pose major food safety and public health concerns worldwide.
- Cd toxicity decreased growth, yield and quality of vegetables.
- Growing low-Cd vegetables can greatly reduce dietary exposure of Cd.
- Agricultural practices with amendments can be used to reduce Cd in vegetables.

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ABSTRACT

Cadmium (Cd) accumulation in vegetables is an important environmental issue that threatens human health globally. Understanding the response of vegetables to Cd stress and applying management strategies may help to reduce the Cd uptake by vegetables. The aim of the present review is to summarize the knowledge concerning the uptake and toxic effects of Cd in vegetables and the different management strategies to combat Cd stress in vegetables. Leafy vegetables grown in Cd contaminated soils potentially accumulate higher concentrations of Cd, posing a threat to food commodities. The Cd toxicity decreases seed germination, growth, biomass and quality of vegetables. This reduces the photosynthesis, stomatal conductance and alteration in mineral nutrition. Toxicity of Cd toxicity also interferes with vegetable biochemistry causing oxidative stress and resulting in decreased antioxidant enzyme activities. Several management options have been employed for the reduction of Cd uptake and toxicity in vegetables. The exogenous application of plant growth regulators, proper mineral nutrition, and the use of organic and inorganic amendments might be useful for reducing Cd toxicity in vegetables. The use of low Cd accumulating vegetable cultivars in conjunction with insolubilizing amendments and proper agricultural practices might be a useful technique for reducing Cd exposure in the food chain.

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1. Introduction

Heavy metals mainly accumulate in the environment due to anthropogenic activities such as mining, use of wastewater for irrigation, sewage sludge application, rock phosphate fertilizers as well as vehicular and industrial activities (Gallego et al., 2012; Adrees et al., 2015a; Yousaf et al., 2016). Heavy metal toxicity caused various morphological, physiological, biochemical and ultrastructural changes in plants (Ali et al., 2015; Gill et al., 2015). Among the heavy metals, cadmium (Cd) is relatively mobile in the soil and can be toxic to both plants and animals (Chaney, 2015; Khan et al., 2015a; Rizwan et al., 2016d). The Cd accumulation in humans is mainly through the food chain cycle (Beccaloni et al., 2013; Rizwan et al., 2016a, 2016b) which may cause a number of disorders such as *Itai-Itai* disease, cancer, and nephrotoxicity (Chaney, 2015; Khan et al., 2016). Vegetables and cereals are the major food sources of the world's population. Cd accumulates in vegetables as most of the vegetables in peri-urban areas receive Cd from irrigation using wastewater and sewage sludge (Ahmad and Goni, 2010; Abbasi et al., 2013; Kim et al., 2015; Amato-Lourenco et al., 2016; Anwar et al., 2016; Baldantoni et al., 2016). Similarly, Cd and other toxic metals can increase in vegetables grown in soils of former mining and industrial areas and in soil exposed to long-term fertilization (Ahmad et al., 2011; Alvarenga et al., 2014; Bui et al., 2016; Antoniadis et al., 2017; Rehman et al., 2017).

The Cd toxicity diminishes vegetable growth, biomass, photosynthesis, yield, and quality (Gharaibeh et al., 2015; Kumar et al., 2016; Mombo et al., 2016). Cadmium toxicity causes an alteration in mineral nutrition for plants (Gonçalves et al., 2009; Bertoli et al., 2012). Excess Cd severely affects the root morphology and growth (Finger-Teixeira et al., 2010), causing oxidative stress in vegetables by producing reactive oxygen species (ROS) which damage the antioxidant enzyme system (Hossain et al., 2010; Gratao et al., 2015). However, plant response to Cd stress varies among vegetables and genotypes and cultivars within the vegetables (Shamsi et al., 2014; Hussain et al., 2015; Xin et al., 2015a; Tang et al., 2016a). Leafy vegetables accumulate more Cd than do tubers and root vegetables (Zhang et al., 2013; Wang et al., 2014). The Cd can accumulate in different consumable parts of the vegetables such as the leaves and tubers, and thus enter the food chain (Baldantoni et al., 2016).

Different methods have been used to reduce Cd uptake, translocation and toxicity in vegetables, including the application of organic and inorganic amendments such as biochar, compost, manures and silicon (Rizwan et al., 2012; Ali et al., 2013a, 2013b; Rehman et al., 2015; Adrees et al., 2015b; Baldantoni et al., 2016; Sun et al., 2016; Ye et al., 2016). The exogenous application of microbes, cropping patterns, co-plantation, and grafting has also been used for the reduction of Cd uptake in vegetables (Wang et al., 2015a; Edelstein et al., 2016; Hu et al., 2016; Shan et al., 2016; Tang et al., 2016b). The proper selection of low Cd-accumulating vegetable cultivars and exogenous application of plant growth regulators (PGR) might also be an effective strategy to reduce Cd uptake by vegetables (Vollmann et al., 2015; Simek et al., 2016; Wang et al., 2016b).

Although Cd uptake by vegetables might pose a threat to human health and various management strategies have been used for the reduction of Cd uptake by vegetables, no comprehensive review article is available related to the minimization of Cd stress in vegetables. Thus, the objective of the present review is to highlight the Cd toxicity and tolerance in vegetables and the different management options with the objective to reduce Cd uptake and toxicity in vegetables.

2. Effects of Cd on vegetables

2.1. Plant growth and biomass

Cadmium affects the growth of plants negatively. Slight but significant decreases in shoot dry matter yield of cucumber reflected a negative effect of Cd concentrations as low as 0.05 μM in hydroponic culture. Cadmium uptake by cucumber plants as affected by fluctuations in nutrient solution Cd concentration