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Review

Cadmium minimization in wheat: A critical review

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ABSTRACT

Cadmium (Cd) accumulation in wheat (*Triticum aestivum* L.) and its subsequent transfer to food chain is a major environmental issue worldwide. Understanding wheat response to Cd stress and its management for aiming to reduce Cd uptake and accumulation in wheat may help to improve wheat growth and grain quality. This paper reviewed the toxic effects, tolerance mechanisms, and management of Cd stress in wheat. It was concluded that Cd decreased germination, growth, mineral nutrients, photosynthesis and grain yield of wheat and plant response to Cd toxicity varies with cultivars, growth conditions and duration of stress applied. Cadmium caused oxidative stress and genotoxicity in wheat plants. Stimulation of antioxidant defense system, osmoregulation, ion homeostasis and over production of signalling molecules are important adaptive strategies of wheat under Cd stress. Exogenous application of plant growth regulators, inorganic amendments, proper fertilization, silicon, and organic, manures and biochar, amendments are commonly used for the reduction of Cd uptake in wheat. Selection of low Cd-accumulating wheat cultivars, crop rotation, soil type, and exogenous application of microbes are among the other agronomic practices successfully employed in reducing Cd uptake by wheat. These management practices could enhance wheat tolerance to Cd stress and reduce the transfer of Cd to the food chain. However, their long-term sustainability in reducing Cd uptake by wheat needs further assessment.

Contents

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1. Introduction

Contamination of agricultural soils with heavy metals is a serious threat to crop production worldwide (Adrees et al., 2015a; Ali et al., 2015; Habiba et al., 2015; Rizwan et al., 2016a). Among heavy metals, Cd is highly toxic to plants and animals even at very low concentrations due to its non-essentiality in living organisms. The Cd-contaminated food is the main source of Cd entry to humans via the food chain (Huang et al., 2008; Dai et al., 2012). Cereal crops such as wheat, rice and maize fulfill the major food requirements worldwide. Among cereals, wheat is the staple food for more than half of the world's population with a world production of about 650 million tons per year (FAO, 2012). As compared to other cereals, wheat could accumulate more Cd mainly through roots and could translocate to aerial parts and finally accumulates in wheat grains (Greger and Löfstedt, 2004; Jafarnejadi et al., 2011). Thus, wheat-derived products are the major source of Cd intake by humans. Cadmium is more toxic to wheat as compared to other toxic metals such as chromium (Lopez-Luna et al., 2016). Cadmium toxicity decreased the uptake and translocation of essential elements by plants, including wheat (Yourtchi and Bayat, 2013). Under Cd stress, wheat root growth and morphology is severely affected. In shoots, Cd toxicity showed many physiological disorders such as a decrease in photosynthesis, sugars and soluble proteins and antioxidant enzyme activities (Ci et al., 2009; Shafi et al., 2011; Wang et al., 2011; Li et al., 2015). Cadmium toxicity also increased the production of reactive oxygen species (ROS) which caused oxidative stress in plants (Lu et al., 2013; Chen et al., 2014; Poghosyan et al., 2014; Tauqeer et al., 2016). This would result in a reduction in plant growth, biomass and grain yield (Ci et al., 2010a). However, plant response to Cd toxicity varies among wheat cultivars i.e. durum wheat accumulates higher Cd concentration as compared to bread wheat (Gao et al., 2011a; Jafarnejadi et al., 2011; Erdem et al., 2012; Naeem et al., 2016). Cadmium accumulated in shoots could translocate to grains and then could transfer to humans and animals via the food chain. Thus, Cd minimization in wheat is an important demand especially in soils contaminated with Cd.

Different mitigation strategies have been employed for the reduction of Cd toxicity in wheat. These strategies may include plant growth regulators (PGRs), proper application of mineral nutrients, silicon, inorganic amendments, biochars, manure and compost (Gondor et al., 2014; Asgher et al., 2015; Huang et al., 2015; Ishikawa et al., 2015; Ok et al., 2015; Rizwan et al., 2015). Agronomic management practices such as low Cd-accumulating wheat cultivars, crop rotation, planting patterns and application of microbes might also be used for the reduction of Cd uptake and toxicity in wheat (Ahmad et al., 2015; Greger and Landberg, 2015a; Qiu et al., 2011; Naeem et al., 2016). The objective of the present review is to discuss the Cd toxicity and tolerance mechanisms in wheat and some possible management measures to alleviate Cd toxicity in wheat.

2. Cadmium uptake by wheat

Cadmium enters into the soil through geogenic and anthropogenic activities (Boussen et al., 2013). Human activities contribute about 13,000 of the total 30,000 t of annual Cd addition to the environment (Gallego et al., 2012). Cadmium concentration in agricultural and garden soils ranged from 0.01 to 0.7 and 0.27–2.86 mg kg^{-1} respectively (Szolnoki et al., 2013). Cadmium content in phosphate fertilizers ranges between 2 and 200 mg kg^{-1} while sedimentary rocks contain Cd about 15 mg kg^{-1}. Cadmium availability in soils depends upon a large number of factors such as soil Cd content, soil pH, organic matter, clay minerals, cation exchange capacity (CEC) and type of fertilizers (He et al., 2015; Ran et al., 2016). Jafarnejadi et al. (2011) reported that there was a significant correlation between wheat grain Cd and organic carbon, CEC, and DTPA-extractable Cd concentrations in the soil. Among soil factors, soil pH is the most important factor contributing Cd uptake by wheat plants (Nan et al., 2002; Li et al., 2014; Liu et al., 2015a; Ran et al., 2016).

Cadmium mainly enters in wheat plants through roots (Hart et al., 2006; Adeniji et al., 2010; Black et al., 2014). Root exudation also plays an important role in Cd accumulation by wheat (Cieslinski et al., 1998; Greger and Landberg, 2008). Cadmium uptake by wheat varies with soil type, atmospheric pollution and wheat cultivars (Guo et al., 2012; Liu et al., 2015a). More recently, Dahlin et al. (2016) reported that chloride (Cl^{-}) could mobilize Cd in the soil and increase its uptake by wheat especially by mobilizing inherent soil Cd. After root uptake, a higher concentration of Cd is accumulated in roots and less is translocated to shoots depending upon wheat cultivars (Adeniji et al., 2010; Ci et al., 2010a). Higher Cd retention in roots might be due to chelation with organic acids as suggested by (Adeniji et al., 2010). However, Hart et al. (2006) reported that phytochelation might not be a limiting factor in the differential storage of Cd in wheat roots.

Cadmium accumulation in wheat shoots depends upon root-to-shoot Cd translocation while accumulation in grains depends upon root-to-shoot Cd transfer and direct pathway of Cd transport from roots to grain via xylem-to-phloem transfer in the stem (Harris and Taylor, 2004, 2013). Quinn et al., (2011) reported that increased shoot Cd content in 'low' isolines of wheat was associated with transpiration rate while in 'high' isolines Cd accumulation was independent of transpiration. Cadmium transport from root to the shoot might be due to symplastic movement of Cd into the root stele as suggested by Van der Vliet et al. (2007). Riesen and Feller, (2005) reported that Cd could be remobilized in wheat through phloem along with transpiration. Chen and Hale (2004) suggested that Cd content in durum wheat grain was a function of total shoot accumulation.

3. Toxic effects of Cd in wheat

Cadmium is highly toxic to wheat and reduction in seed germination is the first toxic effect of Cd in wheat. Cadmium, for example, decreased seed germination of four wheat cultivars in a dose and cultivar-dependent manner (Ahmad et al., 2012). Cadmium toxicity to seed germination depends upon the growth media (Ahmad et al., 2013). It has been reported that wheat cultivation on soil had better germination, measured in terms of the plumule and radicle length, as compared to filter paper under same Cd levels which might be due to sorption of Cd on the soil exchange sites (Ahmad et al., 2013).

The major visible symptoms of Cd-induced toxicity in wheat are chlorosis, necrosis, browning of root tips, reduced plant growth