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Review

Chromium speciation, bioavailability, uptake, toxicity and detoxification in soil-plant system: A review

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HIGHLIGHTS

- This review summarizes biogeochemical behavior of Cr in soil-plant system.
- Cr speciation governs its biogeochemical behavior in soil-plant system.
- Soil microbes governs biogeochemical behavior of Cr in soil-plant system.
- Cr provokes numerous deleterious effects to biochemical processes.
- Plants tolerate Cr via numerous detoxification mechanisms.

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ABSTRACT

Chromium (Cr) is a potentially toxic heavy metal which does not have any essential metabolic function in plants. Various past and recent studies highlight the biogeochemistry of Cr in the soil-plant system. This review traces a plausible link among Cr speciation, bioavailability, phytouptake, phytotoxicity and detoxification based on available data, especially published from 2010 to 2016. Chromium occurs in different chemical forms (primarily as chromite (Cr(III)) and chromate (Cr(VI)) in soil which vary markedly in term of their biogeochemical behavior. Chromium behavior in soil, its soil-plant transfer and accumulation in different plant parts vary with its chemical form, plant type and soil physico-chemical properties. Soil microbial community plays a key role in governing Cr speciation and behavior in soil. Chromium does not have any specific transporter for its uptake by plants and it primarily enters the plants through specific and non-specific channels of essential ions. Chromium accumulates predominantly in plant root tissues with very limited translocation to shoots. Inside plants, Cr provokes numerous deleterious effects to several physiological, morphological, and biochemical processes. Chromium induces phytotoxicity by interfering plant growth, nutrient uptake and photosynthesis, inducing enhanced generation of reactive oxygen species, causing lipid peroxidation and altering the antioxidant activities. Plants tolerate Cr toxicity via various defense mechanisms such as complexation by organic ligands, compartmentation into the vacuole, and scavenging ROS via antioxidative enzymes. Consumption of Cr-contaminated-food can cause human health risks by inducing severe clinical conditions. Therefore, there is a dire need to monitor biogeochemical behavior of Cr in soil-plant system.

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Contents

1. Introduction

Chromium (Cr) with atomic number 24, molecular weight 51.1 and density 7.19 g/cm^3 is a silver color hard metal. Chromium is the 7th most abundant element (Nriagu, 1988), and 21st most abundant metal (Sinha et al., 2005; Economou-Eliopoulos et al., 2013) of the Earth's crust. Chromium is one of the 18 core hazardous air pollutants (HAPs), 33 urban air toxicants, 188 HAPs (US EPA), and has been ranked 7th among the top 20 hazardous substances by the Agency for Toxic Substances and Disease Registry (Oh et al., 2007). This metal is ranked 5th among the heavy metals in the Comprehensive Environmental Response, Compensation, and Liability Act (Ma et al., 2007). Chromium is also categorized as no.1 carcinogen according to the International Agency for Research on Cancer (IARC, 1987) and the National Toxicology Program. Therefore, this metal requires detailed understanding and in-depth monitoring in the environment, especially soil-plant system.

Chromium has a complex electronic and valence shell chemistry owing to its high potential to easily convert from one oxidation state to another (Prado et al., 2016a). Chromium has several oxidation states (−2 to +6), but hexavalent chromate [Cr (VI)] and trivalent chromite [Cr (III)] forms are the most common and stable in the natural environment (Ashraf et al., 2017). Both these forms [Cr (III) and Cr (VI)] have different chemical, epidemiological and toxicological features; they are separately regulated by Environmental Protection Agency (EPA), which presents a distinctive feature of Cr among the heavy metals. Both the species of Cr differ greatly with respect to their sorption and bioavailability in soil, absorption and translocation to aerial parts and toxicity inside plants (Elzinga and Cirmo, 2010; Amin and Kassem, 2012; Choppala et al., 2016). Cr (III), being necessary for lipid and sugar metabolism (Bai et al., 2015), is an essential trace element for human and animal health (Prasad, 2013; Eskin, 2016), however, it is not required by the plants (Shanker et al., 2005).

Environmental contamination of Cr has gained substantial consideration worldwide because of its high levels in the water and soil originating from numerous natural and anthropogenic activities (Quantin et al., 2008; Ashraf et al., 2017). Chromium eventually accumulates in crops from contaminated soils, and imparts severe health risks in humans via food chain contamination (Broadway et al., 2010; Ahmed et al., 2016). Soil-plant transfer of Cr is controlled by numerous factors related to plant physiology (plant type, rate and type of root secretions, root surface area and transpiration) and soil properties (texture, pH, cation exchange capacity) (Banks et al., 2006; Zeng et al., 2011b; Santos and Rodriguez, 2012). In the majority of plant species, Cr is poorly translocated towards aerial parts and is mainly retained in the root tissues (Jaison and Muthukumar, 2016). However, Cr-hyperaccumulators such as atlantic cord grass (*Spartina argentinensis*), jelutong (*Dyera costulata*) and spleen amaranth (*Amaranthus dubius*) can uptake and translocate high Cr levels in shoot tissues (de Oliveira et al., 2016).