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Silicon alleviated manganese toxicity in cucumber by cell wall compartmentation

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As a consequence of normal root growth and development, a considerable range of organic and inorganic substances are exchanged between the root and soil, which causes changes in the biochemical and physical properties of the rhizosphere. Plants modify their rhizosphere in response to various environmental signals and stresses. Low-molecular-weight metabolites are commonly detected in this region and their exudation from plant roots has been associated with abiotic stress, such as inorganic form of manganese (Mn). In this study we investigated the root exudate constituents (phenolics and enzymes) of cucumber (*Cucumis sativus* L.) plants grown in Mn-free and Mn-contaminated nutrient solutions (0.5 and 100 μM, respectively) with (+Si) or without silicon (–Si) supplied as 1.5 mM silicic acid. High external Mn supply induced both growth inhibition of the whole plant and the appearance of Mn-toxicity symptoms in the leaves, while the simultaneous application of Si alleviated toxicity symptoms. At high Mn supply, concentration of phenolic compounds, as plant-borne substrates for peroxidase (POD) and polyphenol oxidases (PPO), depended on Si application. The increased concentrations of phenolic compounds (e.g., coniferyl alcohol, *p*-coumaric and isoferulic acid) in –Si plants were in agreement with enhanced POD and PPO activities. The activities of both enzymes were kept at a lower level in +Si plants grown at higher Mn concentrations. These results suggest that Si nutrition modulates the metabolism and utilization of phenolic compounds most probably as a consequence of the formation of Si-polyphenol complexes and their subsequent cross-linking with cell wall polymers. In –Si plants increased activity of the PPO and POD/H_2O_2 systems lead to the formation of highly reactive compounds, while in +Si plants, lignin biosynthesis is favored. H_2O_2 in the presence of elevated Mn concentrations produced potentially toxic •OH and Mn^{3+} in the Fenton reaction, which was efficiently suppressed by Si application. Silicon thus prevented the formation of toxic intermediates (•OH and Mn^{3+}) and accumulation/oxidation of free phenolics leading to oxidative browning, the initial indicator of Mn-toxicity symptoms. In summary, we presented the knowledge about how cucumber can overcome hyperaccumulation of Mn by means of Si-complexation suggesting ways of improving future phytoremediation strategies.