DOCTORAL THESIS

Risk assessment and mycorrhizal remediation of cadmium contamination in vegetable farms around the Pearl River Delta, China

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Risk Assessment and Mycorrhizal Remediation of Cadmium Contamination in Vegetable Farms around the Pearl River Delta, China

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Abstract

This study aimed to (1) evaluate the contamination status and potential health risks of Cd and other major heavy metals (HMs), including Cu, Cr, Ni, Pb, and Zn, in market vegetables available in Hong Kong, (2) investigate the transfer pattern of Cd from soil to edible vegetables in farms around the Pearl River Delta (PRD), China, (3) determine the role of arbuscular mycorrhizal (AM) fungi in Cd and P accumulation by remedial plants, i.e. hyper-accumulating (HA) and fast-growing (FG) plants, as well as by neighboring vegetables in intercropping systems, and (4) apply biochar and mycorrhizal intercrops on vegetable production in Cd-contaminated soils.

A systematic survey of HM concentrations and their bioaccessibilities in market vegetables in Hong Kong were carried out for assessing potential health risk to local inhabitants. The average concentrations of Cd, Pb, Cr, Ni, Cu, and Zn in nine major groups of fresh vegetable varied within 0.007–0.053, 0.05–0.17, 0.05–0.24, 0.26–1.1, 0.62–3.0, and 0.96–4.3 mg kg^{-1}, and their average bioaccessibilities varied within 21–96, 20–68, 24–62, 29–64, 30–77, and 69–94%, respectively. The bioaccessible estimated daily intakes (BEDIs) of Cd, Pb, Cr, Ni, Cu, and Zn through consumption of vegetables were far below the tolerable limits set by the Joint FAO/WHO Expert Committee on Food Additives (JECFA). The total bioaccessible target hazard quotient (TBTHQ) of the six HMs was 0.18 and 0.64 for average and high consumers, respectively, with Cd and leafy vegetable being the major risk contributors.

Five random vegetable farms (marked as DDH, SHH, DHH, HG, and SD) around the PRD were selected to investigate Cd bioaccumulation risks. Amongst the major HMs in soils, only total Cd concentrations (1.4–1.8 mg kg^{-1}) were higher than the permissible limit of China (≤0.3 mg kg^{-1}). Soil DTPA-extractable (phytoavailable) Cd

concentrations varied within 0.017–0.17 mg kg^{-1}. About 28.0% of vegetable samples were contaminated with Cd (>0.05 mg kg^{-1}), 71.4% of which belonged to stem/leaf vegetables. The average bioaccumulation factors of Cd from cultivated soil to stem/ leaf vegetables and melon/fruit/bean vegetables varied within 0.021–0.050 and 0.005–0.020 (soil total Cd basis), and 0.50–2.01 and 0.13–0.53 (soil DTPA-extractable Cd basis), respectively. Redundancy analysis (RDA) showed that soil DTPA-extractable Cd concentration, which negatively but significantly correlated (P<0.05) to soil pH, was the key factor in influencing Cd bioaccumulation, notably stem/leaf vegetables.

A pot experiment was conducted to compare Cd phytoextraction efficiencies by Alfred stonecrop (*Sedum alfredii* Hance) and perennial ryegrass (*Lolium perenne* L.) from a Cd-contaminated (1.6 mg kg^{-1}) soil. The FG ryegrass and the HA stonecrop were harvested after growing for 9 and 27 weeks, respectively. Weekly Cd extraction by stonecrop (8.0 μg pot^{-1}) was 4.3 times higher than that by ryegrass (1.5 μg pot^{-1}). Both species of AM fungi *Glomus caledonium* (*Gc*) and *G. mosseae* (*Gm*) increased P acquisitions, shoot biomasses, and Cd acquisitions of stonecrop and ryegrass in most cases, while only *Gc*-inoculated stonecrop significantly accelerated (P<0.05) the phytoextraction efficiency of Cd by 78%. In addition, both *Gc* and *Gm* inoculations significantly decreased (P<0.05) soil DTPA-extractable Cd concentrations by 21–38% via elevating soil pH, causing Cd stabilization effects besides phytoextraction.

An 8-week pot trial was conducted to study Cd acquisition by upland kangkong (*Ipomoea aquatica* Forsk.) intercropped with stonecrop in the Cd-contaminated soil. Stonecrop tended to decrease kangkong Cd acquisition via competition of phyto-accessible Cd. Both species of AM fungi *Gc* and *G. versiforme* (*Gv*) significantly elevated (P<0.05) soil acid phosphatase activities and phytoavailable P, while only *Gc* increased (P<0.05) shoot biomass and Cd acquisition of the host (stonecrop), and hence further lowered Cd concentration as well as Cd acquisition of kangkong. *Gv* significantly increased ($P<0.05$) P acquisition and shoot biomass of the neighboring kangkong rather than the host, causing a significant dilution ($P<0.05$) effect on kangkong shoot Cd concentration. In addition, both *Gc* and *Gv* significantly decreased ($P<0.05$) soil DTPA-extractable Cd by elevating soil pH, and thereby significantly lowered ($P<0.05$) kangkong Cd concentrations in a 6-week post-harvest experiment.

A 10-week pot experiment was conducted to investigate growth performance and Cd accumulation of kangkong intercropped with stonecrop (IS) in a Cd-contaminated soil inoculated with *Gc* (+M) and/or applied with biochar. Regardless of IS and +M, biochar addition (+B) significantly increased ($P<0.05$) kangkong yield via elevating phytoavailable P, and decreased ($P<0.05$) soil Cd phytoavailability and kangkong Cd concentration via increasing soil pH. Compared with the monocultural control, there was a significantly higher shoot yield (+25.5%) with a substantially lower Cd concentration (–62.7%) of kangkong under the treatment of IS+M+B. In addition, *Gc* generated additive effects on soil alkalinization and Cd stabilization to biochar, causing substantially lower soil DTPA-extractable Cd and post-harvest transfer risks.

In summary, human health risk assessment of HMs from vegetables should be modified by taking bioaccessibility into account. Cd was the primary metal of risk in vegetable farms around the PRD, and stem/leaf vegetables posed higher health risks associated with exposure to Cd than melon/fruit/bean vegetables. For *in situ* treatment of Cd-contaminated soil, the hyper-accumulating plant (Alfred stonecrop) associated with AM fungi (notably *Gc*) showed a potential application for both extraction and stabilization of Cd. In addition, AM fungi and biochar played totally different but additive roles in the intercropping systems of kangkong and stonecrop for the dual purposes of vegetable production and phytoremediation of Cd-contaminated soils.

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