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Cadmium contamination in medicinal plants: Bioaccumulation, phytochemica alterations, and implications for human health

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Abstract

Cadmium (Cd) contamination in medicinal plant systems is a critical concern because it can affect b toxicological safety and the biosynthesis of bioactive phytochemical that determine therapeutic effica Unlike staple food crops, medicinal plants are frequently cultivated in marginal or contaminated so processed into concentrated preparations, and consumed chronically or in polyherbal formulation thereby generating exposure dynamics distinct from those of conventional dietary pathways. This revie synthesizes current evidence on Cd sources in cultivation systems, soil factors regulating bioavailabili molecular uptake mechanisms involving zinc-regulated transporter/iron-regulated transporter-like prote (ZIP), natural resistance-associated macrophage protein (NRAMP), and heavy metal ATPase (HM transporters, and species-specific accumulation patterns across leaf- and root-based medicinal tax Reported Cd concentrations in selected species, including *Panax notoginseng* and *Salvia miltiorrhiz* exceed the WHO (World Health Organization) benchmark of 0.3 mg/kg in certain regions, with hazar quotient (HQ) and lifetime cancer risk (LCR) values approaching or surpassing acceptable threshold Processing methods further modify exposure, as *in vitro* digestion studies indicate 40-60% gastri bioaccessibility of plant-bound Cd, challenging reliance on total concentration-based risk estimates. I addition to toxicological implications, Cd exposure may alter phytochemical composition, thereb influencing pharmacological activity and therapeutic consistency of medicinal plant products. Curren assessment frameworks predominantly employ deterministic models derived from food safety paradigm and may inadequately capture cumulative intake, preparation-specific extraction efficiencies, and long term toxicokinetic burden. Integrated mitigation strategies, including low Cd fertilizer selection, soil pH optimization, competitive nutrient management, phytoremediation, cultivar screening, and supply chain monitoring, provide actionable pathways for exposure reduction. Advancing phytomedicine-specific exposure modelling that links soil chemistry, plant physiology, processing effects, and human toxicokinetic is essential for safeguarding the safety, regulatory credibility, and global sustainability of medicinal plant based therapeutics.

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