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Production of Safer Vegetables from Heavy Metals Contaminated Soils: The Current Situation, Concerns Associated with Human Health and Novel Management Strategies

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Abstract

Vegetables play a chief part in the human diet and provide the essential nutrients and vitamins necessary to perform numerous essential physiological functions in the human body. Unfortunately, the consumption of vegetables laden with heavy metals (HMs) is among the most imperative issues of recent years because of their toxic impacts on human health. The toxic HMs accumulated in vegetables after their release into the ecosystem through diverse natural and human-centered activities. The prolonged use of synthetic agrochemicals, irrigation of agricultural lands with untreated municipal and industrial effluents, inappropriate dumping of solid waste, and various other industrial activities are the main causative factors of HMs accumulation in productive soils. The mobility of HMs in the soil and their accumulation in vegetables is remarkably influenced by several soil and plant factors that control their bioavailability. Reduction in growth, biomass, yield and poor nutritional quality are the key symptoms of HMs toxicity after their absorption by the vegetables. Health risks to humans via the consumption of HMs contaminated vegetables have been investigated through different risk assessment equations. Interestingly, different novel remediation techniques such as phytoremediation, immobilization, water management strategies, and applications of microbial inocula could be practiced for safer vegetable production for human consumption from HMs polluted soils.

Keywords

Bioaccumulation · Food chain · Heavy metals · Human health index · Remediation · Vegetables

19.1 Introduction

Rapid industrialization and urban sprawls have significantly increased problems associated with food security, sustainable agriculture, and safe food production (Rai 2018; Toth et al. 2016;

The original version of this chapter was revised: For detailed information, please see Correction. The correction to this chapter is available at https://doi.org/10.1007/978-3-030-89984-4_28

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J. A. Malik (ed.), *Advances in Bioremediation and Phytoremediation for Sustainable Soil Management*,
https://doi.org/10.1007/978-3-030-89984-4_19

Saumel et al. 2012; Clarke 2011). Among different problems, soil pollution with heavy metals (HMs) such as Cd, Pb, Cr, As, Ni, and Hg are becoming a serious environmental concern in recent years (Kumar et al. 2019; Gupta et al. 2018; Oves et al. 2012).

Mainly, anthropogenic activities such as rapid industrialization, aerosols production through the combustion of fossil fuels, mining processes, aerial deposition from smelters, applications of agrochemicals like herbicides or metallo-pesticides, phosphate fertilizers which release diverse HMs such as Cr, Hg, Cd, and Ni in agricultural soils, irrigation with untreated industrial or municipal wastewater, improper handling and dismantling of hazardous waste, additions of livestock manures as well as sewage sludge have significantly accelerated soil contamination with HMs (El-Kady and Abdel-Wahhab 2018; Gall et al. 2015; Woldetsadik et al. 2017; Kihampa et al. 2011; Luo et al. 2009; Chary et al. 2008). The toxic effects of HMs appeared on soil (micro)organisms which ultimately damage soil quality, and its fertility consequently affects safe food production after their deposition in the soil (Gadd 2010).

Vegetables are the most vital part of the human diet and are widely consumed due to the provision of essential nutrients such as carbohydrates, proteins, antioxidants, vitamins, dietary fibers, and essential minerals. Unfortunately, vegetables produced from HMs contaminated soils situated near industrial sources have higher concentrations of HMs in them than others (Slavin and Lloyd 2012). The accumulation and biotoxic effects of HMs are entirely influenced by their concentrations, source of contamination, chemical fraction and speciation, mode of deposition, the accumulation capacity of vegetables, soil, and other environmental factors (Yadav et al. 2018; Lente et al. 2014). Vegetables accumulate HMs either by absorption through their roots or by aerial deposition. Heavy metals are taken up by the vegetables and absorbed in the apoplast of roots which subsequently encourage aerial transport. It was reported that tubers and leafy vegetables accumulate higher concentrations of HMs because roots and leaves of herbaceous plants retain very high concentrations compared to fruits and stems (Singh et al. 2015; Agrawal et al. 2007). Hereafter, this loading of HMs in vegetables and their edible parts from contaminated soils becomes a grave concern owing to the risk of metal toxicity in animals and humans. Humans may experience reduced intellectual abilities in children, dementia in adults, dysfunctions of central nervous system, renal and gastrointestinal failure, insomnia, visionary loss and osteoporosis upon accelerated exposure to HMs (Rai et al. 2018; Emamverdian et al. 2015; Gall et al. 2015; Jan et al. 2011; Gadd 2010). Different risk assessment models are being used to evaluate potential hazards from the exposures to these HMs (Kamunda et al. 2016; Zhou et al. 2016).

Thus, there is a dire need to remediate such HMs affected soils that can pose serious threats to human health. Several remediation techniques have been adopted to reduce HMs accumulation in vegetables. These strategies include phytomanagement (Radziemska et al. 2020), immobilization (Xu et al. 2019; Wang et al. 2014), water management strategies, cropping patterns (De Juan et al. 1996), and applications of different microbial inocula (Edelstein and Ben-Hur 2018). Apart from this, laws have been enforced in many countries to control the release of HMs from different industries. Hence, this chapter aims to highlight HMs toxicity, their accumulation and transfer in vegetables, and associated health risks by consuming the HMs polluted foodstuff.

19.2 Soil Pollution with HMs

Major sources of soil pollution with HMs are categorized as natural and anthropogenic activities. Among natural phenomena, geological rock formation is the most important natural source of HMs discharge in the environment (Gupta et al. 2019). Generally, large quantities of Mn, Co, Cr, Ni, Cu, Zn, Cd, Sn, Pb, and Hg are released by geological processes. Similarly, some igneous rocks such as hornblende, augite, and olivine also share considerable amounts of Ni, Co, Zn, and

Cu in the soils. Moreover, increased levels of different HMs were observed among the categories of sedimentary rocks in the order of shale > limestone > sandstone (Nagajyoti et al. 2010). The volcanic eruption is also contributing its share in releasing Zn, Al, Mn, Ni, Cu, Hg, and Pb, along with some hazardous and toxic gases (Nagajyoti et al. 2010).

Industrial sources of HMs pollution include smelting, mining, transport of ores, metal recycling, and finishing activities. Estimatedly, ore mining is the major source of the release of different HMs in the environment (Yang et al. 2018; Duruibe et al. 2007). Runoff from mine wastes and weathering of metallic materials also contribute to the contamination of water bodies and surrounding lands due to leaching (Li et al. 2015; Pandey et al. 2016). The long-term use of industrial and municipal wastewater considerably increased HMs accumulation in agricultural soils (Turan et al. 2018). Numerous scientists reported the considerable concentrations of different HMs in arable soils followed by in vegetables (Ratul et al. 2018; Chabukdhara et al. 2016; Prashar and Prasad 2013). For example, higher concentrations of HMs were found in tomatoes when irrigated by sewage water (Alghobar and Suresha 2017).

Similarly, the applications of industrial effluents released from electroplating and Pb-acid batteries could cause the contamination of soil with Ni and Pb (Shahbaz et al. 2018; Khan et al. 2020). The atmospheric deposition also results in the precipitation of HMs on soil or nearby vegetation, thus increasing soil pollution with HMs. High-temperature processes, e.g., casting and smelting are involved in releasing different HMs in vapors and particulate forms. These vapors chemically react with water vapors present in the air and produce aerosols. Later, these aerosols are dispersed by the wind (commonly known as a dry deposition) or deposited by rainfall (wet deposition) causing contamination of water and soil (Chen et al. 2014). Energy production units, for example, coal-burning power plants, nuclear power stations, and petroleum combustion also emit different toxic HMs (Liao et al. 2016; Chen et al. 2014).

19.3 Factors Influencing the Mobility and HMs Accumulation in Vegetables

Several soil factors controlled the mobility and accumulation of HMs in vegetables from agricultural soils. The pH values of agricultural soils, an important factor, play a pivotal part in controlling the solubility of HMs. For instance, mobility of HMs increased at acidic pH whereas decreased at alkaline pH (Sheoran et al. 2016). This is because of the adsorption of HMs onto the surfaces of negatively charge soil constituents such as organic matter, the mineral-based clays such as silicates and others as well as the (hydro) oxides of Mn, Al, and Fe. Similarly, the anion exchange capacity (AEC) increases at acidic pH owing to an increase in overall net positive charge which enhanced the bioavailability of HMs and vice versa (Bhargava et al. 2012). Additionally, the presence of organic components in the soil also restricts the solubility of HMs due to the occurrence of more active binding sites and the abundance of ionic and polar functional groups like amino, phenol and carboxyl groups. These functional groups are released from the breakdown of fulvic and humic acids which are soluble at all pH levels. Inner sphere complexation, adsorption, and ion exchange are the key mechanisms involved in retaining HMs by organic matter (Evans 1989). The bioavailability of HMs in agricultural soils was also increased due to a rise in temperature owing to the rapid breakdown of organic matter (Silveira et al. 2003). For instance, rise in temperature significantly increased Zn and Cd transfer from the soil to different parts of plants (Cornu et al. 2016). Likewise, the soil texture also affects the uptake and bioaccumulation of HMs in vegetables. The highest bioavailability of HMs was observed in sand and loam followed by fine-textured and clay loam soils due to the abundant fine pores in fine-textured soils compared to coarse-textured soils (Sheoran et al. 2010). The lowest bioavailability of HMs was observed in soils having higher CEC values such as clay due to their much high adsorption potential (Bhargava et al. 2012).

19.3.1 Factors Associated with Vegetables

The accumulation of HMs in different vegetables varied among them owing to different morphological, physiological, and anatomical traits of plants (Yadav et al. 2018). Branch density, leaf inclination angle, stomata size and density, leaf area, the structure and shape of plant canopy are other factors that favor HMs accumulation in vegetables from aerial deposition (Shahid et al. 2017). Likewise, the transpiration rate also controls HMs uptake and their accumulation in vegetables. Initially, HMs are absorbed by the root apoplast and later ascend with transpiration channels via xylem tissues. Later, HMs were transported to aerial parts of vegetables and subsequently accumulated under the influence of transpiration. Plants that have high and flourishing transpiration rates accumulate higher quantities of HMs. Thus, leafy vegetables store much larger amounts of HMs than non-leafy vegetables owing to their higher transpiration and translocations rates (Hao et al. 2019). Likewise, the transport of HMs from roots to stem followed by fruit during translocation and transpiration processes is longer in non-leafy vegetables which may be attributed to their much lower accumulation (Khan et al. 2009).

19.4 Accumulation of HMs in Vegetables

The accumulation of HMs in vegetables depends upon several plants (vegetable type) and soil factors (bioavailability). Generally, leafy vegetables are good accumulators of HMs as compared to fruits. For example, spinach and lettuce are more efficient in accumulating Cd, when compared with French beans and peas (Alexander et al. 2006).

Much lower Cd uptake was observed in leafy vegetables compared to solanaceous, roots, alliums, melon, and legumes (Yang et al. 2010). The accumulation of different HMs in the vegetable of six different categories (legume, stalk, melon, solanaceous, root, and leafy vegetables) was investigated grown on HMs contaminated agricultural land. Results suggested that leafy vegetables significantly accumulated the higher concentrations of HMs with the least accumulation in melon vegetables. The Pb, As, and Cd concentrations were found above the threshold levels of food contaminants set by the China National Standard (Zhou et al. 2016). Likewise, the accumulation of Cd, Ni, Cr, As, Pb, and Hg were evaluated in different vegetables and the results suggested that *Chicorium endive* and *Coriandrum sativum* L. accumulated Pb and As respectively, while, *Spinacia oleracea* L as well as *Ipomea aquatica,* Forssk and *Phaseolus vulgaris* L. accumulated Cr, Cd, Hg, and Ni, respectively (Anarado et al. 2019; Kumar et al. 2014). The concentrations of Pb, Ni, Cr, and Cd in *Abelmoschus esculentus* were estimated collected from HMs contaminated soil irrigated with wastewater. *Abelmoschus esculentus* remarkably accumulated the concentrations of these HMs above their recommended values (Balkhair and Ashraf 2016). Leafy vegetables such as spinach, cabbage, parsley, and lettuce were also able to store the higher concentrations of Pb in contrast to stem (garlic and white radish) and fruit vegetables (cucumber, pumpkin, capsicum, green beans, and eggplant). However, average values of As, Cr, Se, and Zn in vegetables were higher than their standard values (Cao et al. 2014). Likewise, concentrations of numerous HMs were also assessed in radish, tomato, lady finger, cauliflower, brinjal, spinach, and cabbage (Chauhan and Chauhan 2014). Reportedly, much higher transport of different HMs in roots, stems, and leaves were observed in onion, lettuce, cabbage, and spinach. All reported values were higher than their standard values set by FAO and the WHO/EU combined limits (Akan et al. 2013).

19.5 Toxic Effects of HMs on Vegetables After Their Accumulation

Different plants show variable toxic symptoms on exposure to higher concentrations of HMs. Biomass reduction, growth inhibition, alterations in photosynthesis pigments, restricted water uptake are the usual key indicators of HMs toxicity in plants (Edelstein and Ben-Hur 2018; Sridhar et al. 2011). Numerous studies revealed that HMs stress in plants alters their spectral reflectance, which could cause different biochemical and physiological disorders in them and thus influence nutrients uptake by the vegetables (Sridhar et al. 2017, 2011). Interface with key nucleic acids, (de) activation of essential enzymes, disturbance in electron transport pathways and membrane injury are the known HMs toxicity in plants at the cellular level (Chen et al. 2003). For instance, the higher Cd uptake in lettuce caused a significant reduction of shoot biomass owing to Cd-induced chromosomal aberration (Monteiro et al. 2009; Seregin and Kozhevnikova 2006). Furthermore, alterations in protein synthesis, photosynthetic pigments, and respiration rates significantly reduced morphological traits of leaves of different plants grown on HMs contaminated soils (Chaves et al. 2011). Similarly, the excessive uptake and accumulation of HMs in vegetables resulted in the overproduction of oxygen-based non-radical species such as hydrogen peroxide (H_2O_2), organic hydroperoxide (ROOH), and singlet oxygen as well as oxygen-based free radicals such as peroxyl ($RO_2^{\bullet}$), alkoxyl ($RO^{\bullet}$), hydroxyl (OH•) and superoxide anion radicals ($O_2^{\bullet -}$) (Shahid et al. 2014; Circu and Aw 2010).

19.6 Human Health After the Exposure to HMs Through the Intake of Contaminated Vegetables

The substantial accumulation of HMs in vegetables is of serious concern due to damaging human health even in much lower concentrations (Manzoor et al. 2018). Toxic HMs entered into the food chain via soil-plant-humans and soil-plant-animal-humans pathways, which caused detrimental effects in humans after exposure (Edelstein and Ben-Hur 2018; McLaughlin et al. 2000). Nevertheless, the biotoxic effects of HMs entirely depend upon the total and bioavailable concentrations, speciation, time, and dose of exposure (Manzoor et al. 2018). The ingestion of HMs contaminated vegetables resulted in the depletion of certain crucial nutrients in humans which further caused malnutrition disabilities, growth retardation, neurological and immunological disorders, renal failure, reduced intellectual abilities as well as gastrointestinal and other types of cancer (Türkdogan et al. 2003; Iyengar and Nair 2000). Chronic or acute Pb poisoning damages the gastrointestinal tract and the central nervous system in children (Markowitz 2000). Likewise, appetite loss, abdominal pain, hallucinations, headache, fatigue, arthritis, hypertension, and kidney failure are the symptoms of acute Pb exposure (Khan et al. 2020; Jaishankar et al. 2014). Long-lasting contact with Pb caused congenital disabilities, autism, and damage to brain tissues, dyslexia, hyperactivity, muscular weakness, a significant reduction in weight, psychosis, and even could lead to death (Martin and Griswold 2009). Abnormal heartbeat, leukocytes, vomiting, nausea, damage to blood vessels, reduction of erythrocytes as well as pricking feelings in different body parts, while cancer, hypertension, cardiovascular failure, diabetes mellitus, skin itching, neurological, peripheral, and pulmonary disorders are the common symptoms of acute and chronic As poisoning in humans (Smith et al. 2002). Likewise, the negative impacts of HMs in pregnant women and on the growth of the fetus have been substantially available in the literature. For instance, exposure to HMs affects the ovary resulting in damage to the female reproductive system and disturbing the hormonal production and their discharge mechanisms (Silberstein et al. 2006). Exposure to Pb during pregnancy caused its accumulation in the blood which resulted in premature birth, weight loss in neonates, stillbirths, and hypertension, and even spontaneous abortions (Grant et al. 2013).

19.7 Prediction of Health Risks Associated with Contaminated Vegetables Through Different Models

19.7.1 Risk Evaluation Theory

The risk evaluation process is adopted to determine the health effects caused by HMs in humans after exposure to them. The risk assessment approach mainly contains (i) hazard determination, (ii) exposure estimation, (iii) toxicity assessment (dose-response), and (iv) risk classification. Hazard determination mainly aims to examine the presence, amount, and spatial dispersion of HMs in an ecosystem in a given time (Chen et al. 2015; Huang et al. 2014; Shakoor et al. 2017). In recent findings, many researchers identified the presence of HMs in the ecosystem owing to natural or anthropogenic events recognized as a possible hazard for the community. Different risk assessment models are being used to evaluate potential hazards from these HMs after the acute and chronic exposures (Kamunda et al. 2016; Zhou et al. 2016).

19.7.2 Estimating the Daily HMs Intake

Different methods have been used to estimate health risk assessment based on Provisional Tolerable Daily Intake (PTDI) by consuming HMs enriched vegetables (Chary et al. 2008). The expression for the estimation of daily HMs intake is as follows

$$\mathrm{DIM} = C_{\mathrm{metal}} \times C_{\mathrm{factor}} / B_{\mathrm{averageweight}}$$

In the above expression C_{metal}, C_{factor}, $D_{\mathrm{food\ intake}}$ and $B_{\mathrm{average\ weight}}$ represent HMs concentration in vegetable (mg kg^{-1}), conversion factor, daily intake of HMs enriched vegetables, and average body weight, respectively. The values of DIM were higher for vegetable samples collected from wastewater irrigation zone in contrast to vegetables irrigated with groundwater (Mahmood and Malik 2014).

19.7.3 Hazard Quotients

The hazard quotient index has been previously used to estimate the human health risks associated with HMs intake after consuming vegetables. It is the ratio between the estimated and the standard doses (RD). If the ratio value is less than 1 represents no risk to humans from exposure to toxic HMs. If the values of HQ are equal or greater than 1, it shows a high risk to populations. The expression of HQ is given below

$$\mathrm{HQ} = \left[W_{\mathrm{plant}}\right] \times \left[\mathrm{Metal}_{\mathrm{plant}}\right] / R_f D \times B$$

In the above equation, W_{plant} is the dry weight of HMs in the consumable parts of vegetables (mg d^{-1}), M_{plant} represents the amount of HMs in vegetables (mg kg^{-1}), $R_f D$ expressed standard of reference dose of a HM for food (mg d^{-1}), and B expressed the average body weight (kg).

19.7.4 Health Risk Index

The health risk index calculates the relationship between daily HM intake and standard dose. The mathematical expression of HRI is as follows

$$\mathrm{HRI} = \mathrm{DIM}\ / R_f D$$

It is assumed that the population is at higher risk if HRI values are found higher than 1 in them. Results of HRI revealed that the consumption of HMs contaminated vegetables poses a serious health risk to humans. It was mainly due to irrigation with wastewater having very higher HMs concentrations (Mahmood and Malik 2014).

19.7.5 Carcinogenic Risk

The populations consuming HMs contaminated vegetables may experience cancer risk, which is estimated by the following expression.

$$\mathrm{CR} = \mathrm{CDI} \times \mathrm{SF}$$

Cancer risk is 10–100 times higher in children exposed to Ni and Cr by consuming contaminated foodstuff. Likewise, As also possess serious potential carcinogenic risk in children when exceeded from its tolerable level (Cao et al. 2014).

19.8 Management of HMs Contaminated Soils for Safer Vegetable Production

This section covers different management strategies that remove, render or reduce the uptake of higher concentrations of HMs by the vegetables from the soil environment.

19.8.1 Phytoremediation

Phytoremediation is a "green solution" technique that involve plants to partially or eliminate HMs from the environment (Ali et al. 2013). It can also be used with other remediation methods such as immobilization and other primitive methods as the final step in the remediation process (Radziemska et al. 2019, 2020). Phytoremediation has several advantages such as being cost-effective, high acceptance rate by the community, no harm to the environment, controlling HMs from the root zones of trees, minimal risk of secondary pollution as well as the potential to eliminate multiple HMs from a single site (Tauqeer et al. 2019). Poor plant establishment, growth inhibition because of HMs toxicity, prior knowledge about the site and environmental conditions, required large time, increased solubility and transport of HMs which further enhanced the risk of secondary pollution are the disadvantages of phytoremediation (Tauqeer et al. 2019).

19.8.2 Immobilization

In recent years, the in-situ immobilization remediation method has gained the attention of scientists worldwide owing to its vast applicability, easy availability of raw materials as well as lower labor and energy requirements (Zhai et al. 2018). Numerous organic and inorganic amendments have been known to reduce HMs uptake by vegetables grown on HMs polluted soils (Arshad et al. 2016; Kumar and Chopra 2014). These amendments not only reduced HMs uptake by the vegetables but also improved soil conditions that further supported plant establishment and maintain their nutritional quality (Xu et al. 2019). Likewise, iron and silicon-rich material significantly increased the growth of *B. Chinensis* by reducing As and Cd uptake compared to alkaline clay and synthetic zeolite (Yao et al. 2017). Phosphorus (P) is also a key component of vegetables development in the agricultural system. Phosphorus applications also significantly control HMs uptake by forming a stable metal complex, increasing soil pH and CEC (Yin et al. 2016).

Organic materials have also been considered to be effective additives in reducing HMs bioavailability in agricultural soils (Shan et al. 2016). Compost, pig manure, and wheat straw had noticeably restricted Cd transport to the roots and aerial parts of radish. During the experiment, it was observed that pig manure was the most efficient amendment in reducing Cd uptake compared to wheat straw (Shan et al. 2016). Similarly, in a field experiment, poultry, swine, and cattle manure were added to the Cd polluted soil during a four-year vegetable production period. It was noticed that these amendments had significantly decreased Cd concentrations and its uptake by spinach (Sato et al. 2010). Likewise, biochar, "a substance produced from organic residues such as agricultural wastes, plant, and animal wastes" under the limited supply of oxygen, has recently gained the attention of scientists worldwide due to its vast applications as fertilizer and potential amendment in immobilizing numerous environmental contaminants (Awad et al. 2017; Woldetsadik et al. 2016; Wang et al. 2015). Biochar applications have significantly increased the growth of turnips (*Brassica rapa* L.) by lowering HMs uptake. It was observed that peanut shell-derived biochar was efficient in decreasing HMs uptake by turnips in contrast to soybean, sewage sludge, and rice straw amendments (Khan et al. 2015). Furthermore, paper-mill sludge biochar had also considerably reduced Zn and Cd uptake, while improving the yield of lettuce (Kim et al. 2015). Similarly, biochar applications also reduced HMs concentrations in garlic (Song et al. 2014), Jack bean (Puga et al. 2015) and pepper (Xu et al. 2016).

19.8.3 Water Management Strategies

Constant and prolonged water applications also influence the HMs accumulation in soils and vegetables. Irrigation of contaminated agricultural lands with water significantly increased HMs uptake by vegetables at their critical growth (Tack et al. 2017). However, continuous and long-term field monitoring is required to explore this fact. Likewise, irrigation of arable lands with fresh and surface waters as well as municipal and industrial wastewaters influence HMs accumulation in vegetables (Asgari and Cornelis 2015; Qureshi et al. 2016). Additionally, modes of water use such as surface, drip, and other irrigation practices may also reduce HMs accumulation in soil profile and vegetables grown on them. Reportedly, the use of subsurface pressure-compensating drip irrigation method was able to reduce HMs accumulation in the soil profile and cauliflower curds (Singh et al. 2020).

19.8.4 Soil Applications of Different Microbial Inocula

Soil-microbe-plant interaction plays a key role owing to its potential in improving the growth, yield, nutritional quality, and restricting HMs accumulation in plants. This interaction not only increased microbial mediated HMs tolerance in plants but also improved the overall traits of plants (Tiwari and Lata 2018).

This possibly could be due to precipitation, absorption, and accumulation of HMs in the cell walls of microbes, conversion of HMs into less toxic form through oxidation-reduction reactions, exclusion of HMs from their cell as well as encapsulation (Tiwari and Lata 2018 and references therein). Likewise, the applications of arbuscular mycorrhizal fungi (AMF) in arable lands polluted with HMs have been extensively revealed (Riaz et al. 2020; Chang et al. 2018). Arbuscular mycorrhizal fungi are unique and diverse microorganisms directly associated with the host plant and soil, increasing the minerals and water acquisition and their uptake by the plants which ensure plant establishment under HMs stress (Khan et al. 2020). The presence of AMF in HMs contaminated soils encourage the plant growth through developing root system, by improving the growth and surface area of root hair which increased nutrient acquisition under HMs stress (Pavithra and Yapa 2018).

19.9 Conclusion and Way Forward

Vegetables are the key component of the human diet and provide essential mineral nutrients to maintain numerous physiological functions. Also, they are a good accumulator of HMs without showing any toxic symptoms and pose a severe risk to human health after exposure by consuming HMs contaminated vegetables. Thus, there is a need to take effective remedial measures to control HMs accumulation in vegetables grown on contaminated soils. Applications of different novel remediation techniques such as phytoremediation, water management strategies and utilization of microbial inocula control HMs accumulation in vegetables. It is further suggested that more lab-scale and field studies are required to understand different mechanisms occurring on molecular levels that affect the nutritional components of vegetables produced from HMs contaminated soils.

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