agriculture

MDPI

Review

Agricultural Strategies to Reduce Cadmium Accumulation in Crops for Food Safety

Samavia Mubeen [1,2,†], Wenjuan Ni [1,†], Chuntao He [1,3,*] and Zhongyi Yang [1,*]

1 School of Life Science, Sun Yat-sen University, No. 135, Xingang Road, Haizhu District, Guangzhou 510275, China
2 Guangxi Key Laboratory of Agro-Environment and Agric-Products Safety, Key Laboratory of Plant Genetics and Breeding, College of Agriculture, Guangxi University, Nanning 530004, China
3 School of Agriculture, Shenzhen Campus of Sun Yat-sen University, No. 66, Gongchang Road, Guangming District, Shenzhen 518107, China
* Correspondence: hecht3@mail.sysu.edu.cn (C.H.); adsyzy@mail.sysu.edu.cn (Z.Y.)
† These authors contributed equally to this work.

Abstract: Cadmium (Cd) contamination in edible agricultural products, especially in crops, has raised worldwide concerns regarding food safety consumption. This review summarizes the current knowledge of the applicable methods and perspectives for reducing Cd contamination of agricultural products. Agricultural approaches of soil amendments, irrigation management, microbial agent, and cropping patterns were systematically concluded to illustrate the developments and achievements in crop contamination management. The use of traditional soil amendments as well as novel nano-materials has contributed to producing safe crops in agricultural soil contaminated with Cd. This review provides an inspiring and promising tool for maintaining food safety by reducing Cd accumulation in edible agricultural products.

Keywords: cadmium; crop; food safety; agriculture strategy; bioremediation; nanotechnology

Citation: Mubeen, S.; Ni, W.; He, C.; Yang, Z. Agricultural Strategies to Reduce Cadmium Accumulation in Crops for Food Safety. *Agriculture* **2023**, *13*, 471. https://doi.org/10.3390/agriculture13020471

Academic Editor: Mercè Llugany

Received: 13 November 2022
Revised: 29 January 2023
Accepted: 13 February 2023
Published: 16 February 2023

1. Introduction

Cadmium (Cd) is a non-essential heavy metal widely detected in soil [1,2]. The main sources of Cd contamination in agricultural soil mainly include industrial sources, such as the steel industry, waste incineration, agricultural sources of phosphate fertilizers, pesticides, and sewage sludge applications [3–6]. The continuous use of Cd-contaminated agriculture soil has resulted in Cd pollution in cereal crops, fruits, vegetables, and other dietary crops in recent years [7–9]. Cd exposure through the daily dietary intake of Cd-contaminated agricultural products has been explored in numerous studies [6,10–12]. The most well-known toxicity of the prolonged dietary intake of Cd through rice is itai–itai disease in Japan [13]. The other toxic effects of long-term Cd exposure include kidney failure, reproductive organs impairment, immune system damage, cardiovascular diseases, and prostate, ovarian, and renal carcinogenicity in humans [6,14–16].

Cd accumulations differ greatly among crop species, e.g., between 0.002 and 0.41 mg kg^{-1} DW for wheat in the USA, Netherlands, UK, and Canada [17–20], between 0.012 and 0.64 mg kg^{-1} DW for barley grain in the Netherlands [19], and between 0.04 and 8.2 mg kg^{-1} for rice in Thailand and China [21,22]. Apart from cereal grains, Cd concentrations ranging from 0.08 to 0.28 mg kg^{-1} DW for legumes, from 0.07 to 0.27 mg kg^{-1} for grasses, from 0.001 to 0.054 mg kg^{-1} for nuts, from 1.20 to 1.54 mg kg^{-1} for root vegetables, from 0.94 to 4.13 mg kg^{-1} for leafy vegetables, and from 0.14 to 0.34 mg kg^{-1} for fruits were found in different regions around the world [23–27], some of which have exceeded the Cd limitation suggested by the Food and Agricultural Organization of the United Nations (FAO) (0.02 mg kg^{-1} g DW) [28,29]. Therefore, it is critical to develop applicable methods to reduce cadmium accumulation in edible agricultural products to maintain food safety.

Physical, chemical, and biological solutions were put forward to minimize the potential health risks of Cd pollutants in agricultural products from the Cd-contaminated soil [30,31]. Nevertheless, traditional physical and chemical strategies were difficult to widely promote in agricultural land due to their high costs, high energy consumption, long-term fallow, and potential secondary pollution [32,33]; these agricultural methods in Cd minimization provide promising solutions to maintain crop safety against Cd contamination. This review systematically summarizes the approaches employed in alleviating Cd pollution in edible agricultural products, which provide an effective path for food safety against Cd contamination.

2. Soil Amendment to Reduce Cd Bioavailability

Remediation approaches involving Cd immobilization in the soil have been widely conducted to alleviate the Cd uptake of food crops. A variety of nontoxic mineral amendments are supplied into soils (Table 1) to reduce the soil's Cd mobility and bioavailability through adsorption, precipitation, and complexation mechanisms in soil.

Table 1. Effects of mineral nutrient amendments to reduce Cd immigration from soil to crops.

Amendment Type	Applied Concentration (mg kg^{-1})	Cd Treatment (mg kg^{-1})	Plant	Soil Type	Results/Observation	References
Phosphorous Fertilizer	50, 200, 1000	82	Rice	Sandy loam	Increased soil pH and converted Cd to a less mobile form.	[34]
Diammonium phosphate (DAP)	230	0.19	-	silt loam	Acted as a stabilizing agent to reduce Cd uptake.	[35]
Phosphate Rock (PR)	2500	0.6, 1.5	*Brassica campestris*	Red soil	Immobilized Cd via formation or co-precipitation of insoluble metal phosphates in the soils.	[36,37]
Super Phosphate (SP)	5000	0.20, 0.15, 0.02, 0.04, 0.06	Wheat	Surface agriculture soil	SP efficiently immobilized the soil Cd but caused potential soil acidification risk.	[38]
Phosphate Rock (PR) + Mud compost (CP)	10,000, 20,000 +20,000	0, 10, 30	Maize	Sandy loam	The combined application of PR + CP improved the growth of maize and reduced soil Cd bioavailability.	[39]
Diammonium Phosphate (DAP)	60, 920, 2300	1090	-	Sandy loam	Application of 2300 mg kg^{-1} was the most effective for immobilizing Cd, Pb, and Zn from the contaminated soil.	[40]
Zinc (Zn)	0, 100, 200	0, 1.5, 3	Chamomile	Mixture of sandy + humus garden soil	The addition of Zn to the soils led to a suppressed Cd accumulation into the above-ground plant parts.	[41]
$ZnS0_4$	0, 80.7, 322	104	*Thlaspi caerulescens*	-	Cd competed with Zn uptake while Zn did not compete with Cd uptake.	[42]
Zinc Sulfate ($ZnSO_4{\cdot}7H_2O$)	60	0, 1, 2, 5	Chickpeas, mung beans, wheat, and maize	Sandy loam	Soil-applied Zn antagonized Cd to cope with its toxicity, thus favoring plant growth.	[43]
Zinc Oxide Nanoparticles (ZnO NPs)	0, 25, 50,75, 100	7.38	Wheat	Sandy loam	The Cd concentrations were reduced in the grains (16–78%) with the soil application of ZnO NPs as compared to the control.	[44]
Zinc (Zn)	0, 2, 10, 100, 1000	0, 15, 30, 50	Wheat	Loamy	Zn application decreased Cd concentration in plants.	[45]
Zinc (Zn)	0, 2.5, 10	0, 5	Wheat	Clay loam	Zn treatment alleviated Cd toxicity by decreasing Cd concentrations in wheat.	[46]
Calcium polypeptide	0, 210, 420, 840, 1260, 1680	2.0, 5.0	*Brassica campestris*	Red loam	Competitive inhibition effect of calcium on Cd enrichment in plants.	[47]
Calcium dichloride ($CaCl_2$)	200.4	200, 300	*Brassica juncea*	Peat, Perlite and Sand (1:1:1, *v*/*v*/*v*)	Decreased Cd content and Improved growth and biomass yield of *Brassica* plants.	[48]
$Ca(OH)_2$	5.62–23.1	0–10	*Brassica juncea*	Egmont and Tokomaru soil	Transformed Cd to fewer mobile fractions and reduced phytoavailability.	[49]
Hydroxyapatite (HAP) + *Cupriavidus* sp. strain ZSK	30,000 + 108 cells/g	13.82	Ramie, Dandelion, Daisy	Smelter soil	Combined application of HAP+ *Cupriavidus* sp. reduced Cd accumulation in ramie, dandelion, and daisy by 44.9%, 51.0%, and 38.7%, respectively.	[50]
Calcium Silicate (Ca_2O_4Si)	0, 410, 830, 1650, 3310	6.1	Amaranths	-	Free Cd ions convert into inactive Cd forms by Ca amendment in soil and are sequestered in subcellular compartments.	[51]

Table 1. *Cont.*

Amendment Type	Applied Concentration (mg kg^{-1})	Cd Treatment (mg kg^{-1})	Plant	Soil Type	Results/Observation	References
Potassium Silicate (K_2SiO_3)	8	0, 10, 50, 100	*Pennis etumglaucum* and *Pennisetum glaucum*	peat soil and sand	Significantly increased plant biomass and Si content, reduced Cd content, and decreased the enrichment factor in shoots and roots.	[52]
Sodium Metasilicate (Na_2SiO_3)	400	20, 40	Maize	Weathered acidic soil	Si significantly increased soil pH and decreased soil Cd availability.	[53]
Calcium Silicate ($CaSiO_3$)	50, 100, 150	10	Wheat	Surface soil	Si application caused a decrease in the Cd contents of shoots and grains and the translocation from roots to shoots and grains.	[54]
Hydrous manganese oxides (HMO)	1000	18	Ryegrass, tobacco, and bean	Limed silty soil	The amendment application did not increase biomass production, but treatment with HMO markedly decreased the mobility of Cd, Zn, and Pb.	[55]
Zero-valent iron (Fe(0))	0, 500, 1000, 5000	10	Rice	-	The Fe(0) application increased the less available Cd content, and decreased the exchangeable and Fe-Mn-oxide-bound (more available) Cd content.	[56]
Iron oxide (Fe_2O_3)	50,000	0.5, 1.5, 3.0, 4.0, 8.5	Maize, Barley	Silt loam.	Fe_2O_3 appears to be effective in response to plant yield, metal content in plant tissues, and bioavailable Cd.	[57]
gypsum	0, 2000, 4000, 8000	3.02	Wheat	Sandy clay loam	Increased pH and reduces the availability of Cd due to increased Cd precipitation and surface adsorption on the amendment.	[58]
$CaCO_3$ and CaO	0, 10,000, 30,000, 50,000	15.27		Loam	Increased soil pH; formation of Cd-carbonate, phosphate, or hydroxide.	[59]
Monoammonium phosphate (MAP) and gypsum	0, 2000, 4000, 8000	3.15	Rice	Sandy clay loam	MAP and gypsum increase grain yield and biomass of rice, whereas, decreased gain and straw Cd concentrations and uptake in rice.	[60]
Lime + peat	0, 500, 1250	15.44		Mixed clay	Liming reduced Cd available fraction in soil.	[61]
Eggshell	50,000	0.24		Alkaline soil	Decreased mobility of Pb, Cd, and Zn in the soil by transforming their readily available forms to less accessible fractions.	[62]
Sodium nitroprusside	100 um/L	150 um/L	*Lycopersicon esculentum*	Mixture of sand, perlite, and peat	Improve resistance mechanism by modulation of antioxidative defense system. NO boosts mineral uptake and reduced Cd accumulation.	[63]

2.1. Inorganic Amendments

2.1.1. Phosphorous (P)

Phosphorous-containing materials turned out to be a double-edged sword for controlling Cd in soil. Phosphate compounds reduced the Cd bioavailability in soils through various mechanisms, i.e., direct Cd adsorption by phosphate chemicals, adsorption by P-induced negative charge of soil particles, and Cd precipitation by forming metal phosphates, such as $Cd(H_2PO_4)_2$ and $Cd_3(PO_4)_2$ [64–66]. He, et al. [67] showed that the nano-hydroxyapatite (nHA) application significantly reduced water-soluble (90%), bioaccessible (16.77–34.66%), and phytoavailable (64.6%) Cd through metal adsorption on the surface of nHA and precipitation of Cd-containing phosphates. The extremely high P addition (16,000 mg kg^{-1}) in Cd-contaminated soil might be involved in Cd precipitation ($Cd_3(PO_4)_2$), whereas the low recommended field application of P fertilizer might not precipitate Cd as ($Cd_3(PO_4)_2$ and $CdCO_3$), suggesting the Cd immobilization by adsorption instead of precipitation [68]. Furthermore, P treatments also increased electro-negative ions, such as HPO_4^{2-} and $H_2PO_4^{-1}$, which could absorb Cd onto the cell wall component and further reduce Cd translocation in maize by adsorption, complexation, and precipitation [69]. The superphosphate (SP) application in Cd-contaminated soil is responsible for the inhibition of Cd translocation from the root to the shoot and the decrement of the Cd content in wheat grain through Cd-P complexes and cell wall components [70].

Some phosphate compounds increase Cd solubility through decreasing soil pH. Phosphate fertilizers (1% *w*/*w*) of triple superphosphate (TSP) and phosphate rock (PR) applications in contaminated soil increased Cd uptake by sorghum plants owing to the declined soil pH [71]. High Cd concentrations in TSP and PR fertilizers also liberated soluble forms of Cd, consequently increasing the Cd uptake of the plant. The dissolution of precipitated and absorbed Cd in rhizosphere soil might account for the high Cd concentration in the root and increase the uptake of Cd in the plant roots [72]. Therefore, the application of phosphate amendments and dosages to remediate Cd-contaminated soil must be carefully composed according to the soil's physicochemical properties.

2.1.2. Zinc (Zn)

Zn is an essential microelement for numerous vital enzymes in plants. Zn affected plant Cd uptake by competing for binding sites on the soil and root surfaces [73]. Cd could enter root cells through Zn-specific ZIP (Zn/iron-regulated transporter-like protein) transporters and redistribute within plants by Zn transporters [74]. Transporters from IRT1, HMA2, HMA3, ZIP, and NRAMP family also participate in the uptake and translocation of Zn, Cd, and other ions in plants [75,76]. The influences of Zn on Cd accumulation in plants can either be antagonistic [42,43] or synergistic [77]. Zn activity from $10^{-7.6}$ to $10^{-5.2}$ M could decrease the Cd concentration of the root and shoot from 0.20 to 0.03 mg kg^{-1} DW [78]. Soil-applied Zn through irrigation water reduced Cd accumulation in plant tissues in legumes and cereal crops [43]. Zn could alleviate the Cd uptake in different crop species of wheat [79–81], rice [82,83], barley [84,85], maize [86,87], mustard [88], lettuce, spinach [89], sunflower [90], and tomato [91]. In contrast, several studies reported the synergistic effect between metal absorption and accumulation in plants [92,93]. Increased Cd and Zn concentration in tomatoes induces the accumulation of oxidative stress, suggesting synergistic effects on the growth parameters and oxidative stress [91]. Zn amendments may not always be effective in the reduced Cd uptake in plants. Grant, et al. [94] showed that Zn deficiency in soil had mild effects on wheat grain Cd concentrations. Free Zn^{2+} with sub-phytotoxic levels ($10^{-7.6}$ to $10^{-6.1}$) cannot inhibit Cd accumulation by rice [95].

The Zn application could decrease Cd uptake, translocation, and accumulation by regulating Cd transporter genes. For example, Zhou, et al. [96] reported that foliar Zn applications reduced root Cd translocation to shoots by downregulating leaf TaHMA2 expression, whereas soil Zn applications reduced root Cd concentrations by downregulating root TaLCT1 expression. Zn applications in soil (99 $kgha^{-1}$ $ZnSO_4 \cdot 7H_2O$) and foliar (0.36 $kgha^{-1}$ $ZnSO_4 \cdot 7H_2O$) can effectively reduce Cd in grains. The time-dependent application of Zn fertilizer could also decrease Cd uptake and accumulation in plants [97,98]. Lime application at the basal stage along with Zn application at the tillering stage caused a 73% decrement in Cd phytoavailability and reduced the Cd uptake and accumulation in brown rice [99]. Moreover, reducing the Cd: Zn ratio via Zn fertilizer application in areas with high Cd contamination would be a useful approach to decrease the Cd uptake and accumulation in the foliar parts of plants [100]. A lower Cd: Zn ratio by increasing the Zn concentration significantly reduced the root symplastic accumulation of Cd and decreased Cd xylem loading and transportation, with lowering Cd accumulation in leaves of lettuce [101]. Low Cd uptake and accumulation were observed in legumes, fruits, tubers, and grains when the Cd: Zn ratio in soil was 1:100 [102].

2.1.3. Calcium (Ca)

Ca is also a divalent ion with similar physical and chemical properties to Cd. Generally, Ca is a competitor of Cd adsorption sites on soil surfaces and root plasma membrane transporters [6]. Several Ca plasma membrane transporters/ion channels, such as hyperpolarization-activated calcium channels (HACCs), depolarization-activated calcium channels (DACCs), and voltage-insensitive cation channels (VICCs) are involved in Cd transportation into the root cell in the forms of ions and metal chelates [103]. In addition, the application of Ca to the rhizosphere has been shown to increase the membrane potential of the root epidermal cell to reduce the uptake of Cd by plant roots [104]. Therefore, the exogenous application of Ca supplements in Cd-contaminated soil can reduce the amount of bioavailable Cd in plants [104–106]. It has been noted that Ca reduces the apoplast Cd concentration but not the symplast Cd concentration in the roots of *Picea abies*, which might be ascribed to the Ca and Cd competition of cell wall-binding sites [107]. It was reported that the competition between Cd and Ca ions for influx transporters into the roots of rice plants blocked Cd absorption into rice roots, suggesting the protective effect of Ca on Cd toxicity [108]. A decrease in the root Cd concentration of *Brassica juncea* was observed under a Ca + Cd combination rather than Cd alone [109]. The Ca polypeptide not only promoted the plant growth of the *Brassica campestris* but also showed competitive inhibition of Cd uptake in plants [47].

The application of Ca (through lime, gypsum) increased the Cd bioavailability in soils by exchanging Cd with Ca at exchange sites and releasing free Cd in the soil solution, which was subjected to plant absorption. The effect of Ca supplements on soil bioavailable Cd is dose-dependent. Although a similar significant decrease in Cd accumulation in *Boehmeria nivea* was observed under 5 mM Ca treatment, a contrasting significant increase in Cd uptake and accumulation was unraveled under 1 mM Ca treatment [110], supporting the dose-dependent effect of Ca on Cd uptake in plants. The repression of Cd accumulation by Ca supplements was significant at 2–3 mM; suppression reached its peak when the Ca concentration was at 5 mM [47]. Similar reductions in Cd absorption and accumulation in the wheat and soybean roots were observed at Ca concentrations of 1 mM and 10 mM [111].

2.1.4. Silicon (Si)

Si is a non-essential but beneficial element for plant growth, especially for plants grown under heavy metals, such as Cd, in a stressed environment [112,113]. Si application in soil decreases water-soluble Cd and reduces Cd availability to plants via increasing pH to fulfill Cd immobilization. The supplement of 400 mg kg^{-1} Si against 20 or 40 mg kg^{-1} Cd treatments increased the soil pH significantly and decreased the soil Cd availability by 92% and 98%, respectively [53]. However, few studies have suggested that the effects of Si on Cd reduction mainly rely on metal speciation in the soil rather than soil pH elevation. For example, the calcium silicate treatment in Cd-contaminated soil reduced the Cd concentration in the maize shoot without increasing soil pH. Si is a structural component of the cell wall [114], and the deposition of Si in the surrounding root endodermis partly blocks the apoplast flow and restrains the apoplastic Cd transport [115,116]. The application of Si alone or in combination with selenium (Se) noticeably reduced the Cd concentration by increasing Cd adsorption on the cell wall and restrained the Cd translocation from root to shoot, which lowered the Cd concentration in the shoot of Chinese cabbage [112]. Si application stimulated the development of suberin lamellae, Casparian bands, and root vascular tissues, which led to a considerable decrease in the symplastic Cd concentration of maize shoots [117,118].

To explore the cellular fluxes of the Cd, the rice suspension cell and root cell were exposed to Cd and Si treatments. Researchers discovered that in a wall-bound organosilicon compound, the majority of Si accumulated in the cell walls. When compared to protoplasts from Si-limiting (−Si) cells, total cadmium (Cd) concentrations in protoplasts from Si-accumulating (+Si) cells were significantly lower at moderate concentrations of Cd in the culture medium. It was found that the hemicellulose-bound form of Si with a negative charge is responsible for reducing Cd accumulation in rice cells via the mechanism of the (Si hemicellulose matrix) Cd complexation and co-deposition [119,120]. Furthermore, the exogenous application of Si suppressed the Cd uptake and accumulation in plants via the Si-induced antioxidative mechanism and improved plant growth and photosynthetic characteristics by lowering the reactive oxygen species (ROS) damage [121]. The Si-mediated alleviation of Cd accumulation is also attributed to its role in altering gene expression. Cd uptake and accumulation are related to the downregulation of the Cd transporter (*OsNRAMP5* and *OsHMA2*) by silicon treatment and are associated with the phytochelatin-driven vacuolar Cd compartmentation in rice roots [122]. Downregulation of *LCT1*, *HMA2*, and *NRAMP5* proteins and upregulation of *PCS1* and *IRT1* proteins are also responsible for Cd uptake reduction in wheat and rice after Si addition [123,124].

2.1.5. Liming Materials

Liming material in soil has been used to decrease plant Cd uptake by elevating soil pH [125]. Liming material, including calcium carbonate ($CaCO_3$), calcium hydroxide ($Ca(OH)_2$), calcium oxide (CaO) dolomite [$CaMg(CO_3)_2$], and slag ($CaSiO_3$) [126,127] could effectively relieve soil acidification and decrease Cd availability in soil, varying in their acid-neutralizing capacity. Cd concentration in rice grains [128], lettuce [129], peas [130], radish [131], potato tubers, oat straw, and ryegrass [132] were decreased along with the increased soil pH by liming material. Application of liming materials in contaminated soil can significantly increase soil pH due to the release of hydroxyl ions after hydrolysis of calcium carbonate. Rising pH due to liming leads Cd^{2+} to form $Cd(OH)^{+}$, exerting a strong affinity to soil adsorption sites compared with Cd^{2+} [133,134]. Moreover, liming promotes Cd precipitation in the form of carbonates, phosphates, hydroxides, and oxides at higher soil pH and decreases the mobility of available Cd in contaminated soil [135,136]. However, liming is not always effective at reducing Cd uptake in plants [137]. Few effects of liming have been observed in the Cd uptake of plants. Therefore, the effectiveness of liming on Cd uptake reduction could vary depending on the type of liming amendment, soil, metal, and crop species. Understanding the causes that affect liming effectiveness in the soil is necessary for its application in controlling Cd contamination in soil.

2.1.6. Nitrogen

Nitrogen (N) mineral is present in low quantity in heavy metal-contaminated soils. The low N content in the soil might be ascribed to the lowered nitrogen metabolism associated with Cd stress. N fertilizers are usually applied in the soil as ammonium (NH_4^+), nitrate (NO_3^-), or urea to promote plant growth and pollutant phytoextraction in contaminated soils [138,139]. N supplementations increase Cd tolerance in plants by enhancing photosynthesis. Panković, et al. [140] found that N amendment in soil increased the photosynthesis capability of sunflowers by increasing ribulose 1,5-bisphosphate carboxylase (Rubisco) activity and soluble protein content. The addition of the basic mineral (N, P, K, and Fe) fertilizers in soil could alleviate the inhibitory effects of Cd, Pb, Ni, and Hg in plants [141]. The alleviation of Cd toxicity by N fertilizer application also depends on the N source. There is a substantial difference among N forms on Cd and N uptake. The application of $(NH_4)_2SO_4$ in soil reduced Cd and increased N uptake in rice leaves as compared to $Ca(NO_3)_2$ and NH_4NO_3 application, suggesting a partial antagonistic effect between NH_4^+ -N and Cd and a synergistic effect between NO_3^- -N and Cd [142]. NO_3 supplementation might increase organic acid production and promote Cd translocation via xylem through organic acid complex forms [142]. Several other studies also revealed that N fertilizer in the form of NH_4^+ in soil increased Cd uptake via rhizospheric acidification and root cell proton excretion in sunflower and *S. nigrum* plants [138,143]. Moreover, Xie, et al. [144] found that supplementation with NO_3^- promotes Cd and Zn phytoextraction by *Noccaea* (*Thlaspi*) *caerulescens.* Increased biomass production by enhancing photosynthesis activity under N fertilizer application could be another reason for N-induced alleviation of Cd toxicity. N fertilizer application alleviated Cd toxicity in *Sedum* by promoting chlorophyll synthesis and antioxidant enzymes of SOD, catalase, and peroxidase [145]. Moreover, plant response to N supply varied with genotypes under Cd stress [146], in which Milyang 46 accumulated more Cd than Zhenshan 97B in the presence of N application.

2.1.7. Potassium (K)

Potassium (K) minerals minimize ROS formation during photosynthesis and inhibit oxygen radical-generating NADPH oxidase activation in plants under stress conditions. Umar, et al. [147] found that optimal K supply decreased the inhibitory effect of Cd in mustard plants by enhancing antioxidative enzyme activities and reducing H_2O_2 content and lipid peroxidation. A similar Cd reduction was observed in rice seedlings due to increased antioxidative enzyme activities by exogenously applied K minerals [148]. Similar to N, the Cd toxicity alleviation effects of K application varied among K formations. Zhao, et al. [149] have shown differential effects of K forms on Cd accumulation, among which KCl and K_2SO_4-fed plants had high Cd uptake compared to KNO_3. The 0 to 55 mg kg^{-1} addition of K minerals in soil resulted in a 60–90% reduction in Cd concentration in KCl and K_2SO_4-fed plants, while KNO_3 application mainly functioned in maintaining the dry mass of plant roots and shoots. In conclusion, the reduced Cd toxicity with efficient growth and yield can be attained by selecting suitable forms of N and K, and the proper genotype.

2.1.8. Iron/Manganese (Fe/Mn)

Fe and Mn metal oxides are natural soil components. Small particle sizes, highly reactive surface areas, and low solubility under average soil pH are important characteristics that make Fe and Mn oxides suitable for the immobilization and adsorption of diverse soil pollutants [150,151]. Co-precipitation, formation of inner-surface complexes, and specific sorption are the ubiquitous mechanisms for the immobilization of soil pollutants through metal oxides [66,151]. The oxidation and reduction reactions of Fe oxides in the plant rhizosphere affect the soil Cd bioavailability [152]. Fe oxides present intense capabilities for Cd adsorption and immobilization in soil [153]. The application of zero-valent Fe(0) in Cd-contaminated soil significantly reduces bioavailable Cd in rice plants without toxic effects on plant growth [56]. The release of O_2 oxidant in the soil, and Fe^{2+} to Fe^{3+} oxidation with iron oxide or hydroxide on the root surface area are the common mechanisms for Fe plaque formation on the root surface. Fe plaque could absorb and sequester Cd ions onto root surfaces and prevent Cd uptake by rice plants [154]. Different types of Fe fertilizers and application methods have exerted different effects on Cd uptake and accumulation in plants. The soil application of EDTA–Na_2Fe fertilizer significantly decreased Cd concentration in the roots, shoots, and grains of rice, whereas, increased Cd concentrations in the roots and shoots were observed under foliar application of $FeSO_4$ and EDTA–Na_2Fe fertilizers [155].

Mn oxides were effective sorbents for Cd, Pb, Co, Zn, and Cu [66,156]. Scientific literature dealing with Mn oxides as immobilizing components in contaminated soil is insufficient. A hydrous Mn oxide was applied in contaminated soil and successfully stabilized Cd, Pd, and Zn. Birnessite, todorokite, cryptomelane, manganite, and pyrolusite are commonly occurring Mn oxides in the soil environment [157,158]. The metal adsorption through Mn oxides in the form of hydroxylation cations was responsible for the highest adsorption capacity of metals by birnessite [156]. In addition, an antagonistic relationship between Cd and Mn relied on a competitive mechanism for the same membrane transporter between Cd and Mn [159].

2.2. Organic Amendments

2.2.1. Biochar

Biochar is a soil amendment obtained from the thermal composition of organic materials under oxygen-limited conditions. Due to its physiochemical properties, including porous structure, large particle size, high pH, cation exchange capacity (CEC), high carbon content, and active functional groups [160], biochar amendments not only reduce the bioavailability of heavy metals, such as Cd in soil, but also decrease plant heavy metal uptake through precipitation, complexion, and cation exchange (Table 2) [161–163]. However, the Cd immobilization by biochar largely depends on the soil condition and type of biochar used [161,164,165]. Wang, et al. [166] reported an over 63% reduction in Cd bioavailability after applying three different Fe-derived biochars (rice, wheat, and corn straw) in Cd-As co-contaminated soil. Yang, et al. [167] found 25.35–61.90%, 46.97–72.90%, and 24.17–48.87% reduction of Cd in yellow soil, purple soil, and paddy soil after applying 1%, 3%, and 5% swine biochar produced at 450 °C. Ion exchange, complexation, π bond action, and precipitation on the surface of the biochar were the dominant mechanisms of metal immobilization. Wheat straw biochar pyrolyzed at 550 °C achieved 70.9, 64.8, and 60.9% reduction in Cd bioavailability during a three-year field experiment. Cd immobilization by sorption on clay minerals and precipitate with carbonates might rely on the reduction of soil pH. Furthermore, mineral–organic layers formed on surfaces of biochar were thickened with increasing immobilized Cd over time, [168].

Ahmad, et al. [169] showed that litter-derived biochar produced at a low temperature (<500 °C) is more efficient at immobilizing heavy metals in soils. Accordingly, the immobilization of heavy metal is mainly attributed to the physiochemical properties of biochar, particularly the functional groups and surface area. The O-functional group on the biochar surface is more efficient for metal binding to immobilize organic and inorganic pollutants from soil [169,170]. Cottonseed hull-derived biochar pyrolyzed at a lower temperature (350 °C) contains high O-containing functional groups, resulting in the reduced bioavailability of Cu, Ni, Cd, and Pb in soil [170]. Moreover, in multiple studies, biochar was crushed to a lower particle size and increased the surface area and adsorption capacity [171]. Fahmi, et al. [172] revealed that empty fruit bunch biochar (EFBB) produced at 250 °C with a particle size less than 50 mm exerted higher Cd and Pb adsorption capacities than the biochar with a larger particle size, which was due to the inner pore exposure areas and functional groups. Despite these benefits, the cost and efficiency of biochar are critical issues for its better practice.

Table 2. List of organic amendments and their effectiveness for Cd immobilization.

Amendment	Pyrolysis Temperature	Doses Applied	Cd Treatment mg kg^{-1}	Plant Species	Effects/Results	References
Biochar						
Rice hull	500 °C	0, 0.5, 1, 2, 5, 10%	Cd, Cu, Pb, Zn	Lettuce	No significant increase in yield, a decrease in the bioavailability of heavy metals in soil.	[173]
Rice straw	500 °C	0, 10, 20 ton/ha	3.3, 5.9	Lettuce	Exchangeable Cd decreased due to increased soil pH	[174]
Rice husk + nano-Fe_3O_4 particles coating	400 °C	0.05, 0.1, 0.2, 0.4, 0.8, 1.6%	1.6	Rice	BC-Fe treatments promoted iron plaque formation and increased soil CEC and reduced Cd availability by 6.81–25.0%.	[175]
Rice straw	450 °C and 550 °C	0, 3.0, 5.0%	2.86	Wheat	Increased soil pH, 35, 47, and 57% decrease in roots, shoots, and grains Cd content.	[161]
Wheat straw	485 °C	0, 20, 40 ton/ha	0.9	Rice	Increased soil pH and reduced $CaCl_2$-extractable Cd in soil and grain Cd concentration. The effect decreased over time.	[61]
Wheat straw	450 °C	0.7–2.9%	22.65	Rice	Metal ions Precipitate with CO and/or PO_4 Binding of Cd and Pb to the inner biochar particles, with 8.0–44.6% reduction in exchangeable Cd.	[176]
Willow chips	450 °C and 600 °C	0, 0.2, 1.0, 5%	0, 1, 5	Pepper	Low-temperature biochar was more efficient in immobilizing Cd in soil and higher biochar application decreased the Cd in roots.	[177]
Willow biomass + Zeolite	350 °C and 500 °C	0.50%	2.5	Tall fescue and cocksfoot	Higher biomass production was observed in the tested grasses.	[178]
Sugarcane straw	700 °C	0, 1.5, 3.0, 5.0%	8.4	Jack bean, Mucuna aterrima	Metal bioavailability in the soil and plant uptake by roots was reduced.	[179]
Olive mill waste	450 °C	0, 5, 10, 15%	7.1	Common bean	Increase in shoot length and dry weights of leaves and roots was observed. Cd in leaves was below the detection limit at the highest rate of biochar applied.	[180]
Pigeon pea stalk	300 °C	0, 0.25, 0.5%	0, 5, 10	Spinach	Increased soil pH and organic matter contents, DTPA extractable Cd was decreased in the soil and decreased Cd concentration in leaf and roots was observed.	[181]
Cotton sticks	450 °C	0, 3, 5%	0, 25, 50, 75, 100	Spinach	Decreased the shoot and root Cd concentration and increased the biomass and chlorophyll contents and gas exchange parameters.	[182]
Hickory nutshell and Maize straw		0, 15, 30 ton/ha	0.7, 2.04	Rice	Reduce Cd accumulation in rice grains by immobilizing soil Cd.	[183]

Table 2. *Cont.*

Amendment	Pyrolysis Temperature	Doses Applied	Cd Treatment mg kg^{-1}	Plant Species	Effects/Results	References
Bamboo chips	350 °C	1.00%	3, 20	Rice	Reduced Cd contents in rice plants in highly contaminated soil, supported metal-resistant and growth-promoting bacteria in the rhizosphere.	[184]
Coconut shell and GSA-4 (compositing organic manure with lime and sepiolite)		1%	0.83	Rice and Wheat	Cadmium fractionation showed a significant decrease in the extractable fractions.	[125]
peanut shell and wheat straw	300–350	5%	0.507	Rice	led to significantly higher pH, soil organic carbon (SOC), and cation exchange capacity (CEC) in paddy soil, while the content of $MgCl_2$-extractable Cd and Pb was lower	[185]
wheat chaff	750	0.5, 5%	0, 10, or 50	Juncus Subsecundus	pH increased and $CaCl_2$-extractable Cd decreased significantly. Biochar immobilized soil Cd but did notimprove the growth of the emergent wetland plant species atthe early growth stage	[186]
Sewage sludge, soybean straw, rice straw, and peanut shell		0, 2, 5%	0.81	Turnip	Fresh biomass was the highest with lower biochar (2%) compared to the control and higher biochar (5%) treatment. The highest reduction in metal uptake was recorded with peanut shell biochar.	[187]
Compost						
Agriculturalpostharvest wastecompost		6.25, 12.5%	25	Sorghum and barnyard grass	Compost decreased the solubility and mobilization of Cd (especially in dry soil).	[188]
Bamboo biochar, rice, and wheat straw	750 °C	2% biochar or 1% straw	2	Maize and ryegrass	Increase in soil pH and organic carbon. The Cd concentration in shoots of maize was reduced by 50.9%, 69.5%, and 66.9% with biochar, rice straw, and wheat straw, respectively.	[177]
composted sewage sludge and green waste compost		5, 10,15%	813	Ryegrass	Compost immobilized Cu and Cd in contaminated soils.	[189]
Manure						
chicken manure		0, 5.5, 11, 16.5, 22 ton/ha	0.41	Rice	Converted Cd to more immobilized fractions by decreasing the exchangeable Cd fraction and increasing the carbonate-, oxide-, and organic matter-bound fractions.	[190]
Farmyard manure		20–30 kg/ha	0.35	Wheat	The release of organic ligands immobilizes soil Zn and Cd	[191]
Pig manure		1.3, 4 g/kg	6.79	Rice	Increased the grain yield by 0.3–15.3 fold, and effectively decreased the Cu and Cd concentrations in grain.	[192]
Swine manure		30 g/kg	2.91	Sunflower	Swine manure and salicylic acid reduced the Cd/Zn ratio in the sunflower.	[193]

2.2.2. Compost

In compost, microorganisms and enzyme activities degrade and convert organic waste (animal/plant residue, sewage sludge, and municipal solid waste) into CO_2, H_2O, mineral ions, and humic substances through mesophilic, thermophilic, and maturation phases [194]. Compost, such as humic acid, mineral ions, and microorganisms substantially enhances the heavy metal immobilization in agriculture soils and reduces the ecological and environmental risks of heavy metals [195,196]. Compost from green waste (tree leaves, bark, garden grass, weeds, and mushrooms) are ideal soil amendments due to the high carbon and nitrogen levels and low heavy metal contents. Greenish weed compost reduces the Pb, Cd, and Cu uptake by 22, 55, and 20%, respectively, in contaminated paddy soil [197,198]. The hydroxyl and phenolic groups in humic compounds are the dominant ligands for heavy metals [199]. Milojković, et al. [200] demonstrated that the hydroxyl, carboxyl, carbonyl, and phenyl functional groups on the surfaces of compost derived from *Myriophyllum spicatum*, were active binding sites for heavy metal and immobilize Pb, Cu, Cd, Ni, and Zn in agriculture soil. The available Cd and Cu concentrations in clay loam soil were decreased from 0.057 to 0.005 and 2.20 to 1.90 mg kg^{-1}, respectively, after being treated with mushroom-derived compost [201]. Hanafi and Salwa [202] noted that Cd and Zn appeared primarily as exchangeable in compost-amended soils according to their cation exchange capacity. The application of compost derived from agriculture postharvest waste reduced the solubility and mobility of Cd (especially in dry soil) and Ni (in both soils) [188]. The application of plant-derived compost and biochar improves the compost's immobilization efficiency. Karer, et al. [203] showed that the application of garden green waste compost together with poplar woodchip biochar was capable of reducing the available Cd and Zn concentrations in soil.

2.2.3. Animal Waste/Manure

Animal waste, such as chicken manure/litter, cow manure, and pig manure are commonly used as fertilizers in agricultural soil due to their abundant nutrient content. Some animal waste was involved in the immobilization of heavy metals in soil and improving soil fertility [204]. The application of cow manure to contaminated soil at lower rates (<54 t ha^{-1}) has been shown to reduce Cd availability, while at higher rates (>108 t ha^{-1}), it enhanced Cd phytoavailability due to the formation of soluble metal–DOC complexes in soil [205]. Houben, et al. [206] observed that the chicken manure and bone meal compost application in Cd-contaminated soil reduced the leaching of Cd by 63.1% with cow manure and by 72.9% with bone meal. In addition, farmyard manure, pig manure, and cow manure reduced the Cd translocation and accumulation in rice by decreasing the exchangeable Cd fraction but increasing the carbonate-, oxide-, and organic matter-bound fractions [3,190,207,208]. These manures effectively reduce Cd bioavailability by increasing soil pH and decreasing and transforming Cd into more stable fractions. Moreover, the introduction of pathogens, antibiotics, and secondary pollutants is associated with animal manure–soil applications. Two solutions to overcome these issues are to (i) increase the biodegradation of contaminants in compost during the thermophilic phase and (ii) converse the manure into biochar with degrading organic and microbial contaminants and immobilize unnecessary elements in manure by pyrolyzing at higher temperatures (>700 °C) t. [66]. Hence, animal manure can be applied to contaminated soils as a source of nutrients for crop growth.

Nowadays, numerous inorganic and organic amendments are exhibiting effective soil Cd passivation stability in agricultural soil. However, their application is limited by several problems. The extra high costs and workloads have limited the application of soil amendments to lower soil Cd availability. The same Cd amendments exhibit divergent Cd passivation effects on soil with different physicochemical properties. The soil condition evaluation and cost calculation should be taken before the application of soil Cd amendments. Moreover, the application of soil amendments might bring long-term influences on soil conditions such as pH, porosity, and fertility, which would affect the production capacity of agricultural soil. Therefore, soil amendments combining soil Cd passivation and fertility improvement are promising for agricultural application.

3. Irrigation Management to Reduce Cd Uptake

Water management involves promising, controllable, and environmentally friendly approaches to reduce Cd bioavailability and uptake [209,210] by crops, such as rice, from soil [211]. Under flooding conditions, a lower redox potential (Eh) and higher pH were achieved to reduce Cd bioavailability in soil. At a lower Eh, soil Cd will bind with soil sulfur (S) to form the Cd-S complex to maintain low solubility. The flooding condition has reduced the soil Cd uptake in rice by forming an insoluble Cd compound with S [212]. Likewise, several studies on rice grown in paddy soil under different water regimes and growth stages suggest that low soil Eh and pH are involved in Cd uptake alleviation in rice [213–215].

Moreover, radial oxygen loss (ROL) from the root generates Fe plaque formation on root surfaces under flood irrigation treatment, which influences soil Eh and pH in the rhizosphere [216,217], and affects soil Cd bioavailability and translocation [218]. The anaerobic conditions associated with flood irrigation treatment enhance root porosity, and lead to high rates of ROL from water spinach [219] and rice roots [220], resulting in the alleviation of Cd accumulation in edible parts of these crops. Interestingly, these Cd alleviation effects were cultivar-dependent, i.e., the low Cd-accumulating rice cultivar shows higher levels of ROL and a higher Cd combination with Fe plaque than the high Cd accumulating cultivar under a flooded regime [217]. Moreover, the combined application of continuous flooding with soil amendments significantly reduced Cd bioavailability by changing the chemical forms of Cd in soil [221–223]. Lower Cd contents in rice grains were also documented by intermittent irrigation [214,224]. Furthermore, the plant stage at the time of irrigation is also a critical factor to reduce Cd uptake and accumulation. The flood irrigation before the heading stage significantly reduced Cd uptake into the rice [225]. Cd bioavailability could be restrained by continuous flooding at the full tillering stage and flood irrigation during the reproductive stage of rice is efficient at alleviating Cd concentration in rice plants [212,226]. In addition, the salt anion in irrigation water also influences the Cd content of the plants [94,227,228]. Khoshgoftar, et al. [229] reported that enhanced NaCl levels in irrigation water impacted the Cd uptake by plants through the chlorine–Cd ion complexation ($CdCl_n^{2-n}$) in soil solution. The lower Cd charge in the chlorine–Cd complexation decreases Cd sorption and enhances the Cd uptake of plants [230] either through the direct uptake of the Cd ion complex or through the diffusion of Cd into the root apoplast.

4. Effect of the Cropping Pattern on the Cd Contamination of Crop

Intercropping and crop rotations are traditional cropping systems that allow maximum use of light, heat, water, and soil resources to improve the quintessence of a conventional agriculture system. Significant contributions were also made to remediate the heavy metal-contaminated soils and safe crop production (Figure 1).

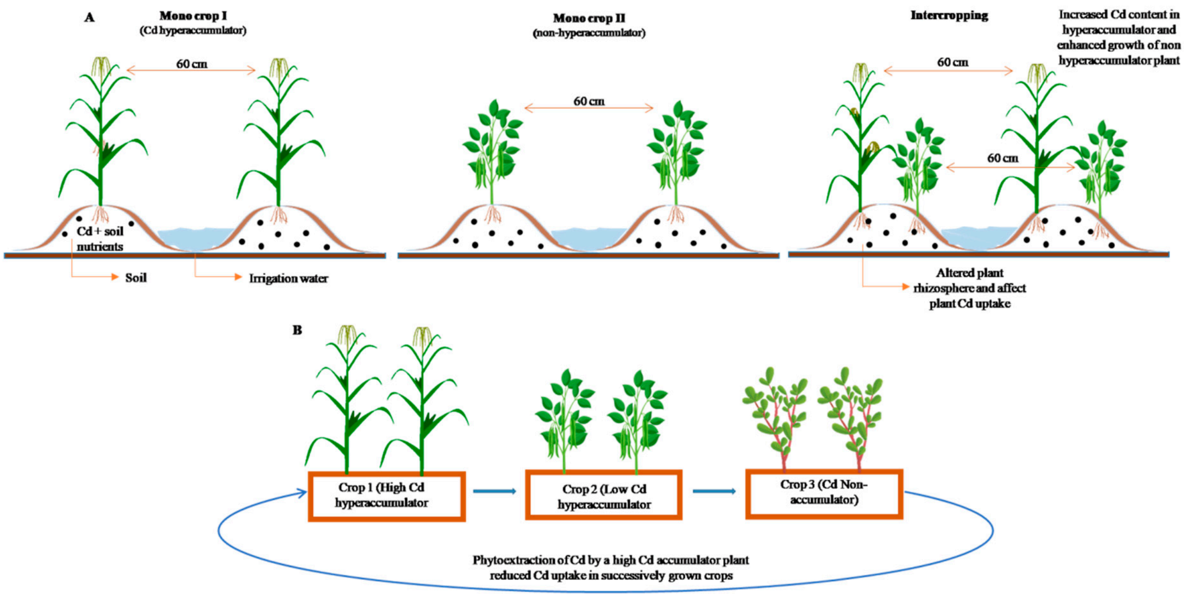

Figure 1. Schematic representation of (**A**) intercropping and (**B**) crop rotation to reduce Cd accumulation in crop plants.

4.1. Intercropping

Intercropping is a traditional agricultural system that has high nutrient bioavailability for plants, improves ecological functions, regulates the rhizospheric environment, and alters root-secreted organic acid composition and profiles. These characteristics contribute to the regulation of the Cd fraction in intercropped plants and a decrease in Cd uptake.

Intercropping with hyperaccumulators significantly increases heavy metal content in the hyperaccumulator and decreases metal concentrations in non-hyperaccumulator plants [231]. The root morphology and activity are changed under intercropping interactions [232]. The roots of metal hyperaccumulators are inclined to grow toward metal contamination while the crop root can decrease the heavy metal accumulation in soil. *Thlaspi caerulescens* is a strong hyperaccumulator of Zn and Cd, and its root morphology is apt for increasing heavy metal accumulation [233].

The intercropping between eggplant seedlings and two Cd hyperaccumulator *Solanum* species (*S. nigrum* and *Solanum photeinocarpum*) decrease Cd uptake and enhance antioxidant enzyme activities in the eggplant seedling through the inter-crop [234]. In addition, organic acid in the soil solution largely affects the adsorption and desorption of heavy metal ions through the soil pH; compared to the other organic acids, citric acid could increase Cd availability in the soil at a pH of 5–6 [235]. The much lower Cd content in a grape crop intercropped with different floricultural Cd accumulators (sunflower, sulfur cosmos, garden cosmos, and garden balsam) is partially ascribed to the higher soil pH, suggesting the release of organic acid and other root exudates from intercropped plants compared with grape monoculture [231]. Hei, et al. [236] also reported increased soil pH and solubility of organic compounds due to the intercropped maize by providing more soluble Zn and Cd for the hyperaccumulator *Sedum alfredii.* The influence of intercropping on the crop Cd uptake was dependent on the intercropped species. A higher foliar Cd concentration (5.05 mg kg^{-1}) was observed in maize intercropped with legumes compared to those intercropped with non-legumes (2.42 mg kg^{-1}) [237]. Similarly, higher Cd uptakes were also found in other crops intercropped with legumes [238,239].

4.2. Crop Rotation

Crop rotation is a promising approach used to improve soil fertility, crop yield, and tolerance to heavy metals [240]. In a crop rotation system, the phytoextraction of Cd by a high-Cd-accumulative rice cultivar significantly reduces the Cd content of successive soybean and rice grains in Cd-contaminated paddy soil [241,242]. Crop rotation with high Cd-accumulating oilseed rape (*Brassica campestris*) significantly decreases the Cd concentration in subsequent rice grains and Chinese cabbages [243,244]. Plant root excretion not only influences the soil pH but also influences the Cd availability in soil. Thus, the oilseed rape plant not only phytoextracts Cd from the soil by changing its environment but also influences the Cd contents of successive crops. When fast-growing, economically important oilseeds crops that are not used for food are grown in different rotation systems i.e., oilseed rape–sunflower, oilseed rape–peanut, and oilseed rape–sesame, the Cd removal efficiency is 458.6, 285.7, and 134.5 g ha^{-1}, respectively, from contaminated soil [240]. The Cd concentrations in the seed oils of all crops meet the Chinese standards ($\leqq$0.05 mg kg^{-1} DW), suggesting their usability for biodiesel and biofuel production [240].

The combined application of crop rotation with other amendments could increase the efficiency to reduce the bioavailable Cd in soil. Hyperaccumulator *Sedum alfredii* rotation with low Cd accumulators of water spinach and Chinese cabbage combined with denitrifying microbes, CO_2 fertilization, water management, and fermentation residue significantly increase the biomass and Cd uptake of *S. alfredii* and decrease Cd and nitrate concentrations in water spinach and Chinese cabbage [245]. The CO_2 fertilizer application is responsible for the increased root exudation and decreased soil pH [246], which increase the Cd bioavailability in the *S. alfredii* rhizosphere [247]. The cucumber–sweet potato–oilseed rape rotation in contaminated agriculture soil decreased the Cd and Pb concentrations of all three crops with increasing biochar doses in a 1-year field experiment [248]. The application of biochar with crop rotation changes the soil's physiochemical properties to reduce bioavailable Cd concentration by increasing the pH, CEC, and DOC of the soil. Similarly, several other studies on the combined use of crop rotation and fertilizer application have exhibited remarkable effects on heavy metal contamination management [249,250].

In conclusion, despite the immense potential of intercropping and crop rotation, several issues need to be addressed for wider applicability of intercropping and crop rotation to reduce Cd bioavailability in the soil. Identifying the Cd hyperaccumulator plant germplasm with higher biomass should be encouraged. Further, site-specific management practices need to be developed for sustainable and safe utilization/disposal of metal-contaminated biomass. Production of biomass-based energy (biodiesel and biofuel production) and utilization in small industries (paper, timber, and biomass bricks with impermeable coating) would lead to a promising economic return.

5. Effect of Microorganisms

Compared to conventional physicochemical remediations, the use of microorganisms in remediating heavy metal-contaminated soil is an eco-friendly and cost-effective strategy [251,252]. Bacteria and fungi are the ubiquitous microorganisms for soil heavy metal passivation (Table 3), whereas yeast and algae also exhibit the potential for metal passivation in contaminated soils [253]. Microorganisms do not degrade heavy metals but transform them into less harmful forms by changing their physical and chemical states [254]. Figure 2 depicts the mechanisms of Cd removal from soil by microbes.

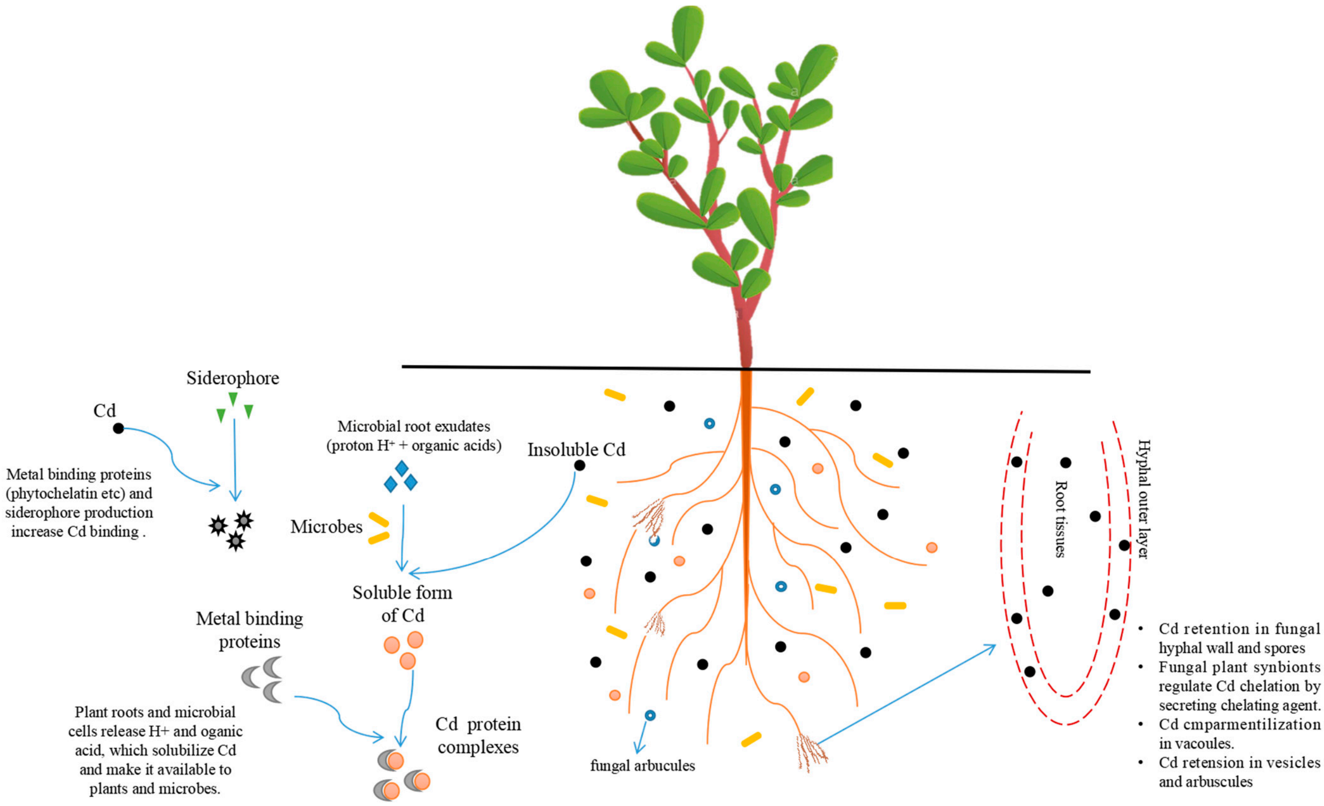

Figure 2. Mechanism of Cd removal from soil by soil microbes.

Table 3. Microorganisms (fungi and bacteria) and their mechanisms to alleviate Cd contamination in plants.

Group	Species	Type	Plant/Crop	Resistance Mechanism/References	References
Fungi	*Glomus versiforme*	AMF	*Solanum nigrum*	Enhancement of soil acid phosphate activity	[255]
	Aureobasidium pullulans	Endophytic fungi	*Cucumis sativus*	Regulate soil enzymatic activities to reduce Cd uptake	[256]
	Rhizophagus irregularis	AMF	*Lotus japonicus*	Enhanced intraradical immobilization of Cd	[257]
	Rhizophagus intraradices and Glomus versiforme	AMF	*Zea mays*	PC and GSH transformed Cd into the inactive form	[258]
	Funneliformis mosseae	Endo-mycorrhizal fungus	*Nicotiana tabacum*	Enhanced GSH content reduced Cd accumulation	[259]
	Funneliformis mosseae, *Glomus versiforme*, and Rhizophagus intraradices	AMF	*Brassica chinensis*	Altered plant–soil interaction by increased soil pH and electrical conductivity	[260]
	Penicillium janthinellum	Endophytic fungi	*Solanum lycopersicum*	Reduced electrolytes and lipid peroxidation and increased glutathione content and catalase activity	[261]
	Fusarium tricinctum and Alternaria alternata	Endophytic fungi	*Solanum nigrum*	Improve tolerance mechanism by low POD and PPO activities and high CAT activity	[262]
Bacteria	*Methylobacterium oryzae* and Burkholderia sp.	PGPB	*Lycopersicon esculentum*	Reduced stressed ethylene and ACC deaminase activity	[263]
	Ralstonia eutropha and Chryseobacterium humii	PGPR	*Zea mays*	Cd retention in roots by immobilization and reduced Cd translocation to shoots	[264]
	Pseudomonas putida	Acidophilic bacteria	*Vigna radiata*	Metallothioneins and ABC transporter/P-type ATPase, intracellular Cd bioaccumulation	[265]
	Rhodobacter sphaeroides	Purple non-sulfur bacteria	*Triticum aestivum*	Reduced the bioavailable Cd fractions (e.g., exchangeable and carbonate-bound phases)	[251]
	Bacillus megaterium and Neorhizobium huautlense	PGPB	*Oryza sativa*	Increased Cd immobilization in rhizosphere soil and reduced Cd uptake	[266]
	Pseudomonas aeruginosa and *Burkholderia gladioli*	PGPR	*Lycopersicon esculentum*	Improve resistance mechanism by modulation of antioxidative defense system	[267,268]
	Azotobacter sp.	Nitrogen-fixing bacteria	*Triticum aestivum*	Metal ion complexation either through f extracellular polymeric substance (EPS) or through cell wall lipopolysaccharides (LPS)	[269]

5.1. Bacteria

Bacterial populations account for 70–90% of the total microorganism amount in the soil. Several bacterial species are reported to be involved in reducing Cd bioavailability from contaminated soil [266,270,271]. The inoculation of the *Neorhizobium huautlense* strain T1–17 decreases the available Cd/Pb and restricts Cd uptake in the hot pepper plant by increasing the pH of rhizospheric soil [271]. Metal resistant-bacteria alleviates Cd accumulation in rice grains by reducing the available Cd in soil [272]. Likewise, *Pseudomonas aeruginosa* in the Cd-contaminated soil adsorbs more Cd and decreases the Cd content of rice grains compared to *Beauveria bassiana* and *Bacillus subtilis* [273].

Rhodobacter sphaeroides, a purple non-sulfur, Gram-negative bacteria, has a high tolerance for different pollutants [266,274]. This bacterium generates sulfides (S^{2-}) through the activity of desulfhydrase and helps to decrease the heavy metal mobility in soil [270,274]. The inoculation of *R. sphaeroides* in Cd-contaminated soil reduces the Cd bioavailability by changing its chemical form [270]. Similarly, the application of *R. sphaeroides* in a wheat seedling experiment reduced phytoavailable Cd by 30.7% [251], which was also observed with sulfate-reducing bacteria (SRB) [275]. Bacteria could be used to decrease Cd bioavailability by microbially induced calcium carbonate precipitation (MICP) [276]. The consortium of bacterial strains shows better performance in reducing Cd bioavailability in soil rather than single strains. The synergistic effects of a bacterial mixture of *Sporosarcina soli* strain B-22, *Viridibacillus arenosi* strain B-21, *Enterobacter cloacae* strain KJ-46, and *E. cloacae* strain KJ-47 improve heavy metal resistance and decrease Cd, Pb, and Cu bioavailability from contaminated soil as compared to single strain cultures [277]. The Cd removal efficiency from Cd-contaminated soil is the highest in a combined leaching system (32.09%) as compared to autotrophic bacteria (isolated from acid mine drainage) (23.24%) and heterotrophic bacteria (isolated from Cd-contaminated soil) (0.74%) systems [278]. Further, combining both organic and inorganic supplements with microorganisms is more efficient to clean up polluted soil [279]. These combinations could both reduce the Cd bioavailability and improve soil properties by modifying the local soil microbial communities [280].

5.2. Fungi

Soil fungi play a critical role in Cd detoxification from contaminated soil and reduce plant Cd bioavailability [256]. The carboxylic–hydroxylic group-mediated negatively charged fungal cell wall could bind with positively charged metalloid ions and reduce Cd bioavailability in soil [281]. The Cd removal efficiency reached 84% with 0.7 g L^{-1} biomass of *Aspergillus niger* [282]. The *Aspergillus* species isolated from coastal water and sediments showed 13.87% biosorption efficiency of Cd from contaminated soil [283]. Furthermore, *Trametes versicolor* fungi absorbs 100 mg kg^{-1} and 350 mg kg^{-1} Cd after 2 and 7 days of exposure, respectively, suggesting its potential at reducing Cd bioavailability in soil [284]. *Trichoderma harzianum* is capable of reducing plant Cd concentrations by 47.5% and the plant enhances Cd resistance through its Cd biosorption capability [285]. The Cd biosorption capability of *T. harzianum* is likely fulfilled via the induction of glutathione and its precursor's metabolism [286].

The mutual interaction of endophytic fungi with plants exerts a significant influence on plant resistance against Cd stress and alleviates Cd toxicity from contaminated soils [262]. The inoculation of the *Triticum aestivum* root with the endophyte *Piriformospora indica* reduces the Cd uptake in roots and promotes plant growth under Cd stress [287]. Similarly, ubiquitously present arbuscular mycorrhizal fungi (AMF) in highly contaminated soil form a symbiotic mycorrhizal association with the plant species [288], and would reduce Cd uptake from the contaminated soil. A dense mycelium layer of AMF fungi around the root cortical tissues serves as an intermediate link between plant roots and soil [289]. The AMF colonization in maize leads to increased Cd accumulation in roots but decreases translocation in shoots [290,291]. Mycorrhizal colonization also increases Cd immobilization in the roots of *Lotus japonicus* and decreases Cd translocation to plant shoots [257]. However, direct evidence for Cd immobilization in mycorrhizal roots by AM fungi is absent.

5.3. Algae

Algae are non-vascular plants, and "phytoremediation", or bioremediation by algae, is an effective way to remove heavy metals from wastewater [292]. They are very good at reducing abiotic stresses in plants and stress damage [293,294]. Algae are excellent candidates for heavy metal removal because they can grow both heterotrophically and autotrophically, have high surface-to-volume ratios, are tolerant of HMs, are phototaxis, have the ability to be genetically modified, and express phytochelatins [295]. In recent decades, there has been a lot of interest in using algae to treat Cd-contaminated wastewater [296,297]. However, far fewer studies have been conducted to investigate Cd remediation in soil using algae. Cd accumulates internally in algae as a result of a two-phase uptake process [298]. The first phase is characterized by rapid physicochemical adsorption of Cd onto cell wall-binding sites, which are most likely proteins and/or polysaccharides. This is followed by a lag phase and then a steady intracellular uptake. This latter phase is energy-dependent and could involve the transport systems used to accumulate other divalent cations, such as Mn and Ca. Some evidence suggests that plasmid-encoded genes control Cd resistance and possibly the uptake in algae and cyanobacteria [299,300]. The algal isolate *C. sorokiniana* ANA9 is highly resistant to heavy metals, such as Cd, with a minimal inhibitory concentration of 4 mM. Algae could absorb heavy metal ions, i.e., Cd, Zn, and Cu, at 43.0, 42.0, and 46.4 g/mg of dry weight, respectively, and have the potential to reduce heavy metal mobility in soil [301]. Moreover, algal extracts (biostimulants) are used to alleviate Cd uptake from the soil. The algal biostimulant has no effect on the Cd content of *N. officinale* roots, increases Cd extraction by the roots, and inhibits Cd transport from the roots to shoots, resulting in lower Cd contents in the shoots; the algal biostimulant increases the soil's urease activity while decreases the soil's catalase activity, but only the 600-fold dilution increases soil invertase activity. The algal biostimulant reduces the soil pH, which increases the activity of some soil enzymes and changes the soil exchangeable Cd concentration [302]. In conclusion, algal biostimulants are thought to be effective and eco-friendly in nature, with the ability to persist and establish themselves in any ecosystem. The use of renewable sources as carrier systems, such as clay, soil, vermicompost, and paddy straw, makes them environmentally preferable. As a result, further research into algae and algal extracts as biostimulants will demonstrate their utility in preventing Cd diffusion in the soil's environment.

6. Novel Sustainable Strategies for Mitigating Cd Toxicity

6.1. Nanoremediation

Nanotechnology is an interdisciplinary field of study concerned with the development of nanoscale structures for advanced applications. Nanotechnology has sparked intense research interests in the field of environmental remediation in recent decades [303,304]. Due to their large surface areas, higher adsorption sites, higher surface activities, and excellent mechanical properties due to the size quantization effect, nanoparticles with sizes in the range of 1–100 nm are thought to be promising absorbents for the immobilization of heavy metals in contaminated soil [44,305–307].

Several studies have been conducted in order to better understand the underlying mechanisms of action of nanoparticles in order to reduce HM stress [308]. The HMs present in the soil are transformed or absorbed by NPs, reducing their bioavailability and mobility. For example, the application of Fe_3O_4 NPs has been shown to reduce cadmium mobility [309]. Cadmium can be converted into a more stable form when exposed to mercapto Si NPs [310]. An X-ray diffraction analysis revealed that the key mechanisms for Pb/Cd immobilization in soil involve both surface complexation on the surface of nano-hydroxyapatite (nHA) and dissolution of the nHA amendments, as well as precipitation of Pb/Cd-containing phosphates. In contaminated soil, nHA reduces the phytoavailability of Pb and Cd by 65.3% and 64.6%, respectively [67]. Furthermore, the performance of NPs when combined with other remediation strategies is a hot topic. Through phytoremediation and bioremediation (bacteria, fungus, yeast, and actinomycetes), nanomaterials (NMs) can significantly alleviate heavy metal stress. For instance, the impact of TiO_2

(nano-titanium dioxide) on Cd accumulation from the soil in *Glycine max* plants was reported. TiO_2 nanoparticles decrease Cd toxicity and increase Cd absorption by protecting plants from oxidative damage and scavenging free radicals produced by Cd toxicity [311]. According to Gong, et al. [312], the dosage of nanoparticles used in phytoremediation varies. Starch-stabilized (s-nZVI) nanoparticles alleviate oxidative damage in ramie under Cd-stress at 100 mg kg^{-1}, whereas plant growth is inhibited and oxidative damage to plants is exacerbated at 500 and 1000 mg kg^{-1} S-nZVI. These findings show that the application of nZVI in combination with phytoremediation may be a promising and practical way to treat Cd-contaminated land because it effectively promotes plant growth while reducing Cd-induced toxicity in plants, enhances Cd uptake, accumulates in plants, and promotes the immobilization of Cd ions in the soil. Similarly, FeO nanoparticles coated with polyvinylpyrrolidone (PVP) have been widely used by *Halomonas* sp. (Gram-negative bacteria) to improve the bioremediation of Pb and Cd-polluted land. This method eliminates almost 100% of Pb after 24 h and almost 100% of Cd after 48 h when compared to bacteria or just NPs [313].

The use of nanomaterials for cleaning heavy metal-polluted soils is considered promising and efficient; they are capable of reducing/immobilizing heavy metals in contaminated soils. Any technology, though, has two sides to it. The widespread use of nanomaterials might be followed by risks to the environment, so one must not ignore this possibility. According to recent reports, nanoparticles pose significant issues for agriculture. It has been reported that pH could be altered in soils containing nanoparticles, which is one of the most important parameters affecting soil nutrient availability, soil microbiology, soil health, and plant growth and development [314]. An important step toward applying nanomaterials for the remediation of heavy metal is having a thorough understanding of the advantages and disadvantages of using them to clean up heavy metal-contaminated soil. This knowledge also serves as a theoretical foundation for future practical applications.

6.2. Phytoremediation

Phytoremediation is a cost-effective and environmentally friendly technique that uses green plants to remove Cd from contaminated soil and water [315]. Phytoremediation uses a variety of mechanisms to remove Cd from the soil, including phytoextraction, phytofiltration (accumulation), phytostabilization, phytovolatilization, and phytostimulation [316,317]. Metal bioavailability, soil properties, plant species, uptake capacity, mutual fitness of plant–soil relationships, and the nature of metal are all factors that influence the mechanisms and efficacy of phytoremediation [318,319]. Hyperaccumulators are plants that have high heavy metal accumulation and tolerance characteristics. Hyperaccumulating plants typically have well-developed roots capable of absorbing high levels of heavy metals in the soil and transferring them to aboveground parts [320]. A large number of plant species and cultivars have been studied in the last few decades to determine their accumulation for the phytoremediation of Cd-contaminated soil [321,322], and it has been discovered that *Sedum alfredii, Phytolacca americana, Arabis gemmifera*, and *Prosopis laevigata* can hyperaccumulate Cd to above 2000 mg kg^{-1} in shoots [320].

Different hyperaccumulators have varying abilities to extract Cd from the soil. This is because Cd has a low affinity and mobile nature [323]. Soil and hydroponic systems were studied to find more efficient soil plants for Cd remediation. *S. nigrum* has also been reported to accumulate high concentrations of Cd, as well as Cu and Zn [324]. *B. napus* was shown to be more stable when exposed to Cd, as lipid changes in *B. napus* cell membranes were observed upon direct exposure to metal [325]. *B. pekinensis*, also known as Chinese cabbage, was also investigated for Cd extraction from soil, and six different varieties were discovered to extract a significant amount of Cd [326]. Despite this, only a few field trials for the phytoremediation of Cd metal have been reported [327]. In agricultural fields in Mae Sot District, Thailand, five different plant species—*Chromolaena odorata, Gynura pseudochina, Conyza sumatrensis, Nicotiana tabacum*, and *Crassocephalum crepidioides* were tested; all four species, aside from *Chromolaena odorata*, were successful at removing Cd from the soil [328]. Similarly, eleven native Turkish species were evaluated for their ability to help with phytoremediation in the Gümüşköy mining region. In this region, contaminated soil was found to contain a high concentration of Cd (82.8 mg kg^{-1}). The native plants under investigation accumulated 55.4 mg kg^{-1} Cd in their roots and 43.5 mg kg^{-1} Cd in their shoots, respectively. *Carduus nutans* and *Phlomis* sp. were shown to be the most effective of the eleven native-tested species [329]. Although there are many potential resources for phytoremediation, the efficiency of this process is hindered by the small biomass of plants, slow growth rates, regional distribution, and a lack of plant species that are suitable for Cd-contaminated soils. In this context, it is equally crucial to select and/or breed plant resources for phytoremediation that have strong heavy metal tolerance and accumulation capacities, large biomasses, and rapid growth rates.

7. Conclusions

Cadmium contamination has become a major concern for global food safety production and consumption. The high concentrations of Cd in crops retard plant growth, reduce crop production, and even promote severe Cd contamination in agricultural products. In this article, we reviewed Cd immobilization with various soil amendments to minimize the bioavailability and toxicity of Cd. A range of organic and inorganic amendments, such as phosphate, Zn, Si, metal oxides, biochar, compost, manure, etc., are commonly used as immobilizing agents of Cd. However, some important factors must be considered when selecting a suitable immobilizing agent. (i) The soil's physicochemical properties and Cd behaviors under different environmental conditions should be determined for effective remediation. (ii) Long-term field trials are needed to determine the benefits and risk assessments of the applied amendment. (iii) Combining the applications of organic, inorganic, and other amendments should be conducted to increase the efficiency of these treatments. Moreover, soil microorganisms, especially bacteria and fungi, play a vital role in Cd immobilization in different soil environments. The changes in microbial activity, diversity, and processes with respect to Cd immobilization in farmlands are essential to promote their remediation efficiencies. Identifying hyperaccumulator plants with fast growth and higher biomasses under Cd stress in connection with strategies that utilize Cd-contaminated biomasses is a key issue for the functional application of crop rotation and inter-cropping remediation techniques. Moreover, irrigation management can provide economically viable and environmentally friendly options for the remediation of Cd-contaminated soil, but the mechanism of this strategy is still not well known and needs further study. Nanoremediation to mitigate Cd availability and toxicity holds great potential for reducing plant Cd uptake. The development and combination of these various solutions will contribute to the sustainable and safe utilization of Cd-contaminated soil.

Author Contributions: S.M.: writing—original draft, visualization and investigation. W.N.: revising—original draft. C.H.: conceptualization, writing—review and editing. Z.Y.: conceptualization and supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by grants from Shenzhen Science and Technology Program (grant no. 202206193000001, 20220815095750002) and the National Natural Science Foundation of China (grant nos. 21277178 and 21777195).

Data Availability Statement: There is no new data created in this review.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kubier, A.; Wilkin, R.T.; Pichler, T. Cadmium in soils and groundwater: A review. *Appl. Geochem.* **2019**, *108*, 104388. [CrossRef] [PubMed]
2. Liu, Y.; Xiao, T.; Zhu, J.-M.; Gao, T.; Xiong, Y.; Zhu, Z.; Ning, Z.; Liu, C. Redistribution and isotope fractionation of endogenous Cd in soil profiles with geogenic Cd enrichment. *Sci. Total Environ.* **2022**, *852*, 158447. [CrossRef]
3. Wang, F.; Peng, L.; Zhou, X.; Zeng, Q.; Luo, S. Typical sources of Cd to paddy fields in different contaminated areas and their impacts on Cd accumulation in topsoil and rice in Changzhutan, China. *Environ. Res.* **2021**, *193*, 110523. [CrossRef] [PubMed]

4. Lin, Y.; Wang, J.; Lin, C. Response of toxic metal distributions and sources to anthropogenic activities and pedogenic processes in the Albic Luvisol profile of northeastern China. *Environ. Adv.* **2021**, *6*, 100142. [CrossRef]
5. Yin, X.; Wei, R.; Chen, H.; Zhu, C.; Liu, Y.; Wen, H.; Guo, Q.; Ma, J. Cadmium isotope constraints on heavy metal sources in a riverine system impacted by multiple anthropogenic activities. *Sci. Total Environ.* **2021**, *750*, 141233. [CrossRef]
6. Huang, Y.; He, C.; Shen, C.; Guo, J.; Mubeen, S.; Yuan, J.; Yang, Z. Toxicity of cadmium and its health risks from leafy vegetable consumption. *Food Funct.* **2017**, *8*, 1373–1401. [CrossRef] [PubMed]
7. Romero-Estévez, D.; Yánez-Jácome, G.S.; Navarrete, H. Non-essential metal contamination in Ecuadorian agricultural production: A critical review. *J. Food Compos. Anal.* **2023**, *115*, 104932. [CrossRef]
8. Han, Y.; Gu, X. Enrichment, contamination, ecological and health risks of toxic metals in agricultural soils of an industrial city, northwestern China. *J. Trace Elem. Miner.* **2023**, *3*, 100043. [CrossRef]
9. Mazumder, P.; Khwairakpam, M.; Kalamdhad, A.S. Assessment of multi-metal contaminant in agricultural soil amended with organic wastes, speciation and translocation–an approach towards sustainable crop production. *Total Environ. Res.* **2023**, *5*, 100025. [CrossRef]
10. Tariq, F. Heavy metals concentration in vegetables irrigated with municipal wastewater and their human daily intake in Erbil city. *Environ. Nanotechnol. Monit. Manag.* **2021**, *16*, 100475. [CrossRef]
11. Marini, M.; Angouria-Tsorochidou, E.; Caro, D.; Thomsen, M. Daily intake of heavy metals and minerals in food–a case study of four Danish dietary profiles. *J. Clean. Prod.* **2021**, *280*, 124279. [CrossRef]
12. Huo, J.; Huang, Z.; Li, R.; Song, Y.; Lan, Z.; Ma, S.; Wu, Y.; Chen, J.; Zhang, L. Dietary cadmium exposure assessment in rural areas of Southwest China. *PLoS ONE* **2018**, *13*, e0201454. [CrossRef]
13. Nishijo, M.; Nakagawa, H.; Suwazono, Y.; Nogawa, K.; Kido, T. Causes of death in patients with Itai-itai disease suffering from severe chronic cadmium poisoning: A nested case–control analysis of a follow-up study in Japan. *BMJ Open* **2017**, *7*, e015694. [CrossRef] [PubMed]
14. Melila, M.; Rajaram, R.; Ganeshkumar, A.; Kpemissi, M.; Pakoussi, T.; Agbere, S.; Lazar, I.M.; Lazar, G.; Paray, B.A.; Gulnaz, A. Assessment of renal and hepatic dysfunction by co-exposure to toxic metals (Cd, Pb) and fluoride in people living nearby an industrial zone. *J. Trace Elem. Med. Biol.* **2022**, *69*, 126890. [CrossRef]
15. Wang, K.; Ma, J.-Y.; Li, M.-Y.; Qin, Y.-S.; Bao, X.-C.; Wang, C.-C.; Cui, D.-L.; Xiang, P.; Ma, L.Q. Mechanisms of Cd and Cu induced toxicity in human gastric epithelial cells: Oxidative stress, cell cycle arrest and apoptosis. *Sci. Total Environ.* **2021**, *756*, 143951. [CrossRef] [PubMed]
16. Pan, B.; Cai, Y.; Liu, B.; Cai, K.; Lv, W.; Tian, J.; Wang, W. Abatement of Cd in rice grain and toxic risks to human health by the split application of silicon at transplanting and jointing period. *J. Environ. Manag.* **2022**, *302*, 114039. [CrossRef] [PubMed]
17. Chaudri, A.; Zhao, F.; McGrath, S.; Crosland, A. The cadmium content of British wheat grain. *J. Environ. Qual.* **1995**, *24*, 850–855. [CrossRef]
18. Gawalko, E.J.; Garrett, R.G.; Nowicki, T.W. Trace elements in western Canadian hard red spring wheat (*Triticum aestivum* L.): Levels and quality assurance. *J. AOAC Int.* **2001**, *84*, 1953–1963. [CrossRef]
19. Wiersma, D.; Van Goor, B.J.; Van der Veen, N.G. Cadmium, lead, mercury and arsenic concentrations in crops and corresponding soils in the Netherlands. *J. Agric. Food Chem.* **1986**, *34*, 1067–1074. [CrossRef]
20. Wolnik, K.A.; Fricke, F.L.; Capar, S.G.; Braude, G.L.; Meyer, M.W.; Satzger, R.D.; Bonnin, E. Elements in major raw agricultural crops in the United States. 1. Cadmium and lead in lettuce, peanuts, potatoes, soybeans, sweet corn, and wheat. *J. Agric. Food Chem.* **1983**, *31*, 1240–1244. [CrossRef]
21. Sriprachote, A.; Kanyawongha, P.; Ochiai, K.; Matoh, T. Current situation of cadmium-polluted paddy soil, rice and soybean in the Mae Sot District, Tak Province, Thailand. *Soil Sci. Plant Nutr.* **2012**, *58*, 349–359. [CrossRef]
22. Song, W.-e.; Chen, S. The toxicity thresholds (ECx) of cadmium to rice cultivars as determined by root elongation tests in soils and its predicted models. *Sci. Agric. Sin.* **2014**, *47*, 3434–3443.
23. US Food and Drug Administration. *Total Diet Study Statistics on Element Results Market Baskets 2006-1 through 2008-4*; US Food and Drug Administration: College Park, MD, USA, 2010.
24. Kabata-Pendias, A.; Pendias, H. *Trace Elements in Soils and Plants*, 3rd ed.; CRC Press: Boca Raton, FL, USA, 2001.
25. Parveen, Z.; Khuhro, M.; Rafiq, N. Market basket survey for lead, cadmium, copper, chromium, nickel, and zinc in fruits and vegetables. *Bull. Environ. Contam. Toxicol.* **2003**, *71*, 1260–1264. [CrossRef] [PubMed]
26. Ali, M.H.; Al-Qahtani, K.M. Assessment of some heavy metals in vegetables, cereals and fruits in Saudi Arabian markets. *Egypt. J. Aquat. Res.* **2012**, *38*, 31–37. [CrossRef]
27. Zhou, H.; Yang, W.-T.; Zhou, X.; Liu, L.; Gu, J.-F.; Wang, W.-L.; Zou, J.-L.; Tian, T.; Peng, P.-Q.; Liao, B.-H. Accumulation of heavy metals in vegetable species planted in contaminated soils and the health risk assessment. *Int. J. Environ. Res. Public Health* **2016**, *13*, 289. [CrossRef] [PubMed]
28. Lee, J.-G.; Lee, Y.; Kim, C.S.; Han, S.B. Codex Alimentarius commission on ensuring food safety and promoting fair trade: Harmonization of standards between Korea and codex. *Food Sci. Biotechnol.* **2021**, *30*, 1151–1170. [CrossRef]
29. Nazir, R.; Khan, M.; Masab, M.; Rehman, H.U.; Rauf, N.U.; Shahab, S.; Ameer, N.; Sajed, M.; Ullah, M.; Rafeeq, M. Accumulation of heavy metals (Ni, Cu, Cd, Cr, Pb, Zn, Fe) in the soil, water and plants and analysis of physico-chemical parameters of soil and water collected from Tanda Dam Kohat. *J. Pharm. Sci. Res.* **2015**, *7*, 89.

30. Kulsum, P.G.P.S.; Khanam, R.; Das, S.; Nayak, A.K.; Tack, F.M.; Meers, E.; Vithanage, M.; Shahid, M.; Kumar, A.; Chakraborty, S. A state-of-the-art review on cadmium uptake, toxicity, and tolerance in rice: From physiological response to remediation process. *Environ. Res.* **2022**, *220*, 115098. [CrossRef]
31. ur Rehman, Z.; Junaid, M.F.; Ijaz, N.; Khalid, U.; Ijaz, Z. Remediation methods of heavy metal contaminated soils from environmental and geotechnical standpoints. *Sci. Total Environ.* **2023**, *864*, 161468. [CrossRef] [PubMed]
32. Khalid, S.; Shahid, M.; Niazi, N.K.; Murtaza, B.; Bibi, I.; Dumat, C. A comparison of technologies for remediation of heavy metal contaminated soils. *J. Geochem. Explor.* **2017**, *182*, 247–268.
33. Wang, X.-L.; Wang, M.-H.; Quan, S.-X.; Yan, B.; Xiao, X.-M. Influence of thermal treatment on fixation rate and leaching behavior of heavy metals in soils from a typical e-waste processing site. *J. Environ. Chem. Eng.* **2016**, *4*, 82–88. [CrossRef]
34. Siebers, N.; Siangliw, M.; Tongcumpou, C. Cadmium uptake and subcellular distribution in rice plants as affected by phosphorus: Soil and hydroponic experiments. *J. Soil Sci. Plant Nutr.* **2013**, *13*, 833–844. [CrossRef]
35. Khan, M.J.; Azeem, M.T.; Jan, M.T.; Perveen, S. Effect of amendments on chemical immobilization of heavy metals in sugar mill contaminated soils. *Soil Environ.* **2012**, *31*, 55–66.
36. Chen, S.; Xu, M.; Ma, Y.; Yang, J. Evaluation of different phosphate amendments on availability of metals in contaminated soil. *Ecotoxicol. Environ. Saf.* **2007**, *67*, 278–285. [CrossRef]
37. Fei, C.; Jing, D.; Wang, F.; Wu, F.; Zhang, G.; Li, G.; Chen, Z.; Chen, J.; Kang, W. Identification of barley genotypes with low grain Cd accumulation and its interaction with four microelements. *Chemosphere* **2007**, *67*, 2082–2088.
38. Zhou, C.; Yuan, H.; Ning, C.; Li, S.; Xia, Z.; Zhu, M.; Ma, Q.; Yu, W. Evaluation of Different Types and Amounts of Amendments on Soil Cd Immobilization and its Uptake to Wheat. *Environ. Manag.* **2020**, *65*, 818–828. [CrossRef] [PubMed]
39. Akhtar, M.J.; Ali, Q.; Javid, R.; Asghar, H.N.; Ahmad, I.; Iqbal, M.Z.; Khaliq, A. Organic and Inorganic Amendments Immobilized Cadmium and Improved Maize Growth and Yield in Cd-Contaminated Soil. *Int. J. Agric. Biol.* **2019**, *22*, 1497–1506.
40. McGowen, S.; Basta, N.; Brown, G. Use of diammonium phosphate to reduce heavy metal solubility and transport in smelter-contaminated soil. *J. Environ. Qual.* **2001**, *30*, 493–500. [CrossRef]
41. Chizzola, R.; Mitteregger, U.S. Cadmium and zinc interactions in trace element accumulation in chamomile. *J. Plant Nutr.* **2005**, *28*, 1383–1396. [CrossRef]
42. Ueno, D.; Zhao, F.-l.; Ma, J.F. Interactions between Cd and Zn in relation to their hyperaccumulation in *Thlaspi caerulescens*. *Soil Sci. Plant Nutr.* **2004**, *50*, 591–597. [CrossRef]
43. Murtaza, G.; Javed, W.; Hussain, A.; Qadir, M.; Aslam, M. Soil-applied zinc and copper suppress cadmium uptake and improve the performance of cereals and legumes. *Int. J. Phytoremediation* **2017**, *19*, 199–206. [CrossRef] [PubMed]
44. Hussain, A.; Ali, S.; Rizwan, M.; ur Rehman, M.Z.; Javed, M.R.; Imran, M.; Chatha, S.A.S.; Nazir, R. Zinc oxide nanoparticles alter the wheat physiological response and reduce the cadmium uptake by plants. *Environ. Pollut.* **2018**, *242*, 1518–1526. [CrossRef] [PubMed]
45. Zhu, Y.; Zhao, Z.; Li, H.; Smith, S.; Smith, F. Effect of zinc–cadmium interactions on the uptake of zinc and cadmium by winter wheat (Triticum aestivum) grown in pot culture. *Bull. Environ. Contam. Toxicol.* **2003**, *71*, 1289–1296. [CrossRef]
46. Erdem, H.; Tosun, Y.K.; Ozturk, M. Effect of cadmium-zinc interactions on growth and Cd-Zn concentration in durum and bread wheats. *Fresenius Environ. Bull* **2012**, *21*, 1046–1051.
47. Chen, H.; Shu, F.; Yang, S.; Li, Y.; Wang, S. Competitive Inhibitory Effect of Calcium Polypeptides on Cd Enrichment of *Brassia campestris* L. *Int. J. Environ. Res. Public Health* **2019**, *16*, 4472. [CrossRef]
48. Ahmad, P.; Sarwat, M.; Bhat, N.A.; Wani, M.R.; Kazi, A.G.; Tran, L.-S.P. Alleviation of cadmium toxicity in Brassica juncea L. (Czern. & Coss.) by calcium application involves various physiological and biochemical strategies. *PLoS ONE* **2015**, *10*, e0114571.
49. Bolan, N.S.; Adriano, D.C.; Duraisamy, P.; Mani, A.; Arulmozhiselvan, K. Immobilization and phytoavailability of cadmium in variable charge soils. I. Effect of phosphate addition. *Plant Soil* **2003**, *250*, 83–94. [CrossRef]
50. Zeng, X.; Xu, H.; Lu, J.; Chen, Q.; Li, W.; Wu, L.; Tang, J.; Ma, L. The immobilization of Soil cadmium by the combined Amendment of Bacteria and Hydroxyapatite. *Sci. Rep.* **2020**, *10*, 2189. [CrossRef]
51. Lu, H.; Li, Z.; Wu, J.; Shen, Y.; Li, Y.; Zou, B.; Tang, Y.; Zhuang, P. Influences of calcium silicate on chemical forms and subcellular distribution of cadmium in *Amaranthus hypochondriacus* L. *Sci. Rep.* **2017**, *7*, 40583. [CrossRef] [PubMed]
52. Dong, Q.; Fang, J.; Huang, F.; Cai, K. Silicon amendment reduces soil Cd availability and Cd uptake of two Pennisetum species. *Int. J. Environ. Res. Public Health* **2019**, *16*, 1624. [CrossRef] [PubMed]
53. Liang, Y.; Wong, J.W.; Wei, L. Silicon-mediated enhancement of cadmium tolerance in maize (*Zea mays* L.) grown in cadmium contaminated soil. *Chemosphere* **2005**, *58*, 475–483. [CrossRef]
54. Naeem, A.; Ghafoor, A.; Farooq, M. Suppression of cadmium concentration in wheat grains by silicon is related to its application rate and cadmium accumulating abilities of cultivars. *J. Sci. Food Agric.* **2015**, *95*, 2467–2472. [CrossRef] [PubMed]
55. Mench, M.; Vangronsveld, J.; Didier, V.; Clijsters, H. Evaluation of metal mobility, plant availability and immobilization by chemical agents in a limed-silty soil. *Environ. Pollut.* **1994**, *86*, 279–286. [CrossRef] [PubMed]
56. Watanabe, T.; Murata, Y.; Nakamura, T.; Sakai, Y.; Osaki, M. Effect of zero-valent iron application on cadmium uptake in rice plants grown in cadmium-contaminated soils. *J. Plant Nutr.* **2009**, *32*, 1164–1172. [CrossRef]
57. Chlopecka, A.; Adriano, D. Influence of zeolite, apatite and Fe-oxide on Cd and Pb uptake by crops. *Sci. Total Environ.* **1997**, *207*, 195–206. [CrossRef] [PubMed]

58. Qayyum, M.F.; ur Rehman, M.Z.; Ali, S.; Rizwan, M.; Naeem, A.; Maqsood, M.A.; Khalid, H.; Rinklebe, J.; Ok, Y.S. Residual effects of monoammonium phosphate, gypsum and elemental sulfur on cadmium phytoavailability and translocation from soil to wheat in an effluent irrigated field. *Chemosphere* **2017**, *174*, 515–523. [CrossRef] [PubMed]
59. Lim, J.E.; Ahmad, M.; Usman, A.R.; Lee, S.S.; Jeon, W.-T.; Oh, S.-E.; Yang, J.E.; Ok, Y.S. Effects of natural and calcined poultry waste on Cd, Pb and As mobility in contaminated soil. *Environ. Earth Sci.* **2013**, *69*, 11–20. [CrossRef]
60. Rehman, M.Z.-u.; Rizwan, M.; Ghafoor, A.; Naeem, A.; Ali, S.; Sabir, M.; Qayyum, M.F. Effect of inorganic amendments for in situ stabilization of cadmium in contaminated soils and its phyto-availability to wheat and rice under rotation. *Environ. Sci. Pollut. Res.* **2015**, *22*, 16897–16906. [CrossRef]
61. Chen, D.; Guo, H.; Li, R.; Li, L.; Pan, G.; Chang, A.; Joseph, S. Low uptake affinity cultivars with biochar to tackle Cd-tainted rice—A field study over four rice seasons in Hunan, China. *Sci. Total Environ.* **2016**, *541*, 1489–1498. [CrossRef]
62. Ashrafi, M.; Mohamad, S.; Yusoff, I.; Shahul Hamid, F. Immobilization of Pb, Cd, and Zn in a contaminated soil using eggshell and banana stem amendments: Metal leachability and a sequential extraction study. *Environ. Sci. Pollut. Res.* **2015**, *22*, 223–230. [CrossRef] [PubMed]
63. Ahmad, P.; Ahanger, M.A.; Alyemeni, M.N.; Wijaya, L.; Alam, P. Exogenous application of nitric oxide modulates osmolyte metabolism, antioxidants, enzymes of ascorbate-glutathione cycle and promotes growth under cadmium stress in tomato. *Protoplasma* **2018**, *255*, 79–93. [CrossRef] [PubMed]
64. Matusik, J.; Bajda, T.; Manecki, M. Immobilization of aqueous cadmium by addition of phosphates. *J. Hazard. Mater.* **2008**, *152*, 1332–1339. [CrossRef] [PubMed]
65. Hong, C.O.; Owens, V.N.; Kim, Y.G.; Lee, S.M.; Park, H.C.; Kim, K.K.; Son, H.J.; Suh, J.M.; Kim, P.J. Soil pH effect on phosphate induced cadmium precipitation in arable soil. *Bull. Environ. Contam. Toxicol.* **2014**, *93*, 101–105. [CrossRef] [PubMed]
66. Palansooriya, K.N.; Shaheen, S.M.; Chen, S.S.; Tsang, D.C.; Hashimoto, Y.; Hou, D.; Bolan, N.S.; Rinklebe, J.; Ok, Y.S. Soil amendments for immobilization of potentially toxic elements in contaminated soils: A critical review. *Environ. Int.* **2020**, *134*, 105046.
67. He, M.; Shi, H.; Zhao, X.; Yu, Y.; Qu, B. Immobilization of Pb and Cd in contaminated soil using nano-crystallite hydroxyapatite. *Procedia Environ. Sci.* **2013**, *18*, 657–665. [CrossRef]
68. Ruangcharus, C.; Kim, S.U.; Hong, C.O. Mechanism of cadmium immobilization in phosphate-amended arable soils. *Appl. Biol. Chem.* **2020**, *63*, 36. [CrossRef]
69. Jiang, H.M.; Yang, J.C.; Zhang, J.F. Effects of external phosphorus on the cell ultrastructure and the chlorophyll content of maize under cadmium and zinc stress. *Environ. Pollut.* **2007**, *147*, 750–756. [CrossRef]
70. Qiu, Q.; Wang, Y.; Yang, Z.; Yuan, J. Effects of phosphorus supplied in soil on subcellular distribution and chemical forms of cadmium in two Chinese flowering cabbage (*Brassica parachinensis* L.) cultivars differing in cadmium accumulation. *Food Chem. Toxicol.* **2011**, *49*, 2260–2267. [CrossRef] [PubMed]
71. Shaheen, S.M.; Shams, M.S.; Khalifa, M.R.; Mohamed, A.; Rinklebe, J. Various soil amendments and environmental wastes affect the (im) mobilization and phytoavailability of potentially toxic elements in a sewage effluent irrigated sandy soil. *Ecotoxicol. Environ. Saf.* **2017**, *142*, 375–387. [CrossRef] [PubMed]
72. Shaheen, S.M.; Rinklebe, J. Phytoextraction of potentially toxic elements by Indian mustard, rapeseed, and sunflower from a contaminated riparian soil. *Environ. Geochem. Health* **2015**, *37*, 953–967. [CrossRef]
73. Zare, A.; Khoshgoftarmanesh, A.; Malakouti, M.; Bahrami, H.; Chaney, R. Root uptake and shoot accumulation of cadmium by lettuce at various Cd: Zn ratios in nutrient solution. *Ecotoxicol. Environ. Saf.* **2018**, *148*, 441–446. [CrossRef]
74. Küpper, H.; Kochian, L.V. Transcriptional regulation of metal transport genes and mineral nutrition during acclimatization to cadmium and zinc in the Cd/Zn hyperaccumulator, *Thlaspi caerulescens* (Ganges population). *New Phytol.* **2010**, *185*, 114–129. [CrossRef] [PubMed]
75. Sterckeman, T.; Thomine, S. Mechanisms of cadmium accumulation in plants. *Crit. Rev. Plant Sci.* **2020**, *39*, 322–359. [CrossRef]
76. Palusińska, M.; Barabasz, A.; Kozak, K.; Papierniak, A.; Maślińska, K.; Antosiewicz, D.M. Zn/Cd status-dependent accumulation of Zn and Cd in root parts in tobacco is accompanied by specific expression of *ZIP* genes. *BMC Plant Biol.* **2020**, *20*, 1–19. [CrossRef]
77. Cojocaru, P.; Gusiatin, Z.M.; Cretescu, I. Phytoextraction of Cd and Zn as single or mixed pollutants from soil by rape (*Brassica napus*). *Environ. Sci. Pollut. Res.* **2016**, *23*, 10693–10701. [CrossRef]
78. Green, C.E.; Chaney, R.L.; Bouwkamp, J. Interactions Between Cadmium Uptake and Phytotoxic Levels of Zinc in Hard Red Spring Wheat. *J. Plant Nutr.* **2003**, *26*, 417–430. [CrossRef]
79. Hart, J.J.; Welch, R.M.; Norvell, W.A.; Clarke, J.M.; Kochian, L.V. Zinc effects on cadmium accumulation and partitioning in near-isogenic lines of durum wheat that differ in grain cadmium concentration. *New Phytol.* **2005**, *167*, 391–401. [CrossRef] [PubMed]
80. Köleli, N.; Eker, S.; Cakmak, I. Effect of zinc fertilization on cadmium toxicity in durum and bread wheat grown in zinc-deficient soil. *Environ. Pollut* **2004**, *131*, 453–459. [CrossRef] [PubMed]
81. Qaswar, M.; Hussain, S.; Rengel, Z. Zinc fertilisation increases grain zinc and reduces grain lead and cadmium concentrations more in zinc-biofortified than standard wheat cultivar. *Sci. Total Environ.* **2017**, *606*, 454–460. [CrossRef] [PubMed]

82. Wang, H.; Xu, C.; Luo, Z.-c.; Zhu, H.-h.; Wang, S.; Zhu, Q.-h.; Huang, D.-y.; Zhang, Y.-z.; Xiong, J.; He, Y.-b. Foliar application of Zn can reduce Cd concentrations in rice (*Oryza sativa* L.) under field conditions. *Environ. Sci. Pollut. Res.* **2018**, *25*, 29287–29294. [CrossRef]
83. Huang, G.; Ding, C.; Zhou, Z.; Zhang, T.; Wang, X. A tillering application of zinc fertilizer based on basal stabilization reduces Cd accumulation in rice (*Oryza sativa* L.). *Ecotoxicol Environ. Saf* **2019**, *167*, 338–344. [CrossRef] [PubMed]
84. Wu, F.; Zhang, G.P. Genotypic Differences in Effect of Cd on Growth and Mineral Concentrations in Barley Seedlings. *Bull. Environ. Contam. Toxicol.* **2002**, *69*, 219–227. [CrossRef] [PubMed]
85. Wu, F.; Zhang, G.; Yu, J. Interaction of Cadmium and Four Microelements for Uptake and Translocation in Different Barley Genotypes. *Commun. Soil Sci. Plant Anal.* **2003**, *34*, 2003–2020. [CrossRef]
86. Wang, M.; Zou, J.; Duan, X.; Jiang, W.; Liu, D. Cadmium accumulation and its effects on metal uptake in maize (*Zea mays* L.). *Bioresour. Technol.* **2007**, *98*, 82–88. [CrossRef] [PubMed]
87. Khurana, M.; Kansal, B. Influence of zinc supply on the phytotoxicity of cadmium in maize (*Zea mays* L.) grown on cadmium-contaminated soil. *Acta Agron. Hung.* **2012**, *60*, 37–46. [CrossRef]
88. Sikka, R.; Nayyar, V. Cadmium Accumulation and Its Effects on Uptake of Micronutrients in Indian Mustard [*Brassica juncea* (L.) Czern.] Grown in a Loamy Sand Soil Artificially Contaminated with Cadmium. *Commun. Soil Sci. Plan* **2012**, *43*, 672–688. [CrossRef]
89. McKenna, I.M.; Chaney, R.L.; Williams, F.M. The effects of cadmium and zinc interactions on the accumulation and tissue distribution of zinc and cadmium in lettuce and spinach. *Environ. Pollut.* **1993**, *79*, 113–120. [CrossRef] [PubMed]
90. Chaney, R.; Li, Y.; Schneiter, A.; Green, C.; Miller, J.; Hopkins, D. Progress in developing technologies to produce low Cd concentration sunflower kernels. In Proceedings of the 15th Sunflower Research Workshop, Fargo, ND, USA, 14–15 January 1993; pp. 14–15.
91. Cherif, J.; Mediouni, C.; Ben Ammar, W.; Jemal, F. Interactions of zinc and cadmium toxicity in their effects on growth and in antioxidative systems in tomato plants (*Solanum lycopersicum*). *J Environ. Sci.* **2011**, *23*, 837–844. [CrossRef] [PubMed]
92. Herath, D.; Weerasinghe, A.; Bandara, D.; Wijayawardhana, D. Synergistic Effect of Zinc and Cadmium for Uptake, Accumulation and Growth Responses in Rice (*Oryza sativa*) Varieties. *Int. J. Chem. Environ. Biol. Sci.* **2016**, *4*, 69–73.
93. Nan, Z.; Li, J.; Zhang, J.; Cheng, G. Cadmium and zinc interactions and their transfer in soil-crop system under actual field conditions—ScienceDirect. *Sci. Total Environ.* **2002**, *285*, 187–195. [CrossRef]
94. Grant, C.; Buckley, W.; Bailey, L.; Selles, F. Cadmium accumulation in crops. *Can. J. Plant Sci.* **1998**, *78*, 1–17. [CrossRef]
95. Green, C.E.; Chaney, R.L.; Bouwkamp, J. Increased Zinc Supply Does Not Inhibit Cadmium Accumulation by Rice (*Oryza sativa* L.). *J. Plant Nutr.* **2016**, *40*, 869–877. [CrossRef]
96. Zhou, J.; Zhang, C.; Du, B.; Cui, H.; Fan, X.; Zhou, D.; Zhou, J. Effects of zinc application on cadmium (Cd) accumulation and plant growth through modulation of the antioxidant system and translocation of Cd in low-and high-Cd wheat cultivars. *Environ. Pollut.* **2020**, *265*, 115045. [CrossRef]
97. Wang, C.X.; Mo, Z.; Wang, H.; Wang, Z.J.; Cao, Z.H. The transportation, time-dependent distribution of heavy metals in paddy crops. *Chemosphere* **2003**, *50*, 717–723. [CrossRef] [PubMed]
98. Li, B.; Yang, J.; Wei, D.; Chen, S.; Li, J.; Ma, Y. Field Evidence of Cadmium Phytoavailability Decreased Effectively by Rape Straw and/or Red Mud with Zinc Sulphate in a Cd-Contaminated Calcareous Soil. *PLoS ONE* **2014**, *9*, e109967. [CrossRef] [PubMed]
99. Bozena, G.; Zakrzewska, D.; Szymczycha, B. Sorption of Cr, Pb, Cu, Zn, Cd, Ni, and Co to nano-TiO_2 in seawater. *Water Sci. Technol.* **2018**, *77*, 145–158. [CrossRef]
100. Chaney, R.L. How Does Contamination of Rice Soils with Cd and Zn Cause High Incidence of Human Cd Disease in Subsistence Rice Farmers. *Curr. Pollut. Rep.* **2015**, *1*, 13–22. [CrossRef]
101. Hui, Y.; Junli, W.; Wei, F.; Jiangang, Y.; Zhongyi, Y. Cadmium accumulation in different rice cultivars and screening for pollution-safe cultivars of rice. *Sci. Total Environ.* **2006**, *370*, 302–309.
102. Chaney, R.L.; Ryan, J.A.; Reeves, P.G. Cadmium in Soils and its Transfer to Plants and the Human Food Chain. *Cell* **2013**, *301*, 395–4852.
103. Chen, X.; Ouyang, Y.; Fan, Y.; Qiu, B.; Zhang, G.; Zeng, F. The pathway of transmembrane cadmium influx via calcium-permeable channels and its spatial characteristics along rice root. *J. Exp. Bot.* **2018**, *69*, 5279–5291. [CrossRef]
104. Hayakawa, N.; Tomioka, R.; Takenaka, C. Effects of calcium on cadmium uptake and transport in the tree species *Gamblea innovans*. *Soil Sci. Plant Nutr.* **2011**, *57*, 691–695. [CrossRef]
105. Suzuki, N. Alleviation by calcium of cadmium-induced root growth inhibition in *Arabidopsis* seedlings. *Plant Biotechnol.* **2005**, *22*, 19–25. [CrossRef]
106. Kurtyka, R.; MbBkowski, E.; Kita, A.; Karcz, W. Effect of Calcium and Cadmium on Growth and Accumulation of Cadmium, Calcium, Potassium and Sodium in Maize Seedlings. *Pol. J. Environ. Stud.* **2008**, *17*, 51–56.
107. Godbold, D.L. Cadmium uptake in Norway spruce (*Picea abies* (L.) Karst.) seedlings. *Tree Physiol.* **1991**, *9*, 349–357. [CrossRef] [PubMed]
108. Kim, Y.-Y.; Yang, Y.-Y.; Lee, Y. Pb and Cd uptake in rice roots. *Physiol. Plant.* **2002**, *116*, 368–372. [CrossRef]
109. Jiang, X.J.; Luo, Y.M.; Liu, Q.; Liu, S.L.; Zhao, Q.G. Effects of Cadmium on Nutrient Uptake and Translocation by Indian Mustard. *Environ. Geochem. Health* **2004**, *26*, 319–324. [CrossRef]

110. Gong, X.; Liu, Y.; Huang, D.; Zeng, G.; Liu, S.; Tang, H.; Zhou, L.; Hu, X.; Zhou, Y.; Tan, X. Effects of exogenous calcium and spermidine on cadmium stress moderation and metal accumulation in *Boehmeria nivea* (L.) Gaudich. *Environ. Sci. Pollut. Res.* **2016**, *23*, 8699–8708. [CrossRef] [PubMed]
111. Yang, C.-M.; Juang, K. Alleviation effects of calcium and potassium on cadmium rhizotoxicity and absorption by soybean and wheat roots. *J. Plant Nutr. Soil Sci.* **2015**, *178*, 748–754. [CrossRef]
112. Wu, Z.; Wang, F.; Liu, S.; Du, Y.; Li, F.; Du, R.; Wen, D.; Zhao, J. Comparative responses to silicon and selenium in relation to cadmium uptake, compartmentation in roots, and xylem transport in flowering Chinese cabbage (*Brassica campestris* L. sp. *chinensis* var. *utilis*) under cadmium stress. *Environ. Exp. Bot.* **2016**, *131*, 173–180. [CrossRef]
113. Rizwan, M.; Meunier, J.-D.; Davidian, J.-C.; Pokrovsky, O.; Bovet, N.; Keller, C. Silicon alleviates Cd stress of wheat seedlings (*Triticum turgidum* L. cv. Claudio) grown in hydroponics. *Environ. Sci. Pollut. Res.* **2016**, *23*, 1414–1427. [CrossRef] [PubMed]
114. Głazowska, S.; Baldwin, L.; Mravec, J.; Bukh, C.; Hansen, T.H.; Jensen, M.M.; Fangel, J.U.; Willats, W.G.T.; Glasius, M.; Felby, C.; et al. The impact of silicon on cell wall composition and enzymatic saccharification of Brachypodium distachyon. *Biotechnol. Biofuels* **2018**, *11*, 171. [CrossRef] [PubMed]
115. Shi, X.; Zhang, C.; Wang, H.; Zhang, F. Effect of Si on the distribution of Cd in rice seedlings. *Plant Soil* **2005**, *272*, 53–60. [CrossRef]
116. Shi, G.; Cai, Q.; Liu, C.; Wu, L. Silicon alleviates cadmium toxicity in peanut plants in relation to cadmium distribution and stimulation of antioxidative enzymes. *Plant Growth Regul.* **2010**, *61*, 45–52. [CrossRef]
117. Lukačová, Z.; Švubová, R.; Kohanová, J.; Lux, A. Silicon mitigates the Cd toxicity in maize in relation to cadmium translocation, cell distribution, antioxidant enzymes stimulation and enhanced endodermal apoplasmic barrier development. *Plant Growth Regul.* **2013**, *70*, 89–103. [CrossRef]
118. Farooq, M.A.; Ali, S.; Hameed, A.; Ishaque, W.; Mahmood, K.; Iqbal, Z. Silicon alleviates cadmium toxicity by enhanced photosynthetic rate and modified bundle sheath's cell chloroplasts ultrastructure in maize. *Ecotoxicol. Environ. Saf.* **2013**, *96*, 242–249. [CrossRef] [PubMed]
119. Liu, J.; Ma, J.; He, C.; Li, X.; Zhang, W.; Xu, F.; Lin, Y.; Wang, L. Inhibition of cadmium ion uptake in rice (*Oryza sativa*) cells by a wall-bound form of silicon. *New Phytol* **2013**, *200*, 691–699. [CrossRef] [PubMed]
120. Ma, J.; Cai, H.; He, C.; Zhang, W.; Wang, L. A hemicellulose-bound form of silicon inhibits cadmium ion uptake in rice (*Oryza sativa*) cells. *New Phytol* **2015**, *206*, 1063–1074. [CrossRef] [PubMed]
121. Carneiro, J.M.T.; Chacón-Madrid, K.; Galazzi, R.M.; Campos, B.K.; Arruda, S.C.C.; Azevedo, R.A.; Arruda, M.A.Z. Evaluation of silicon influence on the mitigation of cadmium-stress in the development of Arabidopsis thaliana through total metal content, proteomic and enzymatic approaches. *J. Trace Elem. Med. Biol.* **2017**, *44*, 50–58. [CrossRef] [PubMed]
122. Bari, M.A.; Prity, S.A.; Das, U.; Akther, M.S.; Sajib, S.A.; Reza, M.A.; Kabir, A.H. Silicon induces phytochelatin and ROS scavengers facilitating cadmium detoxification in rice. *Plant Biol.* **2020**, *22*, 472–479. [CrossRef] [PubMed]
123. Greger, M.; Kabir, A.H.; Landberg, T.; Maity, P.J.; Lindberg, S. Silicate reduces cadmium uptake into cells of wheat. *Environ. Pollut.* **2016**, *211*, 90–97. [CrossRef] [PubMed]
124. Shao, J.F.; Fujii-Kashino, M.; Yamaji, N.; Fukuoka, S.; Shen, R.F.; Ma, J.F. Isolation and characterization of a rice line with high Cd accumulation for potential use in phytoremediation. *Plant Soil* **2017**, *410*, 357–368. [CrossRef]
125. Hamid, Y.; Tang, L.; Yaseen, M.; Hussain, B.; Zehra, A.; Aziz, M.Z.; He, Z.-l.; Yang, X. Comparative efficacy of organic and inorganic amendments for cadmium and lead immobilization in contaminated soil under rice-wheat cropping system. *Chemosphere* **2019**, *214*, 259–268. [CrossRef] [PubMed]
126. Kong, L.; Guo, Z.; Peng, C.; Xiao, X.; He, Y. Factors influencing the effectiveness of liming on cadmium reduction in rice: A meta-analysis and decision tree analysis. *Sci. Total Environ.* **2021**, *779*, 146477. [CrossRef] [PubMed]
127. Hamid, Y.; Tang, L.; Sohail, M.I.; Cao, X.; Hussain, B.; Aziz, M.Z.; Usman, M.; He, Z.-l.; Yang, X. An explanation of soil amendments to reduce cadmium phytoavailability and transfer to food chain. *Sci. Total Environ.* **2019**, *660*, 80–96. [CrossRef] [PubMed]
128. Liu, A.; Zhou, Z.; Yi, Y.; Chen, G. Transcriptome analysis reveals the roles of stem nodes in cadmium transport to rice grain. *BMC Genom.* **2020**, *21*, 1–16. [CrossRef]
129. Chaney, R.L.; Green, C.E.; Ajwa, H.A.; Smith, R.F. Zinc fertilization plus liming to reduce cadmium uptake by Romaine lettuce on Cd-mineralized Lockwood soil. In *Proceedings of the International Plant Nutrition Colloquium XVI*; University of California: Oakland, CA, USA, 2009.
130. Krebs, R.; Gupta, S.K.; Furrer, G.; Schulin, R. Solubility and Plant Uptake of Metals with and without Liming of Sludge-Amended Soils. *J. Environ. Qual.* **1998**, *27*, 18–23. [CrossRef]
131. Hong, C.O.; Lee, D.K.; Chung, D.Y.; Kim, P.J. Liming effects on cadmium stabilization in upland soil affected by gold mining activity. *Arch. Environ. Contam. Toxicol.* **2007**, *52*, 496–502. [CrossRef]
132. Smith, S. Effect of soil pH on availability to crops of metals in sewage sludge-treated soils. II. Cadmium uptake by crops and implications for human dietary intake. *Environ. Pollut.* **1994**, *86*, 5–13. [CrossRef]
133. Cavallaro, N.; McBride, M. Activities of Cu2+ and Cd2+ in soil solutions as affected by pH. *Soil Sci. Soc. Am. J.* **1980**, *44*, 729–732. [CrossRef]
134. Elliott, H.; Liberati, M.; Huang, C. *Competitive Adsorption of Heavy Metals by Soils*; 0047-2425; Wiley Online Library: Hoboken, NJ, USA, 1986.

135. Knox, A.; Seaman, J.; Mench, M.; Vangronsveld, J. Remediation of metal-and radionuclides-contaminated soils by in situ stabilization techniques. In *Environmental Restoration of Metals-Contaminated Soils*; CRC Press: Boca Raton, FL, USA, 2000; pp. 21–60.
136. Park, J.H.; Lamb, D.; Paneerselvam, P.; Choppala, G.; Bolan, N.; Chung, J.-W. Role of organic amendments on enhanced bioremediation of heavy metal (loid) contaminated soils. *J. Hazard. Mater.* **2011**, *185*, 549–574.
137. He, Q.; Singh, B. Crop uptake of cadmium from phosphorus fertilizers: I. Yield and cadmium content. *Water Air Soil Pollut.* **1994**, *74*, 251–265. [CrossRef]
138. Zaccheo, P.; Crippa, L.; Pasta, V.D.M. Ammonium nutrition as a strategy for cadmium mobilisation in the rhizosphere of sunflower. *Plant Soil* **2006**, *283*, 43–56. [CrossRef]
139. Giansoldati, V.; Tassi, E.; Morelli, E.; Gabellieri, E.; Pedron, F.; Barbafieri, M. Nitrogen fertilizer improves boron phytoextraction by Brassica juncea grown in contaminated sediments and alleviates plant stress. *Chemosphere* **2012**, *87*, 1119–1125. [CrossRef] [PubMed]
140. Panković, D.; Plesničar, M.; Arsenijević-Maksimović, I.; Petrović, N.; Sakač, Z.; Kastori, R. Effects of nitrogen nutrition on photosynthesis in Cd-treated sunflower plants. *Ann. Bot.* **2000**, *86*, 841–847. [CrossRef]
141. An, Z.; Wang, X.; Shi, W.; Yan, W.; Cao, Z. Plant physiological responses to the interactions between heavy metal and nutrients. *Soil Environ. Sci.* **2002**, *11*, 392–396.
142. Hassan, M.J.; Wang, F.; Ali, S.; Zhang, G. Toxic Effect of Cadmium on Rice as Affected by Nitrogen Fertilizer Form. *Plant Soil* **2005**, *277*, 359–365. [CrossRef]
143. Maqbool, A.; Ali, S.; Rizwan, M.; Arif, M.S.; Yasmeen, T.; Riaz, M.; Hussain, A.; Noreen, S.; Abdel-Daim, M.M.; Alkahtani, S. N-Fertilizer (Urea) Enhances the Phytoextraction of Cadmium through *Solanum nigrum* L. *Int. J. Environ. Res. Public Health* **2020**, *17*, 3850. [CrossRef]
144. Xie, H.L.; Jiang, R.F.; Zhang, F.S.; McGrath, S.P.; Zhao, F.J. Effect of nitrogen form on the rhizosphere dynamics and uptake of cadmium and zinc by the hyperaccumulator *Thlaspi caerulescens*. *Plant Soil* **2009**, *318*, 205–215. [CrossRef]
145. Zhu, E.; Liu, D.; Li, J.G.; Li, T.Q.; Yang, X.E.; He, Z.L.; Stoffella, P.J. Effect of Nitrogen Fertilizer on Growth and Cadmium Accumulation in *Sedum alfredii* Hance. *J. Plant Nutr.* **2010**, *34*, 115–126. [CrossRef]
146. Qin, D.; Chen, M.-X.; Rong, Z.; Chao, Z.-Y.; Zhu, Z.-W.; Shao, G.-S.; Wang, G.-M. Cd toxicity and accumulation in rice plants vary with soil nitrogen status and their genotypic difference can be partly attributed to nitrogen uptake capacity. *Rice Sci.* **2009**, *16*, 283–291.
147. Umar, S.; Diva, I.; Anjum, N.; Iqbal, M. Potassium nutrition reduces cadmium accumulation and oxidative burst in mustard (*Brassica campestris* L.). *Electron. Int. Fertil. Corresp.* **2008**, *16*, 6–9.
148. Sun, Y.; Li, Z.; Guo, B.; Chu, G.; Wei, C.; Liang, Y. Arsenic mitigates cadmium toxicity in rice seedlings. *Environ. Exp. Bot.* **2008**, *64*, 264–270. [CrossRef]
149. Zhao, Z.Q.; Zhu, Y.G.; Li, H.Y.; Smith, S.E.; Smith, F.A. Effects of forms and rates of potassium fertilizers on cadmium uptake by two cultivars of spring wheat (*Triticum aestivum* L.). *Environ. Int.* **2004**, *29*, 973–978. [CrossRef] [PubMed]
150. Bolan, N.; Kunhikrishnan, A.; Thangarajan, R.; Kumpiene, J.; Park, J.; Makino, T.; Kirkham, M.B.; Scheckel, K. Remediation of heavy metal (loid) s contaminated soils–to mobilize or to immobilize? *J. Hazard. Mater.* **2014**, *266*, 141–166. [PubMed]
151. Kumpiene, J. *Trace Element Immobilization in Soil Using Amendments*; Chapter 15; Wiley: Hoboken, NJ, USA, 2010.
152. Zhang, C.; Ge, Y.; Yao, H.; Chen, X.; Hu, M. Iron oxidation-reduction and its impacts on cadmium bioavailability in paddy soils: A review. *Front. Environ. Sci. Eng.* **2012**, *6*, 509–517. [CrossRef]
153. Ran, L.; Altschul, E.B.; Hedin, R.S.; Nakles, D.V.; Dzombak, D.A. Sequestration Enhancement of Metals in Soils by Addition of Iron Oxides Recovered from Coal Mine Drainage Sites. *J. Soil Contam.* **2014**, *23*, 374–388.
154. Liu, H.; Zhang, J.; Christie, P.; Zhang, F. Influence of iron plaque on uptake and accumulation of Cd by rice (*Oryza sativa* L.) seedlings grown in soil. *Sci. Total Environ.* **2008**, *394*, 361–368. [CrossRef] [PubMed]
155. Shao, G.; Chen, M.; Wang, D.; Xu, C.; Mou, R.; Cao, Z.; Zhang, X. Using iron fertilizer to control Cd accumulation in rice plants: A new promising technology. *Sci. China Ser. C Life Sci.* **2008**, *51*, 245–253. [CrossRef]
156. Feng, X.H.; Zhai, L.M.; Tan, W.F.; Liu, F.; He, J.Z. Adsorption and redox reactions of heavy metals on synthesized Mn oxide minerals. *Environ. Pollut.* **2007**, *147*, 366–373. [CrossRef]
157. Hettiarachchi, G.M.; Pierzynski, G.M.; Ransom, M.D. In Situ Stabilization of Soil Lead Using Phosphorus and Manganese Oxide. *Environ. Sci. Technol.* **2000**, *34*, 4614–4619. [CrossRef]
158. Komárek, M.; Vaněk, A.; Ettler, V. Chemical stabilization of metals and arsenic in contaminated soils using oxides—A review. *Environ. Pollut.* **2013**, *172*, 9–22. [CrossRef] [PubMed]
159. Ramachandran, V.; D'Souza, T. Plant uptake of cadmium, zinc, and manganese from four contrasting soils amended with Cd-enriched sewage sludge. *J. Environ. Sci. Health Part A* **2002**, *37*, 1337–1346. [CrossRef]
160. Chang, R.; Sohi, S.P.; Jing, F.; Liu, Y.; Chen, J. A comparative study on biochar properties and Cd adsorption behavior under effects of ageing processes of leaching, acidification and oxidation. *Environ. Pollut.* **2019**, *254*, 113123. [CrossRef] [PubMed]
161. Abbas, T.; Rizwan, M.; Ali, S.; Zia-ur-Rehman, M.; Farooq Qayyum, M.; Abbas, F.; Hannan, F.; Rinklebe, J.; Sik Ok, Y. Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. *Ecotoxicol. Environ. Saf.* **2017**, *140*, 37–47. [CrossRef] [PubMed]

162. Yang, X.; Liu, J.; McGrouther, K.; Huang, H.; Lu, K.; Guo, X.; He, L.; Lin, X.; Che, L.; Ye, Z.; et al. Effect of biochar on the extractability of heavy metals (Cd, Cu, Pb, and Zn) and enzyme activity in soil. *Environ. Sci. Pollut. Res. Int.* **2016**, *23*, 974–984. [CrossRef]
163. Amirahmadi, E.; Mohammad Hojjati, S.; Kammann, C.; Ghorbani, M.; Biparva, P. The Potential Effectiveness of Biochar Application to Reduce Soil Cd Bioavailability and Encourage Oak Seedling Growth. *Appl. Sci.* **2020**, *10*, 3410. [CrossRef]
164. Shaheen, S.M.; El-Naggar, A.; Wang, J.; Hassan, N.E.E.; Niazi, N.K.; Wang, H.; Tsang, D.C.W.; Ok, Y.S.; Bolan, N.; Rinklebe, J. Chapter 14—Biochar as an (Im)mobilizing Agent for the Potentially Toxic Elements in Contaminated Soils. In *Biochar from Biomass and Waste*; Ok, Y.S., Tsang, D.C.W., Bolan, N., Novak, J.M., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 255–274.
165. Hu, Y.; Zhang, P.; Yang, M.; Liu, Y.; Zhang, X.; Feng, S.; Guo, D.; Dang, X. Biochar is an effective amendment to remediate Cd-contaminated soils—A meta-analysis. *J. Soils Sediments* **2020**, *20*, 3884–3895. [CrossRef]
166. Wang, Y.-M.; Wang, S.-W.; Wang, C.-Q.; Zhang, Z.-Y.; Zhang, J.-Q.; Meng, M.; Li, M.; Uchimiya, M.; Yuan, X.Y. Simultaneous Immobilization of Soil Cd(II) and As(V) by Fe-Modified Biochar. *Int. J. Environ. Res. Public Health* **2020**, *17*, 827. [CrossRef] [PubMed]
167. Yang, F.; Wang, B.; Shi, Z.; Li, L.; Li, Y.; Mao, Z.; Liao, L.; Zhang, H.; Wu, Y. Immobilization of heavy metals (Cd, Zn, and Pb) in different contaminated soils with swine manure biochar. *Environ. Pollut. Bioavailab.* **2021**, *33*, 55–65. [CrossRef]
168. Bian, R.; Joseph, S.; Cui, L.; Pan, G.; Li, L.; Liu, X.; Zhang, A.; Rutlidge, H.; Wong, S.; Chia, C.; et al. A three-year experiment confirms continuous immobilization of cadmium and lead in contaminated paddy field with biochar amendment. *J. Hazard. Mater.* **2014**, *272*, 121–128. [CrossRef]
169. Ahmad, M.; Rajapaksha, A.U.; Lim, J.E.; Zhang, M.; Bolan, N.; Mohan, D.; Vithanage, M.; Lee, S.S.; Ok, Y.S. Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere* **2014**, *99*, 19–33. [CrossRef] [PubMed]
170. Uchimiya, M.; Klasson, K.T.; Wartelle, L.H.; Lima, I.M. Influence of soil properties on heavy metal sequestration by biochar amendment: 1. Copper sorption isotherms and the release of cations. *Chemosphere* **2011**, *82*, 1431–1437. [CrossRef] [PubMed]
171. Shen, Z.; Jin, F.; Wang, F.; McMillan, O.; Al-Tabbaa, A. Sorption of lead by Salisbury biochar produced from British broadleaf hardwood. *Bioresour. Technol.* **2015**, *193*, 553–556. [CrossRef]
172. Fahmi, A.H.; Samsuri, A.W.; Jol, H.; Singh, D. Bioavailability and leaching of Cd and Pb from contaminated soil amended with different sizes of biochar. *R Soc. Open Sci.* **2018**, *5*, 181328. [CrossRef]
173. Kim, H.-S.; Kim, K.-R.; Kim, H.-J.; Yoon, J.-H.; Yang, J.E.; Ok, Y.S.; Owens, G.; Kim, K.-H. Effect of biochar on heavy metal immobilization and uptake by lettuce (*Lactuca sativa* L.) in agricultural soil. *Environ. Earth Sci.* **2015**, *74*, 1249–1259. [CrossRef]
174. Zhang, R.-H.; Li, Z.-G.; Liu, X.-D.; Wang, B.-c.; Zhou, G.-L.; Huang, X.-X.; Lin, C.-F.; Wang, A.-h.; Brooks, M. Immobilization and bioavailability of heavy metals in greenhouse soils amended with rice straw-derived biochar. *Ecol. Eng.* **2017**, *98*, 183–188. [CrossRef]
175. Zhang, J.-Y.; Zhou, H.; Gu, J.-F.; Huang, F.; Yang, W.-J.; Wang, S.-L.; Yuan, T.-Y.; Liao, B.-H. Effects of nano-Fe3O4-modified biochar on iron plaque formation and Cd accumulation in rice (*Oryza sativa* L.). *Environ. Pollut.* **2020**, *260*, 113970. [CrossRef]
176. Cui, L.; Pan, G.; Li, L.; Bian, R.; Liu, X.; Yan, J.; Quan, G.; Ding, C.; Chen, T.; Liu, Y. Continuous immobilization of cadmium and lead in biochar amended contaminated paddy soil: A five-year field experiment. *Ecol. Eng.* **2016**, *93*, 1–8. [CrossRef]
177. Xu, P.; Sun, C.-X.; Ye, X.-Z.; Xiao, W.-D.; Zhang, Q.; Wang, Q. The effect of biochar and crop straws on heavy metal bioavailability and plant accumulation in a Cd and Pb polluted soil. *Ecotoxicol. Environ. Saf.* **2016**, *132*, 94–100. [CrossRef] [PubMed]
178. Głąb, T.; Gondek, K.; Mierzwa–Hersztek, M. Biological effects of biochar and zeolite used for remediation of soil contaminated with toxic heavy metals. *Sci. Rep.* **2021**, *11*, 6998. [CrossRef]
179. Puga, A.; Abreu, C.; Melo, L.; Paz-Ferreiro, J.; Beesley, L. Cadmium, lead, and zinc mobility and plant uptake in a mine soil amended with sugarcane straw biochar. *Environ. Sci. Pollut. Res.* **2015**, *22*, 17606–17614. [CrossRef] [PubMed]
180. Hmid, A.; Al Chami, Z.; Sillen, W.; De Vocht, A.; Vangronsveld, J. Olive mill waste biochar: A promising soil amendment for metal immobilization in contaminated soils. *Environ. Sci. Pollut. Res.* **2015**, *22*, 1444–1456. [CrossRef] [PubMed]
181. Coumar, M.V.; Parihar, R.; Dwivedi, A.; Saha, J.; Rajendiran, S.; Dotaniya, M.; Kundu, S. Impact of pigeon pea biochar on cadmium mobility in soil and transfer rate to leafy vegetable spinach. *Environ. Monit. Assess.* **2016**, *188*, 1–10. [CrossRef] [PubMed]
182. Younis, U.; Malik, S.A.; Rizwan, M.; Qayyum, M.F.; Ok, Y.S.; Shah, M.H.R.; Rehman, R.A.; Ahmad, N. Biochar enhances the cadmium tolerance in spinach (*Spinacia oleracea*) through modification of Cd uptake and physiological and biochemical attributes. *Environ. Sci. Pollut. Res.* **2016**, *23*, 21385–21394. [CrossRef] [PubMed]
183. Zhang, M.; Shan, S.; Chen, Y.; Wang, F.; Yang, D.; Ren, J.; Lu, H.; Ping, L.; Chai, Y. Biochar reduces cadmium accumulation in rice grains in a tungsten mining area-field experiment: Effects of biochar type and dosage, rice variety, and pollution level. *Environ. Geochem. Health* **2019**, *41*, 43–52. [CrossRef] [PubMed]
184. Wang, R.; Wei, S.; Jia, P.; Liu, T.; Hou, D.; Xie, R.; Lin, Z.; Ge, J.; Qiao, Y.; Chang, X. Biochar significantly alters rhizobacterial communities and reduces Cd concentration in rice grains grown on Cd-contaminated soils. *Sci. Total Environ.* **2019**, *676*, 627–638. [CrossRef] [PubMed]
185. Xu, Y.; Seshadri, B.; Sarkar, B.; Wang, H.; Rumpel, C.; Sparks, D.; Farrell, M.; Hall, T.; Yang, X.; Bolan, N. Biochar modulates heavy metal toxicity and improves microbial carbon use efficiency in soil. *Sci. Total Environ.* **2018**, *621*, 148–159. [CrossRef]
186. Zhang, Z.; Solaiman, Z.M.; Meney, K.; Murphy, D.V.; Rengel, Z. Biochars immobilize soil cadmium, but do not improve growth of emergent wetland species Juncus subsecundus in cadmium-contaminated soil. *J. Soils Sediments* **2013**, *13*, 140–151. [CrossRef]

187. Khan, S.; Waqas, M.; Ding, F.; Shamshad, I.; Arp, H.P.H.; Li, G. The influence of various biochars on the bioaccessibility and bioaccumulation of PAHs and potentially toxic elements to turnips (*Brassica rapa* L.). *J. Hazard. Mater.* **2015**, *300*, 243–253. [CrossRef] [PubMed]
188. Shaheen, S.M.; Balbaa, A.A.; Khatab, A.M.; Rinklebe, J. Compost and sulfur affect the mobilization and phyto-availability of Cd and Ni to sorghum and barnyard grass in a spiked fluvial soil. *Environ. Geochem. Health* **2017**, *39*, 1305–1324. [CrossRef] [PubMed]
189. Gadepalle, V.P.; Ouki, S.K.; Hutchings, T. Remediation of copper and cadmium in contaminated soils using compost with inorganic amendments. *Water Air Soil Pollut.* **2009**, *196*, 355–368. [CrossRef]
190. Huang, Q.; Wan, Y.; Luo, Z.; Qiao, Y.; Su, D.; Li, H. The effects of chicken manure on the immobilization and bioavailability of cadmium in the soil-rice system. *Arch. Agron. Soil Sci.* **2020**, *66*, 1753–1764. [CrossRef]
191. Grüter, R.; Meister, A.; Schulin, R.; Tandy, S. Green manure effects on zinc and cadmium accumulation in wheat grains (*Triticum aestivum* L.) on high and low zinc soils. *Plant Soil* **2018**, *422*, 437–453. [CrossRef]
192. Ping, L.; Xingxiang, W.; Zhang, T.; Dongmei, Z.; Yuanqiu, H. Effects of several amendments on rice growth and uptake of copper and cadmium from a contaminated soil. *J. Environ. Sci.* **2008**, *20*, 449–455.
193. Xiu-Zhen, H.; Dong-Mei, Z.; Dan-Dan, L.; Jiang, P. Growth, cadmium and zinc accumulation of ornamental sunflower (*Helianthus annuus* L.) in contaminated soil with different amendments. *Pedosphere* **2012**, *22*, 631–639.
194. Białobrzewski, I.; Mikš-Krajnik, M.; Dach, J.; Markowski, M.; Czekała, W.; Głuchowska, K. Model of the sewage sludge-straw composting process integrating different heat generation capacities of mesophilic and thermophilic microorganisms. *Waste Manag.* **2015**, *43*, 72–83. [CrossRef]
195. de la Fuente, C.; Clemente, R.; Martínez-Alcalá, I.; Tortosa, G.; Bernal, M.P. Impact of fresh and composted solid olive husk and their water-soluble fractions on soil heavy metal fractionation; microbial biomass and plant uptake. *J. Hazard. Mater.* **2011**, *186*, 1283–1289. [CrossRef] [PubMed]
196. Udovic, M.; McBride, M.B. Influence of compost addition on lead and arsenic bioavailability in reclaimed orchard soil assessed using Porcellio scaber bioaccumulation test. *J. Hazard. Mater.* **2012**, *205*, 144–149. [CrossRef]
197. Clemente, R.; Escolar, Á.; Bernal, M.P. Heavy metals fractionation and organic matter mineralisation in contaminated calcareous soil amended with organic materials. *Bioresour. Technol.* **2006**, *97*, 1894–1901. [CrossRef] [PubMed]
198. van Herwijnen, R.; Hutchings, T.R.; Al-Tabbaa, A.; Moffat, A.J.; Johns, M.L.; Ouki, S.K. Remediation of metal contaminated soil with mineral-amended composts. *Environ. Pollut.* **2007**, *150*, 347–354. [CrossRef]
199. Yang, F.; Tang, C.; Antonietti, M. Natural and artificial humic substances to manage minerals, ions, water, and soil microorganisms. *Chem. Soc. Rev.* **2021**, *50*, 6221–6239. [CrossRef] [PubMed]
200. Milojković, J.; Pezo, L.; Stojanović, M.; Mihajlović, M.; Lopičić, Z.; Petrović, J.; Stanojević, M.; Kragović, M. Selected heavy metal biosorption by compost of Myriophyllum spicatum—A chemometric approach. *Ecol. Eng.* **2016**, *93*, 112–119. [CrossRef]
201. Karaca, A. Effect of organic wastes on the extractability of cadmium, copper, nickel, and zinc in soil. *Geoderma* **2004**, *122*, 297–303. [CrossRef]
202. Hanafi, M.M.; Salwa, H. Cadmium and zinc in acid tropical soils: Il influence of humic acid addition on soil properties and their adsorption. *Commun. Soil Sci. Plant Anal.* **1998**, *29*, 1933–1947. [CrossRef]
203. Karer, J.; Wawra, A.; Zehetner, F.; Dunst, G.; Wagner, M.; Pavel, P.-B.; Puschenreiter, M.; Friesl-Hanl, W.; Soja, G. Effects of biochars and compost mixtures and inorganic additives on immobilisation of heavy metals in contaminated soils. *Water Air Soil Pollut.* **2015**, *226*, 342. [CrossRef]
204. Bolan, N.; Adriano, D.; Mani, S.; Khan, A. Adsorption, complexation, and phytoavailability of copper as influenced by organic manure. *Environ. Toxicol. Chem. Int. J.* **2003**, *22*, 450–456. [CrossRef]
205. Li, M.; Mohamed, I.; Raleve, D.; Chen, W.; Huang, Q. RETRACTED ARTICLE: Field evaluation of intensive compost application on Cd fractionation and phytoavailability in a mining-contaminated soil. *Environ. Geochem. Health* **2016**, *38*, 1193–1201. [CrossRef]
206. Houben, D.; Pircar, J.; Sonnet, P. Heavy metal immobilization by cost-effective amendments in a contaminated soil: Effects on metal leaching and phytoavailability. *J. Geochem. Explor.* **2012**, *123*, 87–94. [CrossRef]
207. Li, F.; Li, Z.; Mao, P.; Li, Y.; Li, Y.; McBride, M.B.; Wu, J.; Zhuang, P. Heavy metal availability, bioaccessibility, and leachability in contaminated soil: Effects of pig manure and earthworms. *Environ. Sci. Pollut. Res.* **2019**, *26*, 20030–20039. [CrossRef] [PubMed]
208. Rizwan, M.; Ali, S.; Adrees, M.; Rizvi, H.; Zia-ur-Rehman, M.; Hannan, F.; Qayyum, M.F.; Hafeez, F.; Ok, Y.S. Cadmium stress in rice: Toxic effects, tolerance mechanisms, and management: A critical review. *Environ. Sci. Pollut. Res.* **2016**, *23*, 17859–17879. [CrossRef]
209. Bingham, F.; Page, A.; Mahler, R.; Ganje, T. Cadmium availability to rice in sludge-amended soil under "flood" and "nonflood" culture. *Soil Sci. Soc. Am. J.* **1976**, *40*, 715–719. [CrossRef]
210. Qingqing, H.; Yiyun, L.; Xu, Q.; Lijie, Z.; Xuefeng, L.; Yingming, X. Selenite mitigates cadmium-induced oxidative stress and affects Cd uptake in rice seedlings under different water management systems. *Ecotoxicol. Environ. Saf.* **2019**, *168*, 486–494. [CrossRef]
211. Wan, Y.; Huang, Q.; Camara, A.Y.; Wang, Q.; Li, H. Water management impacts on the solubility of Cd, Pb, As, and Cr and their uptake by rice in two contaminated paddy soils. *Chemosphere* **2019**, *228*, 360–369. [CrossRef] [PubMed]
212. Hu, P.; Ouyang, Y.; Wu, L.; Shen, L.; Luo, Y.; Christie, P. Effects of water management on arsenic and cadmium speciation and accumulation in an upland rice cultivar. *J. Environ. Sci.* **2015**, *27*, 225–231. [CrossRef] [PubMed]

213. Tian, T.; Zhou, H.; Gu, J.; Jia, R.; Li, H.; Wang, Q.; Zeng, M.; Liao, B. Cadmium accumulation and bioavailability in paddy soil under different water regimes for different growth stages of rice (*Oryza sativa* L.). *Plant Soil* **2019**, *440*, 327–339. [CrossRef]
214. Honma, T.; Ohba, H.; Kaneko-Kadokura, A.; Makino, T.; Nakamura, K.; Katou, H. Optimal soil Eh, pH, and water management for simultaneously minimizing arsenic and cadmium concentrations in rice grains. *Environ. Sci. Technol.* **2016**, *50*, 4178–4185. [CrossRef] [PubMed]
215. Zhao, F.-J.; Wang, P. Arsenic and cadmium accumulation in rice and mitigation strategies. *Plant Soil* **2020**, *446*, 1–21. [CrossRef]
216. Mei, X.-Q.; Yang, Y.; Tam, N.F.-Y.; Wang, Y.-W.; Li, L. Roles of root porosity, radial oxygen loss, Fe plaque formation on nutrient removal and tolerance of wetland plants to domestic wastewater. *Water Res.* **2014**, *50*, 147–159. [CrossRef]
217. Mei, X.; Li, Q.; Wang, H.; Fang, H.; Chen, H.; Chen, X.; Yang, Y.; Rizwan, M.; Ye, Z. Effects of cultivars, water regimes, and growth stages on cadmium accumulation in rice with different radial oxygen loss. *Plant Soil* **2020**, *453*, 529–543. [CrossRef]
218. Cheng, H.; Wang, M.; Wong, M.H.; Ye, Z. Does radial oxygen loss and iron plaque formation on roots alter Cd and Pb uptake and distribution in rice plant tissues? *Plant Soil* **2014**, *375*, 137–148. [CrossRef]
219. Xiao, Q.; Wong, M.H.; Huang, L.; Ye, Z. Effects of cultivars and water management on cadmium accumulation in water spinach (*Ipomoea aquatica* Forsk.). *Plant Soil* **2015**, *391*, 33–49. [CrossRef]
220. Jackson, M.; Armstrong, W. Formation of aerenchyma and the processes of plant ventilation in relation to soil flooding and submergence. *Plant Biol.* **1999**, *1*, 274–287. [CrossRef]
221. Li, J.; Xu, Y. Immobilization remediation of Cd-polluted soil with different water condition. *J. Environ. Manag.* **2017**, *193*, 607–612. [CrossRef]
222. Cattani, I.; Romani, M.; Boccelli, R. Effect of cultivation practices on cadmium concentration in rice grain. *Agron. Sustain. Dev.* **2008**, *28*, 265–271. [CrossRef]
223. Luo, W.; Yang, S.; Khan, M.A.; Ma, J.; Xu, W.; Li, Y.; Xiang, Z.; Jin, G.; Jia, J.; Zhong, B. Mitigation of Cd accumulation in rice with water management and calcium-magnesium phosphate fertilizer in field environment. *Environ. Geochem. Health* **2020**, *42*, 3877–3886. [CrossRef] [PubMed]
224. Spanu, A.; Valente, M.; Langasco, I.; Barracu, F.; Orlandoni, A.M.; Sanna, G. Sprinkler irrigation is effective in reducing cadmium concentration in rice (*Oryza sativa* L.) grain: A new twist on an old tale? *Sci. Total Environ.* **2018**, *628*, 1567–1581. [CrossRef] [PubMed]
225. Arao, T.; Kawasaki, A.; Baba, K.; Mori, S.; Matsumoto, S. Effects of Water Management on Cadmium and Arsenic Accumulation and Dimethylarsinic Acid Concentrations in Japanese Rice. *Environ. Sci. Technol.* **2009**, *43*, 9361–9367. [CrossRef]
226. Hu, P.; Li, Z.; Yuan, C.; Ouyang, Y.; Zhou, L.; Huang, J.; Huang, Y.; Luo, Y.; Christie, P.; Wu, L. Effect of water management on cadmium and arsenic accumulation by rice (*Oryza sativa* L.) with different metal accumulation capacities. *J. Soils Sediments* **2013**, *13*, 916–924. [CrossRef]
227. Smolders, E.; McLaughlin, M.J. Chloride increases cadmium uptake in Swiss chard in a resin-buffered nutrient solution. *Soil Sci. Soc. Am. J.* **1996**, *60*, 1443–1447. [CrossRef]
228. Salimi, M.; Amin, M.M.; Ebrahimi, A.; Ghazifard, A.; Najafi, P. Influence of electrical conductivity on the phytoremediation of contaminated soils to Cd 2+ and Zn^{2+}. *Int. J. Environ. Health Eng.* **2012**, *1*, 11.
229. Khoshgoftar, A.; Shariatmadari, H.; Karimian, N.; Kalbasi, M.; Van der Zee, S.; Parker, D. Salinity and zinc application effects on phytoavailability of cadmium and zinc. *Soil Sci. Soc. Am. J.* **2004**, *68*, 1885–1889. [CrossRef]
230. Hattori, H.; Kuniyasu, K.; Chiba, K.; Chino, M. Effect of chloride application and low soil pH on cadmium uptake from soil by plants. *Soil Sci. Plant Nutr.* **2006**, *52*, 89–94. [CrossRef]
231. Chen, H.; Lin, L.; Liao, M.a.; Wang, J.; Tang, Y.; Sun, G.; Liang, D.; Xia, H.; Deng, Q.; Wang, X. Effects of intercropping with floricultural accumulator plants on cadmium accumulation in grapevine. *Environ. Sci. Pollut. Res.* **2019**, *26*, 24474–24481. [CrossRef]
232. Zu, Y.; Qin, L.; Zhan, F.; Wu, J.; Li, Y.; Chen, J.; Wang, J.; Hu, W. Intercropping of Sonchus asper and Vicia faba affects plant cadmium accumulation and root responses. *Pedosphere* **2020**, *30*, 457–465. [CrossRef]
233. Whiting, S.N.; Leake, J.R.; McGrath, S.P.; Baker, A.J. Assessment of Zn mobilization in the rhizosphere of *Thlaspi caerulescens* by bioassay with non-accumulator plants and soil extraction. *Plant Soil* **2001**, *237*, 147–156. [CrossRef]
234. Yi, T.; Juan, H.; Xuena, Y.; Yongdong, X.; Lijin, L.; Guochao, S.; Huanxiu, L.; Mingan, L.; LIANG, D.; Hui, X. Intercropping with Solanum nigrum and Solanum photeinocarpum from two ecoclimatic regions promotes growth and reduces cadmium uptake of eggplant seedlings. *Pedosphere* **2017**, *27*, 638–644.
235. Yongzhen, D.; Shirong, T.; Zhian, L.; Murray, M. Effects of low molecule weight organic acids on Cd solubility in paddy and red soils in South China. *Res. J. Chem. Environ.* **2008**, *12*, 7–16.
236. Hei, L.; Wu, Q.-T.; Long, X.-X.; Hu, Y.-M. Effect of co-planting of Sedum alfredii and Zea mays on Zn-contaminated sewage sludge. *Huan Jing Ke Xue = Huanjing Kexue* **2007**, *28*, 852–858. [PubMed]
237. Li, N.Y.; Li, Z.A.; Zhuang, P.; Zou, B.; McBride, M. Cadmium Uptake From Soil by Maize with Intercrops. *Water Air Soil Pollut.* **2009**, *199*, 45–56. [CrossRef]
238. Liu, L.; Li, Y.; Tang, J.; Hu, L.; Chen, X. Plant coexistence can enhance phytoextraction of cadmium by tobacco (*Nicotiana tabacum* L.) in contaminated soil. *J. Environ. Sci.* **2011**, *23*, 453–460. [CrossRef]

239. Azeez, J.O.; Hassan, O.A.; Adesodun, J.K.; Arowolo, T.A. Soil metal sorption characteristics and its influence on the comparative effectiveness of EDTA and legume intercrop on the phytoremediative abilities of Maize (*Zea mays*), Mucuna (*Mucuna pruriens*), Okra (*Abelmoschus esculentus*), and Kenaf (*Hibiscus cannabinus*). *Soil Sediment Contam. Int. J.* **2013**, *22*, 930–957.
240. Yang, Y.; Zhou, X.; Tie, B.; Peng, L.; Li, H.; Wang, K.; Zeng, Q. Comparison of three types of oil crop rotation systems for effective use and remediation of heavy metal contaminated agricultural soil. *Chemosphere* **2017**, *188*, 148–156. [CrossRef] [PubMed]
241. Murakami, M.; Ae, N.; Ishikawa, S.; Ibaraki, T.; Ito, M. Phytoextraction by a high-Cd-accumulating rice: Reduction of Cd content of soybean seeds. *Environ. Sci. Technol.* **2008**, *42*, 6167–6172. [CrossRef]
242. Murakami, M.; Nakagawa, F.; Ae, N.; Ito, M.; Arao, T. Phytoextraction by rice capable of accumulating Cd at high levels: Reduction of Cd content of rice grain. *Environ. Sci. Technol.* **2009**, *43*, 5878–5883. [CrossRef]
243. Wu, F.-L.; Lin, D.-Y.; Su, D.-C. The effect of planting oilseed rape and compost application on heavy metal forms in soil and Cd and Pb uptake in rice. *Agric. Sci. China* **2011**, *10*, 267–274. [CrossRef]
244. Su, D.; Lu, X.; Wong, J. Could cocropping or successive cropping with Cd accumulator oilseed rape reduce Cd uptake of sensitive Chinese Cabbage? *Pract. Period. Hazard. Toxic Radioact. Waste Manag.* **2008**, *12*, 224–228. [CrossRef]
245. Tang, L.; Luo, W.; Chen, W.; He, Z.; Gurajala, H.K.; Hamid, Y.; Deng, M.; Yang, X. Field crops (*Ipomoea aquatica* Forsk. and *Brassica chinensis* L.) for phytoremediation of cadmium and nitrate co-contaminated soils via rotation with *Sedum alfredii* Hance. *Environ. Sci. Pollut. Res.* **2017**, *24*, 19293–19305. [CrossRef] [PubMed]
246. Li, T.; Tao, Q.; Liang, C.; Yang, X. Elevated CO_2 concentration increase the mobility of Cd and Zn in the rhizosphere of hyperaccumulator Sedum alfredii. *Environ. Sci. Pollut. Res.* **2014**, *21*, 5899–5908. [CrossRef]
247. Li, W.C.; Wong, M.H. Interaction of Cd/Zn hyperaccumulating plant (*Sedum alfredii*) and rhizosphere bacteria on metal uptake and removal of phenanthrene. *J. Hazard. Mater.* **2012**, *209*, 421–433. [CrossRef] [PubMed]
248. Jiang, S.; Liu, J.; Wu, J.; Dai, G.; Wei, D.; Shu, Y. Assessing biochar application to immobilize Cd and Pb in a contaminated soil: A field experiment under a cucumber–sweet potato–rape rotation. *Environ. Geochem. Health* **2020**, *42*, 4233–4244. [CrossRef] [PubMed]
249. Ran, H.; Guo, Z.; Shi, L.; Feng, W.; Xiao, X.; Peng, C.; Xue, Q. Effects of mixed amendments on the phytoavailability of Cd in contaminated paddy soil under a rice-rape rotation system. *Environ. Sci. Pollut. Res.* **2019**, *26*, 14128–14136. [CrossRef]
250. Guo, L.; Wu, G.; Li, Y.; Li, C.; Liu, W.; Meng, J.; Liu, H.; Yu, X.; Jiang, G. Effects of cattle manure compost combined with chemical fertilizer on topsoil organic matter, bulk density and earthworm activity in a wheat–maize rotation system in Eastern China. *Soil Tillage Res.* **2016**, *156*, 140–147. [CrossRef]
251. Peng, W.; Li, X.; Song, J.; Jiang, W.; Liu, Y.; Fan, W. Bioremediation of cadmium-and zinc-contaminated soil using Rhodobacter sphaeroides. *Chemosphere* **2018**, *197*, 33–41. [CrossRef]
252. Ojuederie, O.B.; Babalola, O.O. Microbial and plant-assisted bioremediation of heavy metal polluted environments: A review. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1504. [CrossRef] [PubMed]
253. Coelho, L.M.; Rezende, H.C.; Coelho, L.M.; de Sousa, P.; Melo, D.; Coelho, N. Bioremediation of polluted waters using microorganisms. *Adv. Bioremediation Wastewater Polluted Soil* **2015**, *10*, 60770.
254. Igiri, B.E.; Okoduwa, S.I.; Idoko, G.O.; Akabuogu, E.P.; Adeyi, A.O.; Ejiogu, I.K. Toxicity and bioremediation of heavy metals contaminated ecosystem from tannery wastewater: A review. *J. Toxicol.* **2018**, *2018*, 2568038. [CrossRef]
255. Liu, H.; Yuan, M.; Tan, S.; Yang, X.; Lan, Z.; Jiang, Q.; Ye, Z.; Jing, Y. Enhancement of arbuscular mycorrhizal fungus (*Glomus versiforme*) on the growth and Cd uptake by Cd-hyperaccumulator *Solanum nigrum*. *Appl. Soil Ecol.* **2015**, *89*, 44–49. [CrossRef]
256. Ali, A.; Bilal, S.; Khan, A.L.; Mabood, F.; Al-Harrasi, A.; Lee, I.-J. Endophytic *Aureobasidium pullulans* BSS6 assisted developments in phytoremediation potentials of *Cucumis sativus* under Cd and Pb stress. *J. Plant Interact.* **2019**, *14*, 303–313. [CrossRef]
257. Chen, B.; Nayuki, K.; Kuga, Y.; Zhang, X.; Wu, S.; Ohtomo, R. Uptake and Intraradical Immobilization of Cadmium by Arbuscular Mycorrhizal Fungi as Revealed by a Stable Isotope Tracer and Synchrotron Radiation μX-Ray Fluorescence Analysis. *Microbes Environ.* **2018**, *33*, 257–263. [CrossRef]
258. Zhang, X.-F.; Hu, Z.-H.; Yan, T.-X.; Lu, R.-R.; Peng, C.-L.; Li, S.-S.; Jing, Y.-X. Arbuscular mycorrhizal fungi alleviate Cd phytotoxicity by altering Cd subcellular distribution and chemical forms in *Zea mays*. *Ecotoxicol. Environ. Saf.* **2019**, *171*, 352–360. [CrossRef]
259. Degola, F.; Fattorini, L.; Bona, E.; Sprimuto, C.T.; Argese, E.; Berta, G.; di Toppi, L.S. The symbiosis between *Nicotiana tabacum* and the endomycorrhizal fungus *Funneliformis mosseae* increases the plant glutathione level and decreases leaf cadmium and root arsenic contents. *Plant Physiol. Biochem.* **2015**, *92*, 11–18. [CrossRef] [PubMed]
260. Zhipeng, W.; Weidong, W.; Shenglu, Z.; Shaohua, W. Mycorrhizal inoculation affects Pb and Cd accumulation and translocation in Pakchoi (*Brassica chinensis* L.). *Pedosphere* **2016**, *26*, 13–26.
261. Khan, A.L.; Waqas, M.; Hussain, J.; Al-Harrasi, A.; Lee, I.-J. Fungal endophyte *Penicillium janthinellum* LK5 can reduce cadmium toxicity in *Solanum lycopersicum* (*Sitiens* and *Rhe*). *Biol. Fertil. Soils* **2014**, *50*, 75–85. [CrossRef]
262. Khan, A.R.; Ullah, I.; Waqas, M.; Park, G.-S.; Khan, A.L.; Hong, S.-J.; Ullah, R.; Jung, B.K.; Park, C.E.; Ur-Rehman, S. Host plant growth promotion and cadmium detoxification in *Solanum nigrum*, mediated by endophytic fungi. *Ecotoxicol. Environ. Saf.* **2017**, *136*, 180–188. [CrossRef]
263. Madhaiyan, M.; Poonguzhali, S.; Sa, T. Metal tolerating methylotrophic bacteria reduces nickel and cadmium toxicity and promotes plant growth of tomato (*Lycopersicon esculentum* L.). *Chemosphere* **2007**, *69*, 220–228. [CrossRef] [PubMed]

264. Moreira, H.; Marques, A.P.; Franco, A.R.; Rangel, A.O.; Castro, P.M. Phytomanagement of Cd-contaminated soils using maize (*Zea mays* L.) assisted by plant growth-promoting rhizobacteria. *Environ. Sci. Pollut. Res.* **2014**, *21*, 9742–9753. [CrossRef]
265. Saluja, B.; Sharma, V. Cadmium resistance mechanism in acidophilic and alkalophilic bacterial isolates and their application in bioremediation of metal-contaminated soil. *Soil Sediment Contam. Int. J.* **2014**, *23*, 1–17. [CrossRef]
266. Li, Y.; Pang, H.-D.; He, L.-Y.; Wang, Q.; Sheng, X.-F. Cd immobilization and reduced tissue Cd accumulation of rice (*Oryza sativa* wuyun-23) in the presence of heavy metal-resistant bacteria. *Ecotoxicol. Environ. Saf.* **2017**, *138*, 56–63. [CrossRef] [PubMed]
267. Khanna, K.; Jamwal, V.L.; Kohli, S.K.; Gandhi, S.G.; Ohri, P.; Bhardwaj, R.; Abd_Allah, E.F.; Hashem, A.; Ahmad, P. Plant growth promoting rhizobacteria induced Cd tolerance in *Lycopersicon esculentum* through altered antioxidative defense expression. *Chemosphere* **2019**, *217*, 463–474. [CrossRef]
268. Khanna, K.; Jamwal, V.L.; Sharma, A.; Gandhi, S.G.; Ohri, P.; Bhardwaj, R.; Al-Huqail, A.A.; Siddiqui, M.H.; Ali, H.M.; Ahmad, P. Supplementation with plant growth promoting rhizobacteria (PGPR) alleviates cadmium toxicity in *Solanum lycopersicum* by modulating the expression of secondary metabolites. *Chemosphere* **2019**, *230*, 628–639. [CrossRef] [PubMed]
269. Joshi, P.M.; Juwarkar, A.A. In vivo studies to elucidate the role of extracellular polymeric substances from *Azotobacter* in immobilization of heavy metals. *Environ. Sci. Technol.* **2009**, *43*, 5884–5889. [CrossRef] [PubMed]
270. Fan, W.; Jia, Y.; Li, X.; Jiang, W.; Lu, L. Phytoavailability and geospeciation of cadmium in contaminated soil remediated by *Rhodobacter sphaeroides*. *Chemosphere* **2012**, *88*, 751–756. [CrossRef]
271. Chen, L.; He, L.-y.; Wang, Q.; Sheng, X.-f. Synergistic effects of plant growth-promoting *Neorhizobium huautlense* T1-17 and immobilizers on the growth and heavy metal accumulation of edible tissues of hot pepper. *J. Hazard. Mater.* **2016**, *312*, 123–131. [CrossRef] [PubMed]
272. Lin, X.; Mou, R.; Cao, Z.; Xu, P.; Wu, X. Characterization of cadmium-resistant bacteria and their potential for reducing accumulation of cadmium in rice grains. *Sci. Total Environ.* **2016**, *569*, 97–104. [CrossRef]
273. Suksabye, P.; Pimthong, A.; Dhurakit, P.; Mekvichitsaeng, P.; Thiravetyan, P. Effect of biochars and microorganisms on cadmium accumulation in rice grains grown in Cd-contaminated soil. *Environ. Sci. Pollut. Res.* **2016**, *23*, 962–973. [CrossRef]
274. Li, X.; Peng, W.; Jia, Y.; Lu, L.; Fan, W. Bioremediation of lead contaminated soil with *Rhodobacter sphaeroides*. *Chemosphere* **2016**, *156*, 228–235. [CrossRef] [PubMed]
275. Jiang, W.; Fan, W. Bioremediation of Heavy Metal–Contaminated Soils by Sulfate-Reducing Bacteria. *Ann. N. Y. Acad. Sci.* **2008**, *1140*, 446–454. [CrossRef] [PubMed]
276. Zhao, Y.; Yao, J.; Yuan, Z.; Wang, T.; Zhang, Y.; Wang, F. Bioremediation of Cd by strain GZ-22 isolated from mine soil based on biosorption and microbially induced carbonate precipitation. *Environ. Sci. Pollut. Res.* **2017**, *24*, 372–380. [CrossRef] [PubMed]
277. Kang, C.-H.; Kwon, Y.-J.; So, J.-S. Bioremediation of heavy metals by using bacterial mixtures. *Ecol. Eng.* **2016**, *89*, 64–69. [CrossRef]
278. Xu, M.; Liu, Y.; Deng, Y.; Zhang, S.; Jiang, H. Bioremediation of cadmium-contaminated paddy soil using an autotrophic and heterotrophic mixture. *RSC Adv.* **2020**, *10*, 26090–26101. [CrossRef] [PubMed]
279. Zhang, Q.; Qin, W.D.; Yang, L.Y.; An, J.; Zhang, X.X.; Hong, H.; Xu, L.Z.; Wang, Y.P. Microcystis bloom containing microcystin-LR induces type 2 diabetes mellitus. *Toxicol. Lett.* **2018**, *294*, 87–94. [CrossRef] [PubMed]
280. Yu, H.-Y.; Liu, C.; Zhu, J.; Li, F.; Deng, D.-M.; Wang, Q.; Liu, C. Cadmium availability in rice paddy fields from a mining area: The effects of soil properties highlighting iron fractions and pH value. *Environ. Pollut.* **2016**, *209*, 38–45. [CrossRef] [PubMed]
281. Meier, S.; Borie, F.; Bolan, N.; Cornejo, P. Phytoremediation of metal-polluted soils by arbuscular mycorrhizal fungi. *Crit. Rev. Environ. Sci. Technol.* **2012**, *42*, 741–775. [CrossRef]
282. Júnior, L.B.; Macedo, G.; Duarte, M.; Silva, E.; Lobato, A.K.C.L. Biosorption of cadmium using the fungus *Aspergillus niger*. *Braz. J. Chem. Eng.* **2003**, *20*, 229–239. [CrossRef]
283. Manguilimotan, L.C.; Bitacura, J.G. Biosorption of cadmium by filamentous fungi isolated from coastal water and sediments. *J. Toxicol.* **2018**, *2018*, 7170510. [CrossRef]
284. Abhijit, M.; Ellairaja, S.; Chinnaiah, A.; Sivasamy, V.V. Efficient Removal of Cadmium Using Edible Fungus and Its Quantitative Fluorimetric Estimation Using (Z)-2-(4*H*-1,2,4-Triazol-4-yl)iminomethylphenol. *ACS Omega* **2018**, *3*, 6243–6250.
285. Abeed, A.H.A.; Mahdy, R.E.; Alshehri, D.; Hammami, I.; Eissa, M.A.; Abdel Latef, A.A.H.; Mahmoud, G.A. Induction of resilience strategies against biochemical deteriorations prompted by severe cadmium stress in sunflower plant when *Trichoderma* and bacterial inoculation were used as biofertilizers. *Front Plant Sci.* **2022**, *13*, 1004173. [CrossRef] [PubMed]
286. Oshiquiri, L.H.; Dos Santos, K.R.A.; Ferreira Junior, S.A.; Steindorff, A.S.; Barbosa Filho, J.R.; Mota, T.M.; Ulhoa, C.J.; Georg, R.C. *Trichoderma harzianum* transcriptome in response to cadmium exposure. *Fungal Genet. Biol.* **2020**, *134*, 103281. [CrossRef]
287. Shahabivand, S.; Maivan, H.Z.; Goltapeh, E.M.; Sharifi, M.; Aliloo, A.A. The effects of root endophyte and arbuscular mycorrhizal fungi on growth and cadmium accumulation in wheat under cadmium toxicity. *Plant Physiol. Biochem.* **2012**, *60*, 53–58. [CrossRef]
288. Luo, N.; Li, X.; Chen, A.Y.; Zhang, L.J.; Zhao, H.M.; Xiang, L.; Cai, Q.Y.; Mo, C.H.; Wong, M.H.; Li, H. Does arbuscular mycorrhizal fungus affect cadmium uptake and chemical forms in rice at different growth stages? *Sci. Total Environ.* **2017**, *599*, 1564–1572. [CrossRef]
289. Sidhu, G.P.S.; Bali, A.S.; Bhardwaj, R. Use of fungi in mitigating cadmium toxicity in plants. In *Cadmium Toxicity and Tolerance in Plants*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 397–426.
290. Chen, B.; Liu, Y.; Shen, H.; Li, X.; Christie, P. Uptake of cadmium from an experimentally contaminated calcareous soil by arbuscular mycorrhizal maize (*Zea mays* L.). *Mycorrhiza* **2004**, *14*, 347–354. [CrossRef]

291. Huang, H.; Zhang, S.; Chen, B.-D.; Wu, N.; Shan, X.-Q.; Christy, P. Uptake of Atrazine and Cadmium from Soil by Maize (*Zea mays* L.) in Association with the Arbuscular Mycorrhizal Fungus Glomus etunicatum. *J. Agric. Food Chem.* **2006**, *54*, 9377–9382. [CrossRef]
292. Bauddh, K.; Korstad, J. Phycoremediation: Use of algae to sequester heavy metals. *Hydrobiology* **2022**, *1*, 288–303.
293. Van Oosten, M.J.; Pepe, O.; De Pascale, S.; Silletti, S.; Maggio, A. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chem. Biol. Technol. Agric.* **2017**, *4*, 5. [CrossRef]
294. Jayakumar, V.; Govindaradjane, S.; Rajamohan, N.; Rajasimman, M. Biosorption potential of brown algae, *Sargassum polycystum*, for the removal of toxic metals, cadmium and zinc. *Environ. Sci. Pollut. Res.* **2021**, *29*, 41909–41922. [CrossRef]
295. Saini, S.; Dhania, G. Cadmium as an environmental pollutant: Ecotoxicological effects, health hazards, and bioremediation approaches for its detoxification from contaminated sites. In *Bioremediation of Industrial Waste for Environmental Safety: Volume II: Biological Agents and Methods for Industrial Waste Management*; Springer: Singapore, 2020; pp. 357–387.
296. Lodeiro, P.; Herrero, R.; de Vicente, M.S. The use of protonated Sargassum muticum as biosorbent for cadmium removal in a fixed-bed column. *J. Hazard. Mater.* **2006**, *137*, 244–253. [CrossRef]
297. Al-Homaidan, A.A.; Alabdullatif, J.A.; Al-Hazzani, A.A.; Al-Ghanayem, A.A.; Alabbad, A.F. Adsorptive removal of cadmium ions by *Spirulina platensis* dry biomass. *Saudi J. Biol. Sci.* **2015**, *22*, 795–800. [CrossRef] [PubMed]
298. Pérez-Rama, M.; Alonso, J.A.; López, C.H.; Vaamonde, E.T. Cadmium removal by living cells of the marine microalga *Tetraselmis suecica*. *Bioresour. Technol.* **2002**, *84*, 265–270. [CrossRef] [PubMed]
299. Ren, L.; Shi, D.; Dai, J.; Ru, B. Expression of the mouse metallothionein-I gene conferring cadmium resistance in a transgenic cyanobacterium. *FEMS Microbiol. Lett.* **1998**, *158*, 127–132. [CrossRef] [PubMed]
300. Cobbett, C.S.; May, M.J.; Howden, R.; Rolls, B. The glutathione-deficient, cadmium-sensitive mutant, *cad2–1*, of *Arabidopsis thaliana* is deficient in γ-glutamylcysteine synthetase. *Plant J.* **1998**, *16*, 73–78. [CrossRef]
301. Yoshida, N.; Ikeda, R.; Okuno, T. Identification and characterization of heavy metal-resistant unicellular alga isolated from soil and its potential for phytoremediation. *Bioresour. Technol.* **2006**, *97*, 1843–1849. [CrossRef]
302. Hu, R.; Wang, H.; Liu, Q.; Lin, L.; Liao, M.A.; Deng, H.; Wang, Z.; Liang, D.; Wang, X.; Xia, H. An algal biostimulant promotes growth and decreases cadmium uptake in accumulator plant *Nasturtium officinale*. *Int. J. Environ. Anal. Chem.* **2022**, *102*, 4403–4411. [CrossRef]
303. Kabir, E.; Kumar, V.; Kim, K.-H.; Yip, A.C.; Sohn, J. Environmental impacts of nanomaterials. *J. Environ. Manag.* **2018**, *225*, 261–271. [CrossRef] [PubMed]
304. Cai, C.; Zhao, M.; Yu, Z.; Rong, H.; Zhang, C. Utilization of nanomaterials for in-situ remediation of heavy metal(loid) contaminated sediments: A review. *Sci. Total Environ.* **2019**, *662*, 205–217. [CrossRef] [PubMed]
305. Baragaño, D.; Forján, R.; Álvarez, N.; Gallego, J.; González, A. Zero valent iron nanoparticles and organic fertilizer assisted phytoremediation in a mining soil: Arsenic and mercury accumulation and effects on the antioxidative system of *Medicago sativa* L. *J. Hazard. Mater.* **2022**, *433*, 128748. [CrossRef]
306. Bakshi, M.; Abhilash, P. Nanotechnology for soil remediation: Revitalizing the tarnished resource. In *Nano-Materials as Photocatalysts for Degradation of Environmental Pollutants*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 345–370.
307. Hussain, A.; Rehman, F.; Rafeeq, H.; Waqas, M.; Asghar, A.; Afsheen, N.; Rahdar, A.; Bilal, M.; Iqbal, H.M. In-situ, Ex-situ, and nano-remediation strategies to treat polluted soil, water, and air—A review. *Chemosphere* **2022**, *289*, 133252. [CrossRef] [PubMed]
308. Rizwan, M.; Ali, S.; Ali, B.; Adrees, M.; Arshad, M.; Hussain, A.; ur Rehman, M.Z.; Waris, A.A. Zinc and iron oxide nanoparticles improved the plant growth and reduced the oxidative stress and cadmium concentration in wheat. *Chemosphere* **2019**, *214*, 269–277. [CrossRef]
309. Rizwan, M.; Noureen, S.; Ali, S.; Anwar, S.; Rehman, M.Z.U.; Qayyum, M.F.; Hussain, A. Influence of biochar amendment and foliar application of iron oxide nanoparticles on growth, photosynthesis, and cadmium accumulation in rice biomass. *J. Soils Sediments* **2019**, *19*, 3749–3759. [CrossRef]
310. Li, P.; Wen, J.; Chen, P.; Guo, P.; Ke, Y.; Wang, M.; Liu, M.; Tran, L.P.; Li, J.; Du, H. MYB Superfamily in Brassica napus: Evidence for Hormone-Mediated Expression Profiles, Large Expansion, and Functions in Root Hair Development. *Biomolecules* **2020**, *10*, 875. [CrossRef] [PubMed]
311. Usman, M.; Farooq, M.; Wakeel, A.; Nawaz, A.; Cheema, S.A.; ur Rehman, H.; Ashraf, I.; Sanaullah, M. Nanotechnology in agriculture: Current status, challenges and future opportunities. *Sci. Total Environ.* **2020**, *721*, 137778. [CrossRef]
312. Gong, X.; Huang, D.; Liu, Y.; Peng, Z.; Zeng, G.; Xu, P.; Cheng, M.; Wang, R.; Wan, J. Remediation of contaminated soils by biotechnology with nanomaterials: Bio-behavior, applications, and perspectives. *Crit. Rev. Biotechnol.* **2018**, *38*, 455–468. [CrossRef] [PubMed]
313. Alabresm, A.; Chen, Y.P.; Decho, A.W.; Lead, J. A novel method for the synergistic remediation of oil-water mixtures using nanoparticles and oil-degrading bacteria. *Sci. Total Environ.* **2018**, *630*, 1292–1297. [CrossRef] [PubMed]
314. Shi, J.; Ye, J.; Fang, H.; Zhang, S.; Xu, C. Effects of copper oxide nanoparticles on paddy soil properties and components. *Nanomaterials* **2018**, *8*, 839. [CrossRef]
315. Ashraf, S.; Ali, Q.; Zahir, Z.A.; Ashraf, S.; Asghar, H.N. Phytoremediation: Environmentally sustainable way for reclamation of heavy metal polluted soils. *Ecotoxicol. Environ. Saf.* **2019**, *174*, 714–727. [PubMed]
316. Kafle, A.; Timilsina, A.; Gautam, A.; Adhikari, K.; Bhattarai, A.; Aryal, N. Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. *Environ. Adv.* **2022**, *8*, 100203. [CrossRef]

317. Jacob, J.M.; Karthik, C.; Saratale, R.G.; Kumar, S.S.; Prabakar, D.; Kadirvelu, K.; Pugazhendhi, A. Biological approaches to tackle heavy metal pollution: A survey of literature. *J. Environ. Manag.* **2018**, *217*, 56–70. [CrossRef] [PubMed]
318. Huang, R.; Dong, M.; Mao, P.; Zhuang, P.; Paz-Ferreiro, J.; Li, Y.; Li, Y.; Hu, X.; Netherway, P.; Li, Z. Evaluation of phytoremediation potential of five Cd (hyper) accumulators in two Cd contaminated soils. *Sci. Total Environ.* **2020**, *721*, 137581. [CrossRef]
319. Iqbal, N.; Hayat, M.T.; Zeb, B.S.; Abbas, Z.; Ahmed, T. Phytoremediation of Cd-contaminated soil and water. In *Cadmium Toxicity and Tolerance in Plants*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 531–543.
320. Luo, J.-S.; Zhang, Z. Mechanisms of cadmium phytoremediation and detoxification in plants. *Crop J.* **2021**, *9*, 521–529. [CrossRef]
321. Reeves, R.D.; Baker, A.J.; Jaffré, T.; Erskine, P.D.; Echevarria, G.; van Der Ent, A. A global database for plants that hyperaccumulate metal and metalloid trace elements. *New Phytol.* **2018**, *218*, 407–411. [CrossRef]
322. Sarwar, N.; Imran, M.; Shaheen, M.R.; Ishaque, W.; Kamran, M.A.; Matloob, A.; Rehim, A.; Hussain, S. Phytoremediation strategies for soils contaminated with heavy metals: Modifications and future perspectives. *Chemosphere* **2017**, *171*, 710–721. [CrossRef]
323. Mahajan, P.; Kaushal, J. Role of phytoremediation in reducing cadmium toxicity in soil and water. *J. Toxicol.* **2018**, *2018*, 4864365. [CrossRef] [PubMed]
324. Wei, S.; Zhou, Q.; Wang, X.; Zhang, K.; Guo, G.; Ma, L.Q. A newly-discovered Cd-hyperaccumulator *Solatium nigrum* L. *Chin. Sci. Bull.* **2005**, *50*, 33–38. [CrossRef]
325. Sheng, X.-F.; Xia, J.-J. Improvement of rape (*Brassica napus*) plant growth and cadmium uptake by cadmium-resistant bacteria. *Chemosphere* **2006**, *64*, 1036–1042. [CrossRef] [PubMed]
326. Liu, W.; Zhou, Q.; Zhang, Z.; Hua, T.; Cai, Z. Evaluation of cadmium phytoremediation potential in Chinese cabbage cultivars. *J. Agric. Food Chem.* **2011**, *59*, 8324–8330. [CrossRef]
327. Saad-Allah, K.M.; Elhaak, M. Hyperaccumulation activity and metabolic responses of Solanum nigrum in two differentially polluted growth habitats. *J. Saudi Soc. Agric. Sci.* **2017**, *16*, 227–235. [CrossRef]
328. Khaokaew, S.; Landrot, G. A field-scale study of cadmium phytoremediation in a contaminated agricultural soil at Mae Sot District, Tak Province, Thailand: (1) Determination of Cd-hyperaccumulating plants. *Chemosphere* **2015**, *138*, 883–887. [CrossRef]
329. Palutoglu, M.; Akgul, B.; Suyarko, V.; Yakovenko, M.; Kryuchenko, N.; Sasmaz, A. Phytoremediation of cadmium by native plants grown on mining soil. *Bull. Environ. Contam. Toxicol.* **2018**, *100*, 293–297. [CrossRef] [PubMed]