Harnessing of Biogenic silicon Nanoparticles and biochar amendments to Improve the Growth and yields of Crops in Cd Heavy Metal-Contaminated Soils. A review

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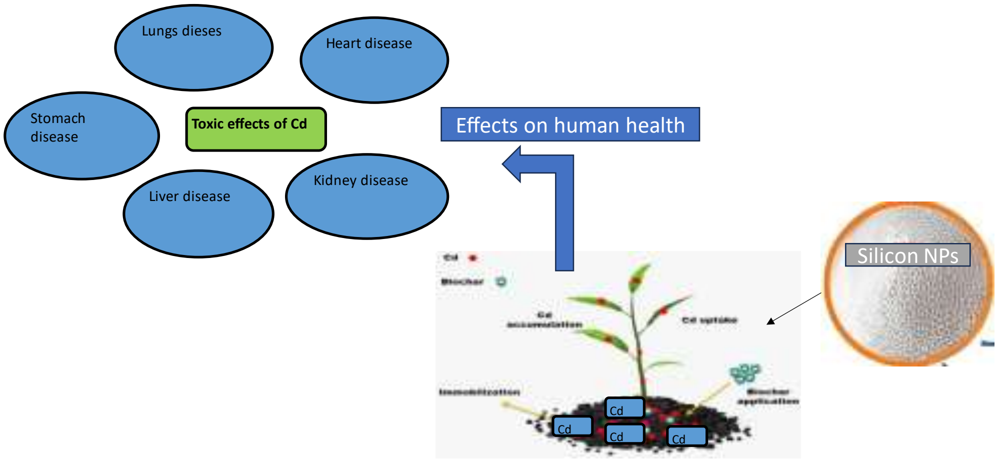
Abstract

Using of Phyto-synthesis silicon Nanoparticles and biochar in the agriculture field has gained more attention at present. The application of silicon nanoparticles and biochar in agriculture has been economically and environmentally beneficial. Silicon nanoparticles and biochar increase soil fertility and improve the growth of crops. This paper reviews the positive effects of the application of both silicon nanoparticles and biochar on the growth of crops and summarizes the prior research on the use of silicon nanoparticles and biochar in agriculture. Phyto-synthesis silicon nanoparticles and biochar are better for the growing of crops. This review paper also revealed the remediation of Cd heavy metal from soil by using the application of silicon nanoparticles and biochar. More research and investigation are needed in the future to understand the better results of the application of silicon nanoparticles and biochar in agriculture.

Graphical Abstract;



Key points: Cd heavy metal, silicon nanoparticles, Biochar, remediation, crop growth, etc.

Introduction

Cadmium (Cd) is well-acknowledged as a toxic chemical and is categorized as a heavy metal (Kubra et al., 2022). It is one of the well-known HMs that negatively impacts the aquatic ecology, raising ongoing environmental problems and perhaps being hazardous to living things (Abd Elnabi et al., 2023). Numerous plant species experience the phytotoxic effects of cadmium, as documented by published studies regularly. These negative consequences include reduced photosynthetic activity, altered enzymatic and biochemical activity, and stunted plant growth and output (Eissa & Abeed, 2019; J. Li et al., 2021). Furthermore, chronic exposure to the buildup of Cd in the human body results in serious health issues such as lung, skin, and kidney malignancies as well as neurological and cardiovascular disorders (Fatima, Raza, Hadi, Nigam, & Mahdi, 2019; Genchi, Sinicropi, Lauria, Carocci, & Catalano, 2020).

Many physicochemical and agronomic approaches have been used in the past ten years to treat HMs-contaminated soils; nevertheless, these approaches come with several drawbacks, including the potential for harm to the environment, high costs, and dangers to soil microbial populations (Ahmed et al., 2023; Noman et al., 2020). Nanotechnology-enabled approaches have gained recognition recently as viable substitutes for traditional remediation methods in addressing HM-related damages in an eco-friendly manner (Ahmed et al., 2021). Pollutants can be effectively, economically, and environmentally removed from the water, air, and soil by using nanotechnology (Chaudhary, Chen, Rajput, & Jaiswal, 2023). Prior research has demonstrated that artificial nanoparticles (NPs) may be used to remediate soil contaminated with heavy metals (HMs) (J. Liu, Simms, Song, King, & Cobb, 2018). One tetravalent metalloid is silicon (Si). It is the majority of plant life's mineral substrate (Imtiaz et al., 2016). By increasing the amounts of total protein, phenolic compounds, chlorophyll a, and chlorophyll b, and lowering the levels of reactive oxygen species, such as malondialdehyde contents and H_2O_2 activity, the silicon nanoparticle amendments lessened the Cd toxicity in B. rapa (L.) plants (Rafi et al., 2022). Prior research has demonstrated that Si improved plant growth, yield, nutrition availability, and tolerance to Cd stress (Linan Liu et al., 2023) By enhancing plant growth, essential oil output, and antioxidant capacity in summer savory (Satureja hortensis L.), foliar treatment of silicon nanoparticles reduced Cd toxicity. Recently, plant-mediated synthesis has gained popularity as a non-toxic, economical, and environmentally beneficial way to prepare nanoparticles for use in agricultural settings (Memari-Tabrizi, Yousefpour-Dokhanieh, & Babashpour-Asl, 2021; Periakaruppan, S, P, S, & Danaraj, 2022).

More recently, several studies have demonstrated that adding biochar to soils can boost crop yields and lessen drought-related stress on plants (Akhtar, Li, Andersen, & Liu, 2014; Liang et al., 2014). Plant-based biomass pyrolysis produces biochar (BC), which is essential for cleaning up HM-polluted soils and enhancing plant well-being and carbon sequestration (K. Wang, Sun, Tang, He, & Sun, 2020). Furthermore, by immobilizing HMs through their substantial area of surface, Pollutants can be effectively, economically, and environmentally removed from the water, air, and soil by using nanotechnology (J. Huang, Zimmerman, Chen, & Gao, 2020; Wen et al., 2021).

The objectives of this review are to function and characterize the biochar and biogenic silicon nanoparticles and assess their potential to alleviate Cd toxicity from contaminated soils. Additionally, we aimed to investigate the stress-relieving impact of bio-nanoparticles on different crops, and physiological parameters, including chlorophyll content, yields, and the expression of antioxidative defense-related genes, under Cd spiked conditions. This study provides novel insights into the mechanisms by which biochar and biogenic nanoparticles mitigate Cd toxicity in soils and crops and highlights their potential as a sustainable approach for managing soil contaminates with excessive HMs.

What is biochar

Biochar is a pyrogenic carbon that is typically made from biomass or carbon-rich materials, particularly leftovers from agriculture (Inyang et al., 2016) (Z. Liu, Zhang, Bhandari, & Wang, 2017). (Z. Liu et al., 2017). Pyrolysis can occur at temperatures between 200°C and 1000°C, and it can proceed quickly or slowly. It is best to use slow pyrolysis to produce biochar (Lian & Xing, 2017). BC is a kind of charcoal made by pyrolysis, a method in which enough heat and no oxygen are needed to sufficiently carbonize the starting material. Various research have utilized wood, other biomass sources, and agricultural wastes as preparation materials for BC (F. U. Haider et al., 2022). Prior research has created BC utilizing a variety of unprocessed products as carbon sources, from sewage solid waste to agricultural wastes (Xing et al., 2021). In addition, several thermochemical processes including pyrolysis, carbonization, gasification, hydrothermal, microwave-mediated, and torrefaction have been developed to produce BC. While agricultural wastes are being pyrolyzed to generate BC for use in agriculture, pyrolysis of carbon-rich material from animal feces has generally been studied to occur at temperatures around 300 and 700 °C (Foong et al., 2023).

Cadmium sources

Cadmium (Cd) is a rare metal that is mostly found in zinc deposits as a result of volcanic activity, forest fires, and weathering of cadmium-rich rocks (Waseem et al., 2023). First, forest fires and eruptions of volcanoes cause mountains and soil to gradually deteriorate and wear down, which is how lead (Cd) ends up in the atmosphere. Moreover, the chemical industry, waste incineration, smelting, mining, coal burning, Cd electroplating, manufacturing of fertilizers, and trash burning are the primary ways in which Cd from industrial production is discharged into the environment. The primary cause of indoor air pollution with lead (Cd) is environmental smoking, which poses a significant risk to human health (Böhlandt et al., 2012).

According to new research 0. l mg kg^{-1} Cd is present in the earth's crust (Mwalongo, Haneklaus, Lisuma, Kivevele, & Mtei, 2023). A variety of industrial processes, such as pigment synthesis, battery production, and electroplating, are also linked to cadmium emissions into the environment. The discharge of wastewater containing Cd into rivers is a common practice arising from these industrial sectors, which exacerbates the contamination of aquatic environments (Saravanakumar et al., 2022). According to recent research, tobacco plants can collect lead (Cd) from the soil. When tobacco products are smoked, Cd is released into the surrounding environment and enters the human body (Charkiewicz, Omeljaniuk, Nowak, Garley, & Nikliński, 2023).

Important causes of soil Cd pollution also include fuel combustion, phosphate fertilizer, sewage sludge, mining, and smelting air deposits. Soils polluted with cadmium may cause long-term harm to agricultural soils (Lugon-Moulin et al., 2004).

Role of Silicon NPs in the growth of crops

Soil contains silicon, which is the second most common component in nature after oxygen. Because it helps them react to biotic and abiotic challenges, silica is a mineral that plants naturally need. Plant water consumption, photosynthetic potential, structural characteristics, and rigidity are all increased by these interactions, preventing leaves from toppling over and protecting them from disease (Singh et al., 2023; J. Zhao et al., 2022). Additionally, it has been noted that the application of silica nanoparticles to agriculture can improve bioremediation and increase the lifespan of maize seedlings when added to the formulation of smart pesticides (Khan et al., 2023). Pyrolysis can occur at temperatures between 200°C and 1000°C, and it can proceed quickly or slowly. It is best to use slow pyrolysis to produce biochar. Silicon is rarely found as a pure element (Luyckx, Hausman, Lutts, & Guerriero, 2017). Although this element is not thought to be necessary for plant growth, research on it has been much more interesting in the past 20 years, and evidence of Si's useful involvement in plant physiology has been shown (Awasthi, Chauhan, & Srivastava, 2022). Generally speaking, the published findings demonstrate that applying Si as fertilizer plays a significant role in sustaining plant output, particularly not only-in stressful environments (Ranjan et al., 2021). Si's influence on a crop's capacity to adapt to a variety of biotic and abiotic stressors is linked to improvements in crop quality and yield. Therefore, the processes by which Si acts to improve overall plant fitness are crucial for establishing a plant's defenses and capacity to adapt to harsh environments (Coskun et al., 2019).

Increased concentration of phenolic compounds; activation of antioxidant defense, such as a ROS scavenging system; cell wall reinforcement, which renders plants more resilient and resistant to pathogens and decreases plant taste and/or digestion to herbivores; and gene regulation, particularly in terms of improving the activation of pathogenesis-related related proteins and controlling the production of the jasmonic acid/ethylene marker genes that generate resistance against biotic stresses, are the most significant mechanisms connected to Si action in biotic stress (Dallagnol, Rodrigues, DaMatta, Mielli, & Pereira, 2011; Mandlik et al., 2020; Manivannan & Ahn, 2017). Nowadays, a significant portion of soils contain high levels of hazardous metals or metalloids, making them unfit for agricultural use (M. Wang et al., 2021). Even though these lands were disregarded in the past, their restoration or remediation is currently a crucial tactic to raise the proportion of usable land on the planet. Si has been proven in more and more studies to be able to neutralize the harmful effects of elements like As, Zn, Cr, Pb, Al, and Cd that, in excessive concentrations, pose a major threat to living things and the agricultural system (Puccinelli, Malorgio, & Pezzarossa, 2017).

Si application, for example, has been demonstrated to decrease the transport of Al, Cr, Cd, Mn, and Zn from roots to shoots through cell wall the retention and vacuole division, thereby reducing the amount present in the shoots and averting negative effects on photosynthesis machinery and grain production of various crops (Che, Yamaji, Shao, Ma, & Shen, 2016; Feng Shao, Che, Yamaji, Fang Shen, & Feng Ma, 2017). The main role of Si nanoparticles is to remediate the toxic heavy metals like As and Cd from soils (Gao et al., 2021). Additionally, Si strengthens antioxidant mechanisms that scavenge reactive oxygen species, or ROS, brought on by As toxicity, such as catalase (CAT), ascorbate peroxidase (APX), and superoxide dismutase (SOD) (Saleem et al., 2023).

Role of Biochar in the growth and yields of crops

It has been shown in a lab bioassay that the type and rates of application of biochar significantly impacted the early growth of clover, mung beans, and wheat (Solaiman, Murphy, & Abbott, 2012). The application of biochar at a rate of 1-4% by weight to the biochar-treated pot greatly enhanced the development of the pepper plants, as measured by leaf area, canopy dry mass, node count, and fruit, flower, and bud production. Furthermore, with a 1% biochar addition, plant dry biomass generation was enhanced by biochar made from mustard chicken dung by 353, and by 572% for roots and plants, respectively. This may be explained by decreased metal toxicity and more nutritional availability, particularly P and K (Graber et al., 2010; Park, Choppala, Bolan, Chung, & Chuasavathi, 2011). The total dry sunflower plant biomass increased by 8%-24% and 26%-31%, respectively, with the addition of wheat-straw biochar at high rate of application (7.5 t ha-1) and olive-tree-pruning biochar at low application rates (0.5 t ha-1), depending on the type of biochar (Alburquerque et al., 2014).

When plants are exposed to phytopathogens, biochar can induce the expression of genes linked to defense and systemic resistance (Jaiswal et al., 2020). When plants are exposed to abiotic and biotic stress, biochar can "prime" them for a quick upregulation of defense-related processes including oxidative burst. It is commonly known that adding biochar has a major impact on the soil, rhizosphere, pathogens, and plant microbiome. To achieve this, the biochar's absorption of harmful chemicals and release of silicon (Si) increase disease resistance, which in turn suppresses phytopathogen-induced infection. Plants raised in soil supplemented with biochar experience the activation of the induced acquired systemic resistance mechanism (Iacomino, Idbella, Laudonia, Vinale, & Bonanomi, 2022). The concentration of nutrients in plant tissues can change in response to biochar. The Ca, Mg, and Zn concentrations in lettuce leaves were lowered by using biochar made from swine solids (SS), poultry litter (PL), and blends of poultry litter and pine chips PV (Olszyk et al., 2020). Comparably, nutritional concentrations dropped in carrot root. However, the decline was not as noticeable as it was for the lettuce root. In contrast, carrot taproot's K concentration rose when biochar based on PL and PC/PL, 50%/50%, was added. Burkholderia phytobiomass and biochar increased soil fertility, crop production, and grain Fe content. In Chenopodium quinoa grain tissues, siderophore-producing bacteria (PsJN) and organic amendments enhance iron concentrations, particularly in acidic soil environments. In a similar vein, applying Zn and charcoal together increased crop production and Zn coordination in grains (Farooq, Ullah, Usman, & Siddique, 2020).

When a plant needs inorganic and natural nutrients and ions, biochar can function as a mechanism for storing and releasing them (Nair & Mukherjee, 2022). Applying biochar and biochar + compost often enhances the soil's chemical and biophysical characteristics as well as plants' ability to receive nutrients. Additionally, biochar can be used to replenish depleted or marginal soils, freeing up additional agricultural land while raising crop yields to reduce the requirement for new land acquisition (Barrow, 2012). Additionally, notable rises in Applications of biochar to soil have been shown to increase crop output and root biomass (Abiven, Hund, Martinsen, & Cornelissen, 2015; Agegnehu, Bird, Nelson, & Bass, 2015). Few research, meanwhile, have examined the impact of biochar on the germination of seeds and the growth of seedlings in the early phases of plant development (Solaiman et al., 2012; Van Zwieten et al., 2010).

Plant yields have increased as a result of applying biochar to improve soil characteristics and water usage efficiency (Furtado et al., 2016; J. Wang, Pan, Liu, Zhang, & Xiong, 2012). Increasing the rate of biochar application resulted in a considerable improvement in maize yield on arid sandy soil due to increased nitrogen uptake. Applying biochar at 15 and 20 t ha–1 resulted in a considerable increase in maize grain by 150 and 98%, respectively, as compared to the control. Additionally, applying biochar at 10, 15, and 20 t ha–1 boosted the net water use effectiveness (WUE) of the maize crop by around 6, 139, and 91% when compared to the control (Uzoma et al., 2011). In durum wheat (Triticum durum L.), the addition of biochar at levels of 30–60 t ha–1 increased biomass and grain yields by up to 30%, but did not influence grain N content (Vaccari et al., 2011). The application of biochar to nutrient-deficient soils can have a beneficial or negative effect on upland rice productivity, contingent on the state of soil fertility and fertilizer management (Asai et al., 2009).

Use of biochar in deficient sandy soils enhanced plant growth in both well-watered and drought-prone environments by enhancing soil-plant water relations (better relative water content and leaves osmotic potential) and photosynthesis (less stomatal resistance and enhanced photosynthesis by raising the electron transport rate of photosystem II) (G. Haider et al., 2015). The whole-plant physiology of horticulture crops, such as apple trees' water status, nutrient concentration, and gas exchange between leaves, was found to be either positively or negatively impacted by the addition of biochar (Eyles et al., 2015). The stomatal conductance, rate of photosynthesis, relative water content, membrane stability index, stomatal density, stomatal pore aperture, and crop water use efficiency were all significantly increased with biochar treatment at a level of 5% (w/w) using tomato plants and a pot experiment with sandy loam soil. On the other hand, the application of biochar did not significantly impact the rate of photosynthetic rate in the leaves, but it did reduce the ABA content and the chlorophyll content index. In a sandy-clay-loam orchard, grapes (Vitis vinifera L.) showed a greater negative impact on midday leaf water potential when exposed to biochar derived from orchard pruning biomass that underwent a delayed pyrolysis procedure at 500 °C. Furthermore, at a level of 22t $^{ha-1}$, the application of biochar significantly raised stomatal conductance (Akhtar et al., 2014; Baronti et al., 2014).

Cd effects on plants

The plant system becomes unbalanced as a result of the physical substitution of essential cations from the specific binding sites (Shiyu et al., 2020). By transforming soluble or transferable Cd into biologically bound soil apparatuses, soil organic matter decreases the absorption or bioavailability of Cd. Plant proteins are harmed in both structure and function when Cd interacts directly with the sulfhydryl group (-SH). Pollutants such as superoxide ion, hydrogen peroxide, and hydroxyl radicals are produced when plants are exposed to cadmium toxicity, which upsets the plants' antioxidant defense mechanism and damages pigments, lipids, proteins, DNA, and other cellular components (Srivastava, Vaish, Singh, & Singh, 2020; Unsal, Dalkıran, Çiçek, & Kölükçü, 2020). (Fig. 1) demonstrates the harmful consequences of cadmium poisoning on a plant's system. Additionally, Cd demonstrated harmful impacts on soil microbiology, biogeochemical cycles, and enzymatic activities (Aponte et al., 2020).

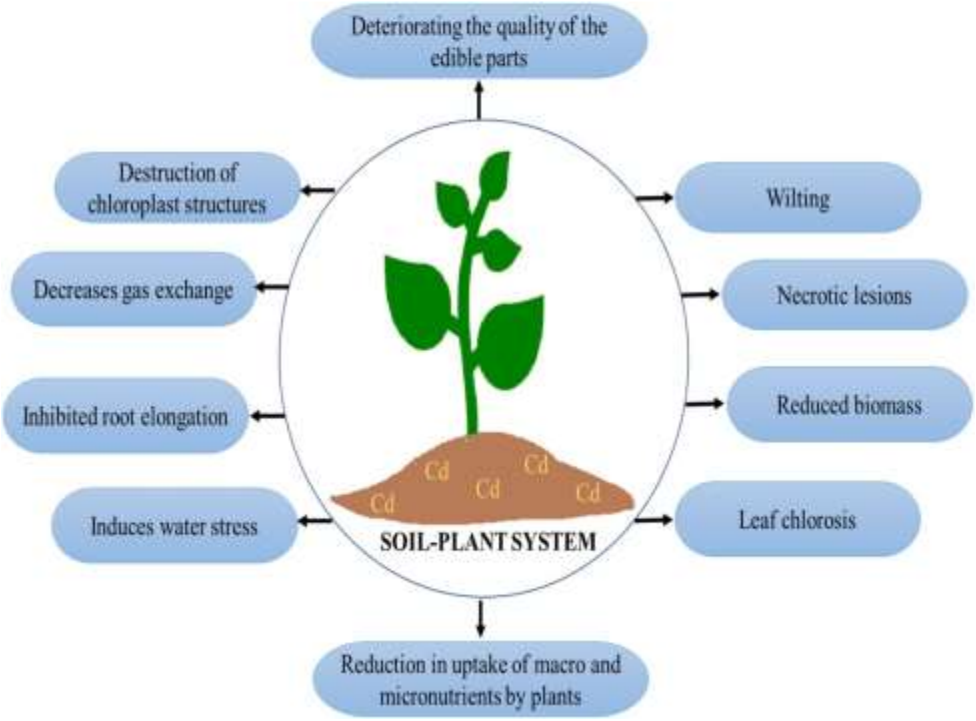


Fig. 1. Cd toxicity effects on enzymatic and physical growth of plants (H. Huang et al., 2021; Shiyu et al., 2020; Unsal et al., 2020).

AtIRT1, ZIP8, HMA4, AtHMA3, OsHMA3, OsLCT1, OsHMA2, OsIRT1, OsIRT2, OsZIP, ZNT5, ZNT1, and MTP1 are among the important genes that have been discovered as being in charge of the translocation and confiscation of Cd in plants (Shiyu et al., 2020; Yan et al., 2019). According to several studies, persons who are exposed to cadmium over an extended period experience decreased mineral density and increased bone fragility. Cadmium acts directly on bone cells in bone culture systems at low concentrations, causing both an increase in bone resorption and a decrease in bone formation (Bhattacharyya, 2009). The lung is one among the organs that cadmium toxicity is thought to target. The inhalation of cadmium comes via smoking, house dust, and/or work-related exposure (Hogervorst et al., 2007). Inhalation causes respiratory stress and damages the respiratory tract. High levels of cadmium in contaminated air have been connected to emphysema, anosmia, and chronic rhinitis. the possible effects of cadmium exposure on lung function using a sample of ninety-six males who had one to three lung function tests performed between 1994 and 2002. Among smokers, they discovered that a decrease in the volume of forced expiration in 1 second, a measure of lung function, was linked to higher urine cadmium levels (Lampe et al., 2008; Sarkar, Ravindran, & Krishnamurthy, 2013). Moreover, cadmium has been demonstrated to cause emphysema, chronic airway inflammation, and pulmonary oxidative stress in rat models that replicate the conditions found in COPD patients. Sprague-Dawley rats administered nebulized Cd by inhaling (0.1% CdCl2 in 0.9% NaCl) showed an initial rise in GSSG within their bronchoalveolar drainage fluid (BALF) during a single treatment lasting one hour, which was countered by a concomitant increase in GSH. Animal groups exposed to Cd once a week for three to five weeks demonstrated a progressive rise in BALF-GSH, which is consistent with observations seen in COPD patients (Kirschvink et al., 2006). Numerous studies have shown that exposure to cadmium impairs testicular function, but it also increases the incidence of reproductive defects in women. The destruction of the vascular endothelium, Leydig and Sertoli cells, intercellular connections, oxidative stress induction, compromised antioxidant defence mechanisms, and the degree of the inflammatory response are some of the mechanisms that lead to cadmium's harmful effects on the testis. These changes affect the testis' morphology and function, impairing spermatogenesis and inhibiting testosterone synthesis (Benoff et al., 2009; Taha et al., 2013).

Cd effects on human health

According to the International Agency for Recherche on Cancer (IARC), cadmium is carcinogenic to humans meaning that exposure to it can increase the risk of developing cancer in several organs, including the lung, breast, prostate, liver, and pancreas (D. Zhao, Wang, & Zhao, 2023). The human body is negatively impacted by lead (Cd), with the kidney and bone being the main organs affected (Aitio & Tritscher, 2004).

It has been demonstrated that cadmium can cause neurodegenerative illnesses and impair cognitive abilities (Górska et al., 2023). By altering the hormonal balance, lowering fertility, causing birth defects, and impeding fetal growth in humans and other mammals, cadmium can also have a serious negative effect on reproductive biology. Cadmium pollution harms aquatic species by interfering with metabolic processes and causing oxidative stress. Numerous studies have shown that elevated Cd concentrations in mammals can cause developmental abnormalities and compromised reproductive health (Priya, Nandhini, & Arockiaraj, 2023). (Fig. 2) is a flowchart illustrating the effects of cadmium toxicity on the human body. Additionally, the body's T cell count and function are altered by the Cd, which hurts the immune system (Ebrahimi et al., 2020).

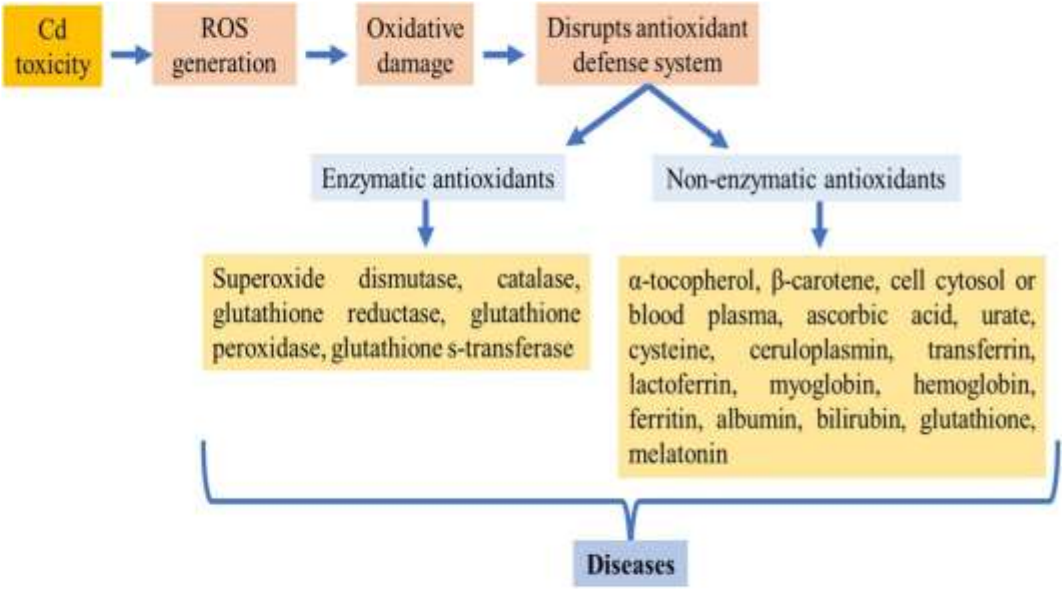


Fig 2. Flowchart illustrating the effects of cadmium toxicity on humans. (Genchi et al., 2020; Saini & Dhania, 2020)

Cadmium poisoning results in infertility, miscarriages, improper embryonic development, and rare morphological and functional problems in the male or female reproductive system. Testicular damage, organ degradation and malfunction, reduced sperm motility, and seminiferous tubule vacuolization, and prostate cancer are a few of the guys' Cd-induced injuries (Bhardwaj, Panchal, & Saraf, 2021).

In cases of renal tubular disease, there may be an increase in the excretion of Cd and other substances. However, Cd is a nephrotoxic substance that can lead to damage to the renal tubules and ultimately lower the glomerular filtration rate (Roels, Hoet, & Lison, 1999). The loss of calcium and phosphorus caused by cadmium exposure also lowers bone density (Järup et al., 2000). Disorders in glucose metabolism are caused by chronic cadmium poisoning (Zhang, Du, Zhai, & Shang, 2014).

Remediation of Cd from the soil by BC

Since farmers developed slash & char farming techniques in antiquity, using BC has been a custom (Zhou et al., 2021). Using BC has been a tradition since farmers invented slash and char farming methods in antiquity as illustrated in (Fig. 3) (Lu et al., 2018; Yoo et al., 2018; Yu et al., 2017). Applying biochar to soil may also have an impact on its physicochemical properties, including pH, microbial populations, redox potential, and organic matter concentration (Beiyuan et al., 2017).

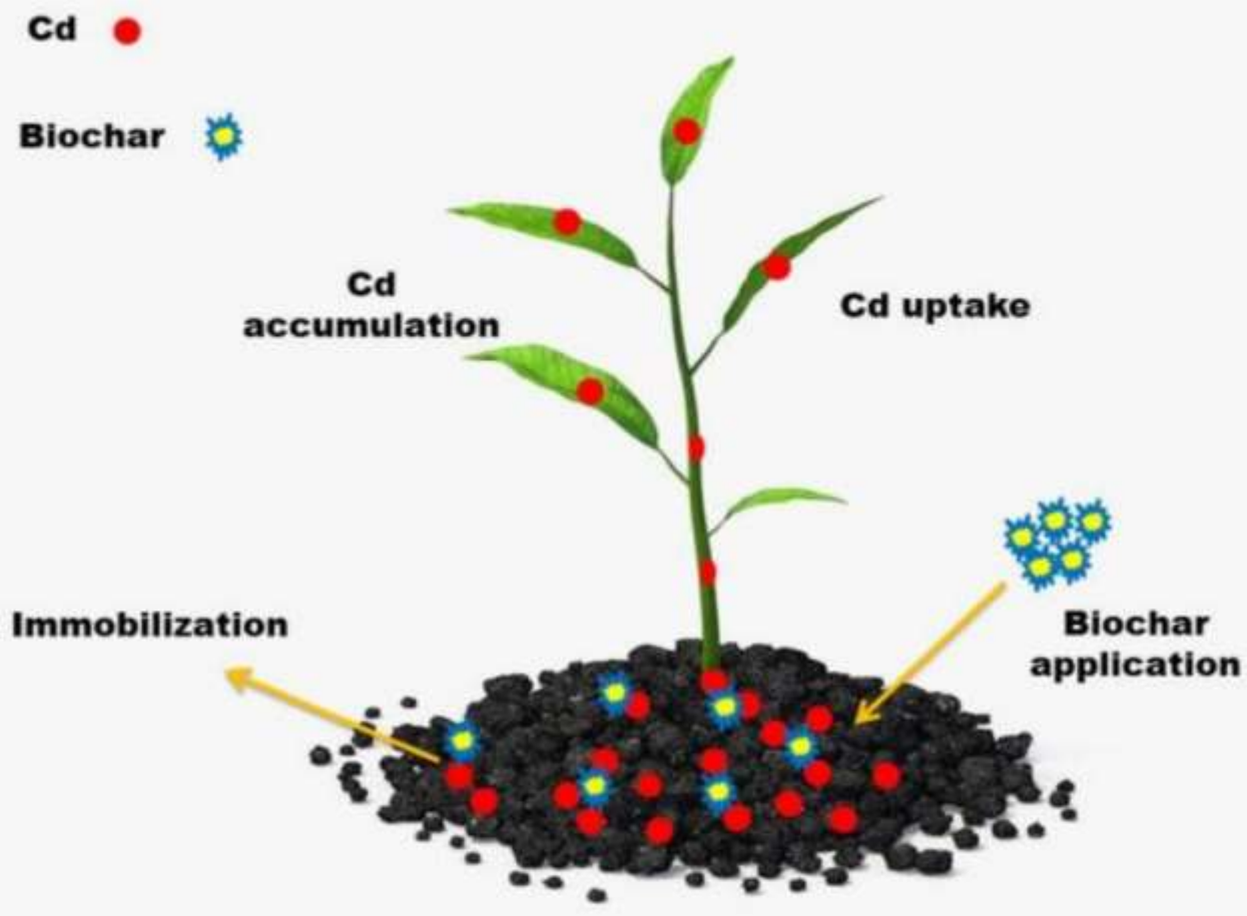


Fig. 3. Cd remediation from soils using biochar. (Rahim, Akbar, & Alatalo, 2022).

Over the last ten years, significant strides have been made in figuring out how biochar can lessen the amount of Cd that soil transfers to cereal crops. In one study, several tools and methods, including FTIR, SEM-EDS, XPS, and XRD, were employed to investigate the processes of interaction between Cd and biochar (Qiu, Chen, Tang, & Zhang, 2018). Subsequent investigation revealed that the primary processes of Cd sorption on biochar in soil were mineral precipitation, surface complexity, and cation-π interactions (Li Liu & Fan, 2018). (Fig. 4) shows the remediation process of Cd through BC. The primary factors influencing the underlying mechanisms of biochar-mediated heavy-metal (Cd) fixation include feedstock properties, biochar surface pore size, oxygen-containing functional groups, and the temperature at which biochar is prepared by pyrolysis (Li Liu & Fan, 2018; Tan, Yuan, Hong, Zhang, & Huang, 2020).

Table 1. Removal rate of Cd heavy metals using biochar from soils

Composite materials or biochar	Heavy metal	Remediation rate	References
Wheat straw	Cd	31.9%	(A. Ali et al., 2019)
Hcl-modified Coconut Shell	Cd	30.1%	(H. Liu et al., 2018)
Wood	Cd	93%	(Debela, Thring, & Arocena, 2012)
Rice straw	Cd	5%	(H. Li et al., 2019)
Orange peel	Cd	10%	(Pande, Pandey, Sati, Bhatt, & Samant, 2022)
Eucalyptus wood	Cd	3%	(Krzyszczak, Dybowski, & Czech, 2021)
Wheat straw	Cd	5%	(Allohverdi, Mohanty, Roy, & Misra, 2021)

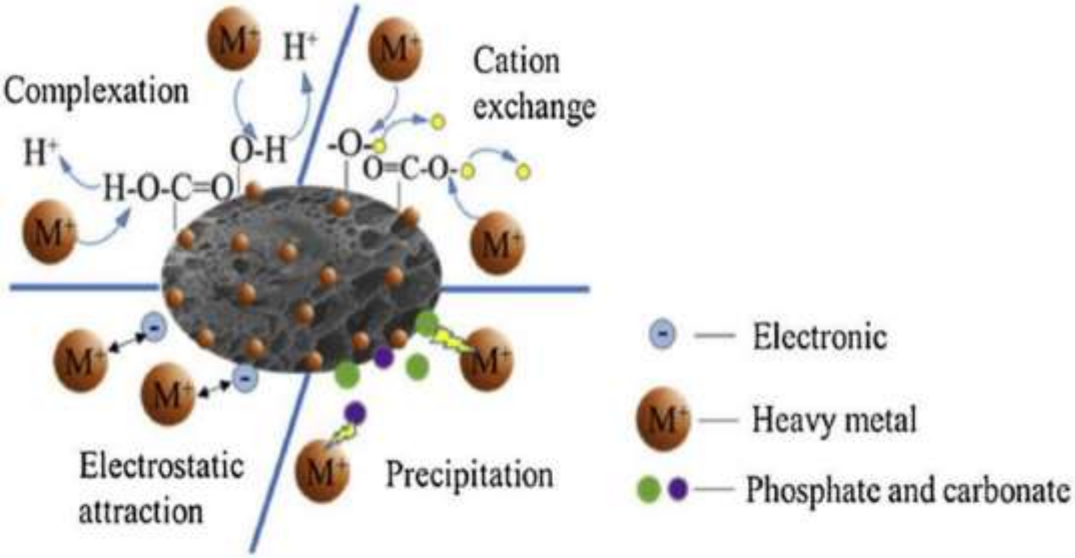


Fig. 4. The remediation process of Cd through BC. (Xiao, Wang, Zhao, & Che, 2020)

Table 2. Biochar characteristics and amendments effects on crop growth and yields.

Crops	Biochar characteristics	Effects	References
Pepper and tomato	citrus wood	Nutrient content in leaves did not differ between treatments and control. Additionally, biochar did not affect the soilless mixture's field capacity.	(Graber et al., 2010)
Maize	virgin pine wood	A one year biochar amendment has a major effect on the biomass output of soil-based biota groups.	(Hamann, Dasari, Kramer, Pressler, & Wurst, 2017)
Rice	wood residues	enhanced xylem sap flow and saturated hydraulic conductivity of the topsoil.	(Asai et al., 2009)
sunflower	wheat straw, pine wood chips	The kind and pace of biochar treatment had an important effect on sunflower seed germination.	(Brennan, Jiménez, Alburquerque, Knapp, & Switzer, 2014)

Potato	Hardwood and softwood	Because biochar may absorb Na+, it can reduce the effects of salinity stress.	(Akhtar, Andersen, & Liu, 2015)
Cotton	Cotton stalk	Increased seed cotton output, leaf water content (RLWC), and chlorophyll stability index (CSI) were seen when biochar was applied, although leaf-accumulated proline was reduced.	(Kannan, 2017)
Soybean	Corn cob	When 20 t ha-1 of biochar was applied, soybean seedlings' chlorophyll and carotenoid levels, shoot length, germination percentage, and seed vigor all rose dramatically in comparison to the control.	(Ali et al., 2017)
Rice	Rice straw	No significant difference	(Yang et al., 2018)

Mung bean	Wheat straw	No significant difference	(Ramzani, Coyne, Anjum, & Iqbal, 2017)
ryegrass	Hardwood	Reduce the amount of lead present in polluted soils	(Beesley, Moreno-Jiménez, & Gomez-Eyles, 2010)
Spinach	Cotton sticks	In spinach and fenugreek, plant biomass rose from 29% to 36% and 32%-36%, respectively.	(Younis et al., 2015)
Mustard	Rice straw	significantly reduced by 14.28% and 53.33%, respectively, the level of activity of MDA and H2O2 levels in leaves.	(Ali et al., 2018)
Spinach	Cotton stalk	increased the protein content of leaves by 20% while reducing the MDA content by 53%.	(Younis et al., 2016)

Remediation of Cd by Silicon NPs

The second most common metalloid found in soil is silicon (Si), mostly found as mono-silicic acid. The literature makes it abundantly clear that Si effectively reduces Cd transport in plants (Kim et al., 2014; Luyckx et al., 2017; H.-Y. Wang et al., 2016). On the other hand, other researchers found that while Si in the form of calcium silicates did not significantly alter the pH of the soil, it can lessen the bioavailability of Cd in the soil and its transport in plants without changing the pH of the soil (Naeem, Saifullah, Ghafoor, & Farooq, 2015).

By forming silicon complexes, it can change the speciation of heavy metals in the soil and reduce the bioavailability of Cd. Furthermore, a large number of silanol groups (Si-OH) are present on the surface of the mineral Si. Because of their capacity for ion exchange, Si-containing groups interacted with Cd to effectively immobilize it in the soil. Therefore, the Fe-O on the surface of hydrate and goliath associates with Si and Cd to form new complexes (Fe-O-Cd and Fe-O-Si), lowering the bioavailability of Cd under the synergistic actions of Si and Cd (Ma et al., 2021). In another study, agricultural soil contaminated with Cd was treated using surface-modified nano-silica (SMNS) soils, and the immobilization and stability of Cd were assessed. The diethylenetriaminepentaacetic (DTPA)-extractable Cd decreased from 1.32 mg/kg to 0.116 mg/kg at the dosage of 1% SMNS on day 180, with a 91.21% stabilization efficiency (Y. Wang et al., 2020). Additionally, it has been demonstrated that foliar spraying with No significant difference at a dose of 20 mg L^{-1} greatly decreased the absorption of Cd and Pb while enhancing the quality and yield of brown rice grains (Hussain et al., 2020). Silicon nanoparticles are also used for the remediation of Cd heavy metals and to reduce the level of Cd in *Oryza sativa* (Cao, Dai, Hao, & Wu, 2020). Silicon nanoparticles are used for the minimization and reduction of the transportation of Cd to aerial parts of the plants (Chen, Zhang, Zhao, Huang, & Liu, 2018). In a different study, silicon oxide (SiO) nanoparticles were applied to wheat to lessen oxidative stress caused by Cd and to decrease its acropetal translocation (S. Ali et al., 2019).

Conclusion

The application of silicon nanoparticles and biochar is summarized in this review. Silicon nanoparticles and biochar both could be helpful in the remediation of Cd heavy metal from contaminated soils and increase the growth and yields of crops. Both biochar and silicon nanoparticles are more beneficial economically as well as environmentally friendly. Moreover, in this review paper the toxic effects of Cd heavy metals on plants' physiological and enzymatic parameters. We need to explore more research on biogenic silicon nanoparticles and biochar for the remediation of Cd heavy metals from soils and uses for increasing the growth of plants in contaminated soil in the future.

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