Tang H *et al.* (2022)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 50, Issue 3, Article number 12778
DOI:10.15835/nbha50312778
Review Article

Biochar: A promising soil amendment to mitigate heavy metals toxicity in plants

Haiying TANG[1a], Shubin WANG [2,3b], Ying LIU[1], Muhammad UMAIR HASSAN[2,3], Ying SONG[1], Guoqin HUANG[2,3]*, Mohamed HASHEM[4,5], Saad ALAMRI[4], Yasser S. MOSTAFA[4]

[1]*Hunan University of Humanities, Science and Technology, College of Agriculture and Biotechnology, Loudi, 417000, China;*
39661026@qq.com; 632084441@qq.com; 402161401@qq.com
[2] *Jiangxi Agricultural University, Research Centre on Ecological Sciences, Nanchang 330045, China; 290598920@qq.com;*
*muhassanuaf@gmail.com; hgqjxes@sina.com (*Corresponding author)*
[3]*Jiangxi Agricultural University, Key Laboratory of Crop Physiology, Ecology and Genetics Breeding, Ministry of Education, China*
[4]*King Khalid University, College of Science, Department of Biology, Abha 61413, Saudi Arabia; mhashem@kku.edu.sa;*
saralomari@kku.edu.sa; ysmosutafa@kku.edu.sa
[5]*Assiut University, Faculty of Science, Botany and Microbiology Department, Assiut, 71516, Egypt;*
[a,b] *These authors contributed equally to the work.*

Abstract

Heavy metals (HMs) toxicity is serious abiotic stress that is significantly reducing crop productivity and posing a serious threat to human health, soil and environmental quality. Therefore, it is urgently needed to find appropriate measures to mitigate the adverse impacts of HMs on soil, plants, humans and the environment. Biochar (BC) has emerged as an excellent soil amendment to minimize the adverse impacts of HMs and to improve soil fertility and environmental quality. Biochar application decreases HMs uptake and their translocation to plant parts by forming complexes and precipitation. Biochar also has improved soil pH, soil fertility and soil cation exchange capacity (CEC) and it also increases adsorption of HMs thus reduces their mobility and subsequent availability to plants. BC application also maintains membrane stability and improves uptake of nutrients, osmolytes accumulation, antioxidant activities, and gene expression, therefore, improves the plant performance under HMs stress. Biochar application also improves the photosynthetic performance by increasing the synthesis of photosynthetic pigments, stomata conductance and increasing the water uptake by plants. Besides this, BC also scavenges ROS by increasing the antioxidant activities, gene expression, and accumulation of proline in HMs contaminated soils. This review highlights the role of BC to mitigate the HMs toxicity in plants. We have discussed the role of BC in the modification of soil properties to induce tolerance against HMs toxicity. Moreover, we have discussed various mechanisms mediated by BC at the plant level to induce tolerance against HMs. Additionally, we also identified research gaps that must be fulfilled in future research studies.

Keywords: anti-oxidant; biochar; heavy metals; oxidative stress; photosynthesis; reactive oxygen species

---

Received: 01 Jul 2022. Received in revised form: 02 Aug 2022. Accepted: 04 Aug 2022. Published online: 25 Aug 2022.
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

Introduction

The rapid increase in urbanization and industrialization has increased heavy metals (HMs) pollution across the globe. HMs are serious concern for humans and animals and it is also negatively affecting soil health, crop productivity and quality (Han *et al.*, 2020; Hassan *et al.*, 2021). Though HMs are easily transportable and have difficult degrading in the environment, therefore they are easily concentrated by plants and enter into the food chain which imposes serious threats to human health (Shen *et al.*, 2018; Han *et al.*, 2020). In recent time, diverse pollutants are exerting negative impacts on soil, humans, plants and overall, the ecosystem (Rai *et al.*, 2019; Rahim *et al.*, 2021). Amid these pollutants, the potential toxic metals (PTM) have raised concern owing to their non-degradable nature, higher mobility and toxicity (Yu *et al.*, 2017). The PTM includes arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), lead (Pb), silver (Ag), manganese (Mn), mercury (Hg), molybdenum (Mo) and nickel (Ni) which are posing serious threats to agriculture productivity, food safety, food security and human health (Wang *et al.*, 2018; Sagbara *et al.*, 2020; Xu *et al.*, 2022).

The higher concentration of HMs imposes negative impacts on crops (Antonangelo and Zhang, 2019) owing to their higher mobility, bio-accumulation behaviour and toxicity (Seneviratne *et al.*, 2019). HMs impact various plant processes ranging from nutrient homeostasis, photosynthesis, gas exchange characteristics, osmolytes accumulation and antioxidant activities (Sanjosé *et al.*, 2021). Toxic metals also develop toxicity by binding the metal ions to sulfhydryl groups (-SH), in the amino acids and proteins which inhibit the plant's physiological activity and degrade structure of different enzymes (Rehman *et al.*, 2018). HMs also induces the production of reactive oxygen species (ROS) which is considered to be a major effect caused due to HMs (Zhang *et al.*, 2019). HMs induced ROS pose serious damage to cellular membranes, proteins, lipids, and various micro as well as macromolecules (Wang *et al.*, 2019). Besides this HMs also reduce the root and shoot growth, photosynthetic pigments, accumulation of proteins and free amino acids (FAA), and increase the accumulation of MDA and H_2O_2 which in turn reduce the overall productivity (Hassan *et al.,* 2019).

It is essential to develop the appropriate measures to reclaim the contaminated soils to ensure healthy soils and ecosystem. Various strategies including immobilization, precipitation, ion exchange, use of organic amendments, nano-materials, adsorption, and bioremediation are being used globally to remediate HMs contaminated soils (Yu *et al.*, 2013; Haider *et al.*, 2022). These conventional remediation strategies require sophisticated instruments and they are very costly to remediate the HMs contaminated soils (Rahim *et al.,* 2022). Thus, it is necessary to shift from conventional strategies to eco-friendly and nono-remediation strategies such as the use of carbon based nano-materials (Huang *et al.*, 2015). Biochar (BC) is a carbon rice material produced by pyrolysis of different feed-stocks in the absence of oxygen. It has gained considerable attention globally as a green, innovative and sustainable tool in agriculture, energy production and environment protection owing to its unique physio-chemical characteristics (Aamer *et al.*, 2020). BC has a high specific area and surface activity, and it also has a better porous structure, oxygen-containing functional groups and higher ion exchange capacity which make him an important amendment to be used in agriculture (Liu *et al.*, 2020; Rahim *et al.*, 2020).

In recent decades BC has got attention as an important tool to manage environmental pollution, and remediate contaminated soils with additional benefits of improved soil fertility, soil quality and carbon sequestration (Rahim *et al.*, 2019; Hu *et al.*, 2020; Azadi and Raiesi, 2021). Recently, BC has emerged as cost effective and environmentally friendly approach for minimizing the effects of HMs (Yuan *et al.*, 2019). BC application reduces the absorption of HMs and it also increases the antioxidant activities which provide protection to plants against HMs (Virk *et al.*, 2021). Besides BC also improves the photosynthetic efficiency, accumulation of osmolytes, soil water holding capacity (WHC), soil quality and reduces the HMs uptake and restricts their entry into the plant body resulting in substantial improvement in plant growth and development on contaminated soils (Virk *et al.*, 2021). Thus, it is imperative to highlight the role of BC in the remediation of polluted soils. The present review article presents the recent progress on the role of BC to remediate HMs contaminated soils. We have presented information on how BC decreases the HMs toxicity by affecting the soil properties. Moreover, we also discussed the role of BC in mediating different responses of plants to alleviate HMs toxicity.

Plant responses to heavy metals

HMs enters into the food chain by plants and they pose serious threats to human and animals. HMs toxicity negatively affects plant biochemical, molecular and physiological processes (Figure 1) which in turn cause a significant reduction in growth and development (Rasheed *et al*., 2020; Raza *et al*., 2021). HMs have been recorded to reduce seed germination, plant growth and cause different morphological changes (Ghori *et al*., 2019). For instance, Hg stress (80 µg ml^{-1}) significantly reduced the root and shoot growth and leaves production in *Jatropha curcas* (Marrugo-Negrete *et al*., 2016). Likewise, in another study, it was noted that Ni toxicity reduced the germination owing to a reduction in protease and α-amylase activities (Ashraf *et al*., 2011). Further, negative effects of Cd on leaf area were also observed in tomatoes and it another study authors also noted Cd induced chlorosis in *Phaseolus vulgaris* (Bahmani *et al*., 2012).

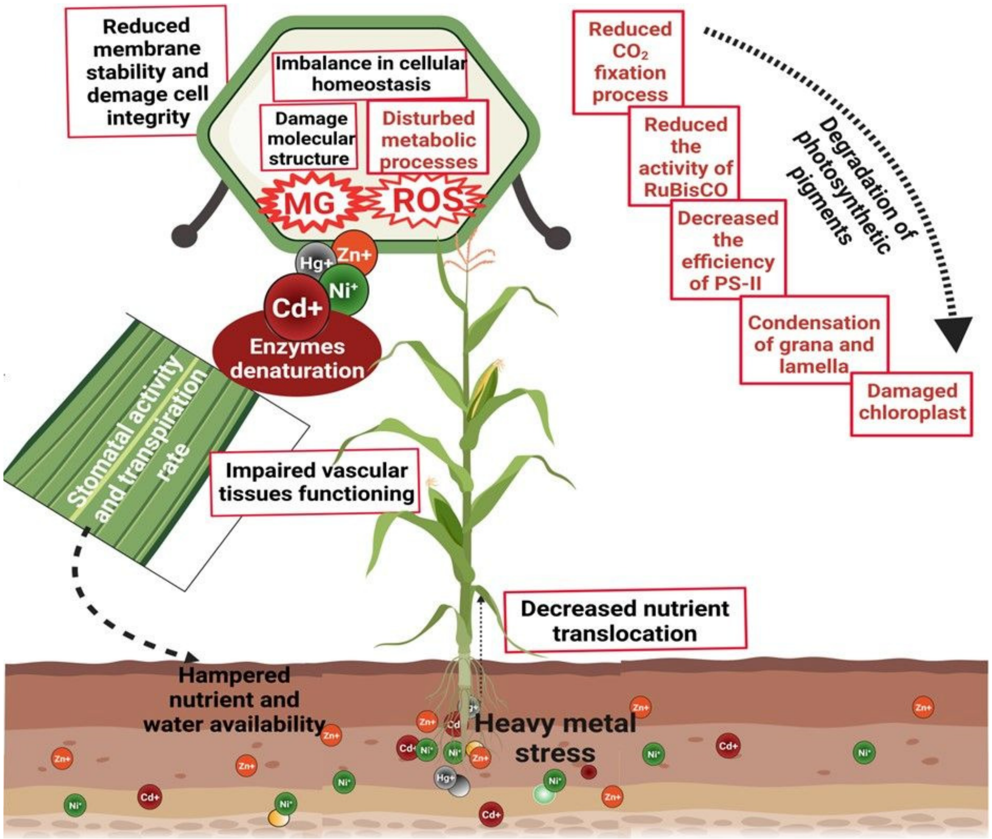

Figure 1. Plant response to HMs. The toxic metals decrease membrane stability, reduce water uptake, efficiency of PS-II, stomata conductance, photosynthetic and transpiration rates thereby resulting in substantial reduction in plant growth and development

Roots are the first plant organ that comes in contact with HMs and these HMs significantly reduced the root growth, root area, and increased root dieback which reduced the water and nutrient uptake resulting in a significant reduction in plant growth (Rucińska-Sobkowiak, 2016). The cell wall of roots also becomes hard with exposure of toxic metals which also inhibit plant growth (Zhao *et al*., 2010). Plant cell membranes prevent the entry of unwanted materials into plant organelles however; HMs disturbs membrane integrity and increase the loss of important solutes on exposure to HMs stress (Janicka-Russak *et al*., 2012). HMs also disrupts uptake of nutrients and water which inhibit the synthesis of photosynthetic pigments which is one of the major reasons of growth reduction under HMs stress (Yang *et al*., 2020). Toxic metals also damage the photosynthetic apparatus and reduce the photosynthesis rate by reducing the chlorophyll synthesis (Table 1) and thickness of mesophyll cells (Schmidt *et al*., 2020). Toxic metals also reduce the rate of electron transport and reduce the efficiency of PS-II by decreasing the reaction site therefore, leading to a significant reduction in photosynthetic efficiency (Mathur *et al*., 2016).

HMs also reduces the nutrient and water uptake and their translocation in the plant body (Raza *et al*., 2021). The reduction in water uptake reduces transpiration, stomata activity, photosynthesis and water uptake (Hussain *et al*., 2013). For instance, a substantial reduction in stomata activity was noted in *Pistacia vera* due to toxicity of Zn (Tavallali, 2017). Moreover, toxic metals also affect the functioning of the xylem and phloem and they also reduce the root xylem area (Vaculík *et al*., 2012). HMs also competes with essential nutrients at the binding sites of different enzymes and inhibit their activity (Ghori *et al*., 2019). Exposure to HMs (Cr) also reduces the chlorophyll contents, starch contents and protein contents (Rath *et al*., 2019), conversely, HMs induced a significant increase in the accumulation of soluble sugars and proline (Song *et al*., 2020). In another study conducted on kenaf; it was noted that Cu reduced the root and shoot growth by increasing the H_2O_2, MDA accumulation, and electrolyte leakage (EL), however, these negative effects were reduced by increasing the activities of antioxidant defense system (Saleem *et al*., 2022). Cowpea plants explored to Fe toxicity also showed an increase in MDA contents and membrane damage (Ifle *et al*., 2020). HMs also induced a substantial increase in MDA and H_2O_2 accumulation (Lokhande *et al*., 2020), however, plants have an excellent defense system that search, neutralize and remove the ROS and protect the plants from HMs induced oxidative stress (Hasanuzzaman *et al*., 2020).

Toxic metals also affect the CO_2 fixation and assimilation activities and it has been reported that toxic metals (Cd and Zn) severely inhibited the CO_2 fixation and assimilation in wheat plants (Paunov *et al*., 2018). Rubisco plays a crucial role in photosynthetic processes however; HMs substantially reduced the Rubisco activity which in turn causes a significant reduction in photosynthetic performance (Son *et al*., 2014). ROS produced owing to HMs damage DNA, proteins, cellular membranes which are also major reasons for reduction in plant performance under HMs stress (Hasanuzzaman *et al*., 2020). Plants also produce diverse metal binding structures and chelating agents and ligands which plant an important role to cope with the toxic effects of HMs (Raza *et al*., 2021). It has been reported that microRNA significantly improved the *Vaccinium myrtillus* tolerance against Cd and it regulated its responses to counter the effects of Cd stress (Casarrubia *et al*., 2020; Ding *et al*., 2020). MicroRNA expression also improves the accumulation of different secondary metabolites that appreciably improved the Al and Cd tolerance in transgenic tobacco plants (Sáenz-de la O *et al*., 2020).

Biochar a potential amendment to improve plant performance under HMs toxicity

Biochar is a carbon rice material produced by pyrolysis (300-1000 °C) from different feedstock including crop residues, wood chips, animal and chicken manure, and municipal solid sludge under partial or anaerobic conditions (Diatta *et al*., 2020). BC is a rich source of carbon besides this it also contains an appreciable amount of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), oxygen (O) and hydrogen (H) (Adnan *et al*., 2020; Seleiman *et al*., 2020). BC has got appreciable attention across the globe in the last two decades owing to its ability to improve carbon sequestration, soil fertility and remediate contaminated soils and waste-water (Alkharabsheh *et al*., 2021). Biochar application improves nutrient retention, microbial activities, soil structure, and nutrient absorption by plants which ultimately increased plant growth and yield (Bonanomi *et al*., 2017). Biochar is considered to be recalcitrant C that slowly degrades in soil and takes thousands of years to full degrade (Pariyar *et al*., 2020).

Table 1. Effect of HMs stress on growth, physiological and biochemical process of various crops

Crop species	Heavy metal stress	Effects	References
Maize	Cu stress (160 mg/L)	Cu stress reduced germination, root and shoot growth and biomass yield increased SOD, POD and CAT activity	(Xin *et al*., 2022)
Maize	As stress (100 mg/kg)	As stress decreased root and shoot growth, RWC, photosynthetic pigments and increase proline and MDA contents, EC and H_2O_2 and activities of APX, CAT, POD and SOD	(Khan *et al*., 2022)
Maize	Cd stress (500 µM)	Cd stress reduced the root and shoot growth, chlorophyll contents and increased MDA and H_2O_2 accumulation and activities of APX, CAT and POD	(Saleem *et al*, 2022)
Maize	Cd stress (100 mg/kg)	Cd stress reduced chlorophyll contents, photosynthetic and transpiration rates, growth and increased ROS production and activities of antioxidants	(Razzaq *et al*., 2022)
Wheat	Cd stress (250 µg/mL)	Cr toxicity reduced germination percentage, root and shoot growth and increased ROS production activities of APX, CAT, POD and SOD	(Ilyas *et al*., 2022)
Mash Bean	Cd stress (20 mg/kg)	Cd stress reduced the root, shoot growth, chlorophyll contents, RWC, antioxidant activities and increased the MDA, H_2O_2 accumulation and EL	(Umer Chattha *et al*., 2021)
Maize	Pb stress (7.5 mM)	Pb stress reduced the growth yield, photosynthetic pigments, N, P and K and increased MDA accumulation, EL and antioxidant activities	(Sofy *et al*., 2020)
Oat	Ni stress (40 mg/kg)	Ni toxicity reduced germination, growth, biomass production, chlorophyll contents and increased SOD activity and proline accumulation	(Gupta *et al*., 2017)
Maize	Pb stress (250 mg/kg)	Pb toxicity causes retarded growth and inhibits germination and reduced the chlorophyll and carotenoids	(Nawaz *et al*., 2017)
Beans	Cu stress (75 µM)	Cu stress reduced biomass production, Zn, K and Fe uptake and increased GPX and CAT activity and accumulation of H_2O_2	(Bouazizi *et al*., 2010)

The field application of BC improves soil carbon, soil pH, soil porosity, bulk density, WHC, nutrient use efficiency, and nutrient availability (N and P) which in turn improved crop growth and yield (Wang *et al*., 2020). Moreover, BC also reduces soil hardening and it also increases soil microbial activities and nutrient cycling (Figure 2) which favours a substantial increase in plant growth (Pariyar *et al*., 2020). Biochar also helps to reclaim the HMs contaminated soils by increasing the adsorption of HMs and other contaminants (Inyang and Dickenson, 2015). Nonetheless, the effect of BC largely depends on the feedstock material, pyrolysis temperature, soil texture and particle size of BC (Gao and DeLuca, 2016). The use of BC also remediates soils, reduces the wastage of resources. Moreover, BC also possesses excellent physiochemical characteristics including porous structure, hydroxyl and carbonyl groups which play an imperative role in the degradation of HMs (Zhu *et al.*, 2015). BC is considered to be an economical, environmentally friendly and superior quality amendment to remediate HMs contaminated soils (Liang *et al.*, 2021).

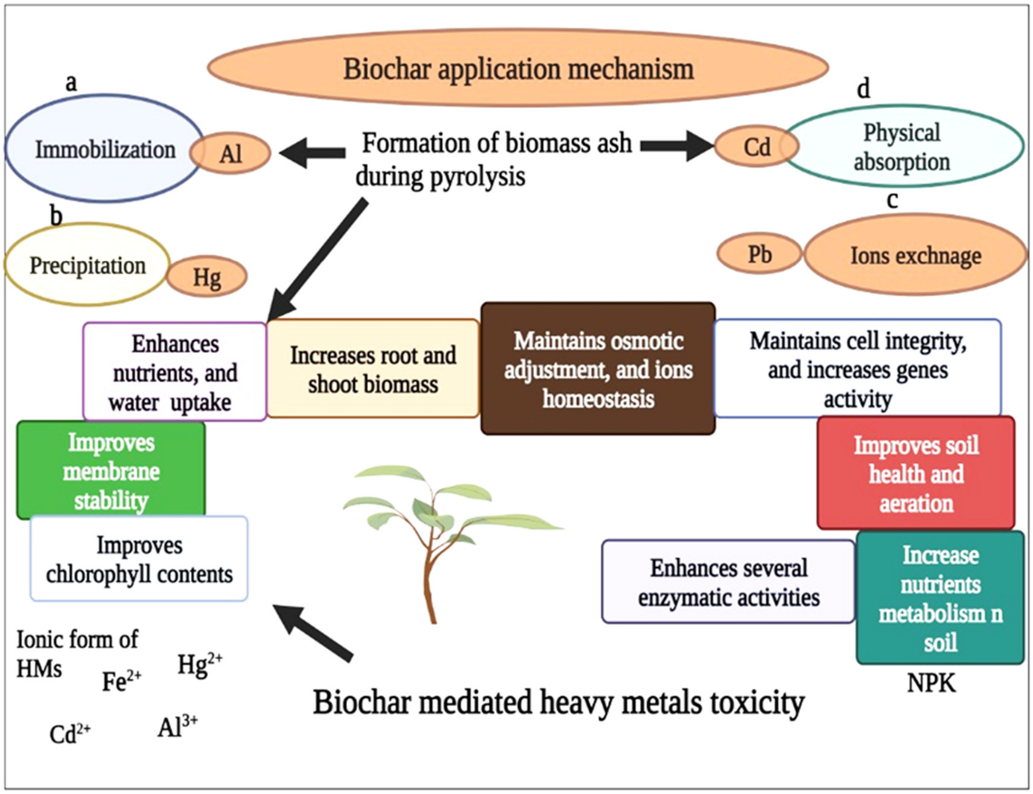

Figure 2. Role of BC in mitigating the HMs toxicity in plants. BC application cause immobilization, precipitation, and absorption of HMs and therefore, reduces toxicity to plants. Moreover, BC also improves chlorophyll contents, nutrient and water uptake, antioxidant activities, osmolyte accumulation and genes which in turn reduce the toxic effects of HMs on plants.

Biochar reduces HMs toxicity by farming complexes and precipitation

BC substantially mobilize the HMs thereby reduce the uptake and subsequent accumulation in plants (Meng *et al.*, 2018). Different functional groups such as carboxyl (COOH) and oxygen groups fix the HMs ions by ion exchange process and reduce their uptake by plants (Ho *et al.*, 2017). BC also releases Ca and Mg on its surfaces owing to higher CEC which fix the HMs ions and reduce their availability (Li *et al.*, 2015). Moreover, increased adsorption capacity of BC also attributed to its higher CEC (Tang *et al.*, 2013). In few studies it has been also reported that BC ensures electrostatic attraction of positively charged owing to its higher electro-negativity (Aamer *et al.*, 2020). The negatively charged surface groups affect electro-negativity which is increased at higher pH which in turn increases the adsorption of HMs (Tong *et al.*, 2011). BC fix the HMs by farming surface complexes which in turn reduce the HMs availability and their deleterious impacts on plants (Xu *et al.*, 2017). Similarly, surface functional grounds of BC also immobilize the HMs by forming surface complexes (Xu *et al.*, 2017). The functional groups like COOH and OH in BC enable the binding site for HMs to complexes which increase the adsorption of HMs (Tan *et al.*, 2017). Moreover, different ions (Si, S and Cl) in BC also combine with HMs and reduce the mobility in soils (Tan *et al*., 2017). The mineral present in BC also form insoluble precipitates with fix the HMs and reduce their availability and mobility in soil (Cao and Harris, 2010). For instance, inorganic P present in BC induced the precipitation of Pb and reduced its mobility and availability (Liu *et al*., 2016; Liang *et al*., 2021).

Biochar mitigates HMs toxicity by modifying soil properties

Biochar improves the soil pH owing to its alkaline pH which in turn affects the HMs availability in soils (*Yu et al*., 2019). The mobility of HMs in soils is governed by soil pH (Ding *et al*., 2020). Similarly, HMs complexation is also significantly affected by soil pH and an increase in soil pH following BC application reduces the HMs desorption in soils (Jiang *et al*., 2012). The increase soil pH by BC substantially reduced the toxicity of HMs. Moreover, BC application also significantly increased the soil CEC owing to the fact BC has very high CEC (Zhang *et al*., 2017). Different authors noted that an increase in soil CEC due to BC significantly decreases the solubility as well as leach-ability of HMs (Bashir *et al*., 2018). Increasing soil CEC owing to the application of BC improves the fixation of Cu and Pb (Ma *et al*., 2010; Rees *et al*., 2014). Similarly, it has been also reported that minerals present in BC increase the adsorption of HMs in soils (Bian *et al*., 2014; Rees *et al*., 2014). Similarly, organic carbon (OC) present in BC also reduces the availability, and mobility of HMs in soils (Zhu *et al*., 2016). The labile forms of HMs are converted into less mobile forms by binding with OC present in BC which reduced HMs mobility in soil (Abdelhafez *et al*., 2014). The carbon present in BC has a porous structure which forms complexes with HMs and reduces their mobility and subsequent availability to plants (Carter *et al*., 2013). Biochar is considered as an effective for agriculture and the management of different environmental issues (Xu *et al*., 2014). The application of BC modifies the polluted soils and reduced the availability of HMs and curtails the adsorption of HMs by plants (Namgay *et al*., 2010). Because of the porous structure of BC, it increases the soil WUC, nutrient uptake and decreases the density of soil thereby improves soil aeration and consequently microbial activities (Mansoor *et al*., 2021). The increase in microbial activity following the application of BC also plays a crucial role to manage the HMs (Liang *et al*., 2014).

Biochar improves membrane stability and plant water relations under HMs

Toxic metals induce oxidative stress which damages the membrane integrity and increases the accumulation of MDA, H_2O_2 and electrolyte leakage (EL) (*Abbas et al*., 2017; Farhangi-Abriz and Torabian, 2017). However, BC has excellent potential and it significantly reduces the HMs induced oxidative damage in plants. For instance, in spinach plants BC markedly reduced the MDA and EL and increased the membrane integrity under Cd stress (Younis *et al*., 2016). The application of BC maintains membrane integrity by decreasing the accumulation of toxic metals in plant parts (Abbas *et al*., 2017). The HMs induced oxidative stress induced ROS production which disturbs plant functioning and the integrity of cellular membranes (Hossain *et al*., 2012).

Nonetheless, the application of BC significantly improved the accumulation of proline (Pro) which improved the antioxidant activities and protected the membranes from the toxic effects of HMs (Mazhar *et al*., 2020). In another study, it was reported that rice residue bases BC reduced the MDA contents in rice plants by increasing CAT, POD and SOD activities under Cd stress (Zhang *et al*., 2014). The application of BC substantially improved the activities of malic enzymes, glutamate dehydrogenase, iso-citrate dehydrogenase, and POD which boosted plant functioning and protected the cellular membrane of bean plants from the toxic effects of Zn stress (Hmid *et al*., 2015). In another study, it was noted that BC application, enhanced photosynthetic pigments (Table 2), relative water contents (RWC), leaves/plant and improved anatomical features of plants (Hafez *et al*., 2020). BC is carbon-rich product and it has a porous structure which increases the soil WHC thereby improve the water uptake and maintains higher RWC in plants growing under stress conditions (Amonette and Joseph, 2009; Verheijen *et al*., 2010; Fiaz *et al*., 2014). The HMs toxicity increased the EL by increasing the formation of ROS, nonetheless, application of BC decreased the EL and increased the RWC which was linked with improved nutrient availability and soil WHC (Beesley *et al*., 2014; Naveed *et al*., 2020a). The increased RWC and decrease in EL following BC application helps the plants to sustain better under HMs toxicity (Bashir *et al*., 2020).

Table 2. Effect of biochar on growth, and physiological attributes under HMs stress

Crop	**Heavy metal stress**	**Biochar application**	**Effects**	**References**
Wheat	Cd stress (20 mg/kg)	50 kg/ha	BC application improved the root and shoot growth, biomass production, chlorophyll contents, and accumulation of TSS, TSP FAA and phenolics	(Hussain *et al*., 2022)
Barberry	Cd stress (30 mg/kg)	125 g/kg	BC application increased plant height, plant biomass, chlorophyll contents, RWC, total phenolics, total flavonoids and antioxidants	(Khosropour *et al*., 2022)
Wheat	Ni (1.5 mg/kg)	50% (W/W)	BC improved the root and shoot growth, photosynthetic parameters and grain yield	(Shahbaz *et al*., 2019)
Sunflower	Ni stress (77 mg/kg)	50% (w/w)	BC reduced the Ni accumulation and increased the biomass production and grain yield	(Shahbaz *et al*., 2018)
Wheat	Cr stress 50 mg/kg)	5% (W/W)	Biochar improves growth, germination, chlorophyll and carbohydrate contents	(Arshad *et al*., 2017)
Wheat	Cd stress (2.86 mg/kg)	5% (w/w)	BC increased plant-height, root dry mass, photosynthetic pigments and gas exchange parameters	(Abbas *et al*, 2017)

Biochar improves uptake of nutrients under HMs stress

A balance between organic as well as inorganic nutrients is considered to be essential for getting maximum plant growth and yield. Toxic metals disturb nutrient uptake, therefore, cause a huge reduction in plant growth. BC application appreciably improved the nutrient uptake and resulted in significant improvement in plant performance under stress conditions. The application of BC increases the concentration of N, P, K, and S which in turn improved the plant growth and yield under stress conditions (Puga *et al*., 2015). In another study, it was noted that sewage sludge BC markedly improved the N and P uptake and decreased the concentration of K in rice plants grown in metal contaminated soils (Khan *et al*., 2014). The application of BC appreciably improved the concentration of P, K, Ca, and Mg in rapeseed shoots grown under metal contaminated soils as compared to un-amended soil (Houben *et al*., 2014). Similarly, Younis *et al*. (2015) also reported a reduction in P and K in spinach plants due to BC application.

Biochar supply also reduced N, P and Ca availability in Cd and Zn polluted soils (Rees *et al*., 2015; Rees *et al*., 2014). Whereas, Yang *et al*. (2016) noted that BC application increased the available P in the soil in dose dependent manner. Moreover, Wagner and Kaupenjohann (2015) concluded that BC application had no impact on N and Mg concentrations however, BC application significantly increased the concentration of K while reduced the concentration of Ca concentration in plants. In another study, the application of maize residue-based BC in Cr polluted soil significantly improved the concentration of N, P and K in lettuce plants (Nigussie *et al*., 2012). Similarly, BC application also increased the concentration of Si owing to the presence of phytoliths in the BC which in turn improved the growth of rice plants (Houben *et al*., 2014; Dad *et al*., 2020). BC also induced an increase in Si availability by increasing the soil pH (Houben *et al*., 2014; Dad *et al*., 2020).

It has been documented that an increase in soil pH following BC application solubilises Si in soil which in turn increases its uptake by plants (Rizwan *et al*., 2012). Many authors also noted that BC application could increase Zn and Mn in plant parts growing in Cd contaminated soils (Abbas *et al*., 2017; Rahi *et al*., 2022). The uptake of N was appreciably increased in rice crop following the application of farm yard manure and BC (Majeed *et al*., 2022). The supply of BC increases the supply of protons to reduce the Cr toxicity (Mansoor *et al*., 2021). Many researchers also noted a substantial increase in nutrient uptake following BC application under HMs contaminated soils (Naveed *et al*., 2020a; Naveed *et al*., 2020b).

Biochar improves plant photosynthetic performance under HMs

Photosynthesis is an imperative physiological process that plays a crucial role in the growth and development of plants (Hassan *et al*., 2022). HMs toxicity significantly decreased the synthesis of photosynthetic pigments and the number of stomata which cause a significant reduction in photosynthetic and transpiration rate, stomata conductance and inter-cellular CO_2 (Akhtar *et al*., 2017; Bertel *et al*., 2017; Li *et al*., 2018). BC application significantly improved the synthesis of photosynthetic pigments, and carotenoids which in turn improved the photosynthetic performance under Cr stress (Zhu *et al*., 2020; Bashir *et al*., 2021). BC application substantially improved the stability of HMs in soil and alleviates the Cd induced toxic effects on chlorophyll synthesis and photosynthesis (Zoghi *et al*., 2019). BC application also improved the gas exchange characteristics, and chlorophyll contents by immobilization of HMS (Mehdizadeh *et al*., 2019; Kang *et al*., 2022). The beneficial effect of BC can be seen in terms of improved physiological and biochemical traits. The application of BC substantially increased the synthesis of photosynthetic pigments which in turn improved the plant photosynthetic efficiency in Cr contaminated soils (Bashir *et al*., 2020). The increase in chlorophyll contents, photosynthetic and transpiration rates following the addition of BC has been well documented under HMs stress (Akhtar *et al*., 2015; Younis *et* al., 2015; Younis *et al*., 2016). The increase in photosynthesis following BC addition could be attributed to the improved ultra-structure of chloroplast (Abbasi *et al*., 2015).

Biochar strengthens anti-oxidant defense system under HMs toxicity

Plants produce ROS in a controlled amount under normal conditions, however, under stress conditions; the production of ROS is increased many times which causes oxidative damage to DNA, proteins and lipids and also leads to cell death (Kohli *et al*., 2019). Plants also have excellent defense system to cope with ROS (Niamat *et al*., 2019). It has been noted that the application of organic amendments improved the plant's tolerance against abiotic stresses by increasing the antioxidant activities (Niamat *et al*., 2019). The application of BC significantly improved the antioxidant activities by reducing the bioavailability of Cr (Naveed *et al*., 2021). In another study conducted on maize and *Brassica rapa* it was reported that BC addition significantly improved the activity of CAT (Arshad *et al*., 2017; Seneviratne *et al*., 2017; Ali *et al*., 2018; Bashir *et al*., 2020). Moreover, Sabir *et al*. (2020) also noted that Cr stress reduced the antioxidant activities (CAT, GSH, GR, GP, GPX and GST) *Brassica* leaves, however, BC significantly increased this antioxidant activity.

Under HMs toxicity burst of ROS is considered to responsible for lipid per oxidation which ultimately reduced the cell membrane permeability (CMP) (Tanveer and Ahmed, 2020; Tanveer and Wang, 2019). The application of BC improved the antioxidant activities which leads to a significantly increase CMP under HMs *(Dad et al*., 2020). BC also reduced the oxidative stress by reducing ROS production and increasing the antioxidant activities (Khan *et al*., 2015). The increase in antioxidant activities following BC application prevents the plants from oxidative damages (Mehdizadeh *et al.*, 2019). BC application appreciably increased the APX activities however; BC had no impact on activity of CAT (Dad *et al., 2020)*. Similarly, in another study, BC application significantly improved the CAT, POD and SOD activities (Table 3) in flag leaf of rice (Zhang *et al.*, 2014). Likewise, BC application significantly improved CAT and POD (Table 3) which in turn decreased the MDA and H_2O_2 accumulation and EL (Farhangi-Abriz and Torabian, 2017). The application of BC and bio-fertilizers increases the activities of antioxidant enzymes which in turn increase the plant response to Cd stress (Nookongbut *et al.*, 2019; Novak *et al.*, 2019). Likewise*, Zhu et al.* (2020) recorded that BC application improved the CAT and SOD activity and alleviated the Cd induced oxidative stress in cotton (Zhu *et al.*, 2020). Besides this BC also increases the activities of CuZn-SOD, Mn-SOD, and Fe-SOD which decompose the H_2O_2 and protect the plants from HMs induced oxidative stress (Zhu *et al.*, 2020). The improved antioxidant activities due to BC application are linked with improved plant health (Bashir *et al.*, 2021; Naveed *et al.*, 2021).

Table 3. Effect of bicochar on oxidative stress markers and antioxidant activities under HMs

Crop	Heavy metal stress	Biochar application	Effects	References
Chili	Ni stress (50 mg/kg)	150 g/kg	BC reduced the H_2O_2 and MDA accumulation and increased CAT, POD, APX and SOD activities	(Turan, 2022)
Mustard	Pb stress (250 mg/kg)	(12.8 mg/g)	BC application decreased the MDA contents and increased activity of antioxidant enzymes (SOD, POD and CAT)	(Rathika *et al.*, 2021)
Quinoa	As stress (30 mg/kg)	2% (W/W)	BC reduced the oxidative stress and increased the CAT, POD and SOD activities	(Shabbir *et al.*, 2021)
Cotton	Cd stress (4 mg/kg)	6.8 t/ha	BC application reduced MDA accumulation and EL and increased the SOD, CAT and POD activities	(Zhu *et al*, 2020)
Cotton	Cd stress (4 mg kg^{-1})	3% (W/W)	BC reduced MDA and EC while increased SOD, POD and CAT activities	(Zhu *et al*, 2020)
Corn mint	Pb stress (32 mg/kg)	4% (w/w)	BC improved the antioxidant (SOD and POD) activity to encounter the Pb induced oxidative damage	(Nigam *et al.*, 2019)

Biochar improves osmolyte accumulation under HMs toxicity

Stress related metabolites such as proline, soluble sugars, free amino acids (FAA) and total soluble proteins (TSP) induce resistance against stress conditions by avoiding cell damage from ROS (Sinay and Karuwal, 2014). Proline plays diverse functions in plants ranging from enzyme protection to osmotic adjustment, detoxification of ROS and maintenance of protein synthesis (Aly and Mohamed, 2012). BC application significantly improved the Pro accumulation which in turn increased the antioxidant activities and protect the plants from oxidative stress (Mazhar *et al.*, 2020). The BC induced increase in Pro improves osmotic adjustment, stabilizes enzymes and proteins and protects the plants from ROS (Szabados and Savouré, 2010). Phenolic compounds play a crucial role in plants and they prevent the plants from various stresses due to their higher antioxidant activities (Rohani *et al.*, 2019). Nonetheless, BC application improved the accumulation of phenolic compounds which in turn improved the antioxidant activities and protect the plants from Cd induced toxic effects (*Dad et al., 2020*).

Similarly, radish plants showed a reduction of 13% in shoot phenolic contents however, BC application markedly improved the phenolic concentration in both roots and shoots of radish plants (Dad *et al.*, 2020). The exposure of radish plants to Cd stress also reduced the root and shoot protein contents however, BC application markedly improved the concentration of protein in roots and shoots of radish plants grown under Cd stress (Dad *et al.*, 2020). In addition, BC application also significantly increase Pro, TSP, FAA and crude fat contents which in turn improved the plant tolerance against Cd stress (Borchard *et al.*, 2014). Similarly, Chen *et al.* (2020) also noted that BC application improved the Pro, soluble sugars and fat concentration by 95.65%, 81.25% and 27.37%, respectively (Chen *et al.*, 2020). However, some authors also noted that BC application decreased the TSP owing to fact BC decreased organic N of soil by decreasing the production of proteins and their use by plants (Prommer *et al.*, 2014). Recently, it has been also documented that BC increased the abiotic stress resistance by affecting the signalling pathways of jasmonic acid and H_2O_2 hydrogen oxide accumulation (Mehari *et al.*, 2015).

Biochar improves genes expression and microbial activities to confer HMs toxicity

Toxic metals reduced the activities of antioxidant which in turn induce significant reduction in plant growth. BC application alleviated the biological activities of toxic metals by causing their inactivation. In another study, it was noted that BC application increased the expression of antioxidant genes (SOD, POD, and *CAT*) and metal-tolerant conferring gene (*OsFSD1*) thereby improved the tolerance against vanadium (Mehmood *et al.*, 2021). Likewise, Mehmood *et al.* (2020) also noted that BC application significantly boosted the expression of four genes (CAT, APX, POD and SOD) encoding antioxidant enzymes and significantly improved the growth and development of soybean plants (Mehmood *et al.*, 2020). Conversely, Kang *et al.* (2022) found that BC down-regulated the expression of MnSOD, CAT, and GR due to a reduction in ROS production and phyto-toxicity of Cd stress (*Kang et al.*, 2022).

The changes in composition and diversity of microbes following BC application have got considerable attention across the globe (Gul *et al.*, 2015). The application of BC considerably increased the abundance and richness of fungi and bacteria (Yao *et al.*, 2017). The addition of BC also increased the relative abundance of dominant soil bacterial phyla which in turn reduces the mobility of HMs in soils (Wang *et al.*, 2021). The application of BC also increased the abundance of *proteobacteria* which reduced the toxicity of HMs owing to their unique metabolic and ecological ability to adapt to HMs contaminated soils (Ghori *et al.*, 2019; Kang *et al.*, 2022).

Biochar improves plant growth, yield and quality under HMs stress

Toxic metals caused a substantial reduction in the growth of plants; however, BC exerts a positive influence on plant growth by decreasing the toxicity of HMs (Chattha *et al.*, 2021). The application of BC significantly improved the growth and biomass yield in HMs contaminated soils by improving the soil physicochemical and biological properties (Chen *et al.*, 2020). In another study, conducted on Brassica it was noted that BC application significantly improved root and shoot growth and biomass production in Cr contaminated soil (Naveed *et al.*, 2021). Likewise, Novak *et al.* (2019) also observed a marked improvement in plant growth under Cd stress after the application of BC. Moreover, Abbas *et al.* (2020) also noted that BC improved the length of shoots (93%), root length (222%), shoot dry biomass (60%) and root dry biomass (164%) of maize plants grown in Cr stress.

Arshad *et al.* (2017) documented that BC made from pine wood appreciable improved the root and shoot growth, biomass production and root surface area of maize plants. Likewise, different authors also noted that BC application caused an appreciable increase plant growth under Cr stress (Agegnehu *et al.*, 2017; Arshad *et al.*, 2017). BC increases SOC that improves soil fertility and overall plant growth (Rizwan *et al.*, 2016; Ali *et al.*, 2018; Cheng *et al.*, 2020). Moreover, BC also improves soil pH, CEC, SOM and availability of nutrients which ultimately increased plant growth and soil fertility (Agegnehu *et al.*, 2017). BC application decreased the availability of HMs (Cr) which enhanced the nutrient uptake, therefore, improved the plant growth (Rizwan *et al.*, 2016) addition also enhanced the mineralization of N and absorbs NH_4^+ more than NO_3^- on its surface, thereby ensuring better availability of N and better plant (Dad *et al.*, 2020).

Biochar application to mustard plants increases their growth and biomass production by improving antioxidant activities and reducing the production of ROS (Al-Wabel *et al.*, 2015; Rodríguez-Vila *et al.*, 2015). Khan *et al.* (2015) noted that BC made from sewage sludge markedly increase growth of turnip. Likewise, BC application also increased the growth and biomass productivity of ryegrass grown under As stress (Gregory *et al.*, 2014). Biochar application improved the plant growth in HMs contaminated soils by improving soil properties, nutrient uptake, antioxidant activities, photosynthetic performance and decreasing the availability of HMs (Rees *et al.*, 2015; Naveed *et al.*, 2021). BC application also improved the SOM, WHC and nutrient availability which in turn improves nutrient uptake in HMs contaminated soils (Chan *et al.*, 2008; Mendez *et al.*, 2012).

Conclusion

The concentration of HMs has been significantly increased due to human activities which are posing a serious threat to crop growth, soil quality and human health. HMs has devastating impacts on humans, agriculture and environment therefore, it urgently needed to develop the appropriate measures to counter the deleterious impacts of HMs. In this context, BC has emerged as an excellent tool to mitigate the adverse impacts of HMs. BC application improves plant performance ranging from growth to yield and providing resistance against HMs. BC application maintains plant water relations and improves the membrane stability which prevents the loss of important osmolytes therefore, improve the plant performance under HMs. BC application also improves nutrient and water uptake, synthesis of photosynthetic pigments and protects the plants from HMs induced toxic effects by increasing antioxidant activities, gene expression and accumulation of osmolytes. Moreover, BC also form complexes and ensures the precipitation adsorption of HMs therefore, reduce the HMs mobility and their uptake by plants. Additionally, BC also increases soil pH and soil CEC which also play a significant role in the immobilization of HMs.

Despite this recent progress the role of BC in plants growing under HMs is not fully explored and there are many un-answered questions. The role of BC in germination mechanism is not explored yet, thus is needed to explore the role of BC in germination mechanism in plants growing under HMs toxicity. The role of BC on nutrient uptake is well studied however, it is needed to explore the role of BC on nutrient channels and ion transporter under HMs toxicity. The effect of BC on photosynthetic enzymes, electron transport, and efficiency of PS-I and PS-II is not studied. Thus, is urgent to conduct research on these aspects to make him an important soil amendment to mitigate adverse impacts of HMs. The role of biochar on reproductive characteristics and crop quality is also not explored, thus it would be fascinating to explore its role in these aspects.

The role of BC on osmolytes and hormone accumulation is not explored yet. In literature, only information is available about the role of BC on proline and soluble sugar accumulation. Moreover, there is no study available about the role of BC on hormone accumulation under HMs. Therefore, it is also needed to explore the role of BC on osmolytes (glycine-betaine) and hormones (abscisic acid, auxin, cytokinin, ethylene and gibberellins) accumulation under HMs. The role of BC on antioxidant activities is also poorly studied and it needs to explore the effect of BC on enzymatic and non-enzymatic antioxidants and genes expression under HMs stress. Moreover, the effect of BC on the accumulation of secondary metabolites, and phenolic compounds must be also explored in depth studies for increasing the tolerance of plants against HMs. The molecular mechanism mediating by BC to induce HMs is not explored in the future therefore, it is needed to conduct in-depth studies to explore the role of BC in mediating molecular mechanism for ensuring tolerance against HMs. In literature most of the studies are conduct in controlled conditions, thus is mandatory to conducted long-term field studies in HMs contaminated soils to explore the role of BC. Moreover, it is also direly needed to optimize the rate of BC application for different field crops under a wide range of climate and soil conditions.

Authors' Contributions

Conceptualization; HT and GH; Writing - original draft: HT and SW; Writing - review and editing: YL, MUH, YS, GH, MH, SA and YSM. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

Not applicable.

Acknowledgements

This work was supported and funded by the National Key Research and Development Program of China (2016YFD0300208), National Natural Science Foundation of China (41661070), Consulting research project of Chinese Academy of Engineering (2017-XY-28), the Project of the youth fund of Hunan University of Humanities, Science and Technology (2010QN23),Key Research and Development Project of Hunan (2021NK2030), Natural Science Foundation of Hunan Province (2021JJ30375).The authors also extend their appreciation to the Deanship of Scientific Research, King Khalid University for supporting this work through research groups program under grant number R.G.P. 1/97/43.

Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

References

Aamer M, Shaaban M, Hassan MU, Guoqin H, Ying L, Ying TH, … Rasheed A (2020). Biochar mitigates the N_2O emissions from acidic soil by increasing the nosZ and nirK gene abundance and soil pH. Journal of Environmental Management 255:109891. https://*doi.org/10.1016/j.jenvman.2019.109891*

Abbas A, Azeem M, Naveed M, Latif A, Bashir S, Ali A, … Ali L (2020). Synergistic use of biochar and acidified manure for improving growth of maize in chromium contaminated soil. International Journal of Phytoremediation 22:52-61. *https://doi.org/10.1080/15226514.2019.1644286*

Abbas T, Rizwan M, Ali S, Zia-ur-Rehman M, Qayyum MF, Abbas F, … Ok YS (2017). Effect of biochar on cadmium bioavailability and uptake in wheat (*Triticum aestivum* L.) grown in a soil with aged contamination. Ecotoxicology and Environmental Safety 140:37-47. *https://doi.org/10.1016/j.ecoenv.2017.02.028*

Abbasi GH, Akhtar J, Anwar-ul-Haq M, Malik W, Ali S, Chen Z-H, Zhang G (2015). Morpho-physiological and micrographic characterization of maize hybrids under NaCl and Cd stress. Plant Growth Regulation 75:115-122. *https://doi.org/10.1007/s10725-014-9936-6*

Abdelhafez AA, Li J, Abbas MH (2014). Feasibility of biochar manufactured from organic wastes on the stabilization of heavy metals in a metal smelter contaminated soil. Chemosphere 117:66-71. *https://doi.org/10.1016/j.chemosphere.2014.05.086*

Adnan M, Fahad S, Zamin M, Shah S, Mian IA, Danish S, … Saeed B (2020). Coupling phosphate-solubilizing bacteria with phosphorus supplements improve maize phosphorus acquisition and growth under lime induced salinity stress. Plants 9:900. *https://doi.org/10.3390/plants9070900*

Agegnehu G, Srivastava AK, Bird MI (2017). The role of biochar and biochar-compost in improving soil quality and crop performance: A review. Applied Soil ecology 119:156-170. *https://doi.org/10.1016/j.apsoil.2017.06.008*

Akhtar SS, Andersen MN, Naveed M, Zahir ZA, Liu F (2015). Interactive effect of biochar and plant growth-promoting bacterial endophytes on ameliorating salinity stress in maize. Functional Plant Biology 42:770-781. *http://dx.doi.org/10.1071/FP15054*

Akhtar T, Zia-ur-Rehman M, Naeem A, Nawaz R, Ali S, Murtaza G, … Rizwan M (2017). Photosynthesis and growth response of maize (*Zea mays* L.) hybrids exposed to cadmium stress. Environmental Science and Pollution Research 24:5521-5529. *https://doi.org.10.1007/s11356-016-8246-0*

Al-Wabel MI, Usman AR, El-Naggar AH, Aly AA, Ibrahim HM, Elmaghraby S, Al-Omran A (2015). Conocarpus biochar as a soil amendment for reducing heavy metal availability and uptake by maize plants. Saudi Journal of Biological Sciences 22:503-511. *https://doi.org/10.1016/j.sjbs.2014.12.003*

Ali S, Rizwan M, Bano R, Bharwana SA, Hussain MB, Al-Wabel MI (2018). Effects of biochar on growth, photosynthesis, and chromium (Cr) uptake in *Brassica rapa* L. under Cr stress. Arabian Journal of Geosciences 11:1-9. *https://doi.org/10.1007/s12517-018-3861-3*

Alkharabsheh HM, Seleiman MF, Battaglia ML, Shami A, Jalal RS, Alhammad BA, Almutairi KF, Al-Saif AM (2021). Biochar and its broad impacts in soil quality and fertility, nutrient leaching and crop productivity: A review. Agronomy 11:993. *https://doi.org/10.3390/agronomy11050993*

Aly AA, Mohamed AA (2012). The impact of copper ion on growth, thiol compounds and lipid peroxidation in two maize cultivars (*Zea mays* L.) grown *in vitro*. Australian Journal of Crop Science 6:541-549.

Amonette JE, Joseph S (2009). Characteristics of biochar: microchemical properties. Biochar for environmental management: Science and Technology 33.

Antonangelo JA, Zhang H (2019). Heavy metal phytoavailability in a contaminated soil of northeaster Oklahoma as affected by biochar amendment. Environmental Science and Pollution Research 26:33582-33593. *https://doi.org/10.1007/s11356-019-06497-w*

Arshad M, Khan AHA, Hussain I, Anees M, Iqbal M, Soja G, Linde C, Yousaf S (2017). The reduction of chromium (VI) phytotoxicity and phytoavailability to wheat (*Triticum aestivum* L.) using biochar and bacteria. Applied Soil Ecology 114:90-98. *https://doi.org/10.1016/j.apsoil.2017.02.021*

Ashraf MY, Sadiq R, Hussain M, Ashraf M, Ahmad M (2011). Toxic effect of nickel (Ni) on growth and metabolism in germinating seeds of sunflower (*Helianthus annuus* L.). Biological Trace Element Research 143:1695-1703. *https://doi.org.10.1007/s12011-011-8955-7*

Azadi N, Raiesi F (2021). Biochar alleviates metal toxicity and improves microbial community functions in a soil co-contaminated with cadmium and lead. Biochar 3:485-498. *https://doi.org/10.1007/s42773-021-00123-0*

Bahmani R, Bihamta M, Habibi D, Forozesh P, Ahmadvand S (2012). Effect of cadmium chloride on growth parameters of different bean genotypes (*Phaseolus vulgaris* L.). ARPN Journal of Agriculture and Biological Sciences 7:35-40.

Bashir MA, Naveed M, Ahmad Z, Gao B, Mustafa A, Núñez-Delgado A (2020). Combined application of biochar and sulfur regulated growth, physiological, antioxidant responses and Cr removal capacity of maize (*Zea mays* L.) in tannery polluted soils. Journal of Environmental Management 259:110051. *https://doi.org/10.1016/j.jenvman.2019.110051*

Bashir MA, Naveed M, Ashraf S, Mustafa A, Ali Q, Rafique M, Alamri S, Siddiqui MH (2021). Performance of *Zea mays* L. cultivars in tannery polluted soils: Management of chromium phytotoxicity through the application of biochar and compost. Physiologia Plantarum 173:129-147. *https://doi.org/10.111/ppl.13277*

Bashir S, Shaaban M, Mehmood S, Zhu J, Fu Q, Hu H (2018). Efficiency of C3 and C4 plant derived-biochar for Cd mobility, nutrient cycling and microbial biomass in contaminated soil. Bulletin of Environmental Contamination and Toxicology 100:834-838. *https://doi.org/10.1007/s00128-018-2332-6*

Beesley L, Inneh OS, Norton GJ, Moreno-Jimenez E, Pardo T, Clemente R, Dawson JJ (2014). Assessing the influence of compost and biochar amendments on the mobility and toxicity of metals and arsenic in a naturally contaminated mine soil. Environmental Pollution 186:195-202. *https://doi.org/10.1016/j.envpol.2013.11.026*

Bertel C, Schönswetter P, Frajman B, Holzinger A, Neuner G (2017). Leaf anatomy of two reciprocally non-monophyletic mountain plants (*Heliosperma* spp.): does heritable adaptation to divergent growing sites accompany the onset of speciation? Protoplasma 254:1411-1420. *https://doi.org/10.1007/s00709-016-1032-5*

Bian R, Zhang A, Li L, Pan G, Zheng J, Zhang X, Zheng J, Joseph S, Chang A (2014). Effect of municipal biowaste biochar on greenhouse gas emissions and metal bioaccumulation in a slightly acidic clay rice paddy. BioResources 9:685-703.

Bonanomi G, Ippolito F, Cesarano G, Nanni B, Lombardi N, Rita A, Saracino A, Scala F (2017). Biochar as plant growth promoter: better off alone or mixed with organic amendments? Frontiers in Plant Science 8:1570. *https://doi.org.10.3389/fpls.2017.01570/full*

Borchard N, Siemens J, Ladd B, Möller A, Amelung W (2014). Application of biochars to sandy and silty soil failed to increase maize yield under common agricultural practice. Soil and Tillage Research 144:184-194. *https://doi.org/10.1016/j.still.2014.07.016*

Bouazizi H, Jouili H, Geitmann A, El Ferjani E (2010). Copper toxicity in expanding leaves of Phaseolus vulgaris L.: antioxidant enzyme response and nutrient element uptake. Ecotoxicology and Environmental Safety 73:1304-1308. *https://doi.org/10.1016/j.ecoenv.2010.05.014*

Cao X, Harris W (2010). Properties of dairy-manure-derived biochar pertinent to its potential use in remediation. Bioresource technology 101:5222-5228. *https://doi.org/10.1016/j.biortech.2010.02.052*

Carter S, Shackley S, Sohi S, Suy TB, Haefele S (2013). The impact of biochar application on soil properties and plant growth of pot grown lettuce (*Lactuca sativa*) and cabbage (*Brassica chinensis*). Agronomy 3:404-418. *https://doi.org/10.3390/agronomy3020404*

Casarrubia S, Martino E, Daghino S, Kohler A, Morin E, Khouja H-R, … Martin FM (2020). Modulation of plant and fungal gene expression upon cd exposure and symbiosis in ericoid mycorrhizal *Vaccinium myrtillus*. Frontiers in Microbiology 11:341. *https://doi.org.10.3389/fmicb.2020.00341/full*

Chen X, He H-Z, Chen G-K, Li H-S (2020). Effects of biochar and crop straws on the bioavailability of cadmium in contaminated soil. Scientific Reports 10:1-12. *https://doi.org/10.1038/s41598-020-65631-8*

Cheng S, Chen T, Xu W, Huang J, Jiang S, Yan B (2020). Application research of biochar for the remediation of soil heavy metals contamination: a review. Molecules 25:3167. *https://doi.org/10.3390/molecules25143167*

Dad FP, Khan W-u-D, Tanveer M, Ramzani PMA, Shaukat R, Muktadir A (2020). Influence of iron-enriched biochar on Cd sorption, its ionic concentration and redox regulation of radish under cadmium toxicity. Agriculture 11:1. *https://doi.org/10.3390/agriculture11010001*

Diatta AA, Fike JH, Battaglia ML, Galbraith JM, Baig MB (2020). Effects of biochar on soil fertility and crop productivity in arid regions: a review. Arabian Journal of Geosciences 13:1-17. *https://doi.org/10.1007/s12517-020-05586-2*

Ding Y, Ding L, Xia Y, Wang F, Zhu C (2020). Emerging roles of microRNAs in plant heavy metal tolerance and homeostasis. Journal of Agricultural and Food Chemistry 68:1958-1965. *https://doi.org/10.1021/acs.jafc.9b07468*

Farhangi-Abriz S, Torabian S (2017). Antioxidant enzyme and osmotic adjustment changes in bean seedlings as affected by biochar under salt stress. Ecotoxicology and Environmental Safety 137:64-70. *https://doi.org/10.1016/j.ecoenv.2016.11.029*

Fiaz K, Danish S, Younis U, Malik S, Raza Shah M, Niaz S (2014). Drought impact on Pb/Cd toxicity remediated by biochar in *Brassica campestris*. Journal of Soil science and Plant Nutrition 14:845-854. *https://doi.org/10.4067/S0718-95162014005000067*

Gao S, DeLuca T (2016). Influence of biochar on soil nutrient transformations, nutrient leaching, and crop yield. Advances in Plants and Agriculture Research 4:1-16. *https://doi.org/10.15406/apar.2016.04.00150*

Ghori N-H, Ghori T, Hayat M, Imadi S, Gul A, Altay V, Ozturk M (2019). Heavy metal stress and responses in plants. International Journal of Environmental Science and Technology 16:1807-1828. *https://doi.org/10.1007/s13762-019-02215-8*

Gregory S, Anderson C, Arbestain MC, McManus M (2014). Response of plant and soil microbes to biochar amendment of an arsenic-contaminated soil. Agriculture, Ecosystems & Environment 191:133-141. *https://doi.org/10.1016/j.agee.2014.03.035*

Gul S, Whalen JK, Thomas BW, Sachdeva V, Deng H (2015). Physico-chemical properties and microbial responses in biochar-amended soils: mechanisms and future directions. Agriculture, Ecosystems & Environment 206:46-59. *https://doi.org/10.1016/j.agee.2015.03.015*

Gupta V, Jatav P, Verma R, Kothari S, Kachhwaha S (2017). Nickel accumulation and its effect on growth, physiological and biochemical parameters in millets and oats. Environmental Science and Pollution Research 24:23915-25. *https://doi.org/10.1080/15320383.2021.1887809*

Hafez Y, Attia K, Alamery S, Ghazy A, Al-Doss A, Ibrahim E, … Abdelaal K (2020). Beneficial effects of biochar and chitosan on antioxidative capacity, osmolytes accumulation, and anatomical characters of water-stressed barley plants. Agronomy 10:630. *https://doi.org/10.3390/agronomy10050630*

Haider FU, Wang X, Farooq M, Hussain S, Cheema SA, ul Ain N, … Liqun C (2022). Biochar application for the remediation of trace metals in contaminated soils: Implications for stress tolerance and crop production. Ecotoxicology and Environmental Safety 230:113165. *https://doi.org/10.1016/j.ecoenv.2022.113165*

Han H, Wu X, Yao L, Chen Z (2020). Heavy metal-immobilizing bacteria combined with calcium polypeptides reduced the uptake of Cd in wheat and shifted the rhizosphere bacterial communities. Environmental Pollution 267:115432. *https://doi.org/10.1016/j.envpol.2020.115432*

Hasanuzzaman M, Bhuyan M, Zulfiqar F, Raza A, Mohsin SM, Mahmud JA, Fujita M, Fotopoulos V (2020). Reactive oxygen species and antioxidant defense in plants under abiotic stress: Revisiting the crucial role of a universal defense regulator. Antioxidants 9:681. *https://doi.org/10.3390/antiox9080681*

Hassan MU, Chattha MU, Khan I, Chattha MB, Aamer M, Nawaz M, Ali A, Khan MAU, Khan TA (2019). Nickel toxicity in plants: reasons, toxic effects, tolerance mechanisms, and remediation possibilities-a review. Environmental Science and Pollution Research 26:12673-12688. *https://doi.org/10.1007/s11356-019-04892-x*

Hassan MU, Chattha MU, Khan I, Chattha MB, Barbanti L, Aamer M, … Ali A (2021). Heat stress in cultivated plants: Nature, impact, mechanisms, and mitigation strategies-A review. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology 155:211-234. *https://doi.org/10.1080/11263504.2020.1727987*

Hassan MU, Ghareeb RY, Nawaz M, Mahmood A, Shah AN, Abdel-Megeed A, … Thabit MA (2022). Melatonin: a vital pro-tectant for crops against heat stress: mechanisms and prospects. Agronomy 12:1116. *https://doi.org/10.3390/agronomy12051116*

Hmid A, Al Chami Z, Sillen W, De Vocht A, Vangronsveld J (2015). Olive mill waste biochar: a promising soil amendment for metal immobilization in contaminated soils. Environmental Science and Pollution Research 22:1444-1456. *https://doi.org/10.1007/s11356-014-3467-6*

Ho S-H, Zhu S, Chang J-S (2017). Recent advances in nanoscale-metal assisted biochar derived from waste biomass used for heavy metals removal. Bioresource Technology 246:123-134. https://*doi.org/10.1016/j.biortech.2017.08.061*

Hossain M, Hanafi M, Saleh G, Foroughi M, Behmaram R, Noori Z (2012). Growth, photosynthesis and biomass allocation of different kenaf (*Hibiscus cannabinus* L.) accessions grown on sandy soil. Australian Journal of Crop Science 6:480-487.

Houben D, Sonnet P, Cornelis JT (2014). Biochar from Miscanthus: a potential silicon fertilizer. Plant and Soil 374:871-882. *https://doi.org/10.1007/s11104-013-1885-8*

Hu B, Ai Y, Jin J, Hayat T, Alsaedi A, Zhuang L, Wang X (2020). Efficient elimination of organic and inorganic pollutants by biochar and biochar-based materials. Biochar 2:47-64. *https://doi.org/10.1007/s42773-020-00044-4*

Huang J, Wu Z, Chen L, Sun Y (2015). Surface complexation modeling of adsorption of Cd (II) on graphene oxides. Journal of Molecular Liquids 209:753-758. https://*doi.org/10.1016/j.molliq.2015.06.047*

Hussain MB, Ali S, Azam A, Hina S, Farooq MA, Ali B, Bharwana SA, Gill MB (2013). Morphological, physiological and biochemical responses of plants to nickel stress: A review. African Journal of Agricultural Research 8:1596-1602. *https://doi.org/10.5897/AJAR12.407*

Hussain S, Irfan M, Sattar A, Hussain S, Ullah S, Abbas T, … Elshikh MS (2022). Alleviation of cadmium stress in wheat through the combined application of boron and biochar via regulating morpho-physiological and antioxidant defense mechanisms. Agronomy 12:434. *https://doi.org/10.3390/agronomy12020434*

Ifle JE, IFIE-ETUMAH SO, IKHAJIAGBE B (2020). Physiological and biochemical responses of selected cowpea (*Vigna unguiculata* (L.) Walp.) accessions to iron toxicity. Acta Agriculturae Slovenica 115:25-38. *https://doi.org/10.14720/aas.2020.115.1.969*

Ilyas N, Akhtar N, Yasmin H, Sahreen S, Hasnain Z, Kaushik P, Ahmad A, Ahmad P (2022). Efficacy of citric acid chelate and *Bacillus* sp. in amelioration of cadmium and chromium toxicity in wheat. Chemosphere 290:133342. https://*doi.org/10.1016/j.chemosphere.2021.133342*

Inyang M, Dickenson E (2015). The potential role of biochar in the removal of organic and microbial contaminants from potable and reuse water: a review. Chemosphere 134:232-240. *https://doi.org/10.1016/j.chemosphere.2015.03.072*

Janicka-Russak M, Kabała K, Burzyński M (2012). Different effect of cadmium and copper on H+-ATPase activity in plasma membrane vesicles from *Cucumis sativus* roots. Journal of Experimental Botany 63:4133-4142. *https://doi.org/10.1093/jxb/ers097*

Jiang T-Y, Jiang J, Xu R-K, Li Z (2012). Adsorption of Pb (II) on variable charge soils amended with rice-straw derived biochar. Chemosphere 89:249-256. h*ttps://doi.org/10.1016/j.chemosphere.2012.04.028*

Kang X, Geng N, Li X, Yu J, Wang H, Pan H, ... Lou Y (2022). Biochar Alleviates Phytotoxicity by Minimizing Bioavailability and Oxidative Stress in Foxtail Millet (*Setaria italica* L.) Cultivated in Cd-and Zn-Contaminated Soil. Frontiers in Plant Science 13:782963-782963. *https://doi.org/10.3389/fpls.2022.782963*

Khan MA, Yasmin H, Shah ZA, Rinklebe J, Alyemeni MN, Ahmad P (2022). Co application of biofertilizer and zinc oxide nanoparticles upregulate protective mechanism culminating improved arsenic resistance in maize. Chemosphere 294:133796. *https://doi.org/10.1016/j.chemosphere.2022.133796*

Khan S, Reid BJ, Li G, Zhu Y-G (2014). Application of biochar to soil reduces cancer risk via rice consumption: a case study in Miaoqian village, Longyan, China. Environment International 68:154-161. *https://doi.org/10.1016/j.envint.2014.03.017*

Khan S, Waqas M, Ding F, Shamshad I, Arp HPH, Li G (2015). The influence of various biochars on the bioaccessibility and bioaccumulation of PAHs and potentially toxic elements to turnips (*Brassica rapa* L.). Journal of Hazardous Materials 300:243-253. *https://doi.org/10.1016/j.jhazmat.2015.06.050*

Khosropour E, Weisany W, Tahir NA-r, Hakimi L (2022). Vermicompost and biochar can alleviate cadmium stress through minimizing its uptake and optimizing biochemical properties in *Berberis integerrima* bunge. Environmental Science and Pollution Research 29:17476-17486. *https://doi.org/10.1007/s11356-021-17073-6*

Kohli SK, Khanna K, Bhardwaj R, Abd_Allah EF, Ahmad P, Corpas FJ (2019). Assessment of subcellular ROS and NO metabolism in higher plants: multifunctional signaling molecules. Antioxidants 8:641. *https://doi.org/10.3390/antiox8120641*

Li L, Ai S, Li Y, Wang Y, Tang M (2018). Exogenous silicon mediates alleviation of cadmium stress by promoting photosynthetic activity and activities of antioxidative enzymes in rice. Journal of Plant Growth Regulation 37:602-611. *https://doi.org/10.1007/s00344-017-9758-7*

Li M, Lou Z, Wang Y, Liu Q, Zhang Y, Zhou J, Qian G (2015). Alkali and alkaline earth metallic (AAEM) species leaching and Cu (II) sorption by biochar. Chemosphere 119:778-785. *https://doi.org/10.1016/j.chemosphere.2014.08.033*

Liang C, Zhu X, Fu S, Méndez A, Gascó G, Paz-Ferreiro J (2014). Biochar alters the resistance and resilience to drought in a tropical soil. Environmental Research Letters 9:064013. *https://doi.org/10.1088/1748-9326/9/6/064013*

Liang M, Lu L, He H, Li J, Zhu Z, Zhu Y (2021). Applications of biochar and modified biochar in heavy metal contaminated soil: a descriptive review. Sustainability 13:14041. *https://doi.org/10.3390/su132414041*

Liu J, Jiang J, Meng Y, Aihemaiti A, Xu Y, Xiang H, Gao Y, Chen X (2020). Preparation, environmental application and prospect of biochar-supported metal nanoparticles: A review. Journal of Hazardous Materials 388:122026. *https://doi.org/10.1016/j.jhazmat.2020.122026*

Liu P, Ptacek CJ, Blowes DW, Landis RC (2016). Mechanisms of mercury removal by biochars produced from different feedstocks determined using X-ray absorption spectroscopy. Journal of Hazardous Materials 308:233-242. *https://doi.org/10.1016/j.jhazmat.2016.01.007*

Lokhande VH, Patade VY, Srivastava S, Suprasanna P, Shrivastava M, Awasthi G (2020). Copper accumulation and biochemical responses of *Sesuvium portulacastrum* (L.). Materials Today: Proceedings 31:679-684. *https://doi.org/10.1016/j.matpr.2020.07.117*

Ma L, Xu R, Jiang J (2010). Adsorption and desorption of Cu (II) and Pb (II) in paddy soils cultivated for various years in the subtropical China. Journal of Environmental Sciences 22:689-695. *https://doi.org/10.1016/S1001-0742(09)60164-9*

Majeed A, Muhmood A, Niaz A, Ditta A, Rajpar MN (2022). Comparative efficacy of different biochars and traditional manures in the attenuation of cadmium toxicity in rice (*Oryza sativa* L.). Arabian Journal of Geosciences 15:1-10. *https://doi.org/10.1007/s12517-022-09548-8*

Mansoor S, Kour N, Manhas S, Zahid S, Wani OA, Sharma V, … El-Serehy HA (2021). Biochar as a tool for effective management of drought and heavy metal toxicity. Chemosphere 271:129458. *https://doi.org/10.1016/j.chemosphere.2020.129458*

Marrugo-Negrete J, Durango-Hernández J, Pinedo-Hernández J, Enamorado-Montes G, Díez S (2016). Mercury uptake and effects on growth in *Jatropha curcas*. Journal of Environmental Sciences 48:120-125. *https://doi.org/10.1016/j.jes.2015.10.036*

Mathur S, Kalaji H, Jajoo A (2016). Investigation of deleterious effects of chromium phytotoxicity and photosynthesis in wheat plant. Photosynthetica 54:185-192. *https://doi.org/10.1007/s11099-016-0198-6*

Mazhar R, Ilyas N, Arshad M, Khalid A (2020). Amelioration potential of biochar for chromium stress in wheat. Pakistan Journal of Botany 52:1159-1168. *http://dx.doi.org/10.30848/PJB2020-4(19)*

Mehari ZH, Elad Y, Rav-David D, Graber ER, Meller Harel Y (2015). Induced systemic resistance in tomato (*Solanum lycopersicum*) against Botrytis cinerea by biochar amendment involves jasmonic acid signaling. Plant and Soil 395:31-44. https://doi.org/10.1007/s11104-015-2445-1

Mehdizadeh L, Moghaddam M, Lakzian A (2019). Response of summer savory at two different growth stages to biochar amendment under NaCl stress. Archives of Agronomy and Soil Science 65:1120-1133. *https://doi.org/10.1080/03650340.2018.1554248*

Mehmood S, Ahmed W, Ikram M, Imtiaz M, Mahmood S, Tu S, Chen D (2020). Chitosan modified biochar increases soybean (*Glycine max* L.) resistance to salt-stress by augmenting root morphology, antioxidant defense mechanisms and the expression of stress-responsive genes. Plants 9:1173. *https://doi.org/10.3390/plants9091173*

Mehmood S, Ahmed W, Rizwan M, Imtiaz M, Elnahal ASMA, Ditta A, Irshad S, Ikram M, Li W (2021). Comparative efficacy of raw and HNO_3-modified biochar derived from rice straw on vanadium transformation and its uptake by rice (*Oryza sativa* L.): Insights from photosynthesis, antioxidative response, and gene-expression profile. Environmental Pollution 289:117916. *https://doi.org/10.1016/j.envpol.2021.117916*

Mendez A, Gomez A, Paz-Ferreiro J, Gasco G (2012). Effects of sewage sludge biochar on plant metal availability after application to a Mediterranean soil. Chemosphere 89:1354-1359. *https://doi.org/10.1016/j.chemosphere.2012.05.092*

Meng J, Tao M, Wang L, Liu X, Xu J (2018). Changes in heavy metal bioavailability and speciation from a Pb-Zn mining soil amended with biochars from co-pyrolysis of rice straw and swine manure. Science of the Total Environment 633:300-307. *https://doi.org/10.1016/j.scitotenv.2018.03.199*

Namgay T, Singh B, Singh BP (2010). Influence of biochar application to soil on the availability of As, Cd, Cu, Pb, and Zn to maize (*Zea mays* L.). Soil Research 48:638-647. *https://doi.org/10.1071/SR10049*

Naveed M, Mustafa A, Azhar SQ-T-A, Kamran M, Zahir ZA, Núñez-Delgado A (2020a). Burkholderia phytofirmans PsJN and tree twigs derived biochar together retrieved Pb-induced growth, physiological and biochemical disturbances by minimizing its uptake and translocation in mung bean (*Vigna radiata* L.). Journal of Environmental Management 257:109974. *https://doi.org/10.1016/j.jenvman.2019.109974*

Naveed M, Mustafa A, Majeed S, Naseem Z, Saeed Q, Khan A, Nawaz A, Baig KS, Chen J-T (2020b). Enhancing cadmium tolerance and pea plant health through *Enterobacter* sp. MN17 inoculation together with biochar and gravel sand. Plants 9:530. *https://doi.org/10.3390/plants9040530*

Naveed M, Tanvir B, Xiukang W, Brtnicky M, Ditta A, Kucerik J, … Saeed Q (2021). Co-composted biochar enhances growth, physiological, and phytostabilization efficiency of brassica napus and reduces associated health risks under chromium stress. Frontiers in Plant Science 12. *https://doi.org/10.3389/fpls.2021.775785*

Nawaz F, Naeem M, Akram A, Ashraf MY, Ahmad KS, Zulfiqar B, … Shehzad MA (2017). Seed priming with KNO3 mediates biochemical processes to inhibit lead toxicity in maize (*Zea mays* L.). Journal of the Science of Food and Agriculture 97:4780-4789. *https://doi.org/10.1002/jsfa.8347*

Niamat B, Naveed M, Ahmad Z, Yaseen M, Ditta A, Mustafa A, … Xu M (2019). Calcium-enriched animal manure alleviates the adverse effects of salt stress on growth, physiology and nutrients homeostasis of *Zea mays* L. Plants 8:480. *https://doi.org/10.3390/plants8110480*

Nigam N, Khare P, Yadav V, Mishra D, Jain S, Karak T, Panja S, Tandon S (2019). Biochar-mediated sequestration of Pb and Cd leads to enhanced productivity in Mentha arvensis. Ecotoxicology and Environmental Safety 172:411-422. *https://doi.org/10.1016/j.ecoenv.2019.02.006*

Nigussie A, Kissi E, Misganaw M, Ambaw G (2012). Effect of biochar application on soil properties and nutrient uptake of lettuces (*Lactuca sativa*) grown in chromium polluted soils. American-Eurasian Journal of Agriculture and Environmental Science 12:369-376. *https://www.idosi.org/aejaes/jaes12(3)12/14.pdf*

Nookongbut P, Kantachote D, Khuong NQ, Sukhoom A, Tantirungkij M, Limtong S (2019). Selection of acid-resistant purple nonsulfur bacteria from peat swamp forests to apply as biofertilizers and biocontrol agents. Journal of Soil Science and Plant Nutrition 19:488-500. *https://10.1007/s42729-019-00044-9*

Novak JM, Ippolito JA, Watts DW, Sigua GC, Ducey TF, Johnson MG (2019). Biochar compost blends facilitate switchgrass growth in mine soils by reducing Cd and Zn bioavailability. Biochar 1:97-114. *https://10.1007/s42773-019-00004-7*

Pariyar P, Kumari K, Jain MK, Jadhao PS (2020). Evaluation of change in biochar properties derived from different feedstock and pyrolysis temperature for environmental and agricultural application. Science of the Total Environment 713:136433. *https://doi.org/10.1016/j.scitotenv.2019.136433*

Paunov M, Koleva L, Vassilev A, Vangronsveld J, Goltsev V (2018). Effects of different metals on photosynthesis: cadmium and zinc affect chlorophyll fluorescence in durum wheat. International journal of molecular sciences 19:787. *https://doi.org/10.3390/ijms19030787*

Prommer J, Wanek W, Hofhansl F, Trojan D, Offre P, Urich T, … Soja G (2014). Biochar decelerates soil organic nitrogen cycling but stimulates soil nitrification in a temperate arable field trial. PloS One 9:e86388. *https://doi.org/10.1371/journal.pone.0086388*

Puga A, Abreu C, Melo L, Beesley L (2015). Biochar application to a contaminated soil reduces the availability and plant uptake of zinc, lead and cadmium. Journal of Environmental Management 159:86-93. *https://doi.org/10.1016/j.jenvman.2015.05.036*

Rahi AA, Hussain S, Hussain B, Baig KS, Tahir MS, Hussain GS, … Fahad S (2022). Alleviation of Cd stress in maize by compost mixed biochar. Journal of King Saud University-Science102014. *https://doi.org/10.1016/j.jksus.2022.102014*

Rahim HU, Ahmad S, Khan Z, Khan MA (2020). Field-based investigation of aged biochar coupled with summer legumes effect on wheat yield in Pakistan. Buletin Agroteknologi 1:1-6. *https://doi.org/10.32663/ba.v1i1.1152*

Rahim HU, Akbar WA, Alatalo JM (2022). A comprehensive literature review on cadmium (Cd) status in the soil environment and its immobilization by biochar-based materials. Agronomy 12:877. *https://doi.org/10.3390/agronomy12040877*

Rahim HU, Mian IA, Arif M, Rahim ZU, Ahmad S, Khan Z, Zada L, Khan MA, Haris M (2019). 3. Residual effect of biochar and summer legumes on soil physical properties and wheat growth. Pure and Applied Biology (PAB) 8:16-26. *https://doi.org/10.19045/bspab.2018.700159*

Rahim HU, Qaswar M, Wang M, Jing X, Cai X (2021). Environmental applications of reduced sulfur species and composites in transformation and detoxification of contaminants. Journal of Environmental Chemical Engineering 9:106696. *https://doi.org/10.1016/j.jece.2021.106696*

Rai PK, Lee SS, Zhang M, Tsang YF, Kim K-H (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environment International 125:365-385. *https://doi.org/10.1016/j.envint.2019.01.067*

Rasheed A, Fahad S, Aamer M, Hassan M, Tahir M, Wu Z (2020a). Role of genetic factors in regulating cadmium uptake, transport and accumulation mechanisms and quantitative trait loci mapping in rice. a review. Applied Ecology and Environmental Research 18:4005-4023. *http://doi.org/10.15666/aeer/1803_40054023*

Rasheed A, Shah F, Muhammad UH, M M -Tahir, Muhammad A, Ziming W (2020b). A review on aluminum toxicity and quantitative trait loci mapping in rice (*Oryza sativa* L). Applied Ecology and Environmental Research1-14. *https://doi.org/10.15666/aeer/1803_39513964*

Rasheed A, Wassan GM, Khanzada H, Solangi AM, Han R, Li H, Bian J, Wu Z (2021c). Identification of genomic regions at seedling related traits in response to aluminium toxicity using a new high-density genetic map in rice (*Oryza sativa* L.). Genetic Resources and Crop Evolution 68:1889-1903. *https://doi.org/10.1007/s10722-020-01103-2*

Rasheed A, Hassan MU, Aamer M, Bian J M, Xu ZR, He XF, Yan G, Wu ZM (2020). Iron toxicity, tolerance and quantitative trait loci mapping in rice; a review. Applied Ecology and Environmental Research 18:7483-7498. *https://doi.org/10.15666/aeer/1806_74837498*

Rath BP, Hota S, Subhadarshini S, Dash D, Das PK (2019). Consequence of chromium-tainted soil on physical and biochemical responses of *Vigna radiata* L. Journal of Applied Biology and Biotechnology 7:3-1. *https://doi.org/10.7324/JABB.2019.70107*

Rathika R, Srinivasan P, Alkahtani J, Al-Humaid L, Alwahibi MS, Mythili R, Selvankumar T (2021). Influence of biochar and EDTA on enhanced phytoremediation of lead contaminated soil by *Brassica juncea*. Chemosphere 271:129513. *https://doi.org/10.1016/j.chemosphere.2020.129513*

Raza A, Habib M, Charagh S, Kakavand SN (2021). Genetic engineering of plants to tolerate toxic metals and metalloids. In: Handbook of Bioremediation. Elsevier, pp 411-436. *https://doi.org/10.1016/B978-0-12-819382-2.00026-0*

Razzaq S, Zhou B, Zia-ur-Rehman M, Aamer Maqsood M, Hussain S, Bakhsh G, … Altaf AR (2022). Cadmium stabilization and redox transformation mechanism in maize using nanoscale zerovalent-iron-enriched biochar in cadmium-contaminated soil. Plants 11:1074. *https://doi.org/10.3390/plants11081074*

Rees F, Germain C, Sterckeman T, Morel J-L (2015). Plant growth and metal uptake by a non-hyperaccumulating species (*Lolium perenne*) and a Cd-Zn hyperaccumulator (*Noccaea caerulescens*) in contaminated soils amended with biochar. Plant and Soil 395:57-73. *https://doi.org10.1007/s11104-015-2384-x*

Rees F, Simonnot M-O, Morel J-L (2014). Short-term effects of biochar on soil heavy metal mobility are controlled by intra-particle diffusion and soil pH increase. European Journal of Soil Science 65:149-161. *https://doi.org/10.1111/ejss.12107*

Rehman RA, Rizwan M, Qayyum MF, Ali S, Zia-ur-Rehman M, Zafar-ul-Hye M, Hafeez F, Iqbal MF (2018). Efficiency of various sewage sludges and their biochars in improving selected soil properties and growth of wheat (*Triticum aestivum*). Journal of Environmental Management 223:607-613. *https://doi.org/10.1016/j.jenvman.2018.06.081*

Rizwan M, Ali S, Qayyum MF, Ibrahim M, Zia-ur-Rehman M, Abbas T, Ok YS (2016). Mechanisms of biochar-mediated alleviation of toxicity of trace elements in plants: a critical review. Environmental Science and Pollution Research 23:2230-2248. DOI: 10.1007/s11356-015-5697-7

Rizwan M, Meunier J-D, Miche H, Keller C (2012). Effect of silicon on reducing cadmium toxicity in durum wheat (*Triticum turgidum* L. cv. Claudio W.) grown in a soil with aged contamination. Journal of hazardous materials 209:326-334. *https://doi.org/10.1016/j.jhazmat.2012.01.033*

Rodríguez-Vila A, Covelo EF, Forján R, Asensio V (2015). Recovering a copper mine soil using organic amendments and phytomanagement with *Brassica juncea* L. Journal of Environmental Management 147:73-80. *https://doi.org/10.1016/j.jenvman.2014.09.011*

Rohani N, Daneshmand F, Vaziri A, Mahmoudi M, Saber-Mahani F (2019). Growth and some physiological characteristics of *Pistacia vera* L. cv Ahmad Aghaei in response to cadmium stress and *Glomus mosseae* symbiosis. South African Journal of Botany 124:499-507. *https://doi.org/10.1016/j.sajb.2019.06.001*

Rucińska-Sobkowiak R (2016). Water relations in plants subjected to heavy metal stresses. Acta Physiologiae Plantarum 38:1-13. *https://doi.org/10.1007/s11738-016-2277-5*

Sabir A, Naveed M, Bashir MA, Hussain A, Mustafa A, Zahir ZA, … Saeed Q (2020). Cadmium mediated phytotoxic impacts in Brassica napus: managing growth, physiological and oxidative disturbances through combined use of biochar and Enterobacter sp. MN17. Journal of Environmental Management 265:110522. https://*doi.org/10.1016/j.jenvman.2020.110522*

Sáenz-de la OD, Cedillo-Jimenez CA, García-Ortega LF, Martínez-Reséndiz M, Arné-Robles D, Cruz-Hernandez A, Guevara-Gonzalez RG (2020). Response of transgenic tobacco overexpressing the CchGLP gene to cadmium and aluminium: phenotypic and microRNAs expression changes. Physiology and Molecular Biology of Plants 26:3-13. *https://doi.org/10.1007/s12298-019-00716-x*

Sagbara G, Zabbey N, Sam K, Nwipie GN (2020). Heavy metal concentration in soil and maize (*Zea mays* L.) in partially reclaimed refuse dumpsite 'borrow-pit'in Port Harcourt, Nigeria. Environmental Technology & Innovation 18:100745. *https://doi.org/10.1016/j.eti.2020.100745*

Saleem MH, Parveen A, Khan SU, Hussain I, Wang X, Alshaya H, El-Sheikh MA, Ali S (2022). Silicon fertigation regimes attenuates cadmium toxicity and phytoremediation potential in two maize (*Zea mays* L.) cultivars by minimizing its uptake and oxidative stress. Sustainability 14:1462. *Https://doi.org/10.3390/su14031462*

Sanjosé I, Navarro-Roldán F, Infante-Izquierdo MD, Martínez-Sagarra G, Devesa JA, Polo A, … Muñoz-Rodríguez AF (2021). Accumulation and effect of heavy metals on the germination and growth of *Salsola vermiculata* L. seedlings. Diversity 13:539. *https://doi.org/10.3390/d13110539*

Schmidt SB, Eisenhut M, Schneider A (2020). Chloroplast transition metal regulation for efficient photosynthesis. Trends in Plant Science 25:817-828. *https://doi.org/10.1016/j.tplants.2020.03.003*

Seleiman MF, Alotaibi MA, Alhammad BA, Alharbi BM, Refay Y, Badawy SA (2020). Effects of ZnO nanoparticles and biochar of rice straw and cow manure on characteristics of contaminated soil and sunflower productivity, oil quality, and heavy metals uptake. Agronomy 10:790. *https://doi.org/10.3390/agronomy10060790*

Seneviratne M, Rajakaruna N, Rizwan M, Madawala H, Ok YS, Vithanage M (2019). Heavy metal-induced oxidative stress on seed germination and seedling development: a critical review. Environmental Geochemistry and Health 41:1813-1831. *https://doi.org/10.1007/s10653-017-0005-8*

Seneviratne M, Weerasundara L, Ok YS, Rinklebe J, Vithanage M (2017). Phytotoxicity attenuation in *Vigna radiata* under heavy metal stress at the presence of biochar and N fixing bacteria. Journal of Environmental Management 186:293-300. *https://doi.org/10.1016/j.jenvman.2016.07.024*

Shabbir A, Saqib M, Murtaza G, Abbas G, Imran M, Rizwan M, Naeem MA, Ali S, Javeed HMR (2021). Biochar mitigates arsenic-induced human health risks and phytotoxicity in quinoa under saline conditions by modulating ionic and oxidative stress responses. Environmental Pollution 287:117348. *https://doi.org/10.1016/j.envpol.2021.117348*

Shahbaz AK, Lewińska K, Iqbal J, Ali Q, Iqbal M, Abbas F, Tauqeer HM, Ramzani PMA (2018). Improvement in productivity, nutritional quality, and antioxidative defense mechanisms of sunflower (*Helianthus annuus* L.) and maize (*Zea mays* L.) in nickel contaminated soil amended with different biochar and zeolite ratios. Journal of Environmental Management 218:256-270. *https://doi.org/10.1016/j.jenvman.2018.04.046*

Shahbaz AK, Ramzani PMA, Saeed R, Turan V, Iqbal M, Lewińska K, … Iqbal M (2019). Effects of biochar and zeolite soil amendments with foliar proline spray on nickel immobilization, nutritional quality and nickel concentrations in wheat. Ecotoxicology and Environmental Safety 173:182-191. *https://doi.org/10.1016/j.ecoenv.2019.02.025*

Shen Z, Hou D, Zhao B, Xu W, Ok YS, Bolan NS, Alessi DS (2018). Stability of heavy metals in soil washing residue with and without biochar addition under accelerated ageing. Science of the Total Environment 619:185-193. *https://doi.org/10.1016/j.scitotenv.2017.11.038*

Sinay H, Karuwal RL (2014). Proline and total soluble sugar content at the vegetative phase of six corn cultivars from Kisar Island Maluku, grown under drought stress conditions. International Journal of Advanced Agricultural Research 2:77-82.

Sofy MR, Seleiman MF, Alhammad BA, Alharbi BM, Mohamed HI (2020). Minimizing adverse effects of pb on maize plants by combined treatment with jasmonic, salicylic acids and proline. Agronomy 10:699. *https://doi.org/10.3390/agronomy10050699*

Son JA, Narayanankutty DP, Roh KS (2014). Influence of exogenous application of glutathione on rubisco and rubisco activase in heavy metal-stressed tobacco plant grown in vitro. Saudi Journal of Biological Sciences 21:89-97. *https://doi.org/10.1016/j.sjbs.2013.06.002*

Song X, Zhang C, Chen W, Zhu Y, Wang Y (2020). Growth responses and physiological and biochemical changes in five ornamental plants grown in urban lead-contaminated soils. Plant-Environment Interactions 1:29-47. *https://doi.org/10.1002/pei3.10013*

Szabados L, Savouré A (2010). Proline: a multifunctional amino acid. Trends in plant science 15:89-97. *https://doi.org/10.1016/j.tplants.2009.11.009*

Tan Z, Wang Y, Zhang L, Huang Q (2017). Study of the mechanism of remediation of Cd-contaminated soil by novel biochars. Environmental Science and Pollution Research 24:24844-24855. *https://doi.org/10.1007/s11356-017-0109-9*

Tang J, Zhu W, Kookana R, Katayama A (2013). Characteristics of biochar and its application in remediation of contaminated soil. Journal of Bioscience and Bioengineering 116:653-659. *https://doi.org/10.1016/j.jbiosc.2013.05.035*

Tanveer M, Ahmed HAI (2020). ROS signalling in modulating salinity stress tolerance in plants. In: Salt and drought stress tolerance in plants. Springer, pp 299-314. *https://doi.org/10.1007/978-3-030-40277-8_11*

Tanveer M, Wang L (2019). Potential targets to reduce beryllium toxicity in plants: A review. Plant Physiology and Biochemistry 139:691-696. *https://doi.org/10.1016/j.plaphy.2019.04.022*

Tavallali V (2017). Interactive effects of zinc and boron on growth, photosynthesis, and water relations in pistachio. Journal of Plant Nutrition 40:1588-1603. *https://doi.org/10.1080/01904167.2016.1270308*

Tong X-j, Li J-y, Yuan J-h, Xu R-k (2011). Adsorption of Cu (II) by biochars generated from three crop straws. Chemical Engineering Journal 172:828-834. *https://doi.org/10.1016/j.cej.2011.06.069*

Turan V (2022). Calcite in combination with olive pulp biochar reduces Ni mobility in soil and its distribution in chili plant. International Journal of Phytoremediation 24:166-176. *https://doi.org/10.1080/15226514.2021.1929826*

Umer Chattha M, Arif W, Khan I, Soufan W, Bilal Chattha M, Hassan MU, … Qari SH (2021). Mitigation of cadmium induced oxidative stress by using organic amendments to improve the growth and yield of mash beans [*Vigna mungo* (L.)]. Agronomy 11:2152. https://doi.org/10.3390/ agronomy11112152

Vaculík M, Konlechner C, Langer I, Adlassnig W, Puschenreiter M, Lux A, Hauser M-T (2012). Root anatomy and element distribution vary between two *Salix caprea* isolates with different Cd accumulation capacities. Environmental Pollution 163:117-126. *https://doi.org/10.1016/j.envpol.2011.12.031*

Verheijen F, Jeffery S, Bastos A, Van der Velde M, Diafas I (2010). Biochar application to soils. A critical scientific review of effects on soil properties, processes, and functions. EUR 24099:162. *https://doi.org/10.2788/472*

Virk AL, Kan Z-R, Liu B-Y, Qi J-Y, He C, Liu Q-Y, Zhao X, Zhang H-L (2021). Impact of biochar water extract addition on soil organic carbon mineralization and C fractions in different tillage systems. Environmental Technology & Innovation 21:101193. *https://doi.org/10.1016/j.eti.2020.101193*

Wagner A, Kaupenjohann M (2015). Biochar addition enhanced growth of *Dactylis glomerata* L. and immobilized Zn and Cd but mobilized Cu and Pb on a former sewage field soil. European Journal of Soil Science 66:505-515. *https://doi.org/10.1111/ejss.12246*

Wang D, Jiang P, Zhang H, Yuan W (2020). Biochar production and applications in agro and forestry systems: A review. Science of the Total Environment 723:137775. *https://doi.org/10.1016/j.scitotenv.2020.137775*

Wang L, Chen L, Tsang DC, Li J-S, Baek K, Hou D, Ding S, Poon C-S (2018). Recycling dredged sediment into fill materials, partition blocks, and paving blocks: Technical and economic assessment. Journal of Cleaner Production 199:69-76. *https://doi.org/10.1016/j.jclepro.2018.07.165*

Wang Y, Wang H-S, Tang C-S, Gu K, Shi B (2019). Remediation of heavy-metal-contaminated soils by biochar: a review. Environmental Geotechnics 40:1-14.

Wang Y, Xu Y, Huang Q, Liang X, Sun Y, Qin X, Zhao L (2021). Effect of sterilization on cadmium immobilization and bacterial community in alkaline soil remediated by mercapto-palygorskite. Environmental Pollution 273:116446. *https://doi.org/10.1016/j.envpol.2021.116446*

Xin X, Zhao F, Judy JD, He Z (2022). Cu stress alleviation in corn (*Zea mays* L.): Comparative efficiency of carbon nanotubes and carbon nanoparticles. NanoImpact 100381. *https://doi.org/10.1016/j.impact.2022.100381*

Xu D, Zhao Y, Sun K, Gao B, Wang Z, Jin J, … Liu X (2014). Cadmium adsorption on plant-and manure-derived biochar and biochar-amended sandy soils: impact of bulk and surface properties. Chemosphere 111:320-326. *https://doi.org/10.1016/j.chemosphere.2014.04.043*

Xu J, Hu C, Wang M, Zhao Z, Zhao X, Cao L, Lu Y, Cai X (2022). Changeable effects of coexisting heavy metals on transfer of cadmium from soils to wheat grains. Journal of Hazardous Materials 423:127182. *https://doi.org/10.1016/j.jhazmat.2021.127182*

Xu X, Zhao Y, Sima J, Zhao L, Mašek O, Cao X (2017). Indispensable role of biochar-inherent mineral constituents in its environmental applications: a review. Bioresource Technology 241:887-899. *https://doi.org/10.1016/j.biortech.2017.06.023*

Yang M, Li Y, Liu Z, Tian J, Liang L, Qiu Y, … Cai H (2020). A high activity zinc transporter OsZIP9 mediates zinc uptake in rice. The Plant Journal 103:1695-1709. *https://doi.org/10.1111/tpj.14855*

Yang X, Liu J, McGrouther K, Huang H, Lu K, Guo X, … Ye Z (2016). Effect of biochar on the extractability of heavy metals (Cd, Cu, Pb, and Zn) and enzyme activity in soil. Environmental Science and Pollution Research 23:974-984. *https://doi.org/10.1007/s11356-015-4233-0*

Yao Q, Liu J, Yu Z, Li Y, Jin J, Liu X, Wang G (2017). Changes of bacterial community compositions after three years of biochar application in a black soil of northeast China. Applied Soil Ecology 113:11-21. *https://doi.org/10.1016/j.apsoil.2017.01.007*

Younis U, Athar M, Malik S, Raza Shah M, Mahmood S (2015). Biochar impact on physiological and biochemical attributes of spinach (*Spinacia oleracea* L.) in nickel contaminated soil. Global Journal of Environmental Science and Management 1:245-254. *https://doi.org/10.1016/j.envpol.2019.05.151*

Younis U, Malik SA, Rizwan M, Qayyum MF, Ok YS, Shah MHR, Rehman RA, Ahmad N (2016). Biochar enhances the cadmium tolerance in spinach (Spinacia oleracea) through modification of Cd uptake and physiological and biochemical attributes. Environmental Science and Pollution Research 23:21385-21394. *https://doi.org/10.1007/s11356-016-7344-3*

Yu M, Meng J, Yu L, Su W, Afzal M, Li Y, … Xu J (2019). Changes in nitrogen related functional genes along soil pH, C and nutrient gradients in the charosphere. Science of the Total Environment 650:626-632. *https://doi.org/10.1016/j.scitotenv.2018.08.372*

Yu Y, Murthy BN, Shapter JG, Constantopoulos KT, Voelcker NH, Ellis AV (2013). Benzene carboxylic acid derivatized graphene oxide nanosheets on natural zeolites as effective adsorbents for cationic dye removal. Journal of hazardous materials 260:330-338. *https://doi.org/10.1016/j.jhazmat.2013.05.041*

Yuan P, Wang J, Pan Y, Shen B, Wu C (2019). Review of biochar for the management of contaminated soil: Preparation, application and prospect. Science of the Total Environment 659:473-490. *https://doi.org/10.1016/j.scitotenv.2018.12.400*

Zhang F, Liu M, Li Y, Che Y, Xiao Y (2019). Effects of arbuscular mycorrhizal fungi, biochar and cadmium on the yield and element uptake of *Medicago sativa*. Science of the Total Environment 655:1150-1158. *https://doi.org/10.1016/j.scitotenv.2018.11.317*

Zhang R-H, Li Z-G, Liu X-D, Wang B-c, Zhou G-L, Huang X-X, … Brooks M (2017). Immobilization and bioavailability of heavy metals in greenhouse soils amended with rice straw-derived biochar. Ecological Engineering 98:183-188. *https://doi.org/10.1016/j.ecoleng.2016.10.057*

Zhang Z-y, Jun M, Shu D, CHEN W-f (2014). Effect of biochar on relieving cadmium stress and reducing accumulation in super japonica rice. Journal of Integrative Agriculture 13:547-553. *https://doi.org/10.1016/S2095-3119(13)60711-X*

Zhao S, Liu Q, Qi Y, Duo L (2010). Responses of root growth and protective enzymes to copper stress in turfgrass. Acta Biologica Cracoviensia Botanica 52:7-11.

Zhu H, Zhong H, Wu J (2016). Incorporating rice residues into paddy soils affects methylmercury accumulation in rice. Chemosphere 152:259-264. *https://doi.org/10.1016/j.chemosphere.2016.02.095*

Zhu L, Lei H, Wang L, Yadavalli G, Zhang X, Wei Y, … Ahring B (2015). Biochar of corn stover: Microwave-assisted pyrolysis condition induced changes in surface functional groups and characteristics. Journal of Analytical and Applied Pyrolysis 115:149-156. *https://doi.org/10.1016/j.jaap.2015.07.012*

Zhu Y, Wang H, Lv X, Zhang Y, Wang W (2020). Effects of biochar and biofertilizer on cadmium-contaminated cotton growth and the antioxidative defense system. Scientific Reports 10:1-12. *https://doi.org/10.1038/s41598-020-77142-7*

Zoghi Z, Hosseini SM, Kouchaksaraei MT, Kooch Y, Guidi L (2019). The effect of biochar amendment on the growth, morphology and physiology of *Quercus castaneifolia* seedlings under water-deficit stress. European Journal of Forest Research 138:967-979. *https://doi.org/10.1007/s10342-019-01217-y*

The journal offers free, immediate, and unrestricted access to peer-reviewed research and scholarly work. Users are allowed to read, download, copy, distribute, print, search, or link to the full texts of the articles, or use them for any other lawful purpose, without asking prior permission from the publisher or the author.

License - Articles published in ***Notulae Botanicae Horti Agrobotanici Cluj-Napoca*** are Open-Access, distributed under the terms and conditions of the Creative Commons Attribution (CC BY 4.0) License.
© Articles by the authors; Licensee UASVM and SHST, Cluj-Napoca, Romania. The journal allows the author(s) to hold the copyright/to retain publishing rights without restriction.

Notes:

- Material disclaimer: The authors are fully responsible for their work and they hold sole responsibility for the articles published in the journal.
- Maps and affiliations: The publisher stay neutral with regard to jurisdictional claims in published maps and institutional affiliations.
- Responsibilities: The editors, editorial board and publisher do not assume any responsibility for the article's contents and for the authors' views expressed in their contributions. The statements and opinions published represent the views of the authors or persons to whom they are credited. Publication of research information does not constitute a recommendation or endorsement of products involved.