**Pennisetum sinese**: A Potential Phytoremediation Plant for Chromium Deletion from Soil

Xiaofei Chen, Jianhua Tong, Yi Su * and Langtao Xiao *

College of Bioscience and Biotechnology, Hunan Agricultural University, Changsha 410128, China; XiaofeiChen@hunau.edu.cn (X.C.); tjh0421@sohu.com (J.T.)

* Correspondence: yisu@hunau.edu.cn (Y.S.); ltxiao@hunau.edu.cn (L.X.); Tel./Fax: +86-0731-84635260 (Y.S.); +86-0731-84635261 (L.X.)

Received: 2 April 2020; Accepted: 28 April 2020; Published: 1 May 2020

**Abstract:** Chromium is one of the major pollutants in water and soil. Thus, it is urgent to develop a new method for chromium removal from the environment. Phytoremediation is a promising approach for heavy metal pollution recovery. As a perennial giant grass with a fast growth rate, *Pennisetum sinese* has been widely used as livestock feed, mushroom culture medium and biomass energy raw material. Interestingly, we have found a high adsorption capacity of *P. sinese* for chromium. *P. sinese* was treated with different concentrations of chromium for 15 days. Results showed that *P. sinese* plantlets grew well under low concentrations (less than 500 µM) of chromium (VI). The plantlet growth was inhibited when treated with high concentrations of chromium (more than 1000 µM). Up to 150.99 and 979.03 mg·kg\(^{-1}\) DW of chromium accumulated in the aerial part and root, respectively, under a treatment of 2000 µM Cr. The bioaccumulation factor (BCF) of *P. sinese* varied from 10.87 to 17.56, and reached a maximum value at the concentration of 500 µM. The results indicated that *P. sinese* showed strong tolerance and high accumulation capability under Cr stress. Therefore, the chromium removal potential of *P. sinese* has a great application prospect in phytoremediation.

**Keywords:** *Pennisetum sinese*; chromium; bioaccumulation factor; phytoremediation

1. Introduction

Along with the increasing discharge of industrial waste, more and more heavy metals are accumulated in soil and water. The indiscriminate release of heavy metals into the environment is becoming a major health concern worldwide, since heavy metals are hard to turn into non-toxic forms under natural conditions, and will therefore have long-lasting effects on ecosystems. A very low dose of heavy metals such as chromium (Cr), arsenic (As), cadmium (Cd), lead (Pb) and mercury (Hg) can also cause serious health problems, because they are not only cytotoxic but also mutagenic and carcinogenic in nature [1]. In the past few decades, the serious contamination caused by Cr has become an increasing threat [2–4]. Cr is widely distributed in soil, water and biological materials [4,5]. Cr exists in several oxidation states, and the stable forms in nature include Cr (0), Cr (III) and Cr (VI). Cr in different valence states shows different characteristics in chemistry, toxicology and epidemiology, and Cr (VI) is more toxic than Cr (III) because of its higher mobility [6–8]. Although it is not essential for plants, Cr may have hermetic effects on plant growth—it can promote the growth of water hyacinths (*Eichhornia crassipes*), with an increased yield at low concentrations [2,9–11]. However, Cr could have deleterious effects on plant physiological processes such as photosynthesis, water relations and mineral nutrition at high concentrations [11–13]. Thus, it is urgent to develop efficient techniques for Cr removal from the environment.

Heavy metal depletion can occur under natural conditions through leaching, plant absorption, erosion and deflation. The bottleneck for these natural processes is their low efficiency. In order to
rectify a contaminated environment, several physico-chemical techniques, e.g., chemical precipitation and oxidation or reduction, filtration, ion-exchange, reverse osmosis, membrane technology, evaporation and electrochemical treatment, were developed to remove heavy metals in soil and water [14–20]. However, physico-chemical approaches are expensive or ineffective for heavy metals at low levels [14,21]. Alternately, sustainable biological remediation methods are promising for the removal of heavy metals through highly efficient biosorption and/or hyper-bioaccumulation, which could rectify and re-establish the natural condition of the soil [1,18,22]. Microorganisms and plants are common acceptors in biological methods [1]. Microorganisms are known to develop and adopt different detoxifying mechanisms, e.g., biosorption, bioaccumulation, biotransformation and biomineralization, which can be exploited for bioremediation either ex situ or in situ [23–25]. Thus, phytoremediation through hyper-accumulators and biological approaches has been regarded as an ideal remediation technique in soils polluted with heavy metals.

Phytoremediation efficiency largely depends on the capability to accumulate heavy metals and the total biomass of the plants [2,9]. Therefore, the plants applied in phytoremediation could accumulate heavy metals in organs and grow on metalliferous soils without suffering phytotoxic effects [26]. Previous reports pointed out that several species could be used for the Cr phytoremediation, such as Leersia hexandra [27], Pluchea indica, Cynodonda ctylon [28,29], Phragmites australis, Typha angustifolia [30,31], Jatropha curcas [32], Pteris vittata (Kalve et al. 2011) and Spartina argentinensis [33] (Susana et al. 2011). Recently, Nopalea cochenillifera was proved to be a potential Cr (VI) hyper-accumulator plant [34]. However, the application of the above chromium hyper-accumulator plants is still limited because most chromium hyper-accumulator plants grow slowly and their biomasses are practically insufficient for phytoremediation.

Pennisetum sinese is a perennial giant grass, which can produce a biomass yield of up to more than 200 t FW·hm$^{-2}$ [35]. P. sinese was widely used as raw material for livestock feed, mushroom culture medium and biomass energy raw material [36,37]. P. sinese can grow vigorously in barren soils and arid areas. Thus, it was also used in the conservation of water and soil, and vegetation restoration. In addition, P. sinese shows a great potential for bioethanol production because of the high content of cellulose. In this study, we detected the capability of Cr absorption from the environment and Cr accumulation of P. sinese and analyzed the effects of Cr accumulation on its growth.

2. Materials and Methods

2.1. Plant Growth Conditions

Mature P. sinese stem cuts were purchased from Fujian Agriculture and Forestry University, and the propagation was later performed in our lab. Stem segments containing two nodes were used in the cottage for propagation. To screen the growth traits, plantlets (about 10 cm height) were transplanted in 60 cm diameter pots (height 40 cm) containing 60 kg soil with a planting density of one plant per pot. One hundred pots were adjacently arranged in a square (about 40 m$^2$). In the second year after planting, the height, length of internode, effective tillers, leaf length, stem circumference and biomass were measured. To analyze the effects of chromium on P. sinese, plantlets (about 20 cm height) with six to seven leaves were transferred from the soil to a Hoagland nutrient solution and cultured in the greenhouse under natural conditions. The nutrient solution was constantly aerated through an air pump, and it was renewed every three days. To test the Cr tolerance capability, P. sinese were treated with 0, 50, 250, 500, 1000 and 2000 µM concentrations of potassium dichromate (K$_2$Cr$_2$O$_7$). To investigate the Cr absorption rate, P. sinese plantlets were cultured in a Hoagland solution containing 400 and 800 µM concentrations of potassium dichromate (K$_2$Cr$_2$O$_7$), respectively, after 48 h pre-culture in deionized water. Roots and shoots were separately collected after 0, 12, 24, 36, 48, 60 and 72 h.
2.2. Analysis of Growth Parameters

The lengths and fresh weights of the shoots and roots were recorded after harvest. Dry weights were measured after oven drying at 70 °C for 48 h. The root to shoot ratio was calculated in dry weight. Abiotic tolerance indices (TIs) were calculated as the increase in fresh weight of chromium-treated plants divided by the increase in fresh weight of untreated plants [38]. The relative growth rate (RGR) was calculated as \( \text{RGR} = \frac{(\ln W_2 - \ln W_1)}{(t_2 - t_1)} \), where \( W_1 \) and \( W_2 \) represent a plant’s dry weights at time \( t_1 \) and \( t_2 \), respectively.

2.3. Determination of Mineral Elements

Dried samples were used to detect Cr and other mineral elements in \( P. \) \( sinese \). 1.0 g of samples was digested by perchloric acid and hydro nitrate \((V/V = 1:1)\) in 90 mL of pure quartz vessels at a high pressure asher (HPA) (Bergh.of Speedwave-2, Reutlingen, Germany) [39]. After digestion through HPA, the content of chromium was determined through IRIS Interpid II XPS ICP (Thermo, USA). The ICP analysis was carried out on axially viewed plasma. The emission intensity measurements were performed under the following conditions: 1150 watt of radio frequency (RF) power, 2.4 mL min\(^{-1}\) plasma flow rate, 2.4 mL min\(^{-1}\) nebulizer flow rate, 25 psi nebulizer pressure and 0.5 L min\(^{-1}\) auxiliary flow rate. The bioaccumulation factor (BCF) was calculated as \( \frac{C_{\text{plant}}}{C_{\text{solution}}} \). \( C_{\text{plant}} \) meant the concentration of Cr in \( P. \) \( sinese \) (mg kg\(^{-1}\) DW), and \( C_{\text{solution}} \) was the concentration of Cr in solution (mg kg\(^{-1}\) DW). The transfer factor (TF) was calculated as \( \frac{C_1}{C_2} \), wherein \( C_1 \) is the metal concentration in the aboveground tissues (mg kg\(^{-1}\) DW) and \( C_2 \) is the metal concentration in the roots (mg kg\(^{-1}\) DW).

2.4. Data Analysis and Statistics

Data analysis and statistics were performed by Microsoft Excel 2010. Three independent biological replicates were analyzed. All significant treatment effects were determined by using Dunnett’s test at \( p < 0.05 \).

3. Results

3.1. Growth Analysis of \( P. \) \( sinese \)

\( P. \) \( sinese \) is a perennial plant and grows well in the tropics, subtropics and temperate zone. Its optimal growth temperature ranges from 25 °C to 35 °C. \( P. \) \( sinese \) has no heading stage in the temperate zone, but a few seeds with low germination rate can be harvested in the subtropical zone. Consequently, stem cuts with strong axillary buds are the main parts for propagation (Figure 1a). \( P. \) \( sinese \) plants are erect and clustered (Figure 1b,c). Generally, the biomass of \( P. \) \( sinese \) tended to be stable in the second year after planting both in pot and field (Figure 1c). In this study, we detected the growth traits and yield of \( P. \) \( sinese \) cultured in pots at maturity in the second year after planting (Table 1). The average plant height was about 4 m (Table 1). Previous researchers reported that \( P. \) \( sinese \) could grow to 3–5 m and even to 7 m in a field [40]. This indicated that \( P. \) \( sinese \) can grow very quickly. Moreover, we obtained a theoretical yield of about 168 t hm\(^{-2}\) FW in the pot experiment. This yield was close to the reported yield (150–255 t hm\(^{-2}\) FW) in field cultivation [35]. The results indicated that \( P. \) \( sinese \) had a huge biomass.
To clarify the Cr tolerance capability of *P. sinese*, plant growth and tolerance were analyzed under treatments with different concentrations of Cr. The growth and development of *P. sinese* were affected by different concentrations of Cr. Compared to the control (0 μM Cr), plant growth was significantly stimulated under the concentrations lower than 250 μM Cr (Figure 2a,b). Plants showed a faster growth at the level of 250 μM Cr and 6–7% increases in length and biomass. The same stimulatory effect was also observed in the ratio of Root/Stem and RGR of plantlets under treatments lower than 250 μM Cr (Figure 2c,d). However, the root to shoot ratio and relative growth rate significantly decreased when the Cr concentration was further increased. When 1000 μM or more of Cr was applied, *P. sinese* plants began to show some toxicity symptoms, e.g., thin and yellow leaves with sporadic brown spots plus serious growth inhibition. By contrast, toxicity symptoms were not obvious and no plant wilted at Cr levels lower than 1000 μM. The tolerance indices (TIs) of *P. sinese* remained stable at Cr levels lower than 500 μM (Figure 2e). Therefore, *P. sinese* showed relatively high tolerance to high Cr exposure.

### Table 1. Growth traits of *P. sinese* cultured in pots at maturity in the second year after planting.

| Traits                              | Range          | Average |
|-------------------------------------|----------------|---------|
| Height (cm)                         | 198.7–372.8    | 335.7   |
| Length of internode (cm)            | 6.4–14.3       | 10.7    |
| Effective tillers                   | 3–8            | 5.8     |
| Leaf length (cm)                    | 33.5–85.6      | 56.7    |
| Maximum stem circumference (cm)     | 1.9–2.9        | 2.5     |
| Root/stem ratio                     | 0.31–0.64      | 0.51    |
| Biomass of aerial part (kg/pot FW)  | /              | 1.68    |
| Theoretical yield (t/hm² FW)        | /              | 168     |

3.2. Effects of Cr on *P. sinese* Growth

Tolerance to heavy metals is one of the most important characteristics for phytoremediation plants. Figure 1. *P. sinese* culture. (a) 3-week-old plantlets from axillary buds cultured in Hoagland solution. (b) 2-month-old plantlets cultured in pot (30 cm diameter, 35 cm height and 15 kg soil per pot). (c) *P. sinese* in second year after planting in pot (60 cm diameter, 40 cm height and 60 kg soil per pot).
Therefore, levels of up to 0.1–1.0% of the dry weight based on the plant biomass produced, depending on the specific metal being taken up [42]. Therefore, *P. sinese* showed a high Cr accumulation and was close to hyperaccumulation level.

3.3. Cr Accumulation in *P. sinese*

Plants cultured for fifteen days were used for Cr distribution analysis. The Cr concentration in *P. sinese* increased along with the increasing Cr levels in the nutrient solution (Figure 3a,b). The highest Cr concentrations accumulated in shoots and roots were 150.99 and 979.03 mg kg⁻¹ DW, respectively, under a treatment with 2000 μM Cr in the solution. The Cr concentrations in the roots were higher than in the shoots. Compared with the control, the differences reached significant levels in all treatments at 5% level (p = 0.05). More Cr accumulated in roots than in shoots indicated that the roots show a stronger affinity for Cr. The bioaccumulation factor (BCF) of *P. sinese* exposed to Cr ranged from 10.87 to 17.56, reaching a maximum value at the Cr concentration of 500 μM. The BCF value decreased along with the concentration increase (Figure 3c). The data might indicate that the bioaccumulation depends on the duration of exposure, and the level in the environment. Generally, in all treatments, TF values obtained from the aerial and underground part of the plant were below 0.2 (Figure 3d). Hyperaccumulators are species capable of accumulating metals at levels 100 times greater than those typically measured in the shoots of common, non-accumulator plants [41]. These plants should accumulate metals at levels of up to 0.1–1.0% of the dry weight based on the plant biomass produced, depending on the specific metal being taken up [42]. Therefore, *P. sinese* showed a high Cr accumulation and was close to hyperaccumulation level.

![Figure 2.](image-url) Growth characteristics of *P. sinese* plantlets treated with hexavalent Cr for 15 days. Plant length (a), total biomass (b), root to shoot ratio (c), relative growth rate (d) and tolerance indices (e) of *P. sinese* treated with various concentrations of Cr. Data shown as means ± SD of three biological replicates (n = 5). The different letters on top of the bars represent the differences between treatments based on Dunnett’s test at 5% level (p = 0.05).
3.4. Dynamic of Cr Accumulation

The results of Cr absorption in *P. sinese* are shown in Figure 4. The total amount of Cr in the plants increased gradually with the extension of treatment time. The plants experienced a rapid absorption and then a slow absorption process under different treatment concentrations (Figure 4a,b). Under treatment with 400 μM Cr, the change of Cr contents in the plants followed an “S” distribution along with the extension of treatment time, and the saturation of Cr accumulation in the plants occurred at 60 h (Figure 4a). Under a treatment with 800 μM Cr, Cr accumulation followed a linear trend in the first 48 h, and then Cr absorption was obviously slowed. Cr absorption was not saturated until 72 h at 800 μM Cr (Figure 4b). The results indicated that the Cr absorption rate and the time to reach Cr accumulation saturation are related to the treatment concentration of Cr.

Figure 3. Cr accumulations in different parts of *P. sinese* treated with various concentrations of Cr. Cr content in roots (a) and shoots (b). Bioaccumulation factor (c) and transfer factor (d) of *P. sinese* for Cr. Data shown as means ± SD of three biological replicates (n = 5). The different letters on top of bars represent the differences between treatments based on Dunnnett’s test at 5% level (p = 0.05).

Figure 4. Total content of Cr in *P. sinese* plants under different treated times at Cr concentrations of 400 μM (a) and 800 μM (b). Data shown as means ± SD of three biological replicates (n = 5).
3.5. Effects of Cr on Element Accumulation

*P. sinense* seedlings can grow normally at a Cr concentration of less than 500 μM. Cr in the range of 500 μM to 1000 μM significantly inhibited the growth of *P. sinense* seedlings but no plant wilted. Furthermore, the contents of part nutrient elements in roots and leaves were determined to analyze the effects of Cr on element absorption. The Cr concentrations of 50, 250, 1000 μM were used according to plant growth performances. Compared with those at 0 μM Cr, the contents of Fe, Mg and Mn increased both in the roots and the shoots under treatments with Cr, but the increase of Mg and Mn was not significant (Figure 5a–c). The contents of Ca, P and K slightly decreased in the roots but increased in the shoots under treatment with Cr (Figure 5d–f). P was significantly higher than the control in the shoots (Figure 5f). The content of S in the roots increased significantly (by 11.1%) under Cr treatment at 50 μM, but it showed a lower content in the shoots under three Cr treatments (Figure 5g). Cr at more than 250 μM significantly affected the Cu content in the roots, but there was no obvious effect in the shoots under all Cr treatments (Figure 5h). Overall, Cr treatment promoted the absorption of Fe, Mg, Mn, and Cu, and slightly inhibited the uptake of Ca, P and S. Cr showed more influence on the accumulation of Fe and Cu compared to other elements.

![Figure 5](image)

**Figure 5.** Nutrient element contents in different parts of *P. sinense* treated with different Cr concentrations. Contents of Fe (a), Mg (b), Mn (c), Ca (d), K (e), P (f), S (g) and Cu (h) in plant tissues. Data shown as means ± SD of three biological replicates (n = 5).

4. Discussion

Cr is not an essential element for plant growth [9,10]. Several reports pointed out that Cr is a stimulator for plants, promoting growth and increasing biomass at low concentrations, but high concentration Cr reduces the seed germination rate, inhibits plant growth and results in a significant biomass decrease [43–45]. In fact, the phenomenon whereby low concentrations of a heavy metal promote plant growth is defined as hermetic effect and frequently occurs in treatments with heavy metals [46–48]. Because of the hermetic effect, *P. sinense* plantlets grew better and obtained a higher biomass than the control plants at low concentrations (<250 μM), and the biomass and the RGR were significantly increased compared to the control plants (Figure 2). A mineral composition analysis revealed that the total contents of Cu, Mn, Fe and Mg in Cr-treated *P. sinense* plantlets were increased compared to those in the control plants (0 μM Cr). So did the K content in the shoots (but not in the roots). The results indicated that Cr presented a certain impact on the absorption of other minerals in *P. sinense*. In this work, hexavalent Cr was supplied with potassium. Due to the lack of the same dose of potassium application treatment, we were unable to determine whether the potassium supplied affected
the promotion of plantlet growth. However, in treatments with CrCl$_3$ (data not shown in this paper) and K$_2$Cr$_2$O$_7$ as a Cr source, plant growth and Cr accumulation did not show any obvious differences at the same Cr concentration. This indicated that the effect of K on *P. sinese* growth promotion was minimal comparing to the Cr effect. Mg contents in roots treated with Cr were higher than those of the control plants. The results indicated that Cr treatment somehow contributed to the absorption of Mg. The inhibitory effects of high concentrations of Cr on plant growth were possibly due to the destruction of normal physiological metabolism or the interference with the absorption of other nutrient elements.

Cultivated *P. sinese* was initially used as forage and mushroom culture medium because of its huge biomass. Recently, researchers have also found that it showed some advantages in resistance to abiotic stresses. *P. sinese* had a certain ability to resist alkali stress [37]. *P. sinese* also showed relatively high tolerance to Cd stress and could be applied to repair the cadmium pollution in the environment [49,50]. In this study, we found that the growth of *P. sinese* plantlets was not inhibited by relatively high concentrations of Cr, indicating that *P. sinese* had a relatively high tolerance to Cr. High Cr accumulation showed that *P. sinese* had a high enrichment capability for Cr. With the concentration increase in the Cr treatment, the accumulation of Cr in *P. sinese* plants also increased, and the plant obtained the largest enrichment of 979.03 mg·kg$^{-1}$ DW under the treatment of 2000 µM Cr. According to the usual standard, hyperaccumulators can accumulate a certain ion at levels 100 times greater than those measured in the shoots of common, non-accumulator plants [41], and the content of metal in plant tissues can range from 0.1% to 1.0% (DW) depending on the specific metal being taken up [42]. The Cr content in *P. sinese* was close to that of hyperaccumulators. Moreover, the TF of Cr varied between 0.28 and 0.53 in *Hemarthria compressa* [51]. Similarly to pumpkin and green vegetables [45,52], the TF of *P. sinese* for Cr was at relative low levels under hydroponic conditions, but it reached 0.317 under soil culture conditions (not shown in this paper).

The excess of Cr the in environment is severely harmful to the human health and a serious source of stress for plants. Under Cr stress, plant growth and development can be inhibited, and crops may be threatened by reduced production [53–55]. Phytoremediation is considered a green and sustainable method for pollutant removal. Thus, some hyperaccumulator plants were screened and had great application value in Cr phytoremediation [27–34,56]. Regretfully, the identified hyperaccumulator plants are mainly small herbs, whose average annual biomass is relatively limited. When they are used as Cr phytoremediation plants, the efficiency of Cr removal from Cr contaminated soils is not high. *P. sinese* showed a huge advantage in the growth rate and biomass (more than 200 t FW·hm$^{-2}$ per year), although the level of Cr accumulation in tissues is lower than in hyperaccumulator plants. Taken together, Cr can be quickly removed from the soil through planting *P. sinese* in Cr contaminated soils and recycling Cr in collected plants. Thus, *P. sinese* has a great potential for retrieving Cr from the soil. It can be applied in phytoremediation for Cr polluted soils.

5. Conclusions

Cr is a main source of heavy metal contamination, since it is widely present in the environment. Screening phytoremediation plants are very important, and using them as a sustainable method for Cr removal is very helpful for restoring the natural conditions of Cr-polluted soils. Under treatment with different concentrations of Cr, concentrations lower than 500 µM did not significantly inhibit the growth and development of *P. sinese* seedlings, although Cr affected the absorption of some necessary elements, suggesting a relatively high tolerance of *P. sinese* to high Cr exposure. Cr accumulation in the shoots and roots can be as high as 150.99 and 979.03 mg·kg$^{-1}$ DW, respectively, when culturing in a Hoagland solution containing 2000 µM Cr, which indicates the high Cr accumulation capability of *P. sinese*. In addition, *P. sinese* is a perennial giant grass with high photosynthetic efficiency and growth rate, and its biomass can reach more than 200 t FW·hm$^{-2}$ per year, which is far greater than that of reported Cr hyperaccumulation plants. Therefore, *P. sinese* can be used to retrieve Cr from soils and has great application prospects in phytoremediation.
**Author Contributions:** Methodology, X.C.; formal analysis, X.C.; investigation, X.C. and J.T.; writing—original draft preparation, X.C.; writing—review and editing, Y.S. and L.X.; project administration, L.X.; funding acquisition, L.X. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research was funded by the National Natural Science Foundation of China (Grant number 31570372), the Scientific Research Fund of the Hunan Provincial Education Department (Grant number 18K042) and the Open Project of the Hunan Provincial Key Laboratory for Crop Germplasm Innovation and Utilization (Grant number 18KFXM06).

**Conflicts of Interest:** The authors declare no conflicts of interest.

**References**

1. Dixit, R.; Malaviya, D.; Pandiyan, K.; Singh, U.B.; Sahu, A.; Shukla, R.; Singh, B.P.; Rai, J.P.; Sharma, P.K.; Lade, H.; et al. Bioremediation of heavy metals from soil and aquatic environment: An overview of principles and criteria of fundamental processes. *Sustainability* 2015, 7, 2189–2212. [CrossRef]

2. Helena, O. Chromium as an environmental pollutant, insights on induced plant toxicity. *J. Bot.* 2012, 2012, 375843. [CrossRef]

3. Kim, Y.; Roh, Y. Environmental Application of Biogenic Magnetite Nanoparticles to RemEDIATE Chromium(III/VI)-Contaminated Water. *Minerals* 2019, 9, 260. [CrossRef]

4. Ramos-Miras, J.J.; Gil, C.; Rodriguez-Martin, J.A.; Boluda, R. Ecological risk assessment of mercury and chromium in greenhouse soils. *Environ. Geochim. Health* 2019, 42. [CrossRef]

5. Bosnir, J.; Puntaric, D.; Cvetkovic, Z.; Pollak, L.; Barusic, L.; Klaric, I.; Miskulin, M.; Puntaric, I.; Puntaric, E.; Milosevic, M. Effects of magnesium, chromium, iron and zinc from food supplements on selected aquatic organisms. *Coll. Antropol.* 2020, 37, 965–971. [CrossRef]

6. Kimbrough, D.E.; Cohen, Y.; Winer, A.M.; Chromium-eelman, L.; Mabuni, C. A critical assessment of chromium in the environment. *Crit. Rev. Environ. Sci. Technol.* 1999, 29, 1–46. [CrossRef]

7. Janusz, B.; Joanna, K. A comparison of the in vitro genotoxicity of tri-hexavalent chromium. *Mutat. Res.* 2000, 469, 135–145. [CrossRef]

8. Yuan, Z.; Cheng, X.; Zhong, L.; Wu, R.; Zheng, Y. Preparation, characterization and performance of an electrospun carbon nanofiber mat applied in hexavalent chromium removal from aqueous solution. *J. Environ. Sci.* 2019, 77, 78–87. [CrossRef]

9. Peralta-Videa, J.R.; Lopez, M.L.; Narayan, M.; Saupé, G.; Gardea-Torresdey, J. The biochemistry of environmental heavy metal uptake by plants, implications for the food chain. *Int. J. Biochem. Cell B* 2009, 41, 1665–1677. [CrossRef]

10. Paiva, L.B.; de Oliveira, J.G.; Azevedo, R.A.; Ribeiro, D.R.; da Silva, M.G.; Vitória, A.P. Ecophysiological responses of water hyacinth exposed to chromium III and chromium VI+. *Environ. Exp. Bot.* 2009, 65, 403–409. [CrossRef]

11. Islam, F.; Yasmeen, T.; Arif, M.S.; Riaz, M.; Shahzad, S.M.; Imran, Q.; Ali, I. Combined ability of chromium (Cr) tolerant plant growth promoting bacteria (PGPB) and stress alleviator (salicylic acid) in attenuation of chromium stress in maize plants. *Plant Physiol. Biochem.* 2016, 108, 456–467. [CrossRef] [PubMed]

12. BavareSCO, J.; Jessé, R.F.; Moraes, M.T.; Sánchez-Rodriguez, A.R.; Anghinoni, I. Chromium from hydrolyzed leather affects soybean growth and nodulation. *Pedosphere* 2017, 29, 95–101. [CrossRef]

13. Diwan, H.; Ahmad, A.; Iqbal, M. Chromium-induced modulation in the antioxidant defense system during phenological growth stages of Indian mustard. *Int. J. Phytoremediat.* 2010, 12, 142–158. [CrossRef] [PubMed]

14. Ahluwalia, S.S.; Goyal, D. Microbial and plant derived biomass for removal of heavy metals from waste water. *Bioreour. Technol.* 2007, 98, 2243–2257. [CrossRef] [PubMed]

15. Hunce, S.Y.; Ackgul, D.; Demir, G.; Mertoğlu, B. Solidification/stabilization of landfill leachate concentrate using different aggregate materials. *Waste Manag.* 2012, 32, 1394–1400. [CrossRef]

16. Wang, L.; Chen, L.; Tsang, D.C.; Li, J.S.; Yeung, T.L.; Ding, S.; Poon, C.S. Green remediation of contaminated sediment by stabilization/solidification with industrial byproducts and CO2 utilization. *Sci. Total Environ.* 2018, 631–632, 1321–1327. [CrossRef]

17. Onireti, O.O.; Lin, C.; Qin, J. Combined effects of low-molecular-weight organic acids on mobilization of arsenic and lead from multi-contaminated soils. *Chemosphere* 2017, 170, 161–168. [CrossRef]

18. Liu, L.; Li, W.; Song, W.; Guo, M. Remediation techniques for heavy metal-contaminated soils: Principles and applicability. *Sci. Total Environ.* 2018, 633, 206–219. [CrossRef]
19. Senneca, O.; Cortese, L.; Di-Martino, R.; Fabbricino, M.; Ferraro, A.; Race, M.; Scopino, A. Mechanisms affecting the delayed efficiency of cement based stabilization/solidification processes. J. Clean. Prod. 2020. [CrossRef]

20. Sun, Y.; Guan, F.; Yang, W.; Wang, F. Removal of chromium from a contaminated soil using oxalic acid, citric acid, and hydrochloric acid: Dynamics, mechanisms, and concomitant removal of non-targeted metals. Int. J. Environ. Res. Public Health 2019, 16, 2771. [CrossRef]

21. Hussein, H.; Farag, S.; Moawad, H. Isolation and characterization of Pseudomonas resistant to heavy metals contaminants. Arab. J. Biotechnol. 2004, 7, 13–22. [CrossRef]

22. Kapoor, A.; Viraraghvan, T. Fungal biosorption—An alternative treatment option for heavy metal bearing wastewaters: A review. Bioresour. Technol. 1995, 53, 195–206. [CrossRef]

23. Malik, A. Metal bioremediation through growing cells. Environ. Int. 2004, 30, 261–278. [CrossRef] [PubMed]

24. Lin, C.C.; Lin, H.L. Remediation of soil contaminated with the heavy metal (Cd\(^{2+}\)). J. Hazard. Mater. 2005, 122, 7–15. [CrossRef] [PubMed]

25. Abhisheka, A.; Saranyab, N.; Chandia, P.; Selvarajua, N. Studies on the remediation of chromium(VI) from soil using Phytoremediation. J. Environ. Qual. 2013, 1, 5.

26. Liu, X.; Li, X.; Chermaine Ong, S.M.; Chu, Z. Progress of phytoremediation focus on new plant and molecular mechanism. J. Plant Biol. Soil Health 2013, 1, 5.

27. Zhang, X.H.; Liu, J.; Huang, H.T.; Chen, J.; Zhu, Y.N.; Wang, D.Q. Chromium accumulation by the hyperaccumulator plant Leersia hexandra Swartz. Chemosphere 2007, 67, 1138–1143. [CrossRef]

28. Sampanpanish, P.; Khaothong, S.; Pongsapich, W.; Khan, E. Alternative for chromium removal, phytoremediation and biosorption with weed plant species in Thailand. Sci. Asia 2007, 33, 353–362. [CrossRef]

29. Sampanpanish, P.; Ongsapich, P.W.; Khaodhiar, S.; Khan, E. Chromium removal from soil by phytoremediation with weed plant species in Thailand. Water Air Soil Pollut. 2006, 191–206. [CrossRef]

30. Xu, S.; Jaffé, P.R. Effects of plants on the removal of hexavalent chromium in wetland sediments. J. Environ. Qual. 2006, 35, 334–341. [CrossRef]

31. Bareen, F.; Khilji, S. Bioaccumulation of metals from tannery sludge by Typha angustifolia L. Afr. J. Biotechnol. 2008, 7, 3314–3320. [CrossRef]

32. Mangkoedihardjo, S.; Ratnawati, R.; Alfianti, N. Phytoremediation of hexavalent chromium polluted soil using Pterocarpus indicus and Jatropha curcas L. World Appl. Sci. J. 2008, 4, 338–342.

33. Susana, R.G.; Enrique, M.N.; Immaculada, V.B.; Susana, R.F. Accumulation and tolerance characteristics of chromium in a cordgrass chromium-hyperaccumulator Spartina argentinensis. J. Hazard. Mater. 2011, 185, 862–869. [CrossRef]

34. Adki, V.S.; Jadhav, J.P.; Bapat, V.A. Nopalea cochenillifera, a potential chromium (VI) hyperaccumulator plant. Environ. Sci. Pollut. Res. 2013, 20, 1173–1180. [CrossRef] [PubMed]

35. Zhang, X.; Yang, Z.; Zhang, Y.; Gao, Q. Introduction experiment of Pennisetum sp. in central and southern region of Hebei. J. Anhui Agric. Sci. 2015, 43, 78–80.

36. Lin, X.S.; Lin, Z.X.; Lin, D.M.; Lin, H.; Luo, H.L.; Hu, Y.P.; Lin, C.M.; Zhu, C.Z. Effects of different years of planting Pennisetum sp. on the plant and insect diversity in Pennisetum sp. communities. Chin. J. Appl. Ecol. 2012, 23, 2849–2854.

37. Lin, X.S.; Lin, Z.X.; Lin, H.; Lin, D.M.; Luo, H.L.; Hu, Y.P.; Lin, C.M.; Zhu, C.Z. Physiological responses and alkaline-tolerance evaluation on 5 species of Juncao under alkaline stress during seedling stage. Plant Physiol. J. 2013, 49, 167–174.

38. Dhir, B.; Srivastava, S. Heavy metal tolerance in metal hyperaccumulator plant, Salvinia natans. Bull. Environ. Contam. Toxicol. 2013, 90, 720–724. [CrossRef]

39. Cho, H.J.; Myung, S.W. Determination of cadmium, chromium and lead in polymers by ICP-OES using a high pressure asher (HPA). Bull. Korean Chem. Soc. 2011, 32, 489–497. [CrossRef]

40. Lin, Z. Plants for Mushroom Culture, 3rd ed.; State Administration College Press: Beijing, China, 2013.

41. Lasat, M.M. Phytoextraction of toxic metals: A review of biological mechanisms. J. Environ. Qual. 2002, 31, 109–120. [CrossRef]

42. Pilon-Smits, E. Phytoremediation. Ann. Rev. Plant Biol. 2005, 56, 15–39. [CrossRef] [PubMed]
43. Samantaray, S.; Rout, G.R.; Das, P. Role of chromium on plant growth and metabolism. *Acta Physiol. Plant.* 1998, 20, 201–212. [CrossRef]
44. Shanker, A.K.; Cervantes, C.; Loza-Tavera, H.; Avudainayagam, S. Chromium toxicity in plants. *Environ. Int.* 2005, 31, 739–753. [CrossRef] [PubMed]
45. Liu, L.; Lv, J.Y.; Zang, W. Effects of chromium $^{6+}$ treatment on chromium accumulation and physiological characteristics of celery (*Apium graveolens*). *J. Nucl. Agric. Sci.* 2010, 24, 639–644. [CrossRef]
46. López, M.L.; Peralta-Videa, J.R.; Benítez, T.; Gardea-Torresdey, J.L. Enhancement of lead uptake by alfalfa (*Medicago sativa*) using EDTA and a plant growth promoter. *Chemosphere* 2005, 61, 595–598. [CrossRef] [PubMed]
47. López, M.L.; Peralta-Videa, J.R.; Benítez, T.; Gardea-Torresdey, J.L. Enhancement of lead uptake by alfalfa (*Medicago sativa*) using EDTA and a plant growth promoter. *Chemosphere* 2005, 61, 595–598. [CrossRef] [PubMed]
48. Clabeaux, B.L.; Navarro, D.A.G.; Aga, D.S.; Bisson, M.A. Cd tolerance and accumulation in the aquatic macrophyte, *Chara australis*: Potential use for charophytes in phytoremediation. *Environ. Sci. Technol.* 2011, 45, 5332–5338. [CrossRef]
49. Yin, G.; Bi, L.; Song, X.; Luo, H.; Ji, P.; Lin, Q.; Liu, Q.; Tang, G. Adsorption of Cd(II) from aqueous solution by *Pennisetum* sp. straw biochars derived from different modification methods. *Environ. Sci. Pollut. Res. Int.* 2019, 26, 7024–7032. [CrossRef]
50. Zhang, S.R.; Tian, Y.K.; Yang, X.M.; Xu, X.X.; Li, T.; Huang, C.Y.; Pu, Y.L.; Li, Y. The Application of *P. sinese* in the Phytoremediation of Heavy metal Cadmium Pollution in Soil. China Patent 102941219A, 13 April 2013.
51. Chen, T.T.; Gao, J.; Liu, Z.F.; He, Y.H. Characteristics of chromium bioaccumulation of *Hemarthria compressa*. *Environ. Sci. Technol.* 2011, 34, 83–87. [CrossRef]
52. Yang, D.; Lv, J.Y.; Cheng, Y.A.; Gao, J.F. Subcellular distribution of chromium and its effects on some enzyme activities in pumpkin. *J. Agro-Environ. Sci.* 2007, 4, 1352–1355.
53. Choudhary, S.P.; Kanwar, M.; Bhardwaj, R.; Yu, J.Q.; Tran, L.S.P. Chromium stress mitigation by polyamine-brassinosteroid application involves phytohormonal and physiological strategies in *Raphanus sativus* L. *PLoS ONE* 2012, 7, e33210. [CrossRef] [PubMed]
54. Shah, F.R.; Ahmad, N.; Masood, K.R.; Zahid, D.M. The Influence of cadmium and chromium on the biomass production of Shisham (*Dalbergia Sissoo Roxb.*) seedlings. *Pak. J. Bot.* 2008, 40, 1341–1348. [CrossRef]
55. Zeng, E.R.; Qiu, B.Y.; Ali, S.; Zhang, G.P. Genotypic differences in nutrient uptake and accumulation in rice under chromium stress. *J. Plant Nutr. Soil* 2010, 33, 518–528. [CrossRef]
56. Kalve, S.; Sarangi, B.K.; Pandey, R.A.; Chakrabarti, T. Arsenic and chromium hyperaccumulation by an ecotype of *Pteris vittata*-prospective for phytoextraction from contaminated water and soil. *Curr. Sci. India* 2011, 100, 888–894. [CrossRef]