Assessment of phytoremediation ability of *Coriander sativum* for soil and water co-contaminated with lead and arsenic: a small-scale study

Nisha Gaur¹ · Aayush Kukreja¹ · Mahavir Yadav¹ · Archana Tiwari¹

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Abstract A study was conducted to access the phytoremediation potential of *Coriandrum sativum* for lead (Pb) and Arsenic (As). Metal tolerance index and pot experiment were conducted. Viable seeds were spread on filter paper and planted in soil placed in pots. The amount of Pb and As in control and in tailing soil was 0.27, 0.141, 1.77, and 0.35 ppm. The study was carried out in triplicates for a period of 4 weeks under natural conditions. The physico-chemical properties of soil were determined using the standard methods. Germination of seeds of *Coriander sativum* was inhibited more rigorously in filter paper as compared to soil medium. Shoot height and root length were significantly reduced in filter paper medium under Pb and As stress. These were inhibited by 33 and 40%, respectively, from the first to fourth weeks. Seedling growth was less affected in soil medium while greatly reduced in filter paper medium. Soil sustained almost equal stress in the fourth week as compared to the third week in filter paper medium. Shoot height was enormously affected by Pb and As compared to root length in filter paper medium, whereas slight inhibition of growth was observed in soil medium. *Coriander sativum* grown in pots was effective in removing Pb and As from control and tailing soils in comparison with seeds grown on filter paper. On this basis, it could be used in restoring soil polluted with Pb and As.

Keywords Phytoremediation · *Coriander sativum* · Pb and As · Metal tolerance index · Pot experiment · MPI

Introduction

Due to industrialization and urbanisation, tremendous use of heavy metals has been seen which leads to the contamination of environment. In addition, these heavy metals enter into the food chain and accumulate in human body leading to death of cells. In Europe, about 20% of total land surface is suffering from soil contamination and degradation. Conventional treatment methods presently available are insufficient to decontaminate the soil contamination as they are incredibly costly and time consuming. According to the report submitted in 2002 to European Union, the cost of cleaning contaminated sites would cost around 100 billion dollars. Likewise, a report came in the late 1990s, estimated congruently high costs in the US. Around one trillion dollars was estimated to clean up more than 500,000 contaminated sites (Saier and Trevors 2010).

Phytoremediation is the green technology which uses green plants and associated microbes to clean up contaminated soil and water. From the past 10 years, this technology gained lot of acceptance as it is cost effective, non-invasive alternative or complementary technology for engineering-based remediation methods (Pilon-Smiths 2005).

Arsenic upon exposure shows variety of adverse health effects on human. It can be acute or chronic. Arsenic toxicity leads to many diseases such as respiratory, pulmonary, cardiovascular, hepatic, and renal. In addition, dermal changes such as pigmentation, hyperkeratosis and ulceration, mutagenic, genotoxic, and carcinogenic effects

✉ Nisha Gaur
gaurnisha2011@gmail.com

¹ School of Biotechnology, Rajiv Gandhi Proudyogiki Vishwavidyalaya, Airport Road, Bhopal 462033, Madhya Pradesh, India

are also caused due to uptake of As contaminated water (Gaur et al. 2014; Mandal and Suzuki 2002).

Pb is ubiquitous metal having unique properties such as softness, highly malleable, ductile, low melting point, and resistance to corrosion. Due to these good properties of Pb, it is used in various industries such as automobile, paint, ceramics, plastic, etc. It also causes various toxic effects to human such as vomiting, encephalopathy, lethargy, delirium, convulsions, and coma. In addition, it also affects various systems of human body such as nervous system, hematopoietic system, renal effects, cardiovascular system, and reproductive health effects by the mechanism of oxidative stress (Flora et al. 2012).

Coriandrum sativum, which is commonly known as Dhanyaka, is commonly found in India, Italy, Netherlands, Central and Eastern Europe, China, and Bangladesh. It is highly reputed ayurvedic medicinal tree of small size which possess antioxidant, anti-convulsant, sedative hypnotic, anti-mutagenic, anthelmintic, and anti-microbial activities (Gogte 2000). Phytochemical and pharmacological studies of different parts of *Coriander sativum* have been conducted. These studies support its potential as a medicinal plant. In addition, more investigation should be done to explore the potential of this plant (Pathak Nimish et al. 2011).

The objective of this study is to find out the phytoremediation efficiency of *C. sativum* plant grown in pots vs filter paper media. The results show that this approach has considerable potential for remediation of Pb and As from contaminated soil and water.

Materials and methods

Soil sample collection and processing

Soil sample used in study was collected from a depth of 0–20 cm from an industrial area of Govindpura, Bhopal (Madhya Pradesh). The collected soil sample was transported to the botanical garden of Rajiv Gandhi Proudhyogiki Vishwavidyalaya, Bhopal (Madhya Pradesh). The collected sample soil was air dried and pre-sieved with mesh of 2 mm diameter. The Physico-chemical properties of sample soil used for the study are given in Table 1. Control sample soil used for study was collected from botanical garden of Rajiv Gandhi Proudhyogiki Vishwavidyalaya, Bhopal (Madhya Pradesh). The taxonomic classification of sample soil was clay with pH of 7.4.

Seed collection (*Coriander sativum*)

Seeds of *C. sativum* were collected from Annapurna Krishi Bhandar, Bhopal. The seeds used for the experimental purpose were fresh, good quality and showed less

generation time. Local seeds were used, because they have ability to tolerate adverse climatic conditions and they easily acclimatize to different environmental conditions.

Effluent collection

Samples of the contaminated water were collected from the industrial area of Govindpura, Bhopal (Madhya Pradesh) as this area is contaminated with different kinds of effluent released from nearby industries. Control water sample was taken as deionized water. Pb, As, and pH values of deionized and waste water are depicted in Table 2.

Cultivation practices and treatment

The study was a pot-based experiment conducted at botanical garden of Rajiv Gandhi Proudhyogiki Vishwavidyalaya, Bhopal (Madhya Pradesh). The design was completely randomized and treatment strategy was conducted in triplicates. The sample soil was aerated and transferred to pots (25 cm diameter and 20 cm depth) which were labelled as the first, second, third, and fourth weeks. The pots were filled with sample soil (pre-sieved with 2 mm mesh size) up to the height of 70% of initial height of pot. The seeds of *C. sativum* (ten seeds per pot) were planted in each pot. Each pot was

Table 1 Physico-chemical characteristics of control and tailing soil

Sample	Value	
	Control soil	Tailing soil
pH	7.9	7.4
Org. carbon (%)	0.57	0.60
Total N (%)	478.8	322.4
Available P (ppm)	21.81	9.12
Available Fe (ppm)	3.25	2.11
Available Zn (ppm)	2.64	1.84
Available Pb (ppm)	0.27	1.77
Available As(ppm)	0.141	0.35
Available K (ppm)	679.88	226.18
Silt (%)	22	26
Sand (%)	43.96	40.35
Clay (%)	34.04	30.11
Soil type	Clay	Clay

Table 2 Physico-chemical characteristics of control and waste water

Sample	Value	
	Control water	Waste water
pH	7.1	6.3
Available Pb (ppm)	0.0024	1.35
Available As (ppm)	0.0012	0.19

sprinkled with 10–20 ml of deionized water daily. Sampling of soil and plants was done on weekly (1–4) basis for estimating residual metal contents in soil and metal uptake rate by plant.

Analysis of lead and As

Pb and As concentrations in soil and water were measured after double digestion method, using hot plate digestion system according to the American Public Health Association (Apha 2005). The triplicates of each treatment pots were harvested in consecutive weeks (1–4 weeks) and pooled together to produce composite sample of each treatment. The plants were washed with tap water to remove dirt, soil, and other associated unwanted products. Finally, plants were washed with deionized water. Each sample was dried in an oven at 70 °C for 24 h. Finally, the amount of Pb and As accumulation was checked by Atomic Absorption Spectrophotometer (ICP-AAS, Perkin Elmer) at the Indian Institute of Soil Science, Bhopal.

Metal tolerance index

Tolerance index represents the relative growth rate of the plant and is equal to the growth in metal containing solution divided by the growth in control solution, the quantity multiplied by hundred (Lee 2003). The tolerance index was calculated using formula given by Igbal and Rehmati (1992):

$$\text{Tolerance index} = \frac{\text{RL or SH in sample}}{\text{RL or SH in control}} \times 100.$$

Growth inhibition was calculated using formula given below (Ahmad et al. 2013):

$$\text{Growth inhibition} = \frac{\text{RL or SH in Control} - \text{RL or SH in sample}}{\text{RL or SH in control}} \times 100,$$

where RL is the root length and SH is the shoot length.

Heavy metal pollution index (HPI)

HPI is a powerful technique which provides the overall quality of water on the basis of concentration of heavy metals present in it. HPI has been developed and calculated as

$$\text{HPI} = \sum_{i=1}^n \frac{W_i \times Q_i}{W_i}, \quad (1)$$

$$Q_i = \sum_{i=1}^n \frac{|M_i - I_i|}{S_i - I_i} \times 100. \quad (2)$$

In Eq. (1), Q_i represents sub-index of the i th parameter,

W_i is the unit weightage of the i th parameter, and n is the total number of parameters. In Eq. (2), M_i is the observed value of heavy metal of the i th parameter, I_i is the ideal value of i th parameter which is taken from Bureau of Indian standard, and S_i is the standard permission limit of the i th parameter.

Statistical analysis

Data are expressed as mean $\pm$ SEM. Data comparisons were carried out using two-way analysis of variance (ANOVA) followed by Tukey's post-hoc test to compare means between the different treatment groups. Difference between unexposed (normal control) and exposed (contaminated soil and water) with a P value <0.05 was considered significant.

Results and discussion

Metal tolerance index

Seed germination and seedling growth

Both the metals (Pb and As) showed the adverse effect on seed germination and growth of *C. sativum* seedlings. Increasing number of weeks significantly inhibited the germination of seeds (Fig. 1). The seed germination was reduced from the first week (70.6%) to the fourth week (41%) compared to the control treatment (Table 3).

The number of roots of crop seedlings did not increase consistently in response to metal exposure with increase in the duration of treatment (first–fourth weeks). While in case of control, it increased significantly with the duration. In addition, the number of roots of crop seedlings in contaminated water increased initially but stopped and became constant after the fourth week.

Pb- and As-induced oxidative stress has been identified as the prime reason for the severe reduction of enzyme activities involved in the seed metabolic process related to germination. In addition, *C. sativum* is known of having Pb permeable seed coat which further delayed and reduced the ability of seed germination in a dose-dependent manner (Wierzbička and Obidzińska 1998).

The root length of crop seedling of sample plants was significantly less (30–40%) as compared to that of the control seedlings. As the number of weeks increased, the root length in test plants was reduced from 3.6 to 2.4 cm (Table 3).

At the end of the third week, the root tip of the seedlings had changed their colour from brown to dark brown and the

Fig. 1 Percent germination of *C. sativum* seeds on filter paper medium (FM). Values are mean $\pm$ SE, $n = 3$, * $P < 0.05$ compared to normal; $P < 0.05$ control sample (tap water) compared to Pb and As exposed industrial water. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

roots were found hairless, dwarf, thick, and curled. On the other hand, seedlings growing in control were white with abundant root hairs and longer lateral branches.

The adverse effects of Pb and As have reportedly caused structural and morphological changes of roots as well as inhibition of root hair of seedlings. The reason behind the reduction in seedling growth and biomass production is metal uptake and their translocation to shoot (Kabir et al. 2011).

Shoot height of *C. sativum* seedlings increased initially, but after the third week, it became constant. Furthermore, no increase in shoot height was observed due to reduction in the tolerance capacity of *C. sativum* after the second week as compared to the control (Table 3). The root/shoot ratios of crop seedlings decreased after the second week as compared to the control seedlings (Table 3).

The level of plant tolerance to heavy metals is associated with the balance between the ratio at which metal ions are taken-up and the proficiency with which they are decontaminated within the plant (Malik et al. 2010).

Pot experiment

The physico-chemical properties of control and tailing soil are presented in Table 1. The pH of the control and tailing soil was alkaline (7.9 and 7.4, respectively). The total nitrogen, available phosphorous, and available potassium were threefold higher in the control soil than in tailing soil. The percentage of iron was determined to check whether the sample was soil or residual slag.

Heavy metals such as Pb and As were present in higher concentration in tailing soil as compared to control soil (1.5 and 0.2%, respectively) (Table 1). Percentage of sand and clay were also higher in control soil than in the tailing soil. In addition, the silt content was more in tailing soil as compared to control soil.

Pb and As caused a decrease in the percentage of seed germination in tailing soil from 76.63 to 70.3% (Table 4). In case of tailing soil, the rate of seed germination was increased with increased time of course.

Although, both the soils had Pb and As contents, but control had lesser percentage of both (70%). Control showed higher germination rate apart from heavy metal contaminants, and it also had a higher percentage of nutrient content which is required for proper growth of the seedlings. Thus, the germination rate also decreased in case of control soil, but the rate was slower as compared to the tailing soil. The root length of the sample plants was decreased significantly by 15% due to decrease in tolerance capacity with increased time course (first–fourth weeks).

Table 3 Seed germination, root growth, shoot height and root: shoot ratio of *C. sativum* in response to Pb and As present in industrial water

<i>Coriander sativum</i> seedlings	No. of weeks	Germination of seeds (%)	No. of roots	Root length (cm)	Shoot height (cm)	Root/shoot
Control						
C1	1	84.6 $\pm$ 1.453	4 $\pm$ 0.57	4.16 $\pm$ 0.02	3.5 $\pm$ 0.043	1.02 $\pm$ 0.081
C2	2	83.3 $\pm$ 0.881	5.6 $\pm$ 0.88	3.65 $\pm$ 0.07	4.13 $\pm$ 0.18	0.81 $\pm$ 0.05
C3	3	69.3 $\pm$ 1.201	7 $\pm$ 0.57	3.46 $\pm$ 0.03	5.03 $\pm$ 0.08	0.62 $\pm$ 0.02
C4	4	69 $\pm$ 2.081	7.3 $\pm$ 0.33	3.4 $\pm$ 0.03	6.11 $\pm$ 0.16	0.53 $\pm$ 0.008
Sample						
S1	1	70.6 $\pm$ 1.453*	4.6 $\pm$ 0.66	3.6 $\pm$ 0.028*	2.4 $\pm$ 0.26*	1.2 $\pm$ 0.173
S2	2	54.6 $\pm$ 1.45*	5.6 $\pm$ 0.33	3.39 $\pm$ 0.038*	3.47 $\pm$ 0.24	0.90 $\pm$ 0.053
S3	3	41.3 $\pm$ 1.76*	6 $\pm$ 0.577	2.9 $\pm$ 0.05*	3.47 $\pm$ 0.09*	0.77 $\pm$ 0.039*
S4	4	41 $\pm$ 0.577*	6.3 $\pm$ 0.33	2.4 $\pm$ 0.26*	3.47 $\pm$ 0.13*	0.69 $\pm$ 0.03*

Values are mean $\pm$ SE; $n = 3$. * $P < 0.05$ compared to normal control; $P < 0.05$ control sample (tap water) compared to lead and arsenic exposed industrial water

Table 4 Seed germination, root length, shoots height, root:shoot ratio, and percent removal of Pb and As of *C. sativum* in response to Pb and As present in garden and tailings soil

<i>Coriander sativum</i> seedlings	No. of weeks	Germination of seeds (%)	Root length (cm)	Shoot height (cm)	Root/shoot	% Pb	% As
Garden (control) soil							
G1	1	85.3 ± 0.408	10.38 ± 0.257	8.1 ± 0.22	1.28 ± 0.049	51.6 ± 0.88	39 ± 1.15
G2	2	83 ± 0.707	10.03 ± 0.108	9.1 ± 0.18	1.10 ± 0.036	56.3 ± 1.20	37 ± 1.15
G3	3	81.6 ± 0.408	9.7 ± 0.07	10.06 ± 0.14	0.96 ± 0.012	52.6 ± 1.45	36.3 ± 1.45
G4	4	80.6 ± 0.40	9.3 ± 0.070	10.3 ± 0.14	0.90 ± 0.006	50 ± 0.57	35.3 ± 1.85
Tailings soil							
T1	1	80.3 ± 1.080*	9.06 ± 0.147*	7.9 ± 0.57	1.14 ± 0.027	60.3 ± 0.88*	52.3 ± 1.45*
T2	2	76.6 ± 1.47*	8.6 ± 0.177*	8.5 ± 0.28	1.01 ± 0.038	81.6 ± 1.20*	55.6 ± 1.20*
T3	3	73.6 ± 1.08*	8.53 ± 0.227*	9.1 ± 0.14*	0.93 ± 0.020	76 ± 1.52*	57.6 ± 1.85*
T4	4	70.3 ± 1.080*	7.8 ± 0.187*	9.4 ± 0.17*	0.82 ± 0.025*	71.6 ± 0.88*	60.3 ± 0.88*

Values are mean ± SE; $n = 3$. * $P < 0.05$ compared to normal control; $P < 0.05$ control sample (Garden soil of RGPV) compared to lead and arsenic exposed tailing soil

In addition, the appearance of root tip had also changed. Change in colour and thickness was also observed in tailing soil. This indicated a more prominent inhibitory effect of heavy metals in tailing soil compared to control soil.

Heavy metals also significantly affected the shoot height of the test plant. Shoot height of *C. sativum* increased initially with the passing of weeks. However, after 4 weeks, the plant died due to decrease in tolerance capacity of plant (Table 4). The root-to-shoot ratio was also decreased from the first week (1.14) to the fourth week (0.82) in tailing soil.

The phytoremediation capacity of *C. sativum* for the removal of Pb and As is shown in Fig. 2. The percentage removal of Pb was initially increased, but after the second week, the level of percentage removal of Pb decreased and became constant in both control and tailing soil,

Fig. 2 Removal (%) of Pb and As by *Coriander sativum*. Values are mean ± SE, $n = 3$, * $P < 0.05$ compared to garden soil; $P < 0.05$ control sample (garden soil) compared to Pb and As exposed tailing soil. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

because the tolerance capacity of *C. sativum* declined due to exposure of heavy metals. In addition, after the second week, the plants died due to increase in heavy metal concentration. While in case of As, the percentage removal significantly increased up to the fourth week. This was due to the fact that As concentration in soil was low and the plant was able to remove it.

Similar investigation was conducted by Xiaohai et al. to check the accumulation of Pb, Zn, and Cu in native plants that were grown on contaminated sites. They used 19 plant species and found that out of 19 plant samples, no plant species were identified as Cu and Zn hyper-accumulators. Moreover, many plant samples showed greater phytoremediation capability towards Pb removal (Liu et al. 2008). In another finding, ability of *Raphanus sativus* L. to extract Pb from contaminated soil was investigated. The result of this study showed the non-linear and positive relation between Pb accumulation in the root and shoot of the plant and in the soil. (Kapourchal et al. 2009). Other investigation has been done on uptake of As, Cd, Zn, and Pb by high biomass producing crops like grazing or energy crops in both field and pot experiment. The results of this study revealed that the Pb and As removal was negligible for all the plant species that were investigated during the work. In field experiment, lower phytoremediation efficiency was determined, but yield was not suppressed (Tlustoš et al. 2006).

Amount of Pb and As accumulation in different parts of *Coriander sativum*

Pb and As concentrations in different tissues of *C. sativum* are shown in Table 5. Amount of As uptake by root, stem, and leaf of *C. sativum* from garden soil (control) on the fourth week were 7.44 ± 0.57 ,

13.2 ± 0.26, and 15.1 ± 0.29 ppm, respectively, whereas the amount of As uptake by root, stem, and leaf of *C. sativum* from tailing soil on the fourth week were 14.51 ± 0.42, 35.92 ± 0.15, and 44.52 ± 0.65 ppm, respectively. The amount of Pb uptake by root, stem, and leaf of *C. sativum* from garden soil (control) on the fourth week were 47.24 ± 0.20, 38.528 ± 0.091, and 23.452 ± 0.63 ppm, respectively, whereas the amount of Pb accumulated in root, stem, and leaf of *C. sativum* from tailing soil on the fourth week were 350.88 ± 0.33, 300.24 ± 0.56, and 160.58 ± 0.55 ppm, respectively. The results are in correlation with the percent removal of As and Pb from garden and tailing soil, respectively, as per the data given in Table 4.

The amount of Pb absorbed in stem and leaf was lower in comparison with the amount absorbed in root system (Table 4). No visual changes have been observed in leaves of *C. sativum* during 28 days of the experiment.

The bioavailability of Pb in the soil is low because of the low solubility of the Pb compounds and its precipitation by sulphate and phosphate present around the roots (Smith 2000). It was documented that most the roots accumulate much higher Pb than the shoot system due to its low mobility (Lee et al. 2013; López-Millán et al. 2009; Waranusantigul et al. 2008). This is due to high retention rate of root for Pb which minimizes transport of Pb to shoot system. Low translocation of metals to aboveground tissues in the 12 species examined might also suggest that plants are capable of well-balanced uptake and translocation of metals under heavy metal-polluted conditions (Nouri et al. 2009; Pulford and Watson 2003). Through this study, it can be concluded that the higher accumulation of Pb in root showed that the process may be phytostabilization. In case of As, the process may be phytoextraction as its

concentration was higher in leaves (Meeinkuirt et al. 2012; Meera and Agamuthu 2012).

Comparative efficacy of different media in causing Pb- and As-induced toxicity to *C. sativum* at seed germination stage

Germination of seedlings (%)

Germination of *C. sativum* seedlings was found to be comparatively better in soil (pot experiment) than in filter paper medium (metal tolerance experiment). With an increase in number of weeks or exposure to heavy metals, seed germination gradually decreased (Fig. 1). It was also observed that *C. sativum* seed germination was inhibited more rigorously in filter paper compared to soil medium. Maximum inhibition was found after the second week in filter paper medium (Fig. 1), while in soil medium, maximum inhibition was found at the fourth week (Fig. 3) which was significant ($P < 0.05$) as compared to control.

Seedling growth

Shoot height and root length were significantly reduced in filter paper medium under Pb and As stress (Fig. 4). They were inhibited by 33 and 40%, respectively, from the first to fourth weeks and were statistically significant as compared to control. In contrast, Pb and As reduced shoot height in soil medium, but the difference was statistically non-significant initially, 2 weeks after that it was statistically significant as compared to control (Fig. 5). The root-to-shoot ratio was found statistically non-significant in the initial 3 weeks, after that it was statistically significant as compared to control in soil medium. Moreover, seedling

Table 5 Mean Pb and As concentration in root, stem, and leaves of *C. sativum* in garden soil and tailing soil

<i>Coriander sativum</i> seedlings	No. of weeks	As uptake (ppm)			Pb uptake (ppm)		
		Root	Stem	Leaf	Root	Stem	Leaf
Garden soil (control)							
G1	1	0.99 ± 0.045*	1.58 ± 0.03*	1.9 ± 0.71*	4.603 ± 0.13*	3.824 ± 0.002*	2.204 ± 0.18*
G2	2	1.8 ± 0.02*	3.9 ± 0.08*	5.8 ± 0.40*	10.806 ± 0.34*	7.798 ± 0.012*	4.473 ± 0.52*
G3	3	4.3 ± 0.21*	7.8 ± 0.07*	9.2 ± 0.56*	22.769 ± 0.19*	20.152 ± 0.035*	10.715 ± 0.14*
G4	4	7.44 ± 0.57*	13.2 ± 0.26*	15.1 ± 0.29*	47.24 ± 0.20*	38.528 ± 0.091*	23.452 ± 0.63*
Tailings soil							
T1	1	1.34 ± 0.037*	2.71 ± 0.056*	3.41 ± 0.81*	5.47 ± 0.38*	4.92 ± 0.35*	2.12 ± 0.23*
T2	2	2.53 ± 0.044*	6.28 ± 0.021*	7.33 ± 0.65*	29.24 ± 0.25*	25.24 ± 0.66*	10.45 ± 0.47*
T3	3	5.81 ± 0.37*	15.33 ± 0.042*	17.82 ± 0.32*	116.96 ± 0.67*	110.11 ± 0.19*	45.52 ± 0.68*
T4	4	14.51 ± 0.42*	35.92 ± 0.15*	44.52 ± 0.65*	350.88 ± 0.33*	300.24 ± 0.56*	160.58 ± 0.55*

Values are mean ± SE; $n = 3$. * $P < 0.05$ compared to normal control; $P < 0.05$ control sample (Garden soil of RGPV) compared to Pb and As exposed tailing soil

Fig. 3 Percent germination of *C. sativum* seedlings on soil medium. Values are mean $\pm$ SE, $n = 3$, * $P < 0.05$ compared to control (Garden soil, RGPV, Bhopal); $P < 0.05$ control sample (garden soil) compared to Pb and As exposed tailing soil. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

Fig. 4 Growth characteristics of *C. sativum* on filter paper medium (FM). Values are mean $\pm$ SE, $n = 3$, * $P < 0.05$ compared to normal; $P < 0.05$ control sample (tap water) compared to Pb and As exposed industrial water. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

growth was less affected in soil medium while greatly reduced in filter paper medium.

Tolerance index

Tolerance index on the basis of root length and shoot height clearly explained the response of growth media in extenuating Pb and As stress (Fig. 6). Soil medium relatively absorbed stress more proficiently than filter paper medium. Increased Pb and As concentration in any medium rigorously inhibited plant growth thus reducing tolerance. Soil sustained almost equal stress at the fourth week as compared to the third week in filter paper medium. Tolerance index were 72.7 and 54.99% on the basis of root

Fig. 5 Growth characteristics of *C. sativum* on soil medium (SM). Values are mean $\pm$ SE, $n = 3$, * $P < 0.05$ compared to control; $P < 0.05$ control sample (garden soil) compared to Pb and As exposed tailing soil. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

length and shoot height, respectively, at the fourth week in filter paper medium, while in the same week in soil medium, it was observed 83.8 and 91.64%, respectively.

Growth inhibition

Shoot height was enormously affected by Pb and As compared to root length in filter paper medium, whereas slight inhibition of growth was observed in soil medium (Fig. 7). Increase in duration of time severely inhibited root and shoot growth, because the plant's tolerance capacity got reduced in filter paper medium as compared to soil medium. In case of soil medium, the root length was inhibited at a greater rate as compared to shoot height, whereas in filter paper medium, the shoot height was inhibited at greater rate (Fig. 7).

Pb and As toxicity has been evaluated by means of seed germination, root length, and shoot height of *C. sativum* seedlings as previously reported by some researchers. They have investigated the As, Zn, and Pb tolerance and accumulation in six populations of *Pteris Vittata* (Verma and Dubey 2003; Wu et al. 2009). In the present study, soil medium provided some assistance to plants grown under Pb and As stress; therefore, some increase in growth parameters has been detected as compared to filter paper medium.

Phytoremediation ability of different plants for Pb and As

Various plants have ability to accumulate heavy metals in their different parts. Phytoremediation ability of various plants for Pb and As is depicted in Table 5.

Fig. 6 Tolerance index of *C. sativum* seedlings (**a** root length, **b** shoot height) on different growth media. FM filter paper medium, SM soil medium. Values are mean $\pm$ SE, $n = 3$, * $P < 0.05$ compared to soil medium; $P < 0.05$ control sample (garden soil) compared to lead and arsenic exposed tailing soil. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

Table 6 represents the amount of Pb and As accumulated by different plants or crop species. It is clearly evident that most of the leafy vegetables are hyper-accumulator of Pb and As. The diverse vegetable crop species showed noticeable difference in respect of heavy metal uptake and their distribution to various parts of plant especially to the edible part, which could be considered as a major factor for selecting a plant for removal of heavy metals from contaminated soil. However, still, most of the plants are not suggested to use for removal of heavy metals from contaminated soils (Singh et al. 2012). *Coriander sativum* suppresses the deposition of Pb by chelating the metals. A sorbent prepared from *C. sativum* was efficiently able to remove organic and methyl mercury from aqueous solution (Kansal et al. 2011). As per the data presented in Table 5, it may be concluded that this plant has the ability to accumulate heavy metals such as Pb and As. Further studies should be done to check the phytoremediation ability of this plant for removal of other heavy metals from contaminated soil.

Heavy metal pollution index

Table 7 depicts the amount of Pb and As present in ground water of Govindpura nearby area. The value of Pb ranges between 0.04 and 0.13 ppm, whereas the amount of As present in ground water varies from 0.03 to 0.08 ppm.

Fig. 7 Growth inhibition (%) of *C. sativum* seedlings (**a** root length, **b** shoot height) on different growth media. FM filter paper medium, SM soil medium. Values are mean $\pm$ SE, $n = 3$, * $P < 0.05$ compared to soil medium; $P < 0.05$ control sample (garden soil) compared to Pb and As exposed tailing soil. Asterisk: Differences between values with matching symbol notations within each bar are statistically significant at 5% level of probability

The HPI values for five water samples were calculated and the results are tabulated in Table 8. These values are used to assess the quality of ground water samples.

Heavy metals such as Pb, As, Cd, etc. cause many adverse effects on human health such as kidney, liver, and nervous system damage if they are present in drinking water above the permissible limit. Quality of water is based on the range of HPI. Very good quality of water has HPI value between 0 and 25. Good quality of water has HPI value between 26 and 50. Poor quality water has HPI value above 51 and its maximum limit is 75. If water has HPI value above 75, it is considered as not suitable for drinking (Sirajudeen et al. 2014). Water sample collected from different sites in Govindpura industrial area has HPI index 150 which is above the critical index value; therefore, this water is considered non fit for drinking and causes effect on human health.

Conclusion

In the present study, the comparative analysis of different media used for phytoremediation purpose was done and the results demonstrate that pot experiment is better than the

Table 6 Phytoremediation ability of different plants for Pb and As

S. no.	Plants	Metal concentration (ppm)				References		
		Plant (Dry)		Soil				
		Pb	As	Pb	As			
1	Spinach	0.11–15.5	–	18.1–24.5	–	Abou Auda et al. (2011)		
2	<i>Glycine max</i> L.	1.46	–	2.13	–	Aransiola et al. (2013)		
3	Radish	16	–	–	–	Singh et al. (2012)		
	Carrot	52	–	–	–			
	Potato	206	–	–	–			
	Onion	56	–	–	–			
	Spinach	57	–	–	–			
	Amaranthus	111	–	–	–			
	Fenugreek	126	–	–	–			
	Mustard	83	–	–	–			
	Cauliflower	133	–	–	–			
	Cabbage	133	–	–	–			
	Soybean	75	–	–	–			
	Cluster bean	104	–	–	–			
	Tomato	55	–	–	–			
	Brinjal	165	–	–	–			
	Peas	100	–	–	–			
	Okra	126	–	–	–			
	4	Spinach	283.31	–	336.9		–	Farraji et al. (2014)
	5	<i>Plantago major</i> L.	107.52	–	17.45		–	Romeh et al. (2016)
	6	<i>P. vittata</i>	–	7.1	–		29.26	Raj and Singh (2015)
<i>A. capillus</i>		–	4.54	–	44.4			
<i>veneris</i>		–	4.87	–	46.57			
<i>C. dentate</i>		–	4.81	–	50.41			
7	<i>P. karka</i>	–	4.81	–	50.41	Díaz et al. (2016)		
	<i>Lupinus microcarpus</i>	–	10.08 (Soil 1)	–	5.3 (Soil 1)			
			3.08 (Soil 2)	–	13.1 (Soil 2)			
			4.47 (Soil 3)	–	4.47 (Soil 3)			
8	Pigeon Pea (<i>C. cajan</i>)	–	251	–	–	Dias et al. (2009)		
	Lead tree (<i>L. leucocephala</i>)		259.3	–	–			
	Wand riverhemp (<i>S. virgate</i>)		826.6	–	–			

Table 7 Sampling site in Govindpura nearby area

Site	Heavy metals (ppm)	
	Pb	As
S1	0.13	0.03
S2	0.07	0.07
S3	0.04	0.08
S4	0.11	0.08
S5	0.09	0.05

metal tolerance experiment for remediation of heavy metals and these results are in line with previous study (Ahmad et al. 2013).

The results of this study revealed very clear effects of both growth media. Germinating ability of *C. sativum* seedlings significantly decreased as the number of weeks increased in filter paper medium which might be due to direct contact of Pb and As to seeds. Although low Pb and As concentration permitted the germination ability, while it was strongly inhibited at higher concentration and increase in passage of time. This implied that *C. sativum* seedlings tolerate Pb and As only up to a certain limit. On the other hand, soil medium provided some assistance to plants grown under Pb and As stress; therefore, some increase in growth parameters has been detected as compared to filter paper medium.

Table 8 HPI calculation for Pb and As of ground water sample near Govindpura area

Heavy metals	Mean value (ppb) M_i	Standard permissible value (ppb) S_i	Highest desirable value (ppb) I_i	Unit weightage W_i	Sub-index Q_i	$W_i \times Q_i$
Pb	0.088	0.05	0.01	0.02	176	3.52
As	0.062	0.05	0.01	0.02	124	2.48
				$\sum W_i = 0.04$	$\sum W_i \times Q_i = 6$	

Heavy metal pollution index = $6/0.04 = 150$

Root length showed considerable reduction with increase in duration of time, while small increase in shoot height was shown in filter paper medium as well as soil medium. In addition, prolonged exposure to Pb and As hampered shoot and root length and dry weight of *C. sativum* leaves (Gallego et al. 1996; Shafiq et al. 2008). Root length was strongly inhibited on both the medium, which showed its higher susceptibility to Pb and As stress. While there was little reduction in shoot height, but it was significant when compared to the control treatment. Tolerance index decreased as the number of weeks increased. Similar results on other metals have been observed by other researchers (Shafiq et al. 2008).

Different tissues of *C. sativum* accumulates Pb and As at different rates. From the present study, it has been observed that Pb was accumulated in sequence as root > stem > leaves. Whereas the amount of As taken-up *C. sativum* was in sequence root < stem < leaves.

In addition, tolerance index on the basis of root and shoot length explained the ability of soil to slack Pb and As stress on *C. sativum*, thus, tolerance index was increased in soil medium. Similarly, growth inhibition results indicated significance of soil over filter paper medium. Being a negatively charged body, soil has ability to reduce toxic effects of Pb and As; thus, it is considered as less sensitive to Pb and As than filter paper medium.

Various vegetable crop species have marked difference in respect of heavy metal uptake from contaminated soil. However, still, most of plants are not recommended for removal of heavy metals from contaminated soils. In addition, *C. sativum* has ability to chelate heavy metals which is further confirmed through recent study. Further studies should be done to check the phytoremediation ability of this plant for heavy metals removal from heavy metal contaminated soil.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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