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SHORT RESEARCH AND DISCUSSION ARTICLE

Evaluation of *Furcraea foetida* (L.)Haw. for phytoremediation of cadmium contaminated soils

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Abstract

In the present study, we evaluated *Furcraea foetida* for the phytoremediation of cadmium (Cd)-contaminated soils. We selected *F. foetida* because it is a drought-resistant plant, produces high biomass, and needs minimum maintenance. It belongs to the leaf fiber group of plants and therefore has economic importance. Since it is a non-edible crop, there is no danger of food chain contamination. Despite possessing these ideal characteristics, surprisingly, to date, the plant is underutilized for phytoremediation purposes. Therefore, to evaluate the phytoremediation potential of the plant, we exposed it to five levels of cadmium (0, 25, 50, 100, and 200 mg Cd kg^{-1} soil) and studied its influence on growth, dry matter production, uptake, and translocation efficiency. The plant showed good tolerance to Cd 200 mg kg^{-1} soil without exhibiting any visible toxicity symptoms. The metal mainly accumulated in the roots (233 μg g^{-1}dw), followed by leaf (51 μg g^{-1} dw). The bioconcentration factor was > 1, but the translocation factor was < 1. The plant was not classified as a hyperaccumulator of Cd; however, because of its high uptake (897 μ g^{-1} plant) and translocation efficiency (78%), we concluded that the plant could be utilized for phytoextraction of Cd from soils with low to moderately contaminated soils.

Keywords Bioconcentration factor · Cadmium · *F. foetida* · Phytoremediation · Translocation factor

Introduction

Cadmium (Cd) is a nonessential, highly toxic environmental pollutant that causes serious health problems. A major part of Cd within the human diet comes from agricultural products grown on contaminated soils. According to the WHO (2003), the leading causes of Cd in agricultural lands are atmospheric deposition and application of phosphatic fertilizers and other soil modifications. Notwithstanding health risks, numerous researchers had investigated and suggested field crops for phytoremediation (Gupta et al. 2013; Vamerali et al. 2010). However, the utilization of edible crops for remediation is not advisable as the heavy metals may enter the food chain (Gupta et al. 2013). Therefore, non-edible crops should be encouraged on contaminated soils to prevent Cd accumulation in edible parts (Bachir et al. 2004). Among the many crop plant species commonly used by humans, fiber-producing plants are in great importance and were placed second only to food plants (http://faculty.ucr.edu/~legneref/botany/fibers.htm). Studies on the use of fiber-yielding plants for phytoremediation of heavy metals are limited (Angelova et al. 2004; Ludvíková and Griga 2019; Ramana et al. 2015, 2016, 2017). *Furcraea foetida* a synonym for *F. gigantea* (Vent.), also known as Mauritius hemp, is one of the essential fiber crops and uses Crassulacean acid metabolism (CAM). Its leaves produce a large quantity of fiber which is used to make several products such as twine, cloth, mats, and ropes. It withstands drought, needs little care to grow, non-edible (including by animals), and produces high biomass. It has been conjectured that the plants which are adapted to drought conditions may also endure heavy metal stress. According to Macnair (2003), the biological and evolutionary significance of metal accumulation in plants is connected to drought resistance and this mechanism may also indirectly contribute to heavy metal

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tolerance, as heavy metal stress is responsible for secondary water stress in plants in a way similar to salt stress (Poschenrieder et al. 1989). The plant has ornamental foliage, which adds aesthetic value. Unlike most hyperaccumulator plants, the leaves remain attached to the plant even after senescence, which prevents the return of the heavy metals to the ground/soil where they are grown. Dhillon and Dhillon (2016) reported that about 200–300 g Se ha^{-1} gets redeposited in the soil because of leaf fall. Despite these ideal characters, limited work has been done on this plant for phytoremediation purposes. So far, we have come across only one report of this plant being studied for phytoremediation purposes. That lone report comes from our group only (Ramana et al. 2015). In that study, we evaluated Mauritius hemp (*F. gigantea*) (a synonym for *F. foetida*) for its phytoremediation potential of Cr. The study revealed that *F .gigantea* was an excluder of Cr and could be utilized for phytostabilization purposes. However, the response of a plant to heavy metals differs from one element to another element. Therefore, the present study aims to understand the effect of Cd on growth, biomass accumulation, and Cd uptake by *F. foetida*, and to evaluate its Cd phytoremediation potential.

Materials and methods

The pot culture experiment was conducted in a screen house at ICAR-Indian Institute of Soil Science, Bhopal. Soil was collected from the nearby farming field and weighed 2 kg in plastic pots whose capacity was 2.5 kg. Subsequently, it was spiked with an aqueous solution of Cd $(NO_3)_2$ to get 25, 50, 100, and 200 mg Cd kg^{-1} soil and incubated for 30 days. For control, ordinary tap water was used. After 30 days, the soil was mixed thoroughly and analyzed for diethylene triamine penta acetate (DTPA) extractable Cd (mg kg^{-1} soil): (Cd_0 traces; Cd_{25} - 7.9; Cd_{50} - 17.1; Cd_{100} - 50.1; and Cd_{200} - 94.7). One uniformly sized bulbil was planted in each pot. After 6 months, the study was terminated. The plants were taken out carefully from the pot with prior watering. After harvest, the roots and leaves were separated, and the roots were washed in running tap water. Scale and leaf area meters were employed for measuring the root length and leaf area, respectively. The plant samples were dried in an oven at 80 °C for 1 week and the data on dry weight (DW) were recorded. The phytotoxicity of Cd was determined by calculating the grade of growth inhibition (GGI) (Leita et al. 1993). For the determination of the concentration of Cd in the plant tissue, 1 g of dried plant sample was digested with a mixture of 10 ml di acid (9 HNO_3: 4 $HClO_4$). The digested material was transferred to a 50-ml volumetric flask and diluted with deionized water, then filtered with Whatman No 42 filter paper. The Cd concentration was determined by ICP-OES (Model Perkin Elmer Optima 2100 DV) and expressed as μg g^{-1} DW. Subsequently, Cd uptake was determined by multiplying the tissue Cd concentration with dry weight and expressed as μg pot^{-1}. Based on the data of concentration of Cd in the plant tissue and its uptake, the phytoremediation potential of the plant was determined by calculating the following parameters:

Bioconcentration factor (BCF)

BCF = $C_{\text{harvested tissue}}/C_{\text{soil}}$; where $C_{\text{harvested tissue}}$ is the concentration of the metal in the plant tissue (roots, stem, or leaves) and C_{soil} is the concentration of the same metal in soil (Zhuang *et al*. 2007). In the present experiment we, have calculated the bioconcentration factor for roots (BCFR) to interpret the excluder capability of the study plant.

Translocation factor (TF)

The TF was calculated by the formula given by Padmavathiamma and Li (2007) and Adesodun et al. (2010).

$$\text{TF} = C_{\text{shoot}}/C_{\text{root}}$$

Translocation efficiency (TE %)

$$\text{TE}\ (\%) = M_{\text{shoot}} \cdot \text{DW}_{\text{shoot}}/[M_{\text{shoot}} \cdot \text{DW}_{\text{shoot}} + M_{\text{root}} \cdot \text{DW}_{\text{root}}] \times 100$$

where M_{shoot}, M_{root} = heavy metal concentration in the shoot and root (μg g^{-}); DW_{shoot}, DW_{root} = dry weight (g) of the shoot and root respectively (Meers et al. 2004).

% Cd crop removal

The following formula calculated the % Cd crop removal (Ramana et al. 2015):

$$\%\text{Cd removal} = (\text{total Cd uptake by plant}/\text{total Cd present in the soil}) \times 100$$

The experiment was conducted in a completely randomized design (CRD) and there were three replications for each treatment. Analysis of variance (ANOVA) was performed to

Table 1 Effect of different levels of Cd on morphological parameters in *F. foetida*

Levels of Cd (mg kg^{-1} soil)	Dry weight (g $plant^{-1}$)			No of leaves $plant^{-1}$	Leaf area (cm^2 pot^{-1})	GGI (%)
	Root	Leaf	Total			
Cd 0	2.31 ± 0.45^{a}	15.81 ± 1.45	18.13 ± 1.00	9.00 ± 1.15	1193 ± 94.0^{a}	-
Cd 25	1.69 ± 0.06^{ab}	15.57 ± 2.12	17.27 ± 2.10	8.67 ± 0.33	1039 ± 74.5^{a}	4.86 ± 10.2
Cd 50	1.61 ± 0.09^{ab}	15.38 ± 0.97	16.99 ± 0.95	8.67 ± 0.33	1038 ± 73.2^{a}	6.26 ± 0.2
Cd 100	1.56 ± 0.15^{b}	14.80 ± 2.69	16.34 ± 2.74	7.67 ± 17.3	570 ± 17.3^{b}	10.18 ± 15.9
Cd 200	1.28 ± 0.11^{b}	12.84 ± 1.25	14.12 ± 1.14	7.67 ± 28.6	552 ± 28.6^{b}	23.87 ± 2.8
CD (0.05)	0.71	NS	NS	NS	459	8.72

Note: Means with same letter are not significantly different based on the CD ($P = 0.05$)

compare treatment means at 5% level of significance using a web-based agricultural statistics software package (ccari.res.in>wasp2.0) and treatment means were compared using critical difference (CD) at 5% probability appropriate for CRD.

Results and discussion

Effect of Cd morphological parameters and grade of growth inhibition

Table 1 shows the effect of different levels of Cd on growth and various morphological parameters in *F. foetida*. Cd significantly decreased the dry weight of the root and leaf area of the plant over control. The harmful effect of Cd on dry root weight and leaf area was evident from Cd 100 mg kg^{-1} soil. The dry weight of the root decreased by 27% at Cd 25 mg kg^{-1} soil, and by 45% at 200 mg Cd kg^{-1} soil. However, the dry weight of leaf and total dry weight were unaffected by Cd except at Cd 200 mg Cd kg^{-1} soil, where there was a marginal decrease. Leaf area more or less unchanged up to 50 mg Cd kg^{-1} soil but decreased significantly from Cd 100 mg Cd kg^{-1} soil. Surprisingly, in the present study, even at 200 mg Cd kg^{-1} soil, the grade of growth inhibition (GGI%) was less than 50%. Though there was 24% growth inhibition at the highest level (200 mg Cd kg^{-1} soil), the plant did not exhibit any visible toxicity symptoms which indicates the plant's tolerance to higher levels of Cd. Reduction in growth is a typical response in a broad range of plants grown in metal-laden soils (Begonia et al. 1998). The inhibition in root growth is a well-documented effect due to heavy metals in plants (Chen et al. 2001**).** The growth reduction and biomass yield with increasing Cd levels have been primarily attributed to perturbed photosynthesis (Chugh and Sawhney 1999).

Partitioning of Cd, its uptake, and percent (%) removal by *F. foetida*

Table 2 shows the partitioning of Cd in roots, leaves, uptake, and the % removal by *F. foetida.* The concentration of Cd in both root and leaf tissues increased significantly as the concentration of soil Cd increased. Invariably, the roots accumulated the higher Cd content compared to leaves. The increase was linear up to Cd 100 mg kg^{-1} soil, after which there was a sharp rise. The highest concentration (233 μg g^{-1} DW) was recorded at Cd 200 mg kg^{-1} soil. In contrast, the concentration in the leaves increased linearly throughout. It grew from 13 μg g^{-1}dw at Cd 25 mg kg^{-1}soil to 51 μg g^{-1} dw at Cd 200 mg kg^{-1}soil. The concentration was less than the critical concentration of 100 μg g^{-1}dw in the shoot/leaf to classify it as a hyperaccumulator for Cd (Baker and Walker 1990; Mganga

Table 2 Effect of Cd on Cd content, its uptake, and removal by *F. foetida*

Levels of Cd (mg kg^{-1} soil)	Concentration (μg g^{-1} DW)		Uptake (μg pot^{-1})			% Cd removal
	Root	Leaf	Root	Leaf	Total	
Cd 0	Traces	Traces	Traces	Traces	Traces	-
Cd 25	27.7 ± 1.3^{d}	12.7 ± 1.2^{c}	46.9 ± 2.3^{c}	193.6 ± 16.7^{b}	240.4 ± 16.8^{c}	0.96 ± 0.07^{a}
Cd 50	61.6 ± 3.0^{c}	28.3 ± 2.7^{b}	98.5 ± 2.9^{bc}	435.7 ± 50.6^{ab}	534.2 ± 53.5^{b}	1.07 ± 0.11^{a}
Cd 100	92.5 ± 6.5^{b}	35.0 ± 3.1^{b}	142.1 ± 5.8^{b}	523.3 ± 110.4^{a}	665.4 ± 113.3^{b}	0.67 ± 0.11^{b}
Cd 200	232.8 ± 12.0^{a}	51.1 ± 3.2^{a}	223.0 ± 38.3^{a}	662.0 ± 92.8^{a}	896.5 ± 62.0^{a}	0.45 ± 0.03^{b}
CD (0.05)	22.9	8.7	63.1	251.0	229.5	0.28

Note: Means with same letter are not significantly different based on the CD ($P = 0.05$)

et al. 2011). A similar trend was noticed in the uptake of Cd also. However, the absorption of Cd was higher in the leaf because of higher leaf biomass. The highest total Cd uptake (897 μg pot^{-1}) was recorded in Cd 200 mg $kg^{-1}$$soil^{-}1$. In contrast, when we exposed the plant to Cr in our previous study, we got a contradictory result. The uptake of Cr in root was higher than the shoot because of lower leaf biomass with applied Cr (Ramana et al. 2015). In the present study, to quantify the phytoremediation potential of Cd, we determined the BCF, TF, TE (%), and % Cd removal by the plant. BCF provides information on the uptake of metal, its translocation to the above-ground plant parts (Newman and Unger 2003); in contrast, TF shows the ability of the plant to translocate heavy metals from roots to shoot of the plant (Adesodun et al. 2010; Padmavathiamma and Li 2007). The average BCF in the present study was 1.16, indicating better uptake and movement of the metal from the soil to the root (Table 3). BCF has been used as a measure of heavy metal (HM) accumulation efficiency in plants. BCF values greater than 1 indicate a potential HM-hyperaccumulator species (Zhang et al. 2002). However, the TF was substantially low (< 1). TF values ranged from 0.46 at Cd 25 mg kg^{-1} soil to 0.22 at Cd 200 mg kg^{-1} soil, indicating reduced translocation from root to the shoot. The internal Cd translocation mechanisms are still unclear. Furthermore, it has been attributed that binding of Cd to the specific root-cell proteins results in its accumulation in roots (Cieslinski et al. 1996). The uptake and translocation of Cd from root to shoot differ among different plant species and genotypes of the same species (Guo et al. 1995). Translocation efficiency (TE%) is another important indicator of the potential of phytoremediation by the plant. Unlike TF, TE (%) takes the uptake of the metal into account. It is a ratio of uptake of metal (Cd) by the shoot to total uptake and multiplied by 100 (Meers et al. 2004). In the present study, the average TE value was reasonably high, i.e., 78%. Furthermore, the plant's Cd removal declined from 0.96% at Cd 25 mg kg^{-1} soil to 0.45% at Cd 200 mg kg^{-1} soil. This value is similar to the mustard (0.4%), a hyperaccumulator of Cd (Wu et al. 2003).

Table 3 Effect of different levels of Cd on phytoremediation potential in *F. foetida*

Levels of Cd (mg kg^{-1} soil)	Bioconcentration factor (BCF)	Translocation factor (TF)	Translocation efficiency (TE%)
Cd 25	1.11 ± 0.05^{ab}	0.46 ± 0.06^{a}	80.32 ± 1.54
Cd 50	1.23 ± 0.06^{a}	0.46 ± 0.06^{a}	81.30 ± 1.28
Cd 100	0.92 ± 0.06^{b}	0.39 ± 0.01^{a}	77.38 ± 3.96
Cd 200	1.16 ± 0.06^{a}	0.22 ± 0.02^{b}	73.13 ± 6.14
CD (0.05)	0.19	0.14	NS

Note: Means with same letter are not significantly different based on the CD ($P = 0.05$)

Conclusion

The present study results demonstrated that *F. foetida* exhibited an excellent tolerance mechanism to Cd by withstanding up to 200 mg Cd kg^{-1} soil without any visible phytotoxicity symptoms. The plant could not be classified as a hyperaccumulator of Cd. However, its bioconcentration factor was >1; uptake and translocation efficiency were also very high. The higher biomass of the plant would compensate for lower metal concentration in the leaf. Therefore, this plant could be utilized for phytoextraction of Cd contaminated soils.

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