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Evaluation of hyperaccumulation potentials to cadmium (Cd) in six ornamental species (compositae)

Zhouli Liu[a], Wei Chen[a], and Xingyuan He[a,b]

[a]CAS Key Laboratory of Forest Ecology and Management, Institute of Applied Ecology, Shenyang, China; [b]University of Chinese Academy of Sciences, Beijing, China

ABSTRACT

Phytoremediation is considered as a promising soil remediation technique. In the present study, the growth responses, cadmium (Cd) accumulation and uptake capability of six popular compositae species, namely, *Taraxacum mongolicum* Hand.-Mazz., *Tagetes erecta* L., *Tagetes patula* L., *Zinnia elegans Jacq.*, *Centaurea cyanus* L. and *Gerbera jamesonii Bolus* under Cd stress were investigated. Among the six compositae species, the growth of *T. erecta* L. and *T. patula* L. improved under 10 mg kg^{-1} Cd exposure in term of the total biomass and height increased along with the increased Cd concentration in soil, and the growth of the two plants had no significant differences at the high Cd concentration (100 mg kg^{-1}), which indicated that they have good tolerance to Cd toxicity. At the same time, the two plants have higher biomass than four other plants. Furthermore, they can accumulate Cd above 100 µg g^{-1} dry tissue, which is the threshold value of a Cd-hyperaccumulator, and have higher Cd uptake ability, translocation factor (TF) and bioconcentration factor (BCF) values. According to these traits, it was shown that *T. erecta* L. and *T. patula* L. had strong tolerance and accumulation capability to Cd, therefore they can become potential hyperaccumulators in phytoremediation of Cd-contaminated soils.

KEY WORDS
Accumulation; compositae species; growth; heavy metal; phytoremediation

Introduction

Cadmium (Cd) is one of the highly toxic environmental pollutants (Rui et al. 2016; Fu et al. 2018). The contamination of Cd are produced from non-ferrous metals smelting, mine exploitation, industrial products and agricultural activities. Cd is non-essential element for plants, however, it can be absorbed easily by plants and eventually enter the human body via the food chain (Yasin et al. 2018). Therefore, Cd-contaminated soil is current concern globally because of the serious threat to human health.

Nowadays several technologies have been developed to cleanup Cd-contaminated soil. Phytoremediation is considered as a promising soil remediation technique where the plants with hyperaccumulation ability are used to remove, assimilate or adsorb hazardous pollutants in soil (He et al. 2013; Midhat et al. 2017; Madejón et al. 2018; Zeng et al. 2018). It has recently become a popular research topic in screening potential hyperaccumulators for phytoremediation. Cd concentration in shoots (dry weight) of some species is generally 0.05–0.2 µg g^{-1} (Solis-Dominguez et al. 2007), however, hyperaccumulators can accumulate Cd above 0.01% dry weight (100 µg g^{-1}) (Liu et al. 2009). Nearly 500 species of hyperaccumulators have been documented all over the world, however, only few plant species such as *Thlaspi caerulescens*, *Arabidopsis halleri*, *Sedum alfredii*, *Brassica napus* L., *Lonicera japonica* Thunb. and *Coronopus didymus* have been reported (Escarré et al. 2000; Huguet et al. 2012; Jaffré et al. 2013; Wang et al. 2013; Xiao et al. 2013; Liu et al. 2015; Angelova et al. 2017; Sidhu et al. 2017). Application of hyperaccumulators in practice is limited because of low biomass and slow growth rate of hyperaccumulators or accumulators (Liu et al. 2018). Thus, it is important and necessary to identify new universal hyperaccumulators or accumulators of Cd. The plant species with fast growth, high biomass and ecological value, such as ornamental plants, may provide a good cleanup method for Cd-contaminated soil. Some ornamental plants have also been used for the bioaccumulation and remediation of heavy metal and VOCs in contaminated environment (Liu et al. 2011, 2013; Han et al. 2015; Jelusic and Lestan 2015; Rafiq et al. 2016; Teiri et al. 2018; Yan et al. 2018). However, little information is available on the accumulation potential of Cd in compositae species.

Compositae (Asteraceae) family is one of the largest flowering plant families throughout the world. Compositae is important primarily for its many beautiful ornamentals, such as Taraxacum, Tagetes, Zinnia, Centaurea and Gerbera. The compositae species are widely used as landscape greening and horticultural ornamentation. In the present study, six popular compositae species, namely, *Taraxacum mongolicum* Hand.-Mazz., *Tagetes erecta* L., *Tagetes patula* L., *Zinnia elegans Jacq.*, *Centaurea cyanus* L. and *Gerbera jamesonii Bolus* were

CONTACT Zhouli Liu liuzhouli@hotmail.com; Wei Chen forestry83@hotmail.com CAS Key Laboratory of Forest Ecology and Management, Institute of Applied Ecology, Shenyang, Liaoning, 110016, China.

selected. The aims of the study were: (1) to evaluate the effects of different concentrations Cd (0, 10 and 100 mg kg^{-1}) on the growth of six ornamental plants and (2) to identify the accumulation and translocation characteristics of six ornamental plants to Cd stress. Furthermore, it can provide a reference for screening new hyperaccumulators for phytoremediation of Cd-contaminated soil.

Materials and methods

Plant culture and Cd exposure

The pot-culture experiment was carried out in July 2017 at the Shenyang Botanical Garden of Chinese Academy of Sciences (41°46′ N and 123°26′ E), which is in the temperate zone with a semi-humid monsoon climate. The average annual temperature is 7.8 °C, the average annual precipitation is 734.5 mm, and the relative air humidity is 65–75%. During the experiment, minimal and maximal temperatures ranged from 15 °C to 20 °C and 25 °C to 31 °C, respectively. The soil used in the pots was collected from the top soil (0–20 cm) of a garden. Table 1 lists physical and chemical properties of the test soil. The air-dried soil samples were sieved through a 3-mm mesh sieve and placed into plastic pots with (20 cm diameter ×15 cm height), mixed uniformly with the specified concentration of $CdCl_2{\cdot}2.5H_2O$ solution. Three Cd concentrations were applied: 0 (CK), 10 and 100 mg kg^{-1}. Seeds of six compositae species (*T. mongolicum* Hand.-Mazz., *T. erecta* L., *T. patula* L., *Z. elegans Jacq.*, *C. cyanus* L. and *G. jamesonii Bolus*) were obtained from Liaoning Academy of Agricultural Sciences. Table 2 lists the natural properties of sampled plants. The seeds of each species were superficially sterilized by contact with ethanol solutions (70%, v/v) for 1 min, followed by distilled water under agitation for 10 min. Twenty seeds of each species were transplanted into each pot. Each Cd concentration was repeated three times in separate pots. The plants were harvested 8 weeks later for analysis.

Measurements of plant biomass and Cd content in plant tissues

The harvested plants were rinsed with tap water, and the roots were immersed in 20 mM Na_2-EDTA for 15 min to remove Cd adhered to the root surface (Yang et al. 2004). Then, the plants were separated into leaves, stems and roots. They were then separately rinsed with running tap water and distilled water, wiped with tissues and weighed. They were then dried at 105 °C for 30 min, then at 70 °C until weight was constant for Cd content measurement.

Dried plant materials were weighed and ground. The powders were digested with a concentrated acid mixture of $HNO_3/HClO_4$ (3:1, v/v). The Cd concentration in plant tissues was determined with an Optima3000 ICP-AES instrument (Perkin-Elmer, USA).

Table 1. Physical and chemical properties of the test soil.

Soil type	Meadow burozem
pH	7.25 ± 0.03
Organic matter (OM) (%)	4.09 ± 0.02
Cation exchange capacity (CEC) (cmol kg^{-1})	19.53 ± 0.08
Total N (g kg^{-1})	3.65 ± 0.03
Total P (g kg^{-1})	2.11 ± 0.01
Total K (g kg^{-1})	16.98 ± 0.06
Cd (mg kg^{-1})	0.15 ± 0.02

Data analysis

The translocation factor (TF) indicated the ability of plants to translocate heavy metals from the roots to the shoots (Mattina et al. 2003). It was calculated as

$$TF = \frac{\text{The metal concentration in shoots}}{\text{The metal concentration in roots}}.$$

The bioconcentration factor (BCF) was described as (Saraswat and Rai 2018):

$$BGF = \frac{\text{The metal concetration in roots}}{\text{The metal concentration in medium}}.$$

Heavy-metal uptake was calculated using the following formula as (Sharma and Agrawal 2006)

$$\text{Uptake}(\mu\text{g plant}^{-1}\text{d}^{-1}) = \frac{M_2W_2 - M_1W_1}{T_2 - T_1},$$

where M_1 and M_2 are metal concentrations in the plant tissue and W_1 and W_2 are the plant biomass at time T_1 (initial sampling) and T_2 (final sampling).

Statistical analyses

All measurements were replicated three times. Means and standard deviations (SD) were calculated by the Microsoft Office Excel 2010 for all the data. One-way analysis of variance was carried out with SPSS 17.0. The significant difference was set between treatments at $p < .05$ or $p < .01$. Multiple comparison was also made by the least significant difference (LSD) test.

Results and discussion

Differences in Cd tolerance among the six compositae species

Heavy metal Cd is a non-essential element but has some influence on plant growth. As shown as Figure 1, after 8 weeks exposure to 10 mg kg^{-1} Cd, the total biomass dry weight of the four plants (*T. mongolicum* Hand.-Mazz., *Z. elegans Jacq.*, *C. cyanus* L. and *G. jamesonii Bolus*) had no significant differences compared with the control, by contrast, the total biomass dry weight of *T. erecta* L. and *T. patula* L. increased significantly ($p < .01$), indicating that a low Cd concentrations might have a stimulating effect on plant growth. The same phenomenon has been found by Kinraide (1993), Calabrese and Baldwin (2003), Scebba et al. (2006) and Jia et al. (2015), which is also proposed as hormesis by de la Rosa et al. (2004). With the concentration of Cd increasing, chlorosis on the leaves of *C. cyanus* L. and

Table 2. The natural properties of sampled plants.

Plant species	Families and genera	Life form	Plant images
Taraxacum mongolicum Hand.-Mazz.	Compositae, Taraxacum	Perennial	
Tagetes erecta L.	Compositae, Tagetes	Annual	
Tagetes patula L.	Compositae, Tagetes	Annual	
Zinnia elegans Jacq.	Compositae, Zinnia	Annual	
Centaurea cyanus L.	Compositae, Centaurea	Annual or biennial	
Gerbera jamesonii Bolus	Compositae, Gerbera	Perennial	

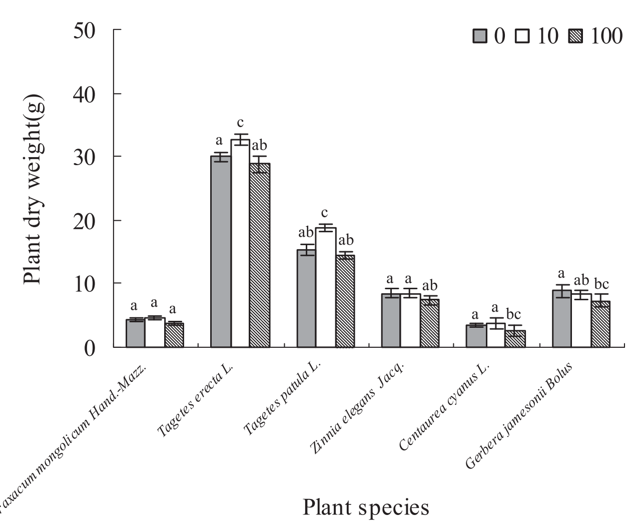

Figure 1. Effects of Cd soil concentrations on total biomass dry weight of six compositae species. Top legend – concentration of Cd. Values represent mean ± SD.

G. jamesonii Bolus was observed, and the total biomass dry weight of the two plants had a significant decrease compared with the control ($p < .01$). However, the total biomass dry weight of the four plants (*T. mongolicum* Hand.-Mazz., *Z. elegans Jacq.*, *T. erecta* L. and *T. patula* L.) had no significant differences compared with the control.

As shown as Figure 2, after 8 weeks exposure to 10 mg kg^{-1} Cd, the height of the three plants (*T. mongolicum* Hand.-Mazz., *Z. elegans Jacq.*, *C. cyanus* L.) had no significant differences compared with the control, and the height of *T. erecta* L. and *T. patula* L. increased significantly ($p < .01$), which is also consistent with the increased total biomass dry weight of the two plants. The phenomenon is also termed as hormesis by other researchers (Kovalchuk et al. 2003; de la Rosa et al. 2004; Aina et al. 2007; Seth et al. 2008; Sidhu et al. 2017), which could result from an overcompensation response of cells and organisms to toxic chemicals or the defense mechanisms induced by oxygen free radicals. The underlying mechanism study needs to be further investigated. By contrast, the height of *G. jamesonii*

Bolus had a significant decrease under 10 mg kg^{-1} Cd exposure compared with the control. When the concentration of Cd was up to 100 mg kg^{-1} in soil, the height of the four plants (*T. mongolicum* Hand.-Mazz., *Z. elegans Jacq.*, *C. cyanus* L. and *G. jamesonii Bolus*), decreased significantly compared with the control ($p < .01$). However, the height of *T. erecta* L. and *T. patula* L. showed no significant differences compared with the control.

Based on these growth traits, it demonstrated that *T. erecta* L. and *T. patula* L. had high tolerance to as much as 100 mg kg^{-1} Cd, which is in agreement with no obvious changes on the leaves of the two plants. The growth of the two plants was improved at the low Cd concentration (10 mg kg^{-1}) in term of the total biomass and height increased along with the increased Cd concentration in soil. Moreover, among the six compositae species, *T. erecta* L. and *T. patula* L. have higher biomass than four other plants.

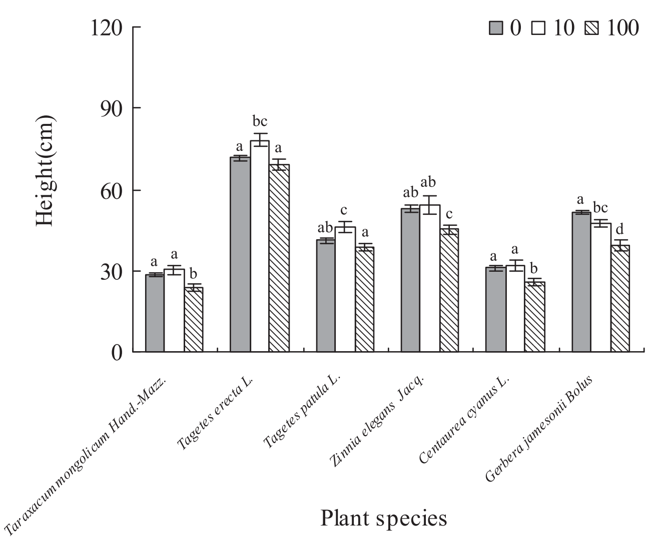

Figure 2. Effects of Cd soil concentrations on height of six compositae species. Top legend – concentration of Cd. Values represent mean ± SD.

This indicates that *T. erecta* L. and *T. patula* L. have good potential in phytoremediation of Cd-contaminated soils, since the tolerance to the toxicity of heavy metal may give an important index to recognize a hyperaccumulator or accumulator (Ernst and Nelissen 2000; Yang et al. 2004; Liu et al. 2009).

Differences in Cd accumulation among the six compositae species

After 8 weeks of Cd-exposure, the effects of Cd soil concentrations on Cd concentration in shoots and roots of six compositae species are shown in Figure 3. The concentrations of accumulated Cd in shoots and roots of the six compositae species all increased significantly with increasing Cd concentrations in soil ($p < .01$). When the concentration of Cd was up to 100 mg kg^{-1} in soil, the concentrations of accumulated Cd in shoots of *T. erecta* L., *T. patula* L. and *Z. elegans Jacq.* reached 166.07 ± 5.13, 231.72 ± 6.87 and 109.89 ± 5.82 μg g^{-1} dry weight (DW), respectively, which is above the threshold value defined for Cd-hyperaccumulator (100 μg g^{-1} DW) (Baker and Brooks 1989; Sun et al. 2008). However, the concentrations of accumulated Cd in shoots of *T. mongolicum* Hand.-Mazz., *C. cyanus* L. and *G. jamesonii Bolus* were all less than 100 μg g^{-1} DW. At the same level of Cd concentration (100 mg kg^{-1}), the concentrations of accumulated Cd in roots of *T. mongolicum* Hand.-Mazz., *T. erecta* L., *T. patula* L. and *Z. elegans Jacq.* reached 109.13 ± 3.29, 177.11 ± 6.65, 202.34 ± 3.67 and 129.18 ± 4.82 μg g^{-1} DW, respectively. By contrast, the concentrations of accumulated Cd in roots of *C. cyanus* L. and *G. jamesonii Bolus* were 85.22 ± 3.91 and 87.79 ± 6.11 μg g^{-1} DW.

The elevated translocation factor (TF) was used to evaluate the ability of the plant to tolerate and translocate Cd from root to shoots (Wei et al. 2016). As shown as Table 3, when the concentration of Cd was 10 mg kg^{-1} in soil, the

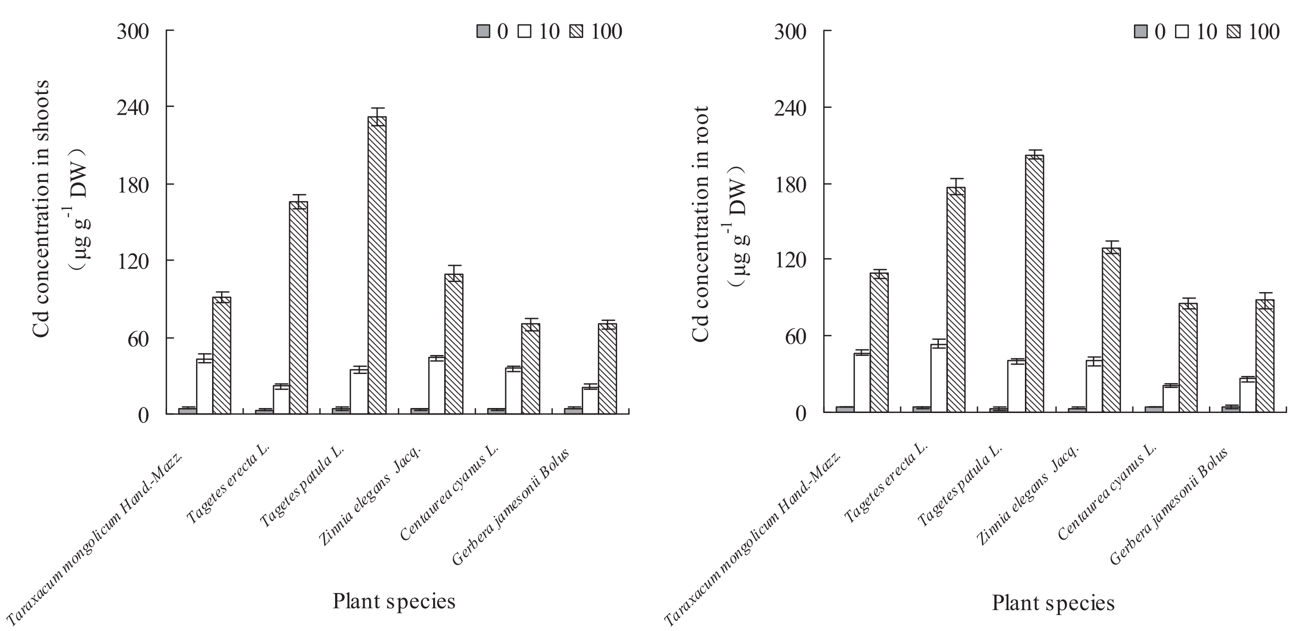

Figure 3. Effects of Cd soil concentrations on Cd concentration in shoots and root of six compositae species. Top legend – concentration of Cd. Values represent mean ± SD.

Table 3. Effects of Cd soil concentrations on Cd uptake, TF and BCF of six compositae species.

	Cd uptake (μg $plant^{-1}d^{-1}$)			TF			BCF		
Plant species	0	10	100	0	10	100	0	10	100
Taraxacum mongolicum Hand.-Mazz.	0.11 ± 0.01	1.13 ± 0.02	2.11 ± 0.07		0.92	0.86		4.68	1.09
Tagetes erecta L.	0.56 ± 0.03	6.79 ± 0.08	27.45 ± 0.16		0.39	0.93		5.37	1.77
Tagetes patula L.	0.29 ± 0.01	3.92 ± 0.05	17.36 ± 0.13		0.87	1.15		3.99	2.02
Zinnia elegans Jacq.	0.17 ± 0.02	1.98 ± 0.01	4.92 ± 0.09		1.08	0.85		4.02	1.29
Centaurea cyanus L.	0.08 ± 0.01	0.59 ± 0.03	1.16 ± 0.02		1.68	0.82		2.12	0.85
Gerbera jamesonii Bolus	0.21 ± 0.03	1.09 ± 0.02	3.21 ± 0.04		0.81	0.79		2.63	0.88

Notes: Values represent mean ± SD. TF: the translocation factor; BCF: the bioconcentration factor.

TF values of *T. mongolicum* Hand.-Mazz., *Z. elegans Jacq.* and *C. cyanus* L. were higher than 0.90. When the concentration of Cd was up to 100 mg kg^{-1} in soil, the TF values of *T. erecta* L. and *T. patula* L. increased significantly and reached 0.93 and 1.15. The bioconcentration factor (BCF) was also used to measure the metal accumulation potential of plants with respect to the metal concentration in soil (Saraswat and Rai 2018). When the concentration of Cd was 10 mg kg^{-1} in soil, the BFC values of *T. mongolicum* Hand.-Mazz., *T. erecta* L., *T. patula* L. and *Z. elegans Jacq.* were higher than 4.00. When the concentration of Cd was up to 100 mg kg^{-1} in soil, the BCF values of *T. erecta* L. and *T. patula* L. still reached 1.77 and 2.02. The results above suggested that the two plants (*T. erecta* L. and *T. patula* L.) had stronger tolerance to high concentration Cd and had better potential in translocating Cd more efficiently.

Cd uptake in six compositae species varied with increasing Cd concentrations in the soil (Table 3). When the concentration of Cd was 10 mg kg^{-1} in soil, Cd uptake of *T. erecta* L. and *T. patula* L. were 6.79 ± 0.08 and 3.92 ± 0.05 μg $plant^{-1}d^{-1}$, which is higher than four other plants. When the concentration of Cd was up to 100 mg kg^{-1} in the soil, Cd uptake of increased significantly and reached 27.45 ± 0.16 and 17.36 ± 0.13 μg $plant^{-1}d^{-1}$, and Cd uptake of the four other plants were all less than 5.00 μg $plant^{-1}d^{-1}$. There was a positive correlation between Cd uptake and Cd accumulation in *T. erecta* L. and *T. patula* L., indicating the two plants may accumulate larger amounts of Cd when exposed to higher Cd concentrations in the soil. Based on higher Cd uptake, TF and BCF values, the higher concentrations of accumulated Cd in shoots and roots of *T. erecta* L. and *T. patula* L. indicating that the two plants have the potential for phytoremediation of Cd-contaminated soils.

Conclusions

In the present study, exposure to 10 mg kg^{-1} Cd, the total biomass and height of *T. erecta* L. and *T. patula* L. all increased significantly, indicating that low Cd concentrations might have a stimulating effect on plant growth. When the concentration of Cd was up to 100 mg kg^{-1}, the total biomass and height of the two plants had no significant differences compared with the control, which is in agreement with the observation of no obvious changes on the leaves of the two plants. At the same time, the two plants have higher biomass than four other plants among the six compositae species. Moreover, *T. erecta* L. and *T. patula* L. can accumulate Cd above 100 μg g^{-1} DW, which is the threshold value of Cd-hyperaccumulator, and have higher Cd uptake ability, TF and BCF values. According to these traits, it is shown *T. erecta* L. and *T. patula* L. can become potential hyperaccumulators in phytoremediation of Cd-contaminated soils. On the one hand, as popular ornamental plants, *T. erecta* L. and *T. patula* L. have the double advantages of beautifying the environment and purifying the soil. On the other hand, coming from the same families and genera, the two plants have the similar capability of Cd hyperaccumulation, and our results might suggest that most of the genera plants possess the same hyperaccumulation characteristics to Cd or not? The present study will also provide an important reference for understanding Cd tolerant strategies in hyperaccumulator cells.

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