Comparison of cadmium accumulation in three Solanum species

Kewen Huang, Yiping Dong, Xu Chen, Yuhui Bie, Yuefeng Hou and Ming’an Liao

College of Horticulture, Sichuan Agricultural University, Chengdu, Sichuan, 611130, China

*Corresponding author’s e-mail: lman@sicau.edu.cn

Abstract. In order to study the difference of cadmium (Cd) accumulation in three species of Solanum, the Cd accumulation characteristics of Solanum nigrum L., Solanum alatum Moench and Solanum nigrum L. var. humile (Bernh.) C. Y. Wu et S. C. Huang were studied by pot experiment under the condition of Cd concentration of 10 mg/L. The results showed that the biomass of all parts of S. nigrum was significantly higher than that of other Solanum species, while the rank order of the Cd content of the Solanum species was as follows: S. nigrum var. humile > S. alatum > S. nigrum. The amount of Cd extracted by the Solanum species observed significant difference, and the amount of Cd extracted by the stems, leaves and shoots of S. alatum was significantly higher than other Solanum species, indicating that S. alatum had the best repair effect on Cd-contaminated soil.

1. Introduction

Due to the intensification of anthropogenic activities such as metal mining and smelting, the use of phosphate fertilizers with cadmium (Cd), soil Cd pollution has become a problem of globalization [1]. Cd is one of the most toxic heavy metals, which has a long half-life and is not easy to degrade. Long-term Cd accumulation in the soil will not only affect the growth and development of plants, but also harm human health through the food chain [2]. In the face of increasingly severe Cd pollution problems, researchers have proposed to purify contaminated soil through soil leaching, land modification, and application of humus [3-5]. However, these technologies have the disadvantages of high cost, difficult operation and long time in improving the soil environment, which limits its application. The phytoremediation technology can effectively reduce the heavy metal content of the soil through the assimilating of heavy metal by hyperaccumulators, and has the advantages of small disturbance, low cost and easy operation [6]. Since Brooks first proposed the concept of “hyperaccumulators”, more than 500 species of hyperaccumulators from 45 different families have been identified [7]. Therefore, the evaluation and screening of such a large number of hyperaccumulators are beneficial to improve the efficiency of phytoremediation technology. Solanum nigrum L. is an annual herb of the genus Solanum, which has the characteristics of strong vitality, and was identified as a Cd hyperaccumulator [8]. Therefore, Solanum nigrum L., Solanum alatum Moench and Solanum nigrum L. var. humile (Bernh.) C. Y. Wu et S. C. Huang were selected as test materials, and the differences in Cd accumulation characteristics of three Solanum species under Cd condition were studied, which provided a theoretical basis for the screening of phytoremediation technology.
2. Materials and methods

2.1. Materials
In March 2018, the *S. nigrum*, *S. alatum* and *S. nigrum* var. humile seeds were collected at the Sichuan Agricultural University Chengdu Campus (30°71' N, 103°87' E), and were sown in a plug plate containing moist substrate in a 25°C, 4000 lx climate chamber. Two weeks later, when the two real leaves of the Solanum seedlings were completely unfolded, the seedlings with the same growth were selected as experimental materials. The soil samples were collected and the farmland around the Sichuan Agricultural University Chengdu Campus, and the background values of soil were: soil pH was 7.09, total nitrogen content was 1.50 g/kg, total phosphorus content was 0.76 g/kg, total potassium content was 18.02 g/kg, alkali nitrogen content was 94.82 mg/kg, available phosphorus content was 6.30 mg/kg, available potassium content was 149.59 mg/kg and the content of total Cd was 0.02 mg/kg. The soil was air-dried, crushed, sieved, and 3.0 kg was weighed into a plastic pot (15 cm height, 18 cm diameter). Then add CdCl₂·2.5H₂O solution to make the Cd content in each pot 10 mg/kg.

2.2. Experimental design
In April 2018, *S. nigrum*, *S. alatum* and *S. nigrum* var. humile seedlings were transplanted into Cd-treated soil respectively, four plants were planted in each pot, and each treatment was repeated four times. During the growth of plants, occasional watering to maintain the moisture of soil about 80%, and timely prevention of pests and diseases. The position of the pots and pots was changed occasionally to reduce the marginal effect. After 40 days, all Solanum seedlings were harvested and split into roots, stems and leaves, and then rinsed repeatedly with deionized water. After drying to a constant weight in an oven at 80°C, weigh the dry samples. And then accurately weigh 0.500 g of dry sample, add nitric acid-perchloric acid (volume ratio of 4:1) for 12 h, digest at high temperature until the solution is transparent, filter, and dilute to 50 mL, and the Cd contents were determined by using an iCAP 6300 inductively coupled plasma spectrometer (Thermo Scientific, Waltham, MA, USA) [9].

2.3. Statistical analyses
Statistical analysis was carried out by using SPSS 18.0 statistical software. The data were analyzed by one-way ANOVA, with the least significant difference at the 5% confidence level.

3. Results and discussion

3.1. Biomass of *S. nigrum*, *S. alatum* and *S. nigrum* var. humile
The biomass of all parts of *S. nigrum*, *S. alatum* and *S. nigrum* var. humile showed significant difference under Cd treatment (*p* < 0.05, Table 1). And the rank order of the biomass of the Solanum species was as follows: *S. nigrum* > *S. alatum* > *S. nigrum* var. humile. The biomass of roots, stems, leaves and shoots in *S. nigrum* were 23.15% (*p* < 0.05), 46.13% (*p* < 0.05), 70.16% (*p* < 0.05) and 59.17% (*p* < 0.05) higher than *S. nigrum* var. humile, respectively.

3.2. Cd content of *S. nigrum*, *S. alatum* and *S. nigrum* var. humile
The Cd content of all parts of *S. nigrum*, *S. alatum* and *S. nigrum* var. humile has a significant difference under Cd treatment (*p* < 0.05, Table 2). And in the opposite order of biomass, the rank order of the Cd content of the Solanum species was as follows: *S. nigrum* var. humile > *S. alatum* > *S. nigrum*. The Cd content of roots, stems, leaves and shoots of *S. nigrum* var. humile were 102.72% (*p* < 0.05), 50.22% (*p* < 0.05), 60.49% (*p* < 0.05) and 58.85% (*p* < 0.05) higher than *S. nigrum*, respectively.
The rank order of the biomass of the Solanum species was as follows: S. nigrum > S. alatum > S. nigrum var. humile, and the biomass of all parts of S. nigrum was significantly higher than other Solanum species. The Cd content of three Solanum species was opposite to the order of biomass, and the Cd content of roots, stems, leaves and shoots in S. nigrum var. humile was significantly higher than other Solanum species. Besides the amount of Cd extracted by the roots of S. nigrum var. humile was significantly higher than other Solanum species, while the stems, leaves and shoots of S. alatum was the largest among the three species.

### Table 1. Biomass of S. nigrum, S. alatum and S. nigrum var. humile

| Treatments      | Roots (g/plant) | Stems (g/plant) | Leaves (g/plant) | Shoots (g/plant) |
|-----------------|-----------------|-----------------|------------------|------------------|
| S. nigrum       | 0.266±0.007a    | 0.529±0.012a    | 0.730±0.018a     | 1.259±0.006a     |
| S. alatum       | 0.248±0.002b    | 0.466±0.006b    | 0.674±0.017b     | 1.140±0.023b     |
| S. nigrum var. humile | 0.216±0.003c | 0.362±0.009c | 0.429±0.012c | 0.791±0.020c |

Values are means ± standard errors of three replicate pots. Different lowercase letters within a column indicate significant differences based on a one-way analysis of variance in SPSS 18.0, followed by the least significant difference test (p < 0.05).

### Table 2. Cd content of S. nigrum, S. alatum and S. nigrum var. humile

| Treatments      | Roots (mg/kg) | Stems (mg/kg) | Leaves (mg/kg) | Shoots (mg/kg) |
|-----------------|---------------|---------------|----------------|----------------|
| S. nigrum       | 33.43±1.06c   | 25.03±0.24c   | 9.82±0.18c     | 16.21±0.38c    |
| S. alatum       | 38.20±1.23b   | 36.68±0.43b   | 12.75±0.51b    | 22.54±0.40b    |
| S. nigrum var. humile | 67.77±1.34a | 37.60±0.68a   | 15.76±0.74a    | 25.75±0.73a    |

Values are means ± standard errors of three replicate pots. Different lowercase letters within a column indicate significant differences based on a one-way analysis of variance in SPSS 18.0, followed by the least significant difference test (p < 0.05).

### Table 3. The amount of Cd extracted by the S. nigrum, S. alatum and S. nigrum var. humile

| Treatments      | Roots (μg/plant) | Stems (μg/plant) | Leaves (μg/plant) | Shoots (μg/plant) |
|-----------------|------------------|------------------|-------------------|-------------------|
| S. nigrum       | 8.90±0.50c       | 13.24±0.42b      | 7.17±0.04b        | 20.41±0.38b       |
| S. alatum       | 9.47±0.38b       | 17.10±0.42a      | 8.59±0.57a        | 25.69±0.99a       |
| S. nigrum var. humile | 14.66±0.10a | 13.61±0.07b      | 6.76±0.14b        | 20.37±0.06b       |

Values are means ± standard errors of three replicate pots. Different lowercase letters within a column indicate significant differences based on a one-way analysis of variance in SPSS 18.0, followed by the least significant difference test (p < 0.05).

### 3.3. The amount of Cd extracted by the S. nigrum, S. alatum and S. nigrum var. humile

The amount of Cd extracted by the roots of Solanum species observed significant difference under Cd treatment (p < 0.05, Table 3), and the rank order was as follows: S. nigrum var. humile > S. alatum > S. nigrum. Additionally, there was no significant difference in the amount of Cd extracted by the stems, leaves and shoots of S. nigrum and S. nigrum var. humile (p > 0.05). But the amount of Cd extracted by the stems, leaves and shoots of S. alatum was significantly higher than other Solanum species (p < 0.05).

### 4. Conclusions

The biomass, Cd content and amount of Cd extracted by the three Solanum species were significantly different under the effect of Cd concentration of 10 mg/L. The rank order of the biomass of the Solanum species was as follows: S. nigrum > S. alatum > S. nigrum var. humile, and the biomass of all parts of S. nigrum was significantly higher than other Solanum species. The Cd content of three Solanum species was opposite to the order of biomass, and the Cd content of roots, stems, leaves and shoots in S. nigrum var. humile was significantly higher than other Solanum species. Besides the amount of Cd extracted by the roots of S. nigrum var. humile was significantly higher than other Solanum species, while the stems, leaves and shoots of S. alatum was the largest among the three species.
Solanum species. The Cd accumulation characteristics of three Solanum species observed significant differences under the condition of Cd concentration of 10 mg/L, which may be related to the differences in the biological characteristics of the plants. And among the three Solanum species, *S. alatum* had the best effect on the repair of Cd-contaminated soil.

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