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Effects of Hyperaccumulator Straw on Growth and Cadmium Accumulation of *Brassica chinensis*

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Abstract: The pot experiment was conducted to study the effects of applying the hyperaccumulator plants (*Bidens pilosa*, *Youngia erythrocarpa*, *Solanum photeinocarpum* and *Galinsoga parviflora*) straw into soil on growth and cadmium (Cd) accumulation of *Brassica chinensis*. Compared with the control, applying hyperaccumulator straw decreased the root biomass, shoot biomass, and photosynthetic pigment contents of *B. chinensis*. The hyperaccumulator straw also decreased the Cd contents in roots and shoots of *B. chinensis*, and the orders of that were ranked as control > applying *B. pilosa* straw > applying *G. parviflora* straw > applying *Y. erythrocarpa* staw > applying *S. photeinocarpum* straw. Therefore, applying hyperaccumulator straw could decrease the Cd uptake of *B. chinensis*, and the straw of *S. photeinocarpum* is the best option.

Introduction

The phytoremediation is a common method for remediation of heavy metal contaminated soil, and can not damage the ecological environment of soil, soil structure and microbial conditions, which uses the roots of plants directly uptakes heavy metals from soil and transfers heavy metals to shoots of plants [1-2]. Some studies show that phytoremediation can be used for cadmium (Cd) contaminated soil [3].

The allelopathy is a direct or indirect, harmful or beneficial effect on plants (including microorganisms), which produces by the process of plant growth or in the process of plant decay [4]. Allelopathy affects soil nutrient availability, soil enzyme activity, microbial population structure and plant growth [5]. Straw application is one of the most important measures to increase soil fertility, which can eliminate the air pollution caused by straw burning, and increases crop yield at the same time [6]. In Cd-contaminated conditions, applying straw of *Mazus japonicus*, *Youngia erythrocarpa*, *Cardamine hirsuta,* and *Conyza canadensis* to soil significantly increased the biomass, Cd content, and Cd-extraction ability of the Cd-hyperaccumulator *Galinsoga parviflora* [7-9]. Similarly, straw of *C. hirsuta*, *Nasturtium officinale*, and *C. Canadensis* significantly reduced Cd accumulation in *Capsella bursa-pastoris* [10]. Therefore, if the straw could be applied directly to crops and vegetables, it could decrease Cd absorption and increase the safety of crops for consumption.

Brassica chinensis is a cruciferous vegetable with adaptability, fast growth and high yield [11]. In this study, the Cd-hyperaccumulation plants *Bidens pilosa* [12], *Youngia erythrocarpa* [13], *Solanum photeinocarpum* [14] and *Galinsoga parviflora* [15] straw were applied into Cd-contaminated soil, and planted the seedlings of *B. chinensis*. The aim of the study was to determine which hyperaccumulator straw could reduce the Cd accumulated in *B. chinensis* seedlings, and to provide a reference for phytoremediation of soils contaminated with heavy metals.

Materials and Methods

Materials. In August 2014, the shoots of *B. pilosa*, *Y. erythrocarpa*, *S. photeinocarpum* and *G. parviflora* were collected from the Ya'an campus farm of the Sichuan Agricultural University (29°59′N, 102°59′E), China, from uncontaminated soil areas. The collected shoots of these plants were dried at 80 °C to constant weight, finely ground and sieved through a 5-mm-mesh nylon sieve. The seeds of *B. chinensis* were purchased in the market.

The inceptisol soil samples (purple soil in the Genetic Soil Classification of China) were collected from the Ya'an campus farm in August 2013. The basic properties of the soil are described in Lin et al. (2014) [7].

Experimental Design. The experiment was conducted in the greenhouse of the Ya'an campus farm from February to June 2015. The soil samples were air dried and passed through a 5-mm sieve. Three kilograms of the air-dried soil was weighed into each polyethylene pot (18 cm high and 21 cm in diameter). Cd was added to soils as $CdCl_2 \cdot 2.5H_2O$ at 10 mg/kg [7] in February 2015. The soil moisture was maintained at 80 % of field capacity for 2 months. The seeds of *B. chinensis* were sown in farmland of the Ya'an campus farm in March 2015. Six-gram shoots were applied to each pot (2 g shoots per kg soil), and the soil moisture was maintained at 80% of field capacity for 1 week. The five experimental treatments in the experiment were control (no straw applied), and straw applied for each of the four plant species (*B. pilosa*, *Y. erythrocarpa*, *S. photeinocarpum* and *G. parviflora*). Each treatment was replicated three times using a completely randomized design with 10-cm spacing between pots. Four uniform seedlings of *B. chinensis* (two euphyllas expanded) were transplanted into each pot in April 2015, and the soil moisture content was maintained at 80 % of field capacity from the time the plants were transplanted into the pots until the time the plants were harvested. 2 months later (June 2015), the upper mature leaves of *B. chinensis* were collected to determine the photosynthetic pigment (chlorophyll *a*, chlorophyll *b*, total chlorophyll, and carotenoid) contents [16]. The plants were then gently removed from the soil, and the roots, stems, and leaves were washed with deionized water and dried at 80 °C to constant weight for dry weight and Cd content determination [17].

Statistical analyses. Statistical analyses were conducted using SPSS 13.0 statistical software (IBM, Chicago, IL, USA). Data were analyzed by one-way analysis of variance with least significant difference (LSD) at the p = 0.05 confidence level. The following calculated were used: translocation factor (TF) = Cd content in shoots/ Cd content in roots [18].

Results and Discussion

Biomass. Under Cd stress, applying the straw of hyperaccumulator straw decreased the root, stem and leaf and shoot biomasses of *B. chinensis* compared with the control (Table 1), indicating that hyperaccumulator straw inhibited the growth of *B. chinensis*. The biomass of *B. chinensis* was ranked as: control > applying *S. photeinocarpum* straw > applying *B. pilosa* straw > applying *G. parviflora* straw > applying *Y. erythrocarpa* staw. The straw of *Y. erythrocarpa* and *G. parviflora* improved the root/ shoot ratio of *B. chinensis*, but the straw of *B. pilosa* and *S. photeinocarpum* reduced that (Table 1).

Table 1 Biomass of *Brassica chinensis*

Treatments	Roots (g/plant)	Stems (g/plant)	leaves (g/plant)	Shoots (g/plant)	Root/ shoot ratio
Control	0.363±0.007a	0.702±0.013a	1.232±0.018a	1.934±0.031a	0.188
B. pilosa	0.270±0.007c	0.544±0.008c	0.926±0.013b	1.470±0.021c	0.184
Y. erythrocarpa	0.257±0.004c	0.357±0.004e	0.838±0.011c	1.195±0.016e	0.215
S. photeinocarpum	0.292±0.006b	0.676±0.006b	0.969±0.016b	1.645±0.021b	0.178
G. parviflora	0.268±0.004c	0.509±0.007d	0.853±0.024c	1.362±0.031d	0.197

Photosynthetic Pigment Content. When applying the straw of hyperaccumulaor into soil, the straw of *B. pilosa*, *Y. erythrocarpa* and *G. parviflora* significantly decreased the chlorophyll *a* and total chlorophyll contents in *B. chinensis* compared with the control (Table 2). There were no significant differences of chlorophyll *a* and total chlorophyll contents in *B. chinensis* by the straw of *S. photeinocarpum*. The straw of *Y. erythrocarpa* and *G. parviflora* significantly decreased the chlorophyll *b* contents in *B. chinensis* compared with the control, but there were no no significant differences by the straw of *B. pilosa* and *S. photeinocarpum.* All of four hyperaccumulator straw significantly decreased the carotenoid content in *B. chinensis* compared with the control. The straw of *B. pilosa*, *Y. erythrocarpa* and *S. photeinocarpum* reduced the chlorophyll a/b of *B. chinensis*, and the straw of *G. parviflora* improved that (Table 2). The order of chlorophyll a/b was applying *G. parviflora* straw > control > applying *B. pilosa* straw > applying *Y. erythrocarpa* staw > applying *S. photeinocarpum* straw.

Table 2 Photosynthetic pigment content in *Brassica chinensis*

Treatments	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total chlorophyll (mg/g)	Chlorophyll a/b	Carotenoid (mg/g)
Control	0.643±0.007a	0.122±0.008ab	0.765±0.015a	5.265	0.236±0.004a
B. pilosa	0.535±0.018b	0.108±0.004bc	0.643±0.023b	4.977	0.205±0.007c
Y. erythrocarpa	0.504±0.007b	0.102±0.004c	0.606±0.003b	4.931	0.181±0.003d
S. photeinocarpum	0.624±0.011a	0.133±0.008a	0.757±0.003a	4.699	0.219±0.003b
G. parviflora	0.532±0.024b	0.100±0.006c	0.632±0.030b	5.306	0.197±0.006c

Cadmium Content. The hyperaccumulator straw decreased the Cd contents in roots, stems, leaves and shoots of *B. chinensis* compared with the control (Table 3). The Cd contents in roots, stems, leaves and shoots of *B. chinensis* were ranked as control > applying *B. pilosa* straw > applying *G. parviflora* straw > applying *Y. erythrocarpa* staw > applying *S. photeinocarpum* straw. The *B. pilosa* straw decreased the Cd contents in roots and shoots of *B. chinensis* by 6.81% ($p > 0.05$) and 5.08% ($p > 0.05$) respectively compared with the control, *Y. erythrocarpa* straw decreased by 25.07% ($p < 0.05$) and 20.81% ($p < 0.05$) respectively compared with the control, *S. photeinocarpum* straw decreased by 37.88% ($p < 0.05$) and 35.03% ($p < 0.05$) respectively compared with the control, and *G. parviflora* straw decreased by 14.99% ($p < 0.05$) and 14.21% ($p < 0.05$) respectively compared with the control. The hyperaccumulator straw improved the TF of *B. chinensis*, and the order of TF was applying *Y. erythrocarpa* staw > applying *S. photeinocarpum* straw > applying *B. pilosa* straw > applying *G. parviflora* straw > control (Table 3).

Table 3 Cadmium content in *Brassica chinensis*

Treatments	Roots (mg/kg)	Stems (mg/kg)	Leaves (mg/kg)	Shoots (mg/kg)	TF
Control	3.67±0.13a	0.44±0.010a	2.84±0.13a	1.97±0.09a	0.537
B. pilosa	3.42±0.16ab	0.41±0.011b	2.72±0.07a	1.87±0.05a	0.547
Y. erythrocarpa	2.75±0.18c	0.23±0.006d	2.13±0.04c	1.56±0.03b	0.567
S. photeinocarpum	2.28±0.11d	0.19±0.008e	2.04±0.05c	1.28±0.03c	0.561
G. parviflora	3.12±0.14bc	0.36±0.007c	2.48±0.10b	1.69±0.06b	0.542

Conclusions

Under Cd stress, applying hyperaccumulator plants (*B. pilosa*, *Y. erythrocarpa*, *S. photeinocarpum* and *G. parviflora*) straw decreased the root biomass, shoot biomass, and photosynthetic pigment contents of *B. chinensis*. The hyperaccumulator straw also decreased the Cd contents in roots and shoots of *B. chinensis*, and the orders of that were ranked as control > applying *B. pilosa* straw >

applying *G. parviflora* straw > applying *Y. erythrocarpa* staw > applying *S. photeinocarpum* straw. Therefore, applying hyperaccumulator straw could decrease the Cd uptake of *B. chinensis*, and the straw of *S. photeinocarpum* is the best option.

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