Cadmium Accumulation Characteristics of *Lycopersicon esculentum* Seedlings

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Abstract: The cadmium (Cd) accumulation characteristics of *Lycopersicon esculentum* seedlings were studied by the pot experiment, and different soil Cd concentrations (0, 1, 5, 10, 15 and 20 mg/kg) were used. With the increase of soil Cd concentration, the biomass and photosynthetic pigment content of *L. esculentum* seedlings had the decreasing trend. The SOD, POD and CAT activities of *L. esculentum* seedlings had the increase trend when the soil Cd concentration was not more than 5 mg/kg, and decreased when the soil Cd concentration was higher than 5 mg/kg. The soluble protein contents of *L. esculentum* seedlings had the decreasing trend with the increase of soil Cd concentrations. The Cd contents in different organs *L. esculentum* seedlings were ranked as root > leaf > shoot > stem. With the increase of Cd concentrations in soil, the Cd contents in roots, stems, leaves and shoots of *L. esculentum* seedlings increased. Therefore, the soil Cd inhibited the growth of *L. esculentum* seedlings.

Introduction

Lycopersicon esculentum is one of the most important vegetable crops in the word [1]. However, the heavy metal polluted vegetable gardens have affected the production of *L. esculentum*, especially cadmium (Cd) [2-3]. The Cd is the most bio-toxic heavy metal elements, and has strong chemical activity, mobility, long-lasting toxicity in the environment [4]. The Cd inhibits the growth of plants, especially in high Cd concentration, the growth of plants was significantly inhibited, and the structure of tissues was obviously deformed [5-6]. However, there are few reports on Cd accumulation characteristics of *L. esculentum*. In this study, different concentrations of Cd (0, 1, 5, 10, 15 and 20 mg/kg) were added into soil, and planted the seedlings of *L. esculentum*. The Cd accumulation characteristics of *L. esculentum* seedlings were studied to provide the reference for reducing Cd accumulation in *L. esculentum*.

Materials and Methods

Materials. The Inceptisol soil samples (purple soil in the Genetic Soil Classification of China) were collected from the Chengdu campus farm of Sichuan Agricultural University (30° 42′N, 103° 51′E) in April 2017. The basic properties of the soil were pH 6.94, organic matter 17.54 g/kg, total nitrogen 3.63 g/kg, total phosphorus 0.38 g/kg, total potassium 17.54 g/kg, alkali soluble nitrogen 195.00 mg/kg, available phosphorus 6.25 mg/kg and available potassium 191.13 mg/kg. The total Cd content was 0.103 mg/kg, and the bioavailable Cd content was 0.022 mg/kg [7]. The seeds of *L. esculentum* buy from the market, and were sown in nutrient soil in April 2017.

Experimental Design. The soil samples were air dried and sieved to 5 mm in April 2017, then 3.0 kg of the air-dried soil was weighed into polyethylene pots (15 cm tall, 18 cm diameter), and Cd was added to the soils as $CdCl_2 \cdot 2.5H_2O$ at 0, 1, 5, 10, 15 and 20 mg/kg [8]. The soil moisture content was maintained at 80% of field capacity for 4 weeks, and then the soil in each pot was mixed. Three uniform seedlings with four euphyllas were transplanted into each pot in May 2017. Each treatment was repeated three times making a total of 18 pots, and put in a completely randomized design with 10 cm spacing between pots. The soil moisture content was maintained at 80% of field capacity until the plants were harvested.

Two months after planting (July 2017), the upper mature leaves of plants were collected to determine the photosynthetic pigment (chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid) contents [9]. The upper young leaves (2 cm in length) were collected to determine the superoxide dismutase (SOD) activity, peroxidase (POD) activity, catalase (CAT) activity and soluble protein content [9]. Then, the whole plants were then gently removed, the roots, stems and leaves were washed with tap water followed by deionized water, and dried at 80°C to constant weight. The biomass was then measured of roots, stems and leaves. The dried tissue samples were finely ground and sieved through a 0.149 mm mesh nylon sieve for chemical analysis. Samples (0.5 g) were digested in $HNO_3/HClO_4$ (4:1, v/v), and then the volume was brought to 50 mL with deionized water [10]. The Cd concentrations in roots, tubers and leaves were determined using an iCAP 6300 ICP-MS spectrometer (Thermo Scientific, Waltham, MA, USA). The translocation factor (TF) is defined as Cd content in shoots/Cd content in roots [11].

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.

Results and Discussion

Biomass of *L. esculentum* Seedlings. With the increase of Cd concentrations in soil, the root, stem leaf and shoot biomasses of *L. esculentum* seedlings had a decreasing trend (Table 1). So, different concentrations of Cd inhibited the growth of *L. esculentum* seedlings. When the soil Cd concentrations were 1, 5, 10, 15 and 20 mg/kg, the root biomass of *L. esculentum* seedlings were decreased by 4.76% ($p > 0.05$), 7.14% ($p > 0.05$), 30.95% ($p < 0.05$), 33.33% ($p < 0.05$) and 35.71% ($p < 0.05$), respectively, compared with the control, and the shoot biomass were decreased by 5.71% ($p < 0.05$), 24.76% ($p < 0.05$), 29.52% ($p < 0.05$), 34.29% ($p < 0.05$) and 41.43% ($p < 0.05$), respectively. The root/shoot ratio of *L. esculentum* seedlings was ranked as 5 mg/kg > 20 mg/kg > 15 mg/kg > 0 mg/kg = 1mg/kg > 10 mg/kg (Table 1).

Table 1 Biomass of *L. esculentum* seedlings

Treatments	Roots (g/plant)	Stems (g/plant)	Leaves (g/plant)	Shoots (g/plant)	Root/shoot ratio
0	0.42±0.02a	0.92±0.05a	1.18±0.04a	2.10±0.06a	0.201
1	0.40±0.02a	0.89±0.02a	1.09±0.05b	1.98±0.07b	0.201
5	0.39±0.02a	0.68±0.02b	0.91±0.03c	1.58±0.04c	0.246
10	0.29±0.01b	0.61±0.01c	0.87±0.03cd	1.48±0.04cd	0.197
15	0.28±0.02b	0.57±0.02cd	0.81±0.02d	1.38±0.05d	0.202
20	0.27±0.01b	0.54±0.02d	0.69±0.04e	1.23±0.02e	0.217

Values are means ± standard errors. Means with the same letter within each column are not significantly different at $p < 0.05$.

Photosynthetic Pigment Content in *L. esculentum* Seedlings. The chlorophyll a, chlorophyll b, total chlorophyll and carotenoid contents of *L. esculentum* seedlings decreased with the increase of Cd concentration in soil (Table 2). When the soil Cd concentrations were 1, 5, 10, 15 and 20 mg/kg, the total chlorophyll contents of *L. esculentum* seedlings were decreased by 3.33% ($p > 0.05$), 9.52% ($p < 0.05$), 11.43% ($p < 0.05$), 20.95% ($p < 0.05$) and 27.62% ($p < 0.05$) respectively, compared with the control, and the carotenoid contents decreased by 1.96% ($p > 0.05$), 5.88% ($p > 0.05$), 7.84% ($p > 0.05$), 17.65% ($p < 0.05$) and 23.53% ($p < 0.05$), respectively. The chlorophyll a/b of *L. esculentum* seedlings had no obvious changes in different concentrations of soil Cd.

Table 2 Photosynthetic pigment content in *L. esculentum* seedlings

Treatments	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total chlorophyll (mg/g)	Chlorophyll a/b	Carotenoid (mg/g)
0	1.47±0.04a	0.63±0.01a	2.10±0.06a	2.34	0.51±0.03a
1	1.42±0.03a	0.61±0.02ab	2.03±0.05a	2.34	0.50±0.03a
5	1.32±0.02b	0.58±0.001bc	1.90±0.02b	2.30	0.48±0.01a
10	1.30±0.04b	0.56±0.01c	1.86±0.06b	2.34	0.47±0.01a
15	1.16±0.02c	0.50±0.01d	1.66±0.01c	2.32	0.42±0.01b
20	1.06±0.03d	0.46±0.02e	1.52±0.01d	2.33	0.39±0.01b

Values are means ± standard errors. Means with the same letter within each column are not significantly different at $p < 0.05$.

Antioxidant Enzyme Activity of *L. esculentum* Seedlings. When the soil Cd concentrations were 1, 5 and 10 mg/kg, the SOD activity of *L. esculentum* seedlings improved by 21.52% ($p < 0.05$), 71.85% ($p < 0.05$) and 4.38% ($p > 0.05$), respectively, compared with the control (Table 3). However, 10 and 20 mg/kg soil Cd reduced the SOD activity of *L. esculentum* seedlings by 16.91% ($p < 0.05$) and 24.15% ($p < 0.05$), respectively, compared with the control. When the soil Cd concentrations were 1 and 5 mg/kg, the POD activity of *L. esculentum* seedlings were had no significant differences compared with the control, and 10, 15 and 20 mg/kg soil Cd reduced the POD activity by 14.65% ($p < 0.05$), 32.96% ($p < 0.05$) and 38.20% ($p < 0.05$), respectively, compared with the control. The CAT activities of *L. esculentum* seedlings were improved by 1 and 5 mg/kg soil Cd, and reduced by 10, 15 and 20 mg/kg soil Cd. With the increase of soil Cd concentrations, the soluble protein contents had the decreasing trend (Table 3).

Table 3 Antioxidant enzyme activity of *L. esculentum* seedlings

Treatments	SOD activity (U/g)	POD activity (U/g/min)	CAT activity (mg/g/min)	Soluble protein content (mg/g)
0	102.02±2.30c	1082.98±29.62a	5.33±0.12c	11.37±0.07a
1	123.97±9.33b	1118.29±49.65a	5.77±0.11b	10.45±0.18b
5	175.32±6.77a	1075.04±29.18a	6.31±0.13a	9.82±0.02c
10	106.49±1.70c	924.36±10.79b	3.33±0.08d	7.74±0.09d
15	84.77±5.59d	726.07±23.08c	3.30±0.06d	6.57±0.07e
20	77.38±3.70d	669.23±16.05d	3.10±0.05d	4.11±0.10f

Values are means ± standard errors. Means with the same letter within each column are not significantly different at $p < 0.05$.

Cd Content in *L. esculentum* Seedlings. The Cd contents in different organs *L. esculentum* seedlings were ranked as root > leaf > shoot > stem (Table 4). With the increase of Cd concentrations in soil, the Cd contents in roots, stems, leaves and shoots of *L. esculentum* seedlings increased. When the soil Cd concentrations were 1, 5, 10, 15 and 20 mg/kg, the Cd contents in roots of *L. esculentum* seedlings were 3.42, 17.09, 32.34, 41.24 and 49.45 times respectively than the control, and the Cd contents in shoots were 4.95, 9.87, 14.67, 19.79 and 22.54 times respectively than the control. The order of TF was 1 mg/kg > 0 mg/kg > 5 mg/kg > 15 mg/kg > 20 mg/kg > 10 mg/kg (Table 4).

Conclusions

With the increase of soil Cd concentration, the biomass and photosynthetic pigment content of *L. esculentum* seedlings had the decreasing trend. The SOD, POD and CAT activities of *L. esculentum* seedlings had the increase trend when the soil Cd concentration was not more than 5 mg/kg, and decreased when the soil Cd concentration was higher than 5 mg/kg. The soluble protein contents of *L.*

esculentum seedlings had the decreasing trend with the increase of soil Cd concentrations. The Cd contents in different organs *L. esculentum* seedlings were ranked as root > leaf > shoot > stem. With the increase of Cd concentrations in soil, the Cd contents in roots, stems, leaves and shoots of *L. esculentum* seedlings increased. Therefore, the soil Cd inhibited the growth of *L. esculentum* seedlings.

Table 4 Cd content in *L. esculentum* seedlings

Treatments	Roots (mg/kg)	Stems (mg/kg)	Leaves (mg/kg)	Shoots (mg/kg)	TF
0	2.40±0.10f	0.80±0.07f	3.05±0.14f	2.07±0.12f	0.863
1	8.21±0.92e	4.19±0.24e	15.19±1.17e	10.24±0.82e	1.247
5	41.02±3.68d	7.93±0.52d	29.69±2.36d	20.43±1.58d	0.498
10	77.61±2.76c	11.59±0.54c	43.46±3.03c	30.36±2.06c	0.391
15	98.97±5.15b	13.85±0.75b	59.94±4.10b	40.97±2.56b	0.414
20	118.69±9.04a	14.87±0.91a	71.66±4.34a	46.65±3.99a	0.393

Values are means ± standard errors. Means with the same letter within each column are not significantly different at $p < 0.05$.

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