

Study on cadmium accumulation characteristics of *Solanum nigrum* with different ploidies

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Abstract. To study the cadmium accumulation characteristics of *Solanum nigrum* with different ploidies, the biomass, cadmium content and cadmium accumulation of diploid (*Solanum photeinocarpum*), tetraploid (*Solanum photeinocarpum*) and hexaploid (*Solanum nigrum*) were measured by a pot experiment. The results showed that the biomass of roots, stems, leaves and shoots of *S. nigrum* plants with different ploidy all ranked as follows: hexaploid > tetraploid > diploid. Cadmium content and cadmium accumulation in stems, leaves and shoots of hexaploid plants were significantly higher than those in tetraploid and diploid plants, and the cadmium translocation factor and translocation accumulation factor of hexaploid were the largest, too. Therefore, hexaploid *S. nigrum* had a highest ability to extract and transport cadmium, which can be used as an ideal plant for remediation of cadmium-contaminated soil.

1 Introduction

In recent years, due to the rapid development of industry and mining industry, as well as the unreasonable application of phosphorus fertilizer and pesticides in agriculture, the problem of heavy metal pollution in soil in China has become increasingly prominent [1-2]. Cadmium (Cd), one of the most toxic heavy metals, is an unnecessary element for plants growth and development, long-term accumulation in soil will not only affect the normal growth of plants, but also endanger human health through the food chain [3]. Faced with the increasingly serious problem of cadmium pollution, researchers have proposed many remediation technologies to purify contaminated soil [4-6], among them, the phytoremediation technology has become one of the most ideal approaches to solve the problem of heavy metal pollution because of its low cost, high efficiency and low side effects on the environment [7].

Solanum nigrum is an annual herb of *Solanaceae* which is widely distributed in China, and as a newly discovered typical plants with excessive enrichment of cadmium [8], *S. nigrum* has attracted much attention because of its strong reproductive capacity, fast growth rate and large biomass, and at present, there are a series of studies on the mechanism of absorption and enrichment of heavy metal cadmium and the repairing effect of heavy metal cadmium pollution by *S. nigrum* [9-10]. Chromosome polyploidy is one of the important ways of plants evolution [11], there are three main types of chromosome ploidy in *S. nigrum* in China at present: *Solanum photeinocarpum* is diploid, induced *Solanum photeinocarpum* is tetraploid and *Solanum photeinocarpum* is hexaploid [12]. Previous studies have shown that polyploidy usually exhibits stronger

resistance, such as drought resistance [13] and salt stress resistance [14], however, studies on the tolerance and accumulation ability of different ploidy plants to heavy metals has not been reported, in view of this, this paper compares the growth and cadmium-accumulation characteristics of *S. nigrum* with different ploidy under cadmium stress, in order to provide theoretical basis for efficient remediation of cadmium-contaminated soil by *S. nigrum*.

2 Materials and methods

2.1 Materials.

Seeds of *S. nigrum* with different ploidy were collected from *S. photeinocarpum* (diploid), *S. photeinocarpum* (tetraploid) and *S. nigrum* (hexaploid) respectively in the farm near the Chengdu Campus of Sichuan Agricultural University (30°42'N, 103°50'E), the soil for the experiment was collected from the same place.

2.2 Experimental design.

In August 2018, after air-drying, crushing and sifting through a 5-mm sieve, 3.0 kg of soil was weighed into a plastic pot of 21 cm × 20 cm (diameter × height), the cadmium concentration in the soil was 10 mg/kg by adding the analytical pure CdCl₂·2.5H₂O solution. Keep the soil moisture content at 80% and leave it naturally to balance for 4 weeks, turn over and mix the soil irregularly to make it fully mixed. In September 2018, the seeds of three different ploidies *S. nigrum* were placed in a climate box for breeding, in October 2018, when the seedlings grew 5 to 6 true leaves, the plants of

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S. nigrum with different ploidy which were strong and grew consistently were transplanted into the prepared cadmium-containing soil.

Three treatments were set up in the experiment: diploid, tetraploid and hexaploid. There were 4 plants per pot for each ploidy *S. nigrum*, each treatment was repeated 3 times. The distance between the pots was 15 cm and was completely random. According to the water shortage in the basin, watering occasionally to meet the plants growth needs, during the whole growth process, the position between the pots was exchanged irregularly to weaken the influence of the marginal effect, and the weeds were removed in time to prevent pests and diseases.

After 60 days, the whole plants of *S. nigrum* with different ploidy were harvested respectively and the roots, stems and leaves were cleaned, dried and then the biomass of which was measured. The cadmium content was measured on an ICP spectrometer (Thermo Scientific, USA), and the cadmium accumulation in various organs, translocation factor, translocation accumulation factor were calculated [8]: cadmium accumulation = cadmium content \times biomass, translocation factor = shoots cadmium content/roots cadmium content, translocation accumulation factor = (shoots cadmium content \times shoots biomass)/(roots cadmium content \times roots biomass).

2.3 Statistical analyses.

Statistical analyses were carried out by SPSS 17.0 statistical software, and the Duncan's new multiple range method was used for multiple comparisons to analyze the difference significance.

3 Results and discussion

3.1 Biomass of *S. nigrum* with different ploidy.

Under cadmium stress, the biomass of roots, stems, leaves and shoots of *S. nigrum* with different ploidy all ranked as follows: hexaploid > tetraploid > diploid (Table 1), and the biomass of each organ of hexaploid plants was significantly higher than that of tetraploid and diploid. The biomass of roots and stems of tetraploid was not significantly different from that of diploid plants, but the biomass of leaves and shoots was significantly higher than that of diploid. In terms of root-shoot ratio, diploid was the largest, while there was no significant difference between tetraploid and hexaploid in root-shoot ratio.

3.2 Cadmium content of *S. nigrum* with different ploidy.

The cadmium content in roots of diploid plants of *S. nigrum* was significantly higher than that of tetraploid and hexaploid plants, reaching 51.59 mg kg⁻¹, almost twice as high as that of hexaploid (Table 2). The cadmium content in stems, leaves and shoots of hexaploid plants was significantly different from that of the other two ploidy plants, the content ranked as follows specifically: hexaploid > tetraploid > diploid. As for the value of the transcription factor, the hexaploid is the largest, followed by the tetraploid, and the diploid is the smallest, moreover, transcription factor of hexaploid was more than 2.5 times than that of diploid.

Table 1. Biomass of *S. nigrum* with different ploidy.

| Treatment | Roots (g plant ⁻¹) | Stems (g plant ⁻¹) | Leaves (g plant ⁻¹) | Shoots (g plant ⁻¹) | Root-shoot ratio |
|------------|--------------------------------|--------------------------------|---------------------------------|---------------------------------|------------------|
| Diploid | 0.251±0.005b | 0.276±0.010b | 0.753±0.026c | 1.029±0.016c | 0.244±0.009a |
| Tetraploid | 0.257±0.002b | 0.264±0.006b | 0.984±0.023b | 1.248±0.016b | 0.206±0.001b |
| Hexaploid | 0.299±0.004a | 0.341±0.011a | 1.077±0.025a | 1.418±0.036a | 0.211±0.002b |

Means with the same letter within each column are not insignificantly different at 0.05 levels.

Table 2. Cadmium content of *S. nigrum* with different ploidy.

| Treatment | Roots (mg kg ⁻¹) | Stems (mg kg ⁻¹) | Leaves (mg kg ⁻¹) | Shoots (mg kg ⁻¹) | Translocation factor |
|------------|------------------------------|------------------------------|-------------------------------|-------------------------------|----------------------|
| Diploid | 51.19±1.221a | 12.66±0.468b | 29.24±0.764b | 24.80±0.458c | 0.484±0.003c |
| Tetraploid | 47.51±1.160b | 13.86±0.506b | 31.61±0.667b | 27.86±0.496b | 0.587±0.025b |
| Hexaploid | 26.25±0.341c | 21.24±0.725a | 39.70±0.919a | 35.26±0.904a | 1.343±0.017a |

Means with the same letter within each column are not insignificantly different at 0.05 levels.

3.3 Cadmium accumulation of *S. nigrum* with different ploidy.

The cadmium accumulation in roots of diploid and tetraploid plants was significantly higher than that of hexaploid (Table 3), but there was no significant

difference between the two. The cadmium accumulation in stems, leaves and shoots of hexaploid plants was the highest, which was 7.247 µg plant⁻¹, 42.75 µg plant⁻¹ and 50.00 µg plant⁻¹ respectively and all reached about twice that of diploid, while the cadmium accumulation in stems, leaves and shoots of tetraploid was between that of

hexaploid and diploid. In terms of translocation accumulation factor, there were significant differences among the three ploidies *S. nigrum*, the order of which was as follows: hexaploid > tetraploid > diploid, among them, the translocation accumulation factor of hexaploid were as high as 6.365.

4 Conclusions

Under cadmium stress, the biomass of three ploidy plants of *S. nigrum* ranked as hexaploid > tetraploid > diploid. The cadmium content and cadmium accumulation in roots of diploid was the highest, but the cadmium content and cadmium accumulation in the stems, leaves and

shoots of it was the lowest. On the contrary, the cadmium content and cadmium accumulation in the stems, leaves and shoots of hexaploid plants was the highest, its transport factor and transport accumulation factor were significantly higher than those of the other two ploidies *S. nigrum*, which indicated that hexaploid had a higher ability to extract and transport cadmium from soil. In general, hexaploid *S. nigrum* have the largest biomass, the highest cadmium content and cadmium accumulation in the shoots, so its cadmium accumulation ability is the strongest, which means that it can be used as an ideal plant for remediation of cadmium-contaminated soil.

Table 3. Cadmium accumulation of *S. nigrum* with different ploidy.

| Treatment | Roots ($\mu\text{g}\cdot\text{plant}^{-1}$) | Stems ($\mu\text{g}\cdot\text{plant}^{-1}$) | Leaves ($\mu\text{g}\cdot\text{plant}^{-1}$) | Shoots ($\mu\text{g}\cdot\text{plant}^{-1}$) | Translocation accumulation factor |
|------------|--|--|---|---|--------------------------------------|
| Diploid | 12.87±0.565a | 3.494±0.254b | 22.02±0.172c | 25.51±0.082c | 1.983±0.081c |
| Tetraploid | 12.23±0.409a | 3.655±0.219b | 31.11±0.058b | 34.76±0.161b | 2.844±0.108b |
| Hexaploid | 7.85±0.015b | 7.247±0.010a | 42.75±0.009a | 50.00±0.001a | 6.365±0.012a |

Means with the same letter within each column are not insignificantly different at 0.05 levels.

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