Study on Selenium Accumulation Characteristics of *Solanum nigrum*

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Abstract. In order to study the effects of different concentrations of selenium on the selenium accumulation characteristics of *Solanum nigrum*, we used the pot experiment to study the effects of different selenium concentrations (0, 5, 10, 25, 50, 75, 100 mg/kg) on the biomass and selenium content of *S. nigrum*. The results showed that all concentrations of selenium inhibited the biomass of *S. nigrum* and high concentrations of selenium inhibited the growth of *S. nigrum* more significantly. In addition, the biomass and selenium content of *S. nigrum* decreased with the increase of selenium concentration. Selenium content in *S. nigrum* roots, stems and leaves were in the ranges of 1.75-59.83 mg/kg, 0.91-47.83 mg/kg, and 0.38-44.50 mg/kg respectively under the selenium stress. The selenium accumulation of each part of *S. nigrum* increased first and then decreased with the increase of selenium concentration. In all treatments, when the concentration of selenium was 10 mg/kg, the selenium accumulation of each part of *S. nigrum* was the highest and the selenium accumulation of *S. nigrum* in shoots and whole plants reached 7.888 μg/plant and 12.893 μg/plant respectively. In a word, *S. nigrum* is most suitable for planting at a selenium concentration of 10 mg/kg.

1. Introduction

In the growth and development of animals and plants, various important elements are needed, and the amount of trace elements required is small but indispensable [1]. Selenium (Se) is one of the trace elements and plays an extremely important role in the life history of animals and plants [2]. The physiological role of Se in the human body is two-sided, and Se excessive or lack of content can affect human health [3]. It is well known that Se is the main synthetic precursor of GSH-Px and the lack of Se leads to a decrease in the activity of GSH-Px, which in turn reduces the stress resistance of the human body [4-5]. Studies have shown that in low-selenium environments, some local diseases such as Keshan is prone to outbreaks. Severe Se deficiency and strong damage to GSH-Px in cell membranes and red blood cells could be observed in the disease [6]. In addition, muscle problems, digestive changes, cardiovascular diseases and rheumatic disorders are closely related to the lack of Se in the human body [7]. Unfortunately, the survey found that Chinese adults consume only 26.63 μg of Se per day, which is far below normal [8]. Therefore, it is important to find more Se sources to improve the body's Se content to maintain human health. At present, the human body mainly supplements Se by using an agent made of inorganic Se, but its absorption rate in the human body is low and there are certain side effects [9]. Finley and Davis (2001) found that eating bio-selenium is the
safe and most effective way to supplement selenium [10]. Therefore, choosing organic Se to maintain normal selenium content can be considered as a healthy way. Plants are producers of nature and have the function of converting inorganic selenium into organic Se. The researches on Se-enriched rice, Se-enriched vegetables and Se-enriched tea have made significant contributions to the development of Se-enriched foods [11-13]. However, different plants have significant differences in the Se accumulation ability of soil and the resistance to high concentrations of Se [14]. Plants can be divided into three types: Primary Se accumulator, Secondary Se accumulator and Non-Se accumulator based on their ability to accumulate Se in soil according to Rosenfeld and Beath [15]. In order to reduce the harm of low Se to human health, it is of great practical significance to screen more Se accumulator. Solanum nigrum is an annual or perennial herb with a variety of medicinal properties [16]. It is distributed in most parts of China and has the advantages of strong vitality and extensive management. Study has shown that S. nigrum is a cadmium hyperaccumulator and its chlorophyll content and biomass are reduced under high cadmium stress to varying degrees [17]. However, the effects of different Se concentrations on the Se accumulation characteristics of S. nigrum have not yet been reported. Therefore, in order to screen more Se sources, S. nigrum was used as the material to study the effects of different concentrations of Se on S. nigrum biomass and Se content.

2. Materials and methods

2.1 Materials collection
The seeds of S. nigrum were collected from the farmland of Chengdu Campus of Sichuan Agricultural University. In March 2018, the S. nigrum seeds were sown in 25°C climate chamber. The unpolluted soil was paddy soil, taken from farmland of Chengdu Campus of Sichuan Agricultural University (30°71'N, 103°86'E), pH 7.42, organic matter 31.73 g/kg, total nitrogen 1.05 g/kg, total phosphorus 0.37 g/kg, total potassium 25.71 g/kg, alkali nitrogen 56.13 mg/kg, available phosphorus 17.15 mg/kg, available potassium 56.65 mg/kg. Soil physicochemical properties were determined according to the method of reference [18].

2.2 Experimental design
The experiment was conducted in Chengdu Campus of Sichuan Agricultural University from April to May 2018. The unpolluted soil was air-dried and passed through a 5-mm sieve in March 2018. 3 kg air-dried soil was weighed into each plastic pot (15 cm high, 18 cm in diameter), soaking uniformly Na2SeO3 by 0, 5, 10, 25, 50, 75, 100 mg/kg respectively and balanced for 4 weeks. In April 2018, the same growing S. nigrum with two real leaves were transplanted into the pots. Four S. nigrum were planted in each pot. Five replicates per treatment and all pots were watered each day to keep the soil moisture about 80%. The distance between pots was 15 cm, and the pot position exchanged aperiodically to weaken the impact of the marginal effects. After 40 days, the whole S. nigrum was harvested, washed with water and then rinsed with distilled water for 3 times. After that, the material was divided into roots, stems and leaves, which were dried at 80 °C until constant weight to weigh. The determination of selenium content of S. alatum was based on Munier-Lamy's method [14]. The translocation factor (TF) = Cd content in shoots / Cd content in roots [19].

2.3 Statistical analyses
Statistical analyses were conducted with statistical software of SPSS 17.0. Data were analyzed by one-way ANOVA with least significant difference at 5% confidence level.

3. Results and discussion

3.1 Biomass of S. nigrum
Compared with the Se concentration of 0 mg/kg, all treatments significantly reduced the roots, stems and leaves of S. nigrum biomass (Table 1). The order of Se concentrations in the roots, stems, shoots
and whole plants of *S. nigrum* biomass from large to small were all ranked: 0 mg/kg, 10 mg/kg, 5 mg/kg, 25 mg/kg, 50 mg/kg, 75 mg/kg, and 100 mg/kg. When the Se concentration started at 5 mg/kg, all parts of *S. nigrum* biomass increased first and then decreased with the increase of Se concentration. When the concentration of Se was 100 mg/kg, the biomass of roots, stems, leaves, shoots and whole plants of *S. nigrum* reached the lowest, which was 97.91% (*P* < 0.05), 99.12% (*P* < 0.05), 98.72% (*P* < 0.05), 98.84% (*P* < 0.05) and 98.63% (*P* < 0.05) lower than that of the control respectively. These results indicate that Se stress inhibits the growth of *S. nigrum*, and the growth of *S. nigrum* was almost stagnant under high concentration of Se stress.

### Table 1. Biomass of *S. nigrum*.

| Selenium concentration (mg/kg) | Roots (g/plant) | Stems (g/plant) | Leaves (g/plant) | Shoots (g/plant) | Whole plants (g/plant) |
|-------------------------------|-----------------|-----------------|------------------|------------------|-----------------------|
| 0                             | 0.671±0.03a     | 0.681±0.03a     | 1.644±0.13a      | 2.325±0.12a      | 2.996±0.16a           |
| 5                             | 0.389±0.01c     | 0.237±0.01c     | 0.589±0.03c      | 0.826±0.05c      | 1.215±0.08c           |
| 10                            | 0.480±0.02b     | 0.399±0.02b     | 0.932±0.05b      | 1.331±0.07b      | 1.811±0.11b           |
| 25                            | 0.188±0.01d     | 0.149±0.01d     | 0.623±0.04c      | 0.772±0.04c      | 0.960±0.05c           |
| 50                            | 0.027±0.00e     | 0.016±0.00e     | 0.048±0.01d      | 0.064±0.01d      | 0.091±0.01d           |
| 75                            | 0.020±0.00e     | 0.012±0.00e     | 0.033±0.00d      | 0.045±0.01d      | 0.065±0.00d           |
| 100                           | 0.014±0.00e     | 0.006±0.00e     | 0.021±0.00d      | 0.027±0.00d      | 0.041±0.00d           |

Means with the same letter within each column are not significantly different at *p* < 0.05.

### Table 2. Selenium content of *S. nigrum*.

| Selenium concentration (mg/kg) | Roots (mg/kg) | Stems (mg/kg) | Leaves (mg/kg) | Shoots (mg/kg) | TF |
|-------------------------------|---------------|---------------|----------------|----------------|----|
| 0                             | 0.00±0.00e    | 0.00±0.00f    | 0.00±0.00e     | 0.00±0.00e     | -  |
| 5                             | 1.75±0.08e    | 0.91±0.04f    | 0.38±0.01c     | 0.53±0.03c     | 0.3 |
| 10                            | 10.43±0.49d   | 7.18±0.38e    | 5.39±0.20d     | 5.93±0.28d     | 0.57 |
| 25                            | 14.54±0.77d   | 12.66±0.63d   | 7.13±0.39d     | 8.20±0.31d     | 0.56 |
| 50                            | 38.26±1.98c   | 27.94±1.47c   | 21.95±1.27c    | 23.45±1.37c    | 0.61 |
| 75                            | 46.71±2.26b   | 35.62±2.88b   | 30.76±1.68b    | 32.04±1.65b    | 0.69 |
| 100                           | 59.83±3.54a   | 47.83±2.45a   | 44.50±2.85a    | 45.26±3.39a    | 0.76 |

Means with the same letter within each column are not significantly different at *p* < 0.05.

### 3.2 Selenium content of *S. nigrum*

For the Se content of *S. nigrum*, except for the Se concentration of 5 mg/kg, all the other treatments made the Se content of the roots, stems and leaves of *S. nigrum* significantly higher than that of the control (Table 2). With the increase of Se concentration, the Se content of *S. nigrum* roots, stems, leaves and shoots increased. When the concentration of Se was 100 mg/kg, the Se content of roots, stems, leaves and shoots of *S. nigrum* reached the maximum (*P* < 0.05). Se content in *S. nigrum* roots, stems and leaves were in the ranges of 1.75-59.83 mg/kg, 0.91-47.83 mg/kg, and 0.38-44.50 mg/kg respectively under the Se stress. Except for the Se concentration of 10 mg/kg, the TF of *S. nigrum* increased with the increase of Se concentration. These results indicated that the Se concentration of each part of *S. nigrum* and the ability to transfer Se to the shoots increased with the increase of soil Se concentration.

### Table 2. Selenium content of *S. nigrum*.

| Selenium concentration (mg/kg) | Roots (mg/kg) | Stems (mg/kg) | Leaves (mg/kg) | Shoots (mg/kg) | TF |
|-------------------------------|---------------|---------------|----------------|----------------|----|
| 0                             | 0.00±0.00e    | 0.00±0.00f    | 0.00±0.00e     | 0.00±0.00e     | -  |
| 5                             | 1.75±0.08e    | 0.91±0.04f    | 0.38±0.01c     | 0.53±0.03c     | 0.3 |
| 10                            | 10.43±0.49d   | 7.18±0.38e    | 5.39±0.20d     | 5.93±0.28d     | 0.57 |
| 25                            | 14.54±0.77d   | 12.66±0.63d   | 7.13±0.39d     | 8.20±0.31d     | 0.56 |
| 50                            | 38.26±1.98c   | 27.94±1.47c   | 21.95±1.27c    | 23.45±1.37c    | 0.61 |
| 75                            | 46.71±2.26b   | 35.62±2.88b   | 30.76±1.68b    | 32.04±1.65b    | 0.69 |
| 100                           | 59.83±3.54a   | 47.83±2.45a   | 44.50±2.85a    | 45.26±3.39a    | 0.76 |

Means with the same letter within each column are not significantly different at *p* < 0.05.
3.3 Selenium accumulation of S. nigrum

For the Se accumulation of S. nigrum, the Se accumulation of roots, stems and leaves increased first and then decreased with the increase of Se concentration (Table 3). At a Se concentration of 10 mg/kg, the Se accumulation of roots, stems and leaves of S. nigrum reached its maximum and was significantly higher than other treatments ($P < 0.05$). Compared with the Se concentration of 5 mg/kg, Se concentration of 10 mg/kg increased the Se accumulation of roots, stems and leaves of S. nigrum by 86.39%, 92.46% and 95.54% respectively. Additionally, the order of Se concentrations in the roots, stems and leaves of S. nigrum Se accumulation from large to small were all ranked: 10 mg/kg, 25 mg/kg, 50 mg/kg, 75 mg/kg, 100 mg/kg 5 mg/kg, 0 mg/kg. Se accumulation in S. nigrum shoots and whole plants were in the range of 0.440-7.888 μg/plant and 1.121-12.893 μg/plant respectively under the Se stress. These results indicated that the accumulation of Se by S. nigrum differs depending on the difference in Se concentration in the environment. In all treatments, when the concentration of Se was 10 mg/kg, the Se accumulation of S. nigrum planting. Although the high concentration of Se stress significantly increased the Se content of each part of S. nigrum, the Se accumulation of S. nigrum decreased with a significant inhibition of the growth of S. nigrum.

Table 3. Selenium accumulation of S. nigrum.

| Selenium concentration (mg/kg) | Roots (μg/plant) | Stems (μg/plant) | Leaves (μg/plant) | Shoots (μg/plant) | Whole plants (μg/plant) |
|--------------------------------|-----------------|-----------------|-----------------|-----------------|------------------------|
| 0                              | 0.000±0.00c     | 0.000±0.00e     | 0.000±0.00d     | 0.000±0.00d     | 0.000±0.00d            |
| 5                              | 0.681±0.03c     | 0.216±0.01d     | 0.224±0.01d     | 0.440±0.02d     | 1.121±0.04cd           |
| 10                             | 5.005±0.28a     | 2.865±0.17a     | 5.023±0.32a     | 7.888±0.46a     | 12.893±0.76a           |
| 25                             | 2.734±0.14b     | 1.886±0.11b     | 4.442±0.20b     | 6.328±0.34b     | 9.062±0.43b            |
| 50                             | 1.033±0.04c     | 0.447±0.02c     | 1.054±0.05c     | 1.501±0.06c     | 2.534±0.12c            |
| 75                             | 0.934±0.05c     | 0.427±0.04c     | 1.015±0.05c     | 1.442±0.05c     | 2.376±0.16c            |
| 100                            | 0.838±0.03c     | 0.287±0.01d     | 0.935±0.03c     | 1.222±0.05c     | 2.060±0.18c            |

Means with the same letter within each column are not significantly different at $p < 0.05$.

4. Conclusions

This study showed that different concentrations of selenium stress had different effects on the biomass and selenium content of Solanum nigrum. For the biomass of S. nigrum, all selenium treatments significantly reduced the biomass of each part of S. nigrum and the biomass of S. nigrum decreased with the increase of selenium concentration. High concentration of selenium inhibited the growth of S. nigrum more significantly, when the concentration of Se was 100 mg/kg, the biomass of roots, stems, leaves, shoots and whole plants of S. nigrum reached the lowest, which was 97.91%, 99.12%, 98.72%, 98.84% and 98.63% lower than that of the control respectively. In addition, in all treatments, the biomass of each part of S. nigrum reached the maximum when the concentration of selenium was 10 mg/kg, which indicated that the inhibition of S. nigrum was the least when the concentration of selenium was 10 mg/kg. For the selenium content of S. nigrum, with the increase of selenium concentration, the selenium content of each part of S. nigrum increased. Selenium content in S. nigrum roots, stems and leaves were in the ranges of 1.75-59.83 mg/kg, 0.91-47.83 mg/kg, and 0.38-44.50 mg/kg respectively under the selenium stress. Except for the selenium concentration of 10 mg/kg, the TF of S. nigrum increased with the increase of selenium concentration too. These results indicated that selenium stress would increase the ability to accumulate and transfer selenium in soil. In addition, the selenium accumulation of each part of S. nigrum increased first and then decreased with the increase of selenium concentration. Selenium accumulation in S. nigrum shoots and whole plants were in the
ranges of 0.440-7.888 μg/plant and 1.121-12.893 μg/plant respectively under the selenium stress. In all treatments, when the concentration of selenium was 10 mg/kg, the selenium accumulation of roots, stems and leaves was the highest. All these results indicated that selenium stress had a significant inhibitory effect on the growth of *S. nigrum* and the growth of *S. nigrum* was almost stagnant under high concentration of selenium stress. In all treatments, only the selenium concentration of 10 mg/kg had little effect on the biomass of *S. nigrum*. When the concentration of selenium was 10 mg/kg, the selenium accumulation of each part of *S. nigrum* reached the maximum. Therefore, *S. nigrum* could grow under selenium stress of 10 mg/kg.

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