Effects of different *Solanum* rootstocks on photosynthetic pigment contents and antioxidant enzyme activities of eggplant seedlings under cadmium stress

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Abstract. In the experiment, *Solanum diphyllum*, *Solanum nigrum*, *Solanum nigrum humile* and *Solanum alatum* as the rootstocks and eggplant seedlings as the scions, and the effects of different *Solanum* rootstocks on photosynthetic pigment contents and antioxidant enzyme activities of eggplant seedlings were studied. The results showed that *S. nigrum* as the rootstock increased the content of chlorophyll *a*, chlorophyll *b* and total chlorophyll of eggplant seedlings, and other treatments decreased the value of the above indicators or had no effects on them. All the *Solanum* rootstocks increased the content of carotenoid. Compared to ungrafted, the content of total chlorophyll and carotenoid of eggplant seedlings with *S. nigrum* as rootstock were the highest, which increased by 7.91% and 45.71%. Different *Solanum* rootstocks had different effects on the antioxidant enzyme activities of eggplant seedlings, but in general, *Solanum* rootstocks increased the antioxidant enzyme activities of eggplant seedlings. In conclusion, *S. nigrum* as the rootstock increased the antioxidant enzyme activities of eggplant seedlings while increasing its chlorophyll content, which was conducive to the growth of eggplant seedlings.

1. Introduction

Eggplant is one of the main vegetables in China. Study had shown that eggplant has a strong ability to transfer and accumulate cadmium, and is mainly enriched cadmium in leaves [1-2]. Photosynthesis is the basis of plant growth, and the antioxidant enzyme system is the first defending line of plant against external stress, so both are essential for plant growth. Under cadmium stress, photosynthesis and synthesis of chlorophyll of plant are inhibited, which leads to hindered plant growth [3-4]. And under cadmium stress, the activity of superoxide dismutase (SOD) in eggplant seedlings decreased, the activity of catalase (CAT) changed irregularly, and the content of malondialdehyde (MDA) increased sharply, which indicated that cadmium stress could cause the destruction of active oxygen scavenging system of eggplant, and the ability of active oxygen scavenging decreased [5].

Grafting is a common breeding method in horticultural production that plays a significant role in improving vegetable yield and quality. After grafting, the resistance and photosynthetic capacity of plant are generally increased [6-8]. Compared with own-root seedlings, the antioxidant enzyme activity of grafted eggplant seedlings was significantly improved, and the photosynthetic system of grafted seedlings was less affected by NaCl stress than own-root seedlings [9]. Grafting affinity affects...
the survival rate of grafted seedlings, and the resistance of grafted seedlings is closely related to the traits of rootstocks [10]. Qin et al. showed that grafting decreased the cadmium accumulation in shoots of eggplant seedlings significantly, and the shoot cadmium concentration of the grafted seedlings with the Solanum torvum rootstock was lower than that of the grafted seedling with the Solanum melongena rootstock [11]. Therefore, screening for the right rootstock is especially important. Solanum nigrum is a cadmium hyperaccumulator, which the same genus with eggplant, has a strong ability to accumulate cadmium [12]. Guo et al. showed that the antioxidant enzyme activity of S. nigrum was stronger than that of eggplant [5]. Solanum diphyllum, Solanum nigrum humile and Solanum alatum are the variants of S. nigrum. Therefore, in the experiment, a grafting was conducted with the above four species of Solanum as rootstocks, eggplant as scion, and studied the effects of Solanum rootstocks on photosynthetic pigment contents and antioxidant enzyme activities of eggplant seedlings.

2. Materials and methods

2.1. Materials

The materials used in the experiment were S. diphyllum, S. nigrum, S. nigrum humile, S. alatum. All the seeds were collected from Chengdu Academy of Agricultural and Forestry Sciences, China, and air-dried and stored at 4 °C. The cultivar of eggplant was self-retained species of the Horticulture Institute of Chengdu Academy of Agricultural and Forestry Sciences. The soil used in the experiment was fluvo-aquic soil, collected from the Chengdu Academy of Agricultural and Forestry Sciences in September, 2018.

2.2. Grafting

The seeds of S. diphyllum, S. nigrum, S. nigrum humile and S. alatum were sown at the Chengdu Academy of Agricultural and Forestry Sciences in October, 2018. On 15, November, 2018, the Solanum seedlings reached a height of ~10 cm, and the eggplant seedlings were 5 cm in length, grafting was conducted. The lower part of Solanum seedling, with height of 6 cm, was the rootstock, and the upper part of eggplant seedling (4 cm) was the scion. All leaves of the rootstock were retained. The grafting method in the experiment was cleft grafting, and the graft union was bound with 1-cm-wide plastic film. After grafting was completed, the soil moisture content was maintained at 80% of field capacity, and all of the seedlings were covered with transparent plastic film and a shade net. After 7 ~ 10 d, the transparent plastic film, shade net, and plastic binding film were removed, progressively. There were five grafting treatments in the experiment: ungrafted, and S. diphyllum, S. nigrum, S. nigrum humile and S. alatum as the rootstock respectively.

2.3. Experimental design

The experiment was conducted in Chengdu Academy of Agricultural and Forestry Sciences from October to December, 2018. In October, 2018, the soil was air-dried, ground and passed through a 5-mm sieve. Each plastic pot (15 cm high, 18 cm in diameter) was filled with 3 kg of ground soil and soaking uniformly cadmium solution with 10 mg/kg Cd (in the form of CdCl₂ · 2.5 H₂O) for 4 weeks [13-14]. All pots were watered every day to keep the soil moisture about 80%, and the soils were mixed again after 4 weeks. On 23, November, 2018, after the grafted seedlings survived, three uniformly grafted seedlings of each treatment were transplanted into each pot. Each treatment was repeated three times. The soil moisture content was maintained at 80% of field capacity until the plants were harvested, and the distance between the pot was 10 cm.

After 30 d, the mature leaves of eggplant seedlings were collected to determine the content of photosynthetic pigment (chlorophyll a, chlorophyll b and carotenoid) [15]. The upper young leaves of eggplant seedlings with 2 cm in length were collected to determine the activities of SOD, POD and CAT, the content of soluble protein and MDA [15].
2.4. Statistical analyses
Statistical analyses were performed using SPSS 22.0 statistical software (SPSS Inc., Chicago, IL, USA). Data were analyzed with one-way analysis of variance with least significant difference at the 5% significance level.

3. Results and discussion

3.1. Photosynthetic pigment content of eggplant seedlings
Compared with ungrafted seedlings, *S. nigrum* as the rootstock increased the content of chlorophyll *a*, chlorophyll *b* and total chlorophyll of eggplant seedlings, and other treatments decreased the value of the above indicators or had no effects on them (Table 1). The total chlorophyll content was ranked as: *S. nigrum* > *S. alatum* > *S. diphyllum* > Ungrafted > *S. nigrum humile*. Compared with ungrafted eggplant seedlings, the content of total chlorophyll for the treatment of *S. nigrum* as rootstock increased by 7.91% (*p* < 0.05). Grafted increased the Chlorophyll *ab* ratio of eggplant seedlings, and the Chlorophyll *ab* ratio was ranked as: *S. nigrum humile* > *S. diphyllum* > *S. alatum* > *S. nigrum* > Ungrafted. Grafted increased the content of carotenoid of eggplant seedlings. The content of carotenoid ranked as: *S. nigrum* > *S. alatum* > *S. diphyllum* > *S. nigrum humile* > Ungrafted, and as the rank, the carotenoid content of eggplant seedlings for the grafted treatments increased by 45.71% (*p* < 0.05), 37.55% (*p* < 0.05), 35.92% (*p* < 0.05) and 27.35% (*p* < 0.05), compared with ungrafted eggplant seedlings, respectively.

3.2. Antioxidant enzyme activities of eggplant seedlings
Different *Solanum* rootstocks had different effects on the antioxidant enzyme activities of eggplant seedlings. Except *S. diphyllum* as the rootstock had no effects on the SOD activity and decreased the POD activity of eggplant seedlings, other *Solanum* rootstocks increased them (Table 2). The SOD activity and POD activity for the treatment of *S. nigrum humile* as the rootstock reached the highest, 50.59% (*p* < 0.05) and 154.1% (*p* < 0.05) higher than which for ungrafted, respectively. *S. alatum* as the rootstock increased the CAT activity of eggplant seedlings, meanwhile *S. nigrum* decreased it. Compared to ungrafted, the CAT activity for the treatment of *S. alatum* as rootstock increased by 6.41% (*p* < 0.05), and for the treatment of *S. nigrum* decreased by 8.72% (*p* < 0.05). *Solanum* as rootstocks increased the soluble protein content of eggplant seedlings. The content of soluble protein ranked as: *S. diphyllum* > *S. nigrum humile* > *S. nigrum* > *S. alatum* > Ungrafted. As the rank, the soluble protein content for the grafted treatments were 154.4% (*p* < 0.05), 79.18% (*p* < 0.05), 65.61% (*p* < 0.05) and 62.85% (*p* < 0.05) higher than that for ungrafted. *S. nigrum humile* as the rootstock decreased the MDA content of eggplant seedlings, and other *Solanum* rootstocks had no effects on it. The MDA content for the treatment of *S. nigrum humile* as the rootstock decreased by 2.41% (*p* < 0.05) compared to ungrafted.

| Treatment    | chlorophyll *a* (mg g⁻¹) | chlorophyll *b* (mg g⁻¹) | Total chlorophyll (mg g⁻¹) | Chlorophyll *ab* | carotenoid (mg g⁻¹) |
|--------------|--------------------------|--------------------------|---------------------------|------------------|-------------------|
| Ungrafted    | 1.584±0.023b             | 0.565±0.007b             | 2.149±0.030bc             | 2.804            | 0.245±0.006d      |
| *S. diphyllum* | 1.640±0.045ab            | 0.550±0.013b             | 2.190±0.058abc            | 2.982            | 0.333±0.003bc     |
| *S. nigrum*  | 1.718±0.049a             | 0.601±0.016a             | 2.319±0.065a              | 2.858            | 0.357±0.007a      |
| *S. nigrum humile* | 1.556±0.040b          | 0.510±0.014c             | 2.066±0.054c              | 3.051            | 0.312±0.011c      |
| *S. alatum*  | 1.647±0.069ab            | 0.573±0.006ab            | 2.220±0.075ab             | 2.874            | 0.337±0.010ab     |

Values are means ± standard error of three replicate pots. Different lowercase letters within a column indicate significant differences based on one-way analysis of variance in SPSS 22.0 followed by the least significant difference (*p* < 0.05).

| Treatment    | SOD activity (U g⁻¹) | POD activity (U g⁻¹ min⁻¹) | CAT activity (mg g⁻¹ min⁻¹) | Soluble protein content (mg g⁻¹) | MDA content (μmol kg⁻¹) |
|--------------|----------------------|----------------------------|-----------------------------|---------------------------------|-------------------------|
| Ungrafted    | 313.7±10.08c         | 1807±67.60d                | 7.202±0.209bc               | 7.59±0.12c                      | 6.796±0.133a            |
S. diphyllum 313.2±8.532c 1195±49.59e 6.984±0.093c 19.31±0.99a 6.829±0.129a  
S. nigrum 411.0±13.11b 3043±52.79c 6.574±0.192d 12.57±0.46b 6.632±0.139a  
S. nigrum humile 472.4±15.73a 4591±45.07a 7.377±0.103ab 13.60±0.26b 5.162±0.124b  
S. alatum 394.9±10.49b 3665±56.58b 7.664±0.094a 12.36±0.30b 6.754±0.135a  

Values are means ± standard error of three replicate pots. Different lowercase letters within a column indicate significant differences based on one-way analysis of variance in SPSS 22.0 followed by the least significant difference (p < 0.05).

4. Conclusions
In the experiment, the results showed that S. nigrum as the rootstock increased the content of chlorophyll a, chlorophyll b and total chlorophyll of eggplant seedlings, and other treatments decreased the value of the above indicators or had no effects on them. All the Solanum rootstocks increased the content of carotenoid. Compared to ungrafted, the content of total chlorophyll and carotenoid of eggplant seedlings with S. nigrum as rootstock were the highest, which increased by 7.91% (p < 0.05) and 45.71% (p < 0.05). In general, Solanum rootstocks increased the antioxidant enzyme activities of eggplant seedlings. S. diphyllum as the rootstock increased the content of soluble protein of eggplant seedlings. S. nigrum as the rootstock increased the SOD activity, POD activity and the content of soluble protein of eggplant seedlings. S. nigrum humile and S. alatum as the rootstocks increased the activity of SOD, POD and CAT, and the content of soluble protein of eggplant seedlings. In conclusion, Solanum rootstocks improved the resistance of eggplant seedlings, and S. nigrum as the rootstock increased the antioxidant enzyme activities of eggplant seedlings while increasing its chlorophyll content, which was conducive to the growth of eggplant seedlings.

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