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Effects of Exogenous Abscisic Acid on Photosynthesis of *Capsella bursa-pastoris* Under Salt Stress

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Abstract: A pot experiment was carried out to study the effects of exogenous abscisic acid (ABA) on the photosynthesis of *Capsella bursa-pastoris* under salt stress. Under salt stress, the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents of *C. bursa-pastoris* showed no obvious changes at low ABA concentrations (1 and 5 μmol/L), but showed significant increases at high ABA concentrations (10 and 20 μmol/L). The ABA treatments improved the chlorophyll *a*/*b* ratio and increased the carotenoid content of *C. bursa-pastoris* compared with those of the control. Only the 20 μmol/L ABA dose significantly increased the Pn of *C. bursa-pastoris* compared with the control, while the other ABA concentrations showed no significant differences compared with the control. When the doses of ABA were 1 and 5 μmol/L, the Tr and Gs values of *C. bursa-pastoris* showed no significant differences compared with their respective controls, while 10 and 20 μmol/L ABA doses significantly increased the Tr and Gs. The Ci and Vpdl under ABA treatments showed no significant differences compared with their respective controls. Thus, high ABA concentrations could increase the photosynthetic ability of *C. bursa-pastoris*.

Introduction

Land salinization is a worldwide problem, especially in China, where almost one-quarter of the cultivated land has been salinized, which seriously affects plant growth [1]. Soil salinization is becoming more serious, but its remediation is not easy [2]. Therefore, improving the salt tolerance of plants is important. Abscisic acid (ABA), a plant hormone, is a sesquiterpenoid compound with interesting physiological properties [3]. In plants, ABA is a 'stress-inducing factor' and is the first messenger to activate the expression of antidepressant genes [4]. It can activate the stress-resistant immune system in plants [5]. Under stressful conditions, the plant begins synthesizing ABA to enhance its own resistance [6]. Under salt stress, the biomass of grafted tomato seedlings is significantly greater than the control after the ABA content in leaves increases, which enhances the salt tolerance [7]. Thus, applying ABA to vegetable species may enhance their resistance to salt stress, but limited studies have addressed this hypothesis. Therefore, to enhance the photosynthesis ability of wild vegetable *C. bursa-pastoris* to salt stress, different concentrations of ABA were used to treat *C. bursa-pastoris* seedlings. The aim of this study was to determine the optimal ABA concentration for enhancing the photosynthesis ability of *C. bursa-pastoris* to salt stress.

Materials and Methods

Materials. Seedlings of *C. bursa-pastoris* with five euphyllas were collected from the Chengdu Campus of Sichuan Agricultural University (30° 42′ N, 103° 51′ E) in October 2015. The culture medium in the experiment was a 1:1 mixture of perlite and vermiculite.

Experimental Design. The culture medium was placed into polyethylene pots (10 cm high, 10 cm in diameter), and three uniform seedlings of *C. bursa-pastoris* were transplanted into each pot. The plant seedlings were irrigated with 20 mL Hoagland nutrient solution (containing 50 mmol/L NaCl) [8] per pot every two days until the plants were harvested. When *C. bursa-pastoris* seedlings had grown for 15 days, five concentrations (0, 1, 5, 10 and 20 μmol/L) of ABA [9], with three replicates, were sprayed independently on the leaves of plants. The second and third ABA sprayings occurred at 18 days and 21 days after transplanting, respectively. At each spraying, 25 mL of ABA solution was used per pot, which just soaked the plants. 30 days after the last ABA spraying, the photosynthesis of each plant was determined using an LI-6400 portable photosynthesis meter (LI-COR Inc., USA). The photosynthetic parameters of the photosynthesis meter were a manual control CO_2 concentration of 450 μmol /mol, temperature of 20 ºC, and light intensity of 1,000 μmol/m^2/s. The determined photosynthetic parameters were net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Gs), intercellular CO_2 concentration (Ci) and leaf vapor pressure deficit (VpdL), and each plant was analyzed three times. Then, the upper mature leaves of *C. bursa-pastoris* were collected to determine the photosynthetic pigment (chlorophyll *a*, chlorophyll *b*, total chlorophyll and carotenoid) contents [10].

Statistical Analyses. Statistical analyses were performed using SPSS 13.0 statistical software (IBM, Chicago, IL, USA). Data were analyzed by a one-way analysis of variance with least significant difference at a 5% confidence level.

Results

Photosynthetic pigment in *C. bursa-pastoris*. When the concentrations of ABA were 1 and 5 μmol/L, there were no significant differences in the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents of *C. bursa-pastoris* compared with their respective controls (Table 1). At doses of 10 and 20 μmol/L ABA significantly increased the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents of *C. bursa-pastoris* increased compared with their respective controls, and 20 μmol/L ABA produced the maximum levels, which increased the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents by 13.62%, 13.90% and 17.47%, respectively, compared with their respective controls. The ABA treatments improved the chlorophyll *a*/*b* ratio of *C. bursa-pastoris* compared with the control, with an order of 10 μmol/L ABA > 5 μmol/L ABA > 1 μmol/L ABA > 20 μmol/L ABA > 0 μmol/L ABA (Table 1). The ABA treatments increased the carotenoid content of *C. bursa-pastoris* compared with that of the control (Table 1). When the doses of ABA were 1, 5, 10 and 20 μmol/L, the carotenoid contents increased by 7.53% ($p < 0.05$), 10.24% ($p < 0.05$), 15.36% ($p < 0.05$) and 17.47% ($p < 0.05$), respectively, compared with that of the control.

Table 1 Photosynthetic pigment content in *Capsella bursa-pastoris*

ABA concentrations (μmol/L)	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total chlorophyll (mg/g)	Chlorophyll *a*/*b*	Carotenoid (mg/g)
0	1.578±0.010b	0.478±0.027c	2.056±0.035b	3.301	0.332±0.004d
1	1.616±0.080b	0.488±0.009bc	2.104±0.077b	3.311	0.357±0.015c
5	1.659±0.008b	0.495±0.012bc	2.154±0.004b	3.352	0.366±0.005bc
10	1.772±0.080a	0.521±0.031ab	2.293±0.106a	3.401	0.383±0.019ab
20	1.793±0.069a	0.543±0.030a	2.336±0.099a	3.302	0.390±0.013a

Values are means (± SE) of three replicate pots. Different lowercase letters within a column indicate significant differences based on a one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$).

Photosynthetic characteristics of *C. bursa-pastoris*. When the doses of ABA were 1, 5 and 10 μmol/L, the Pn values of *C. bursa-pastoris* showed no significant differences compared with the control (Table 2). However, a 20 μmol/L ABA dose increased the Pn of *C. bursa-pastoris* by 12.10% ($p < 0.05$) compared with that of the control. When the doses of ABA were 1 and 5 μmol/L, the Tr and Gs values of *C. bursa-pastoris* showed no significant differences compared with their respective controls (Table 2). However, 10 and 20 μmol/L ABA doses increased the Tr by 45.52% ($p < 0.05$) and 55.97% ($p < 0.05$), respectively, compared with the control, and increased the Gs by 66.02% ($p < 0.05$) and 71.09% ($p < 0.05$), respectively. The Ci and Vpdl values of the ABA treatments showed no significant differences compared with their respective controls (Table 2). Thus, high ABA concentrations could increase the Pn, Tr and Gs of *C. bursa-pastoris*, but had no obvious effects on its Ci and Vpdl.

Table 2 Photosynthetic characteristics of *Capsella bursa-pastoris*

ABA concentrations (μmol/L)	Pn (μmol $CO_2/m^2/s$)	Tr (mmol $H_2O/m^2/s$)	Ci (μmol CO_2/mol)	Gs (mol $H_2O/m^2/s$)	VpdL (kPa)
0	15.45±0.92b	2.68±0.50b	343.20±11.06ab	0.256±0.050b	0.953±0.012ab
1	15.81±0.67b	2.37±0.84b	338.28±8.81b	0.250±0.057b	0.951±0.050ab
5	16.08±0.37b	2.24±0.89b	335.89±8.43b	0.238±0.042b	0.933±0.011b
10	16.28±0.09ab	3.90±0.14a	355.54±10.84a	0.425±0.008a	0.968±0.052ab
20	17.32±0.76a	4.18±0.52a	357.77±11.39a	0.438±0.079a	0.999±0.017a

Values are means (± SE) of three replicate pots. Different lowercase letters within a column indicate significant differences based on a one-way analysis of variance in SPSS 13.0 followed by the least significant difference test ($p < 0.05$).

Discussion

Salt stress destroys the dynamic balance between the synthesis and degradation of the chlorophyll *a* and chlorophyll *b* in plant leaves, resulting in decreased chlorophyll *a* and chlorophyll *b* contents, which inhibits photosynthesis [11]. ABA can increase the chlorophyll and carotenoid contents in plant leaves [12]. In this experiment, the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents of *C. bursa-pastoris* showed no obvious changes at low ABA concentrations (1 and 5 μmol/L), but showed significant increases at high ABA concentrations (10 and 20 μmol/L). The ABA treatments improved the chlorophyll *a*/*b* ratio and increased the carotenoid content of *C. bursa-pastoris* compared with those of the control, which showed benefits to the photosynthesis of *C. bursa-pastoris*. When the plants are subjected to salt stress, the stomata of leaves will change to adapt to the stressful environment [13], such as the stomata closing due to leaf water loss induced by salt stress [13-14]. The stomatal closure leads to the decrease in the Ci and Pn [14]. In this experiment, only the 20 μmol/L ABA dose significantly increased the Pn of *C. bursa-pastoris* compared with the control, while the other ABA concentrations showed no significant differences compared with the control. When the doses of ABA were 1 and 5 μmol/L, the Tr and Gs values of *C. bursa-pastoris* showed no significant differences compared with their respective controls, while 10 and 20 μmol/L ABA doses significantly increased the Tr and Gs. The Ci and Vpdl under ABA treatments showed no significant differences compared with their respective controls. Thus, high ABA concentrations could increase the photosynthetic ability of *C. bursa-pastoris*, which may be related to the low sensitivity of *C. bursa-pastoris* to low ABA concentrations.

Conclusions

Under salt stress, the chlorophyll *a*, chlorophyll *b* and total chlorophyll contents of *C. bursa-pastoris* showed no obvious changes at low ABA concentrations (1 and 5 μmol/L), but showed significant increases at high ABA concentrations (10 and 20 μmol/L). The ABA treatments improved the chlorophyll *a*/*b* ratio and increased the carotenoid content of *C. bursa-pastoris* compared with those of the control. Only the 20 μmol/L ABA dose significantly increased the Pn of *C. bursa-pastoris* compared with the control, while the other ABA concentrations showed no significant differences compared with the control. When the doses of ABA were 1 and 5 μmol/L, the Tr and Gs values of *C. bursa-pastoris* showed no significant differences compared with their respective controls, while 10 and 20 μmol/L ABA doses significantly increased the Tr and Gs. The Ci and Vpdl under ABA treatments showed no significant differences compared with their respective controls. Thus, high ABA concentrations could increase the photosynthetic ability of *C. bursa-pastoris*.

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