Effects of Abscisic Acid (ABA) on Growth of *Malachium Aquaticum* under Salt Stress

Mei Qing[1,a], Li Wang[2,b], Tong Zhang[1,c], Huan Yao[1,d], and Lijin Lin[3,e*]

[1]College of Horticulture, Sichuan Agricultural University, Chengdu, China

[2]College of Animal Science and Technology, Sichuan Agricultural University, Chengdu, China

[3]Institute of Pomology and Olericulture, Sichuan Agricultural University, Chengdu, China

[a]1115435013@qq.com, [b]510830161@qq.com, [c]1014336443@qq.com, [d]272365026@qq.com, [e]llj800924@163.com (Corresponding author)

Mei Qing and Li Wang contributed equally to this work.

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Abstract: The effects of abscisic acid (ABA) on the growth of *Malachium aquaticum* under salt stress were investigated through a pot experiment. The results showed that ABA increased the biomass of *M. aquaticum*. With the increase of ABA concentrations, the root, stem, leaf and shoot biomasses of *M. aquaticum* increased when the dose of ABA was not more than 5 μmol/L, and decreased when the dose of ABA was more than 5μmol/L. ABA also enhanced the photosynthetic pigment content and antioxidant enzyme activity of *M. aquaticum*. When applying ABA on *M. aquaticum*, the soluble sugar content in roots and leaves decreased, and the soluble sugar content in stems increased. Therefore, ABA could promote the growth of *M. aquaticum* under salt stress.

Introduction

In recent years, anti-season vegetables cultivation develop rapidly, and with the increasing cultivation areas for many years planting, the closed cultivation and unreasonable management measures cause high salt content of the soil, which leading to declining soil fertility, soil secondary salinization, and reducing the yield and quality of fruits and vegetables [1]. The effects of salt stress on plants cause the osmotic stress, ionic stress, water loss, ion imbalance and other issues, and seriously affect the growth and development of plants [2]. A variety of physiological functions of plants will be disturbed under salt stress, for example, decrease photosynthesis, protein synthesis disorders [3]. The response and adaptation of plants to salt stress is a complex physiological process, and also is the results of a series of physiological and biochemical processes in plants combined effects [4]. Under salt stress condition, the activities of superoxide dismutase (SOD), peroxidase (POD), ascorbate peroxidase (APX) and catalase (CAT) enhance to remove the large amounts of free radicals [5]. The study shows that the salt stress can damage the plant chlorophyll, photosynthetic enzyme activity degenerating or inactivating, leading to reduced plant photosynthetic rate [6]. The abscisic acid (ABA) is recognized as one of the five plant hormones, a member of one of the defense mechanisms of plants to the abiotic stress [7]. The exogenous ABA can increase the SOD and POD activities of Jasmine seedlings at low salt stress [8]. ABA starts the stress response in plants by stress signal transduction, and increases the variety of plants to resist stress factors [9]. So, study the effects of ABA on the physiological functions and mechanisms of plants under the abiotic stress are helpful to the agricultural production.

Malachium aquaticum is the wild vegetable of Caryophyllaceae [10]. In this study, we grew *M. aquaticum* seedlings under salt stress, and used the different concentrations of ABA to treat *M. aquaticum* seedlings, to study the effects of ABA on the growth of *M. aquaticum* seedlings under salt stress. The aim of the study was to screen the best ABA concentration which could promote the growth of *M. aquaticum* under salt stress, and provided a reference for applying the plant hormones on other wild vegetables production under salt stress.

Materials and Methods

Materials. The *M. aquaticum* seedlings with height of 15 cm were collected from the surrounding farmland of Chengdu campus of Sichuan Agricultural University (30° 42′N, 103° 51′E) in March 2016.

Experimental Design. The vermiculites and pearlites (1:1) were put into polyethylene pot (10 cm high, 10 cm in diameter). Two uniform *M. aquaticum* seedlings were transplanted into each pot in March 2016, and 5 concentrations (0, 1, 5, 10 and 20 μmol/L) of ABA [11] with 6 replicates were sprayed on the leaves of plants for each pot, respectively. After that, all of the seedlings were covered with transparent plastic film and a shade net. After 10 d, the transparent plastic film and the shade net were removed. From the third day of transplanting, the Hogland nutrient solutions containing 50 mmol/L NaCl were watered every two days, and 30 ml solutions for each pot. When *M. aquaticum* seedlings grow two month (May 2016) under salt stress, the upper mature leaves of *M. aquaticum* were collected to determine the photosynthetic pigment (chlorophyll *a*, chlorophyll *b* and total chlorophyll) contents [12]. The upper young shoots (2 cm in length) were collected to determine the superoxide dismutase (SOD) activity, peroxidase (POD) activity and catalase (CAT) activity [12]. Then, the whole plants were then gently removed. The roots and shoots were washed with tap water followed by deionized water, and the biomasses of root, stem and leaf were measured. After that, the roots, stems and leaves of *M. aquaticum* were dried at 80 °C to constant weight. The dried tissue samples were finely ground and sieved through a 0.149-mm-mesh nylon sieve for chemical analysis. The soluble sugar contents in roots, stems and leaves of *M. aquaticum* were determined by anthrone colorimetry with dry weight plant samples [12].

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 Duncan's multiple range test ($p = 0.05$ confidence level).

Results and Discussion

Biomass of *M. aquaticum*. With the increase of ABA concentrations, the root biomass of *M. aquaticum* increased when the dose of ABA was not more than 5 μmol/L, and decreased when the dose of ABA was more than 5 μmol/L (Table 1). At 1, 5, 10 and 20 μmol/L ABA, the root biomass increased by 18.22% ($p < 0.05$), 78.22% ($p < 0.05$), 56.43% ($p < 0.05$) and 42.80% ($p < 0.05$) respectively, compared with the control. When applying ABA on *M. aquaticum*, the stem, leaf and shoot biomasses of *M. aquaticum* increased compared with the control (Table 1). With the increase of ABA concentrations, the trends of stem, leaf and shoot biomasses were the same as the root biomass. At 1, 5, 10 and 20 μmol/L ABA, the shoot biomass increased by 4.78% ($p > 0.05$), 30.16% ($p < 0.05$), 22.90% ($p < 0.05$) and 8.55% ($p < 0.05$) respectively, compared with the control. So, ABA could promote the growth of *M. aquaticum*.

Table 1 The biomass of *M. aquaticum*

ABA concentration (μmol/L)	Roots (g/plant FW)	Stems (g/plant FW)	leaves (g/plant FW)	Shoots (g/plant FW)
0	0.785±0.017e	7.326±0.105d	4.533±0.109c	11.859±0.214d
1	0.928±0.031d	7.755±0.064c	4.671±0.069c	12.426±0.133cd
5	1.399±0.027a	8.872±0.124a	6.564±0.169a	15.436±0.317a
10	1.228±0.021b	8.451±0.211b	6.124±0.122b	14.575±0.332b
20	1.121±0.030c	8.056±0.204c	4.817±0.138c	12.873±0.342c

Values are means (±SE) of six replicate pots. Different lowercase letters within a column indicate significant differences (one-way analysis of variance followed by Duncan's multiple range test; $p < 0.05$).

Photosynthetic Pigment Content of *M. aquaticum*. ABA increased the contents of chlorophyll *a*, chlorophyll *b* and total chlorophyll (Table 2). With the increase of ABA concentrations, the contents

of chlorophyll *a*, chlorophyll *b* and total chlorophyll increased when the dose of ABA was not more than 5 μmol/L, and decreased when the dose of ABA was more than 5 μmol/L. At 1, 5, 10 and 20 μmol/L ABA, the chlorophyll *a* content increased by 0.26% ($p > 0.05$), 6.74% ($p > 0.05$), 4.95% ($p > 0.05$) and 4.01% ($p > 0.05$) respectively, the chlorophyll *b* content increased by 4.18% ($p > 0.05$), 9.89% ($p > 0.05$), 7.22% ($p > 0.05$) and 5.70% ($p > 0.05$) respectively, the total chlorophyll content increased by 0.98% ($p > 0.05$), 7.39% ($p > 0.05$), 5.37% ($p > 0.05$) and 4.32% ($p > 0.05$) respectively, compared with the respective control. For the chlorophyll a/b, ABA increased the chlorophyll a/b of *M. aquaticum*, and had the trend of increasing with the increase of ABA concentrations (Table 2).

Table 2 The photosynthetic pigment content of *M. aquaticum*

ABA concentration (μmol/L)	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total chlorophyll (mg/g)	Chlorophyll a/b
0	1.172±0.038a	0.263±0.011a	1.435±0.049b	4.456
1	1.175±0.006a	0.274±0.009a	1.449±0.015ab	4.288
5	1.251±0.031a	0.289±0.007a	1.541±0.038a	4.329
10	1.230±0.005a	0.282±0.010a	1.512±0.016ab	4.362
20	1.219±0.006a	0.278±0.006a	1.497±0.012ab	4.385

Values are means (±SE) of six replicate pots. Different lowercase letters within a column indicate significant differences (one-way analysis of variance followed by Duncan's multiple range test; $p < 0.05$).

Antioxidant Enzyme Activity of *M. aquaticum*. ABA enhanced the antioxidant enzyme activity of *M. aquaticum* (Table 3). So, ABA could improve the resistance of *M. aquaticum* to salt stress. At 1, 5, 10 and 20 μmol/L ABA, the SOD activity increased by 18.33% ($p < 0.05$), 54.69% ($p < 0.05$), 27.79% ($p < 0.05$) and 21.34% ($p < 0.05$) respectively, the POD activity increased by 6.91% ($p > 0.05$), 71.85% ($p < 0.05$), 44.14% ($p < 0.05$) and 11.04% ($p < 0.05$) respectively, the CAT activity increased by 1.88% ($p > 0.05$), 42.65% ($p < 0.05$), 38.47% ($p < 0.05$) and 27.89% ($p < 0.05$) respectively, compared with the respective control.

Table 3 The antioxidant enzyme activity of *M. aquaticum*

ABA concentration (μmol/L)	SOD activity (U/g)	POD activity (U/g)	CAT activity (U/g)
0	57.82±4.89c	978.53±47.72c	69.56±4.20b
1	68.42±3.08b	1046.19±34.16c	70.87±3.15b
5	89.44±3.90a	1681.61±34.05a	99.23±4.57a
10	73.89±1.62b	1410.46±36.55b	96.32±5.67a
20	70.16±3.97b	1086.59±54.08c	88.96±4.33a

Values are means (±SE) of six replicate pots. Different lowercase letters within a column indicate significant differences (one-way analysis of variance followed by Duncan's multiple range test; $p < 0.05$).

Soluble Sugar Content in *M. aquaticum*. When applying ABA on *M. aquaticum*, the soluble sugar content in roots and leaves of *M. aquaticum* decreased, and the soluble sugar content in stems increased (Table 4). At 1, 5, 10 and 20 μmol/L ABA, the soluble sugar content in roots decreased by 37.85% ($p < 0.05$), 54.42% ($p < 0.05$), 49.75% ($p < 0.05$) and 48.34% ($p < 0.05$) respectively, the soluble sugar content in stems increased by 13.26% ($p < 0.05$), 26.90% ($p < 0.05$), 17.56% ($p < 0.05$) and 16.28% ($p < 0.05$) respectively, the soluble sugar content in leaves decreased by 14.31% ($p < 0.05$), 20.54% ($p < 0.05$), 17.47% ($p < 0.05$) and 16.68% ($p < 0.05$) respectively, compared with the respective control.

Conclusions

Under salt stress, ABA increased the biomass of *M. aquaticum*. With the increase of ABA concentrations, the root, stem, leaf and shoot biomasses of *M. aquaticum* increased when the dose of ABA was not more than 5 μmol/L, and decreased when the dose of ABA was more than 5 μmol/L. ABA also enhanced the photosynthetic pigment content and antioxidant enzyme activity of *M. aquaticum*. When applying ABA on *M. aquaticum*, the soluble sugar content in roots and leaves decreased, and the soluble sugar content in stems increased. Therefore, ABA could promote the growth of *M. aquaticum* under salt stress.

Table 4 The soluble sugar content in *M. aquaticum*

ABA concentration (μmol/L)	Roots (mg/g DW)	Stems (mg/g DW)	leaves (mg/g DW)
0	23.54±0.38d	13.27±0.76c	11.39±0.13a
1	14.63±0.25b	15.03±0.15b	9.76±0.24b
5	10.73±0.13a	16.84±0.78a	9.05±0.16c
10	11.83±0.28c	15.60±0.29ab	9.40±0.12bc
20	12.16±0.48c	15.43±0.61ab	9.49±0.42bc

Values are means (±SE) of six replicate pots. Different lowercase letters within a column indicate significant differences (one-way analysis of variance followed by Duncan's multiple range test; $p < 0.05$).

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