Effects of Cadmium Stress on Photosynthetic Characteristics of Grape Seedlings

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Abstract: The effects of cadmium (Cd) stress on photosynthetic characteristics of grape seedlings were investigated through a pot experiment. The results showed that with the increase of Cd concentrations, the photosynthetic pigment content and net photosynthetic rate decreased. The transpiration rate, CO_2 concentration of intercellular and stomatal conductance increased under Cd stress compared with the control, but water use efficiency decreased. With the increase of Cd concentrations, the vapor pressure deficit of leaf had the trend of increasing when the dose of Cd was not more than 10 mg/kg, and decreased when the dose of Cd was higher than 10 mg/kg. Therefore, Cd treatment could inhibit the photosynthesis of grape seedlings.

Introduction

With the development of industrial and agricultural production, the heavy metal contaminated soil area increases [1-2]. According to the reports, China's cadmium (Cd) contaminated soil area has reached 200,000 km^2, accounting for the total area of arable land 1/6 [3]. In orchard, the research shows that the heavy metal pollution is also more serious, especially the pollution of Cd has been seriously in some areas, the Cd content in fruit of fruit trees has exceeded the standard [4-5].

Grape is one of the world's most important fruit tree species, the fruit of grape is rich in a variety of carbohydrate, antioxidant, anti-aging and anti-cancer substances, etc., with a high nutritional value and health care function, much consumers love [6-7]. China's fresh grape planting area is the second of world for five consecutive years [8-9]. In recent years, the industrial "three wastes" emissions, urban sewage and garbage pollution and containing heavy metals, pesticides, fertilizers and organic fertilizer unreasonable application result the heavy metal pollution in farmland, especially Cd pollution has seriously exceeded [10-11]. So, study the eco-physiology of grape under Cd stress is very important. The aim of this study was to study the effects of Cd stress on photosynthetic characteristics of grape seedlings, and provided a reference for grape production in Cd-contaminated soil areas.

Materials and Methods

Materials. The soil samples used in the experiment were collected from the Chengdu campus of Sichuan Agricultural University (30° 42′N, 103° 51′E) in May 2016, which were uncontaminated by heavy metals. The grape seedlings were 'Jufeng' and 'Xiahei', which were the annual cutting seedlings with 25 cm height of young sprout.

Experimental Design. The soil samples were air-dried and passed through a 5-mm sieve. Four kilograms of the air-dried soil was weighed into each polyethylene pot (18 cm high, 21 cm in diameter). Cd was added to soils as $CdCl_2$•$2.5H_2O$ at 0, 1, 5, 10, 15 and 20 mg/kg in April 2016, and the soil moisture was maintained at 80% of field capacity for one month. The uniform grape seedlings were transplanted into each pot in May 2016, and watered every day to keep the soil moisture content maintaining at 80% of field capacity. One pot planted one seedling, and each treatment was 6

replicates, respectively. After grape seedlings grew two months (July 2016), the upper mature leaves of grape seedlings were collected to determine the photosynthesis and the photosynthetic pigment (chlorophyll *a*, chlorophyll *b* and total chlorophyll) content [12]. The photosynthesis of each plant was determined by using LI-6400 portable photosynthesis meter (LI-COR Inc., USA). The photosynthetic parameters of the photosynthesis meter were manual control CO_2 concentration 400 μmol·CO_2/ mol, temperature 30℃, light intensity 1500 μmol/ m^2·s. The determination of photosynthetic parameters were net photosynthetic rate (Pn), transpiration rate (Tr), stomatal conductance (Gs), CO_2 concentration of intercellular (Ci) and vapor pressure deficit of leaf (VpdL), and each plant was repeated three times.

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 least significant difference (LSD) at the p = 0.05 confidence level. Water use efficiency (WUE) = net photosynthetic rate (Pn)/ transpiration rate (Tr) [13].

Results and Discussion

Photosynthetic Pigment Content. With the increase of Cd concentrations, the contents of chlorophyll *a*, chlorophyll *b* and total chlorophyll of grape seedlings decreased (Table 1). At 1, 5, 10, 15 and 20 mg/kg Cd treatments, the total chlorophyll content of 'Jufeng' seedlings decreased by 3.97% ($p > 0.05$), 10.89% ($p < 0.05$), 31.59% ($p < 0.05$), 32.39% ($p < 0.05$) and 50.65% ($p < 0.05$), respectively, compared with the control, and the total chlorophyll content of 'Xiahei' seedlings decreased by 3.20% ($p > 0.05$), 5.54% ($p < 0.05$), 8.55% ($p < 0.05$), 15.72% ($p < 0.05$) and 16.63% ($p < 0.05$), respectively, compared with the control. So, Cd stress inhibited the growth of grape seedlings.

Table 1 Effects of Cd stress on photosynthetic pigment content of grape seedlings

Treatments	Chlorophyll *a* (mg/g)	Chlorophyll *b* (mg/g)	Total chlorophyll (mg/g)
Jufeng			
0	1.402±0.024a	0.361±0.010a	1.763±0.035a
1	1.373±0.098ab	0.320±0.031b	1.693±0.129ab
5	1.264±0.061b	0.307±0.006b	1.571±0.067b
10	0.959±0.022c	0.247±0.010c	1.206±0.033c
15	0.949±0.029c	0.243±0.001c	1.192±0.030c
20	0.698±0.034d	0.172±0.005d	0.870±0.038d
Xiahei			
0	1.220±0.023a	0.313±0.005a	1.533±0.028a
1	1.177±0.014b	0.307±0.018a	1.484±0.004ab
5	1.149±0.017bc	0.299±0.007a	1.448±0.023bc
10	1.117±0.014c	0.285±0.006ab	1.402±0.020c
15	1.042±0.004d	0.250±0.022bc	1.292±0.025d
20	1.032±0.018d	0.246±0.020c	1.278±0.038d

Net Photosynthetic Rate (Pn). With the increase of Cd concentrations, the Pn of grape seedlings decreased (Table 1). At 1, 5, 10, 15 and 20 mg/kg Cd treatments, the Pn of 'Jufeng' seedlings decreased by 11.07% ($p < 0.05$), 11.33% ($p < 0.05$), 11.67% ($p < 0.05$), 26.24% ($p < 0.05$) and 37.90% ($p < 0.05$), respectively, compared with the control, and the Pn of 'Xiahei' seedlings decreased by 7.67% ($p > 0.05$), 9.25% ($p < 0.05$), 14.25% ($p < 0.05$), 21.83% ($p < 0.05$) and 29.17% ($p < 0.05$), respectively, compared with the control. So, Cd stress inhibited the Pn of grape seedlings.

Transpiration Rate (Tr). The Tr of grape seedlings increased under Cd stress compared with the control (Table 2). With the increase of Cd concentrations from 1 to 20 mg/kg, the Tr of grape seedlings had the trend of decreasing. Compared with the control, the Tr differences of 'Jufeng'

seedlings under 1 and 5 mg/kg Cd treatments were significant, the other concentrations of Cd were not significant. For 'Xiahei' seedlings, all treatments of the Tr differences were not significant.

Water Use Efficiency (WUE). The WUE of grape seedlings decreased under Cd stress compared with the control (Table 2). With the increase of Cd concentrations from 1 to 20 mg/kg, the WUE of grape seedlings had the trend of increasing when the dose of Cd was not more than 10 mg/kg, and decreased when the dose of Cd was higher than 10 mg/kg.

Table 2 Effects of Cd stress on net photosynthetic rate and transpiration rate of grape seedlings

Treatments	Pn ($\mu mol \cdot CO_2/m^2 \cdot s$)	Tr (mmol $H_2O/m^2 \cdot s$)	WUE ($\mu mol \cdot CO_2$/mmol H_2O)
Jufeng			
0	11.74±0.70a	3.71±0.58b	3.16±0.58a
1	10.44±0.17b	4.94±0.36a	2.11±0.12b
5	10.41±0.46b	4.79±0.35a	2.17±0.20b
10	10.37±0.21b	4.53±0.23ab	2.29±0.07b
15	8.66±0.66c	4.12±0.85ab	2.10±0.59b
20	7.29±0.07d	4.11±0.66ab	1.77±0.25b
Xiahei			
0	12.00 ±0.87a	3.04 ±0.47a	3.95 ±0.78a
1	11.08 ±0.62ab	3.60 ±0.94a	3.08 ±0.83ab
5	10.89 ±0.61b	3.50 ±0.20a	3.11 ±0.29ab
10	10.29 ±0.31bc	3.29 ±0.14a	3.13 ±0.20ab
15	9.38 ±0.49cd	3.23 ±0.41a	2.90 ±0.24b
20	8.50 ±0.34d	3.13 ±0.44a	2.72 ±0.46b

CO_2 Concentration of Intercellular (Ci). The same as the Tr, The Ci of grape seedlings increased under Cd stress compared with the control (Table 3). With the increase of Cd concentrations from 1 to 20 mg/kg, the Ci of grape seedlings had the trend of decreasing.

Table 3 Effects of Cd stress on gas exchange parameters of grape seedlings

Treatments	Ci ($\mu mol \cdot CO_2/mol$)	Gs (mol $H_2O/m^2 \cdot s$)	VpdL (kPa)
Jufeng			
0	301±12.55c	0.286±0.071a	1.31±0.075b
1	335±9.81a	0.445±0.012a	1.29±0.087b
5	329±2.80ab	0.384±0.092a	1.35±0.061b
10	323±17.08ab	0.383±0.106a	1.60±0.078a
15	320±7.23abc	0.322±0.158a	1.51±0.081a
20	311±8.45bc	0.304±0.063a	1.48±0.064a
Xiahei			
0	291±9.35d	0.276±0.026c	1.05±0.071b
1	353±10.70a	0.401±0.023a	1.02±0.062b
5	341±11.97ab	0.364±0.021b	1.04±0.072b
10	327±6.30bc	0.334±0.009b	1.17±0.053a
15	320±7.92c	0.331±0.021b	1.11±0.071ab
20	318±5.10c	0.293±0.007c	1.07±0.034ab

Stomatal Conductance (Gs). The same as the Tr, The Gs of grape seedlings increased under Cd stress compared with the control (Table 3). With the increase of Cd concentrations from 1 to 20 mg/kg, the Gs of grape seedlings had the trend of decreasing. Compared with the control, the Gs differences of 'Jufeng' seedlings under Cd treatments were not significant, but 'Xiahei' seedlings were significant.

Vapor Pressure Deficit of Leaf (VpdL). With the increase of Cd concentrations, the Vpdl of grape seedlings had the trend of increasing when the dose of Cd was not more than 10 mg/kg, and decreased when the dose of Cd was higher than 10 mg/kg (Table 3). The maxima of 'Jufeng' and 'Xiahei' seedlings were 1.60 and 1.17 kPa respectively at 10 mg/kg Cd.

Conclusions

Under Cd stress, with the increase of Cd concentrations, the photosynthetic pigment content and net photosynthetic rate decreased. The transpiration rate, CO_2 concentration of intercellular and stomatal conductance increased under Cd stress compared with the control, but water use efficiency decreased. With the increase of Cd concentrations, the vapor pressure deficit of leaf had the trend of increasing when the dose of Cd was not more than 10 mg/kg, and decreased when the dose of Cd was higher than 10 mg/kg.

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