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Full Length Article

Effect of Exogenous Selenium on Activities of Antioxidant Enzymes, Cadmium Accumulation and Chemical Forms of Cadmium in Tomatoes

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Abstract

Pot experiment was conducted to investigated the effect of Na_2SeO_3 treatment at concentrations of 0, 0.5 and 1.0 mg·L^{-1} on biomass, and activities of antioxidant enzymes and chemical forms and accumulation of Cd in two tomato varieties (variety 4641 (V4641) with high Cd enriched variety and Yu powder 109 (YP109) with low Cd enriched variety) when exposed to cadmium (Cd) in soil at the concentration of 20 mg·kg^{-1}. The results showed that foliar spray of selenium (Se) (≤1.0 mg·L^{-1}) increased the dry weights of roots, fruits, and leaves in the two varieties by 1.7%-48.8%, 13.1%-37.5% and 5.4%-47.2%, respectively. The foliar spray of Se significantly increased SOD activity, and reduce CAT and POD activities in both tomato varieties. The Cd proportion of extractable form (F_{NaCl}), residual Cd (F_R) and HCl extractable Cd (F_{HCl}) with low activity accounted for 65.5% of total extractable Cd. The application of Se decreased the contents of total extractable Cd and concentrations of different chemical forms Cd in fruits of both tomato varieties. The foliar spray of Na_2SeO_3 reduced Cd concentrations in leaves, stems, roots and fruits in both tomato varieties by 7.3–41.9%, 9.8–30.9%, 24.5–48.5% and 14.4–37.1%. The concentration of Cd and the accumulation of Cd in fruits of V4641 were higher than in fruits of YP 109 in the present of Na_2SeO_3 when exposed to Cd in soil at the concentration of 20 mg·kg^{-1}. Fruits of YP109 are relatively safer for human body than those of V4641 in Cd-contaminated soil. © 2017 Friends Science Publishers

Keywords: Selenium; Antioxidant enzyme; Cadmium accumulation; Cadmium forms; Tomato (*Solanum lycopersicum* mill.)

Introduction

Cadmium (Cd) is a toxic heavy metal element and has strong teratogenic, carcinogenic and mutagenic effects. It can endanger human and animal health by entering into organism body through food chain (Burger, 2008; Cabral *et al*., 2015; Naz *et al.*, 2016). In recent years, industrial production, the application of agricultural fertilizers and the sewage for irrigation as well as other human factors greatly increase the content of Cd in soil (Nogueira *et al*., 2010; Wu *et al*., 2012; Xu *et al.*, 2016). Currently, the content of Cd in soil from approximately 24.1% of vegetable farms in China beyond the national standard Class Ⅱ(Wei and Zhou, 2006) so that Cd has become one of the major types of heavy metal pollution for soil and vegetables.

Selenium (Se) is an essential trace element, and both the deficiency and excess of Se can cause a variety of ailments of the body. The appropriate amount of Se has anticancer effect in human body (Paul and Dey, 2014). Se also has obvious antagonistic effects on cadmium (Cd), lead (Pb), mercury (Hg) and other heavy metals (Hawrylak-Nowak *et al*., 2014; Han *et al*., 2015). Se at the appropriate concentration in plants is helpful for eliminating excessive free radicals, protecting the integrity of cell membrane structure and retarding the heavy metal toxicity to plants (Saidi *et al*., 2014; Ahmad *et al*., 2016). For example, He *et al*. (2004) determined the accumulation of Cd and Pb in Chinese cabbage (*Brassica rapa* L.) and lettuce (*Lactuca sativa* L.) from a pot experiment in which Se (Se^{4+}) was applied to the soil. They found that the application of Na_2SeO_3 at the concentration of 1 mg kg^{-1} can reduce the concentrations of Cd and Pb in the two vegetables, and increase the concentrations of some essential mineral elements like Mn and Mg. The study from Mozafariyan *et al*. (2014) group has also demonstrated that Se at appropriate concentration can effectively reduce the absorption of Cd in peppers and enhance their antioxidant activity and thus improve the tolerance of plants to Cd stress.

Vegetables have stronger Cd-accumulation ability. Numerous studies have shown that different species and varieties of vegetables have significant differences in Cd accumulation (Cabral *et al*., 2015; Wu *et al*., 2015). Tomato (*Solanum lycopersicum* Mill.) is a favourite vegetable of many people and has been cultivated all over China. Similarly, the study has reported that Cd tolerance and absorption and enrichment of Cd in tomato also revealed genotypic difference (Cherif *et al*., 2011). Currently, the

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interaction between Se and Cd has been investigated in rice (Ding *et al.*, 2014; Wan *et al.*, 2016), rapeseed (Filek *et al.*, 2008; Wu *et al.*, 2017), lettuce (He *et al.*, 2004), cucumber (Sun *et al.*, 2016) and other crops, but the interaction between Se and Cd revealed inconsistent reports (He *et al.*, 2004; Filek *et al.*, 2008; Ding *et al.*, 2014; Wan *et al.*, 2016).

In recent years, the studies regarding physiological and biochemical impact of Cd accumulation on tomato have been well conducted (Hédiji *et al.*, 2010). However, there has been limited research on chemical forms of Cd in tomato fruits. Therefore, in the present study, based on the initial period water culturing and sorting, the tomato variety 4641 (V4641) with plant high Cd-enriched variety and Yu powder 109 (YP109) with plant low Cd-enriched variety were selected for the pot cultivation in soil with mimic Cd pollution environments to explore the interaction between Se and Cd and the effect of Se on biomass, Cd tolerance and its accumulation and chemical forms of Cd in different tomato varieties. The work will provide a theoretical basis for rational arrangement of Cd-contaminated vegetable soil.

Materials and Methods

Plant Materials and Soil Properties

Two tomato (*Solanum lycopersicum* Mill.) varieties of plant high Cd-enriched variety (V4641) and plant low Cd-enriched variety (YP109) were selected as samples. The tested soil samples were collected from Baishiyi vegetable base in Jiulongpo District, Chongqing. The contents of organic matter and total nitrogen in soil were 36.54 and 2.618 $g\cdot kg^{-1}$ and the contents of alkali-degradable nitrogen, available K, available P, Cd and Se in soil were 104.0, 101.3, 13.1, <0.005 and 0.017 $mg\cdot kg^{-1}$, while cation exchange capacity (CEC) and pH of soil were 0.192 $mol\cdot kg^{-1}$ and 6.03, respectively.

Pot Culture Experiment

The experiment was conducted from February 27, 2013 to May 30, 2013 in greenhouse of School of Resources and Environment at Southwest University. The experiment was conducted at three Se concentrations including 0, 0.5 and 1.0 $mg\cdot L^{-1}$ (Na_2SeO_3). The concentration of Cd in Cd-contaminated soil was 20 $mg\cdot kg^{-1}$ ($CdCl_2\cdot 2.5H_2O$). Totally 5 kg air-dry soil was passed through a 40 mesh screen and then treated with $CdCl_2\cdot 2.5H_2O$ at the concentration of 20 $mg\cdot kg^{-1}$. The Cd-treated soil after mixing was put into plastic pots with the diameter of 30 cm and height of 18 cm and kept balance for 2–3 weeks. One tomato seedling was implanted in each plot. During the flowering period of tomato plants, the foliar spray of Na_2SeO_3 nutrition solution on tomato plants was conducted with the individual spray volume of 100 $mL\cdot pot^{-1}$ and the spray interval of 5 days for total seven sprays. The control group was conducted the foliar spray with identical volume of water. The basic fertilizer included P ($NH_4H_2PO_4$), K (KCl) and N ($NH_4H_2PO_4$ and urea) with the amount of 100, 150 and 180 $mg\cdot kg^{-1}$, respectively. The moisture in soil was measured using soil moisture Tachometer (TZS-1K, Zhejiang Tuopu, China) before watering. The average moisture in soil was calculated through 3 times watering to evaluate the amount of water that needs to be filled, which can maintain the maximum water-holding amount of soil up to 60%. The experiment was performed in triplicate, and was randomized complete block arrangement. The first tomato fruit was recorded as the production and harvested all on May 30, 2013. The plants were also harvested and dried to constant weight at 105°C.

Soil and Plant Determinations

The basic physical and chemical properties of soil samples were determined by Sparks *et al.* (1996) method. The content of Cd in soil was determined using atomic absorption spectrophotometer (Perkin Elmer SIMMA 6000, Norwalk, USA) after HCl-HNO_3-$HClO_4$ digestion. The contents of Cd in different parts from plants were determined using atomic absorption spectrophotometer (Perkin Elmer SIMMA 6000, Norwalk, USA) after HCl-HNO_3-$HClO_4$ digestion. The detection limit of Cd was 0.005 $mg\cdot kg^{-1}$. The content of Se in soil was determined by atomic fluorescence spectrometer (PF6.3 Beijing Purkinje General Instrument Co., Ltd.) after HNO_3-H_2SO_4 digestion.

The cadmium fractionation in tomato fruits was done as determined by Wu *et al.* (2015) and Wang *et al.* (2008) methods, and the contents of Cd in each form were determined by atomic absorption spectrophotometer (Perkin Elmer SIMMA 6000, Norwalk, USA). The detection limit of Cd was 0.005 $mg\cdot kg^{-1}$. For quality assurance, the National Institute of Standards and Technology reference plant materials (GBW # 08513) and soils (GBW # 08303) were used to check the efficiency of the digestion/extraction procedures and FAAS measurements. For all samples, the recovery of Cd in plant and soil samples was >95% and analytical precision was <10% relative standard deviation.

Tissue samples of shoot and root in two tomato varieties were homogenized in ice-cold deoxygenated 20 $mmol\cdot L^{-1}$ Tris-HCl buffer (pH 7.4, 1:9, W/V) and centrifuged at 3000 ×g for 10 min. Aliquots of 100 μL were used for enzyme activity measurement. The activity of catalase (CAT) was measured using a microtiter plate assay (Grant *et al.*, 2008). The activity of peroxidase (POD) was determined by monitoring the increase in absorbance at 470 nm during the oxidation of guaiacol (Hemeda and Klein, 1990). The activity of superoxide dismutase (SOD) was determined by the method of Minami and Yoshikawa (1979) with 50 $mmol\cdot L^{-1}$ Tris-Ca-codylic sodium salt buffer (pH 8.2) containing 0.1 mmol L^{-1} EDTA.

Table 1: Analysis of variance (ANOVA) for the dry weight of tomato with different Se concentrations

SOV†	df	Leaf	Stem	Root	Fruit	Plant
Se (Se)	2	53.43**	47.85**	21.31*	310.08**	520.98**
Varieties (V)	1	43.48*	351.18**	24.90*	383.52**	344.20**
Se × V	2	24.29*	65.66**	10.95	24.86*	180.31**

Table 2: Analysis of variance (ANOVA) for the chemical forms of Cd in fruits of tomato varieties with different Se concentrations

SOV†	df	F_W	F_E	F_{HAc}	F_{NaCl}	F_{HCl}	F_R
Se (Se)	2	0.895	418.03**	103.06**	49.51**	45.70**	30.49**
Var (V)	1	113.92**	26.63*	6.82*	19.13*	160.89**	98.55**
Se × V	2	60.55**	233.66**	7.85*	1.68	45.26**	45.18**

Table 3: Analysis of variance (ANOVA) for the concentration of Cd in tomato varieties with different Se concentrations

SOV†	df	Leaf	Stem	Root	Fruit
Se (Se)	2	91.25**	28.85**	70.40**	30.65**
Varieties (V)	1	42.81**	22.58*	86.59**	35.61**
Se × V	2	15.26*	1.36	0.64	3.09

Table 4: Analysis of variance (ANOVA) for Cd accumulation in both varieties with different Se concentrations

SOV†	df	Leaf	Stem	Root	Fruit	Plant
Se (Se)	2	4.16	12.29**	7.71*	9.08*	27.95*
Varieties (V)	1	47.68**	41.62**	61.11**	104.00**	0.04
Se × V	2	0.07	5.30*	1.42	4.65	7.83*

†Source of variation

*stands for significance at $P \leq 0.05$; **stands for significance at $P \leq 0.01$

Statistical Analysis

The statistical analysis was performed using SPSS21.0 statistical software. The effects of interaction between Cd and Se on dry weight of plant, accumulation and chemical forms of Cd for different tomato varieties was subjected to a two-way analysis of variance (ANOVA; i.e., varieties and Se treatments) followed by the least significant difference test ($P \leq 0.05$).

Results

Biomass

Dry weight of roots, leaves, stems and fruits of tomato differed significantly among varieties and Se concentration, and the effects of interaction of different Se concentration and variety on biomass were also significant, except the dry weight of roots (Table 1). When exposed to polluted soil of Cd (20 mg·kg^{-1}), Se (≤1.0 mg·L^{-1}) could result in the increase of dry weights of roots, fruits and leaves (except the dry weight of stems in YP109) from both tomato varieties by 1.7–48.8%, 13.1–37.5% and 5.4–47.2% as compared to the control, respectively (Fig. 1). Meanwhile, Se treatment at concentrations of 0.5 and 1.0 mg·L^{-1} could improve the dry weights of stems from V4641 by 18.1 and 19.0% as compared to the control, respectively. The dry weights of roots and stems from V4641 revealed an increase as the increase of Se concentration; however, the dry weights of leaves and fruits from both tomato varieties exhibited an initial increase with increasing Se concentrations and reached the maximum when Se concentration was 0.5 mg·L^{-1} and then decreased. Among same Se treatments, the dry weights of fruits in V4641 were always higher than those in YP109.

Antioxidant Enzyme Activity in Leaves and Roots

When exposed to the contamination of Cd (20 mg·kg^{-1}), as an increase of Na_2SeO_3 concentration, CAT activity in roots and leaves of both tomato varieties showed different change trends (Fig. 2). CAT activity in leaves and roots of V4641 revealed a reduction with an increase in Se concentration; in contrast, CAT activity in leaves and roots of YP109 revealed an initial decrease as the increase of Se concentration, and reached the minimum at the Se concentration of 0.5 mg·L^{-1} and then increased. Under the condition with same concentration of Se, CAT activity in leaves was higher than that in roots; CAT activity in leaves and roots of V4641 was slightly higher than that in YP109 (except the CAT activity in leaves at the Se concentration of 0.5 mg·L^{-1}). In addition, SOD activity in roots and leaves of both tomato varieties revealed an increase as the increase of Se concentration. Among same Se treatments, SOD activity in roots was higher than that in leaves (Fig. 2); SOD activity in leaves and roots of V4641 was slightly lower than that in YP109 (except the SOD activity in leaves at the Se concentration of 0 mg·L^{-1}). Moreover, POD activity in roots and leaves of YP109 and leaves in V4641 exhibited a changing trend with initial decrease as the increase of Se concentration, and reached the minimum at the Se concentration of 0.5 mg·L^{-1} and then increased. The activity of POD in roots of V4641 indicated as a reduction with the increasing Se concentration (Fig. 2). Among same Se treatments, POD activity in leaves of YP109 was higher than that in roots; POD activity in leaves and roots of V4641 was slightly higher than that in YP109 (except the POD activity in roots at the Se concentration of 1.0 mg·L^{-1}).

Chemical Forms and Concentrations of Cd in Tomato Fruits

Significant difference of the concentrations of different chemical forms of Cd and total extractable Cd in tomato fruits were observed between two tomato varieties and among different Na_2SeO_3 treatments when exposed to Cd contamination of 20 mg·kg^{-1} Cd (Fig. 3; Table 2). Moreover, significant interaction of Se concentration with variety was found in the concentrations of different

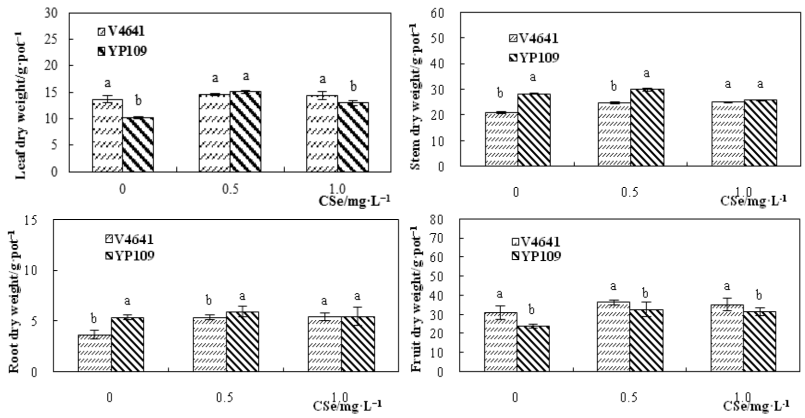

Fig. 1: Effect of Se concentration on the growth of tomato[Ψ]
[Ψ]Different letters (a, b, c) indicate significant difference at $P \leq 0.05$ among different Se concentrations

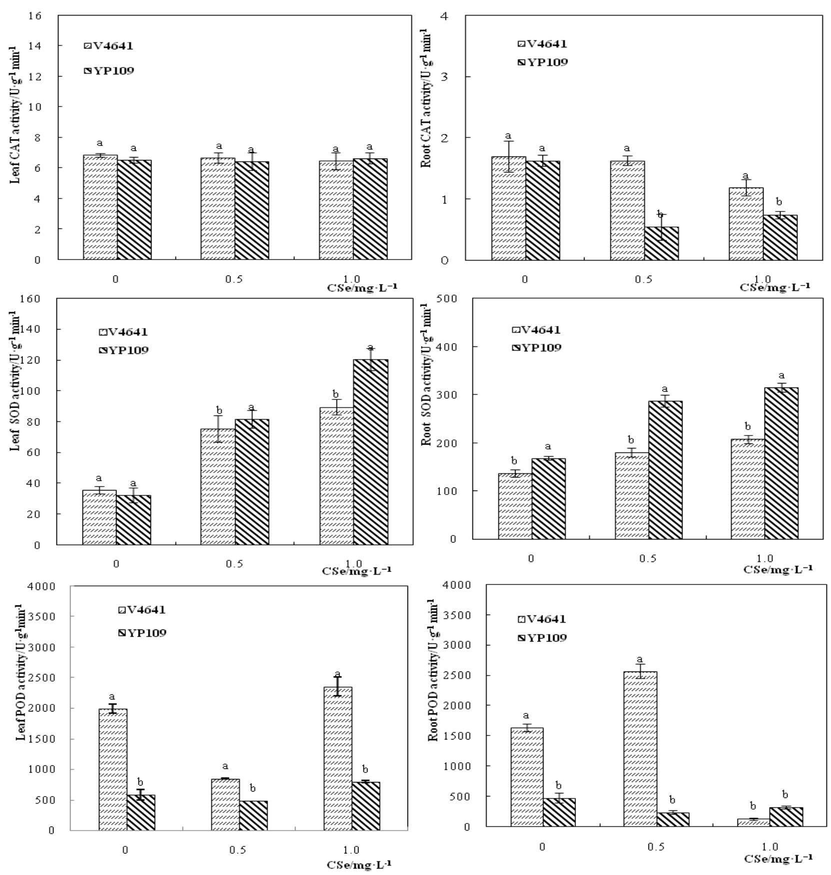

Fig. 2: Influence of Se concentration on CAT, SOD and POD activities of leaf and root in varieties of tomato[Ψ]
[Ψ]Different letters (a, b, c) indicate significant difference at $P \leq 0.05$ among different Se concentrations

chemical forms of Cd in fruits (except the forms of F_{NaCl}). In fruits, the average concentrations of various chemical forms of Cd in both varieties at different Se treatments revealed an order as sodium chloride extractable form (F_{NaCl}) > ethanol extractable Cd (F_E) > residual Cd (F_R) > acetic acid extractable Cd (F_{HAC}) > HCl extractable Cd (F_{HCl}) > water extractable Cd (F_W). The average concentrations of F_{NaCl} in fruits of both tomato varieties at different Se treatments were 2.288 and 2.112 mg·kg^{-1}, which accounted for 42.5 and 42.3% of total extractable Cd, respectively. The average concentrations of F_{HAC} and F_R in fruits of both tomato varieties were 0.563 and 0.634 mg·kg^{-1}, which accounted for 10.9 and 12.2% of total extractable Cd, respectively. F_{NaCl}, F_R and F_{HAC} in soil were low activity, and the average

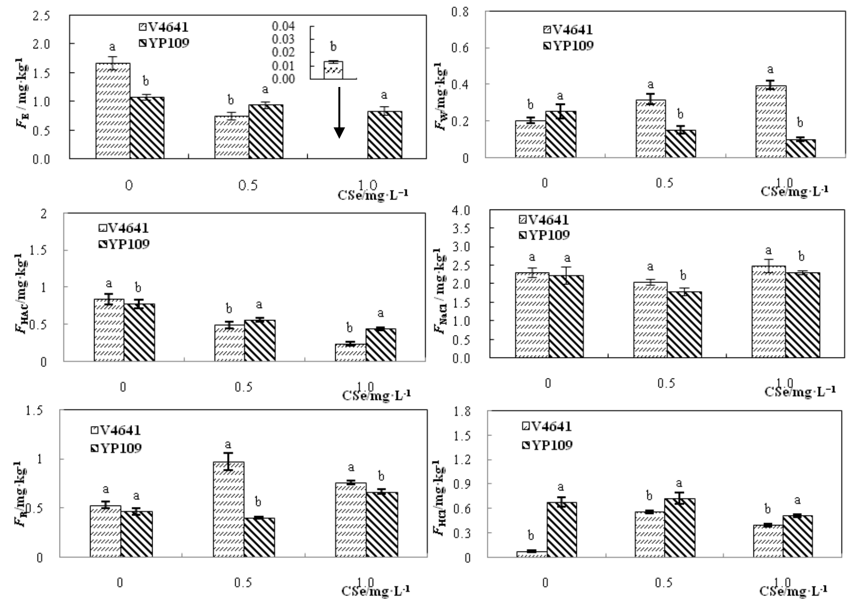

Fig. 3: Effect of Se concentration on chemical forms of Cd in fruits of tomato varieties$^{\psi}$

$^{\psi}F_W$, F_E, F_{HAc}, F_{NaCl}, F_{HCl} and F_R represent water extractable Cd, ethanol extractable Cd, acetic acid extractable Cd, NaCl extractable Cd, HCl extractable Cd and residual Cd. Different letters (a, b, c) indicate significant difference at $P \leq 0.05$ among different Se concentrations

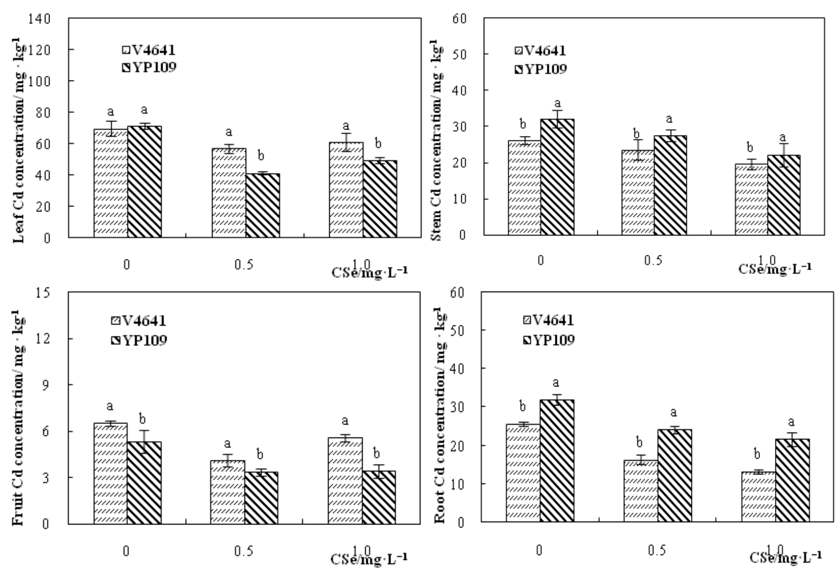

Fig. 4: Effect of Se concentration on concentration of Cd in tomato varieties$^{\psi}$

$^{\psi}$Different letters (a, b, c) indicate significant difference at $P \leq 0.05$ among different Se concentrations

concentration of these three Cd forms was 3.396 mg·kg^{-1}, accounting for 65.5% of total extractable Cd. The average concentrations of F_W and F_E with high activity were 1.058 and 0.240 mg·kg^{-1}, accounting for 20.4 and 4.6% of total extractable Cd, respectively. The average concentration of F_W and F_E was 1.278 mg·kg^{-1}, accounting for 25.0% of total extractable Cd.

In both varieties, the concentrations of F_E and F_{HAC} in fruits decreased by 12.96–99.22% and 28.13–70.67% with the increase of Se concentration as compared to control respectively; but the concentrations of F_{NaCl} and F_R increased by 2.91–7.69% and 42.21–42.52%, respectively. The concentrations of F_W and F_{HCl} in fruits of 4641 variety increased by 55.34–93.20% and 422.08–628.57% as compared to the control, respectively; while the concentration of F_w in fruits of YP109 variety decreased by 40.00–59.22%, and the concentration of F_{HCl} decreased by 24.63% at the Se concentration of 1.0 mg·L^{-1} compared

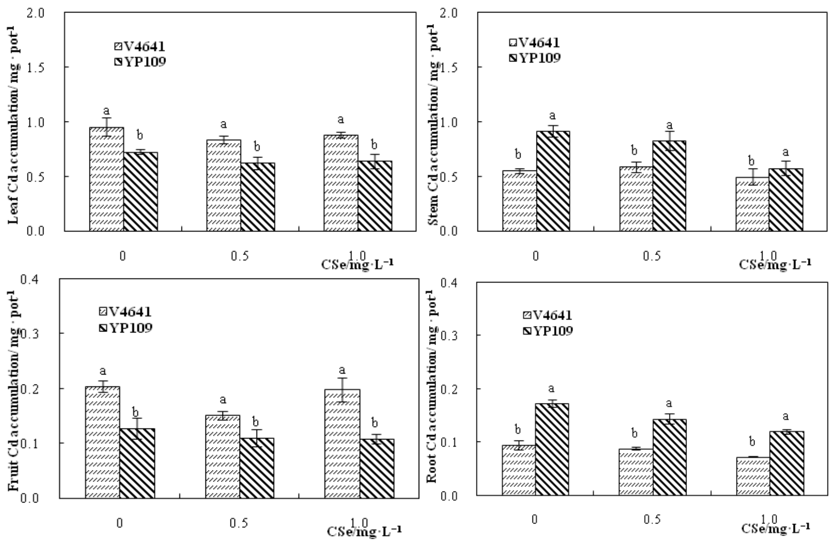

Fig. 5: Effect of Se concentration on Cd accumulation in tomato varieties[ψ]
[ψ]Different letters (a, b, c) indicate significant difference at $P \leq 0.05$ among different Se concentrations

with the control. Se reduced the amount of total extractable Cd by 5.33–8.76% (V4641 variety) and 11.45–16.63% (YP109 variety) as compared to the control, respectively.

As the increase of Se concentration, the concentrations of total extractable Cd in fruits of both tomato varieties decreased at first, reached the minimum with the average reductions by 8.76 and 16.63% compared with the control at Se concentration of 0.5 mg·L^{-1}, respectively and then increased in fruits, the concentration of total extractable Cd of V4641 variety was higher than that in YP109 variety in the presence and absence of Se.

Cd Accumulation in Tomato

The concentrations of Cd in leaves, stems, roots and fruits differed significantly among varieties and Se concentration and the effects of interaction of different Se concentration and variety on the concentrations of Cd in leaves were also significant (Fig. 4; Table 3). The concentration of Cd revealed an order in leaves (58.255 mg kg^{-1}) > stems (25.160 mg·kg^{-1}) > roots (22.130 mg·kg^{-1}) > fruits (4.710 mg·kg^{-1}). In both varieties, the concentration of Cd in leaves, stems, roots and fruits in the Se treatments decreased by 7.3–41.9%, 9.8–30.9%, 24.5–48.5% and 14.4–37.1% as compared to the control, respectively, while as increasing Se concentration, different change trends of Cd concentration in leaves, stems, roots and fruits were also observed. For example, the concentration of Cd in stems and roots of both tomato varieties revealed a decreasing trend as increasing Se concentration; in contrast, the concentration of Cd in leaves and fruits of both tomato varieties decreased at first with the increase of Se concentration, reached the minimum at the Se concentration of 0.5 mg·L^{-1}, and then increased.

Cadmium accumulation in leaves, stems, roots and fruits was calculated by multiplying biomass (g·plant^{-1}) with the respective concentrations of Cd in leaves, stems, roots and fruits for each varieties (per plant basis). The total of Cd accumulation in plant was calculated by summing Cd accumulation in leave, stem, root and fruit tissues for each variety (per plant basis). Significant differences of Se concentration with variety were observed in Cd accumulation in stems and fruits were found between two tomato varieties and among different Na_2SeO_3 treatments when exposed to Cd contamination (Fig. 5; Table 4). The significant interactions of Se concentration with variety were also observed in stems and the total of Cd accumulation in plant. In both varieties, stems and leaves were the dominated tissues of Cd accumulation, with values accounting for 38.8 and 45.6% of the total of Cd accumulation in plant, while Cd accumulation in fruits and roots of tomato varieties was accounting for 8.8 and 6.8% of total accumulation of Cd in plants, respectively. Exogenous Se reduced Cd accumulation in leaves, roots, fruits and the total of Cd accumulation in plant by 8.0–25.6%, 7.7–14.5%, 6.4–30.6% and 2.9–26.0% as compared to the control, respectively. Moreover, Cd accumulation in stems of YP109 variety also reduced by 9.6–37.0% at the Se treatments, but it increased in stems of V4641 variety at the Se concentration of 0.5 mg·L^{-1}. The total of Cd accumulation in plant and root Cd accumulation in roots of both tomato varieties, and Cd accumulation in stems and fruits of YP109 variety significantly decreased with increasing of Se concentrations, while Cd accumulation in leaves of both tomato varieties and Cd accumulation in fruits of V4641 variety decreased at first and then increased At the same Se treatment, the total of Cd accumulation in fruits of V4641 variety were higher than those in YP109 variety.

Discussion

The studies from Ding *et al*. (2014) and Wu *et al*. (2017) have shown that the exogenous Se can reduce Cd toxicity on plants, and increase plant biomass under Cd stress. In the present study, in 20 mg·kg^{-1} Cd contaminated soil, foliar spray of Na_2SeO_3 (≤1.0 mg·L^{-1}) significantly increased the dry weights of roots, fruits and leaves of two tomato varieties, and also increased the dry weight of stems in V4641 variety (Fig. 1), as also reported by Ding *et al*. (2014) and Wu *et al*. (2017). It may be due to the reason that Se is beneficial to plant growth and development, involved in protein synthesis and other cellular activities promote the absorption of P, K, Ca, Mg, Zn and other elements, and increased the chlorophyll content of leaves, enhanced photosynthesis, and strengthening plant resistance to Cd pollution (Hawrylak-Nowak *et al*., 2014; Nawaz *et al*., 2015).

In both tomato varieties, the dry weight of fruits in V4641 variety was higher than that of YP109 with or without Se treatment. It suggests that V4641 variety has stronger tolerance to Cd and higher sensitivity to Na_2SeO_3 as compared to YP109 variety.

It is well documented that Cd caused cell damage by free radicals and peroxidation, due to the induction of producing large amounts of oxygen free radicals and lipid peroxidation in plants (Khan *et al*., 2015). Se has been reported to plays an important role in removing excessive free radical in plants and preventing lipid peroxidation caused by Cd (Wang *et al*., 2014). In the both tomato varieties, foliar spray Se significantly increased SOD activity, which is consistent with the increased tomato biomass as increasing Se concentration (Fig. 2). The results of the present study indicate that Se-induced SOD activity is benefit for the elimination of reactive oxygen species under Cd stress, and reduced the toxicity of Cd, and are in agreement with the results by Wang *et al.* (2014), Saidi *et al*. (2014) and Wu *et al.* (2017). Conversely, in both tomato varieties, the spraying of Se reduced CAT and POD activities. The results suggest that activities of three major antioxidant enzymes (CAT, SOD and POD) maintain a certain balance in order to eliminate free radicals and reduce Cd toxicity on plant. In our study, at same Se treatments, the activities of CAT and POD in leaves and roots of V4641 variety are slightly higher than those of YP109 variety, which is consistent with the results that fruit dry weight of V4641 variety is higher than that of YP109 variety.

Chemical forms of heavy metals in plants can be divided into active state (including water-soluble state, ion exchange state) and inactive state (including sodium chloride state, hydrochloride state, acetate state and residue state). F_{NaCl} has been reported to be the dominated chemical form of Cd may be due to Cd has strong affinity with proteins or sulfhydryl in organic compounds, and Cd is often combined with protein in plants (Sun *et al*., 2016). In the present study, the concentration of F_{NaCl} in fruits accounting for 42.4% of total extractable Cd, which is dominated form of Cd in tomato fruits and are in agreement with the results by Xin *et al*. (2014). The sum of F_{NaCl}, F_R and F_{HAC} with low activity, were 3.396 mg·kg^{-1}, accounting for 65.5% of total extractable Cd. The sum of F_W and F_E with higher activity were 1.278 mg·kg^{-1}, accounting for 25.0% of total extractable Cd. These results suggested that the characteristics of Cd chemical forms in plants are beneficial to reduce the toxicity of Cd on plants (Wei and Zhou, 2006). The foliar spray of Se reduced the concentrations of various chemical forms of Cd and total amount extractable of Cd and suggested that Se and Cd have obvious antagonism maybe due to Se can induce the synthesis of metal lothionein to chelate Cd before entering tomato fruits (Filek *et al*., 2008). In the present study, the concentration of F_{NaCl} in tomato fruits decreased at high Se concentration (1.0 mg·L^{-1}), and is in agreement with the results by Škopíková *et al.* (2008). This demonstrates that synergism and antagonism of Cd and Se can be observed in plants, which maybe depend on exogenous Se level.

In this study, the concentrations of Cd in leaves and stems were significantly higher than those in roots and fruits (Fig. 4). These results differ from those presented by Xin *et al*. (2014) who reported high concentrations of roots than that in other tissues, however different species and different Se levels. The Cd concentrations in fruits was 3.34–5.57 mg·kg^{-1}, which is far exceeding the limit of Cd in vegetables (≤0.05 mg·kg^{-1}) (GB 2762-2005). Our results confirm that tomato fruits have strong enriched-Cd capacity in both varieties, total extractable amount of Cd, the concentration of Cd and total accumulation amount of Cd in fruits of V4641 variety are higher than those in fruits of YP109 variety in the presence and absence of Se, and suggest that fruits of YP109 variety are relatively safer for human body than those of V4641 variety in Cd-contaminated soil.

Conclusion

When exposed to Cd pollution (20 mg·kg^{-1}), the foliar spray of Se (≤1.0 mg·L^{-1}) can increase the dry weights of roots, fruits, leaves of two tomato varieties. Foliar spray of Se significantly increase SOD activity in two tomato varieties, and reduce CAT and POD activities in two tomato varieties. Se can reduce the total extractable of Cd and the concentrations of various forms of Cd in fruits of two tomato varieties. Se can reduce Cd accumulation in leaves, stems and fruits of both varieties. The activities of CAT and POD in V4641 variety are slightly higher than those in YP109 variety. Fruit dry weight and the total extractable of Cd and Cd accumulation in fruits of V4641 are also greater than those of YP109 variety at the same Se treatment.

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