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BRIEF COMMUNICATION

Selenium improves photosynthesis and protects photosystem II in pear (*Pyrus bretschneideri*), grape (*Vitis vinifera*), and peach (*Prunus persica*)

T. FENG, S. S. CHEN, D.Q. GAO, G.Q. LIU, H.X. BAI, A. LI, L.X. PENG, and Z.Y. REN

College of Horticulture and Landscape, Tianjin Agricultural University, Xiqing 300384, Tianjin, China

Abstract

The effects of selenium on photosynthesis and Chl fluorescence in pear, grape, and peach were analyzed. The foliar spray of amino acid-chelated selenium solution was performed soon after fruit setting, totally six times, with an interval of ten days. After seven days from the last spray, the leaves in the middle of shoots were examined. Foliar spray of selenium increased the net photosynthetic rate in pear, grape, and peach. In contrast, the treatment decreased stomatal conductance, transpiration rate, and substomatal CO_2 concentration in all the three species. The selenium treatment improved the maximum quantum yield of PSII, effective quantum yield of PSII, and photochemical quenching in all three species. Conversely, the selenium treatment reduced nonphotochemical quenching in all three species. We suggested that selenium can improve photosynthesis and protect PSII in fruit crops.

Additional key words: foliar feeding; fruit tree; gas exchange; intercellular CO_2 concentration.

Photosynthesis is the most fundamental biological process in plants. It is critical for economical crops, because it determines potential production which crops could gain. Pear (*Pyrus bretschneideri*), grape (*Vitis vinifera*), and peach (*Prunus persica*) are important fruit crops throughout the world. Growers had developed several methods to improve production in fruit crops, such as pruning, irrigation, fertilization, *etc*. Foliar spray with nutrients is a new practice for high production in fruit trees. Researchers have found that foliar spray with nutrients can improve photosynthesis. It was reported that foliar spray with $Ca(NO_3)_2$, $MnSO_4$, or K_2HPO_4 increased photosynthesis, dry matter accumulation, and grain yield in seawater-stressed rice, respectively (Sultana *et al*. 2001).

Selenium is an essential element for human being and animals and it also shows positive effects in plants. Although most plants are sensitive to selenium when growing on seleniferous soils, they can benefit from a low concentration of selenium. Selenium can improve the activities of antioxidant enzymes, such as glutathione peroxidase, catalase, ascorbate peroxidase, superoxide dismutase, and peroxidase, which provide protection from environmental stress in crops (Xue *et al*. 2001, Kong *et al*. 2005, Chen *et al*. 2008, Vítová *et al*. 2011, Feng and Wei 2012). Exogenous selenium can promote growth and increase contents of photosynthetic pigments in sorrel (*Rumex patientia* × *R. tianshanicus*) and in lettuce (*Lactuca sativa*) (Xue *et al*. 2001, Kong *et al*. 2005). Such effects had been also found in sorghum (*Sorghum bicolor*) and barley (*Hordeum vulgare*) (Akbulut and Cakir 2010, Djanaguiraman *et al*. 2010). Selenium can protect photosystems when plants are subjected to environmental stresses, such as cadmium and UV-B radiation (Breznik *et al.* 2005, Filek *et al.* 2010). There is a large scale of

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+Corresponding author; e-mail: tkfg@163.com
Abbreviations: C_i – intercellular CO_2 concentration; E – transpiration rate; F_v/F_m – maximal quantum yield of PSII photochemistry; g_s – stomatal conductance; NPQ – nonphotochemical quenching; P_N – net photosynthetic rate; q_P – photochemical quenching coefficient; Φ_{PSII} – effective quantum yield of PSII photochemistry.
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selenium-deficient soils in a huge area of China. To our knowledge, little is known about the effect of selenium on fruit tree photosynthesis. Among various parameters related to photosynthesis in plants, the net photosynthetic rate (P_N) can reveal the actual efficiency of photosynthesis. The intercellular CO_2 concentration (C_i) reflects CO_2 supply, the transpiration rate (E) reflects the capability for regulating water supply and the potential adaptability to water stress, and the stomatal conductance (g_s) reflects stomatal opening extent. Among chlorophyll (Chl) *a* fluorescence parameters, the maximum quantum yield of PSII (F_v/F_m) indicates potential efficiency of PSII. The effective quantum yield of PSII (Φ_{PSII}) reflects actual efficiency of PSII, photochemical quenching (q_P) reflects the number of opened reaction centers, and nonphotochemical quenching (NPQ) reflects light energy depleted as heat. These Chl fluorescence parameters can be used to reflect the precise state of photosystems. The objective of the present work was to investigate the effect of selenium on photosynthesis and Chl fluorescence in pear, grape, and peach.

The research was carried out in 2012 and 2013. Three orchards were chosen as experimental sites in the Xiqing District, the Tianjin City, China. The soil is alluvial with the organic matter content of 4.5%, pH 7.2, and the total salt content of 0.06%; the selenium content was 0.21 μg g^{-1}. Selenium contents in soil and in leaves were measured using an atomic fluorescence spectrophotometer model *pf6-2* (*Beijing Purkinje General instrument Co., Ltd.*, China), at Animal Medical Experiment Teaching Center, Tianjin Agricultural University. The pear (*Pyrus bretschneideri*, cv. 'Huangguan'), grape (*Vitis vinifera*, cv. 'Kyoho'), and peach (*Prunus persica*, cv. 'Jinliuzaohong'), were used as plant materials. Except for grape cutting plants, we used grafted plants of pear and peach. The rootstock of pear and peach were *Pyrus betulifolia* and *Prunus persica*, respectively. The pear plants were six years old, the grape plants were five years old, and the peach plants were seven years old. Amino acid-chelated selenium solution for foliar spray was kindly gifted by Fruit Tree Research Institute, Chinese Academy of Agricultural Sciences. The experiment was performed according to a randomized block design, with six plants in one plot and three replications. Foliar spray of amino acid-chelated selenium solution was applied soon after fruit setting and after then, with the selenium concentration of 0.017 g L^{-1}. In total, foliar spray was done six times, with an interval of ten days. Seven days after the last spray, the functional leaves in the middle of shoots were used to examine the characteristics of photosynthesis. A *CIRAS-2* portable photosynthesis system (*PP Systems*, Amesbury, MA, USA), integrated with Chl fluorescence module was used to examine photosynthetic parameters (P_N, g_s, E, and C_i) and Chl fluorescence parameters (F_v/F_m, Φ_{PSII}, q_P, and NPQ) at 9:00–11:00 h in clear days. The related setup parameters were set according to the manual. The fixed light source was red light with intensity of 300 μmol(photon) m^{-2} s^{-1}. The ambient CO_2 concentration was set at 380 μmol mol^{-1}. To measure Chl fluorescence parameters, the leaf samples were wrapped up with tin foil and maintained for 30 min to proceed dark adaptation.

Statistical analysis of the data was performed using the software *SPSS 19.0* (*IBM Company*, USA). The data in figures are the means of the experiments carried out in 2012 and 2013. The significance between the treatments and the controls in each species were calculated with paired-sample *t*-test. After the selenium treatments, the pear, grape, and peach plants grew normally, and there was no obvious difference in morphology between the treated plants and the control ones. Seven days after the last spray, the functional leaves in the middle of shoot were used to measure selenium contents.

Species	Se [μg g^{-1}(FM)] Se-treated plants	control plants
pear	0.0041	0.0008
grape	0.0092	0.0017
peach	0.0038	0.0006

Foliar spray of amino acid-chelated selenium solution increased P_N in pear, grape, and peach. (Fig. 1*A*). In contrast, the treatment decreased g_s, E, and C_i in all three species (Fig. 1*B–D*). Foliar spray of amino acid-chelated selenium solution improved the F_v/F_m ratio, Φ_{PSII}, and q_P in all three species (Fig. 2*A–C*). Conversely, the selenium treatment reduced NPQ in all species (Fig. 2*D*).

Many studies reported that selenium can improve photosynthesis in plants. Germ *et al*. (2007) reported that the Se foliar spray treatment induced higher respiratory potential and higher efficiency of energy conversion of PSII in potato (*Solanum tuberosum* L.) leaves. Selenium solution spray mitigated the decrease of Φ_{PSII} caused by UV-B radiation and mitigated a stunting effect of UV-B radiation in buckwheat (*Fagopyrum esculentum* Moench). Selenium led to increase in photosynthesis and light-enhanced dark respiration after UV-treatment in the flagellate (*Euglena gracilis*). Therefore, it was suggested that selenium might play a role in repair mechanisms in *E. gracilis* after UV treatments (Ekelund and Danilov 2001). Selenium also mitigated the decrease in activities of both photosystems induced by cadmium. Traces of selenium enhanced metabolic processes related to photochemical quantum yield and mitochondrial respiration (Germ *et al.* 2009). The application of selenium enhanced photosynthesis by increasing P_N, C_i, and the transpiration efficiency in rice (*Oryza sativa* L.). Selenium treatment enhanced the activity of PSII by increasing F_v, F_m, F_v/F_m, and F_v/F_0 and decreasing F_0 (Zhang *et al.* 2014). The Se-treated tartary buckwheat (*Fagopyrum tataricum*) plants showed higher electron transport system activity compared to controls. Furthermore, the potential photochemical efficiency of PSII was higher in Se-treated progeny plants than that in controls (Kreft *et al.* 2013).

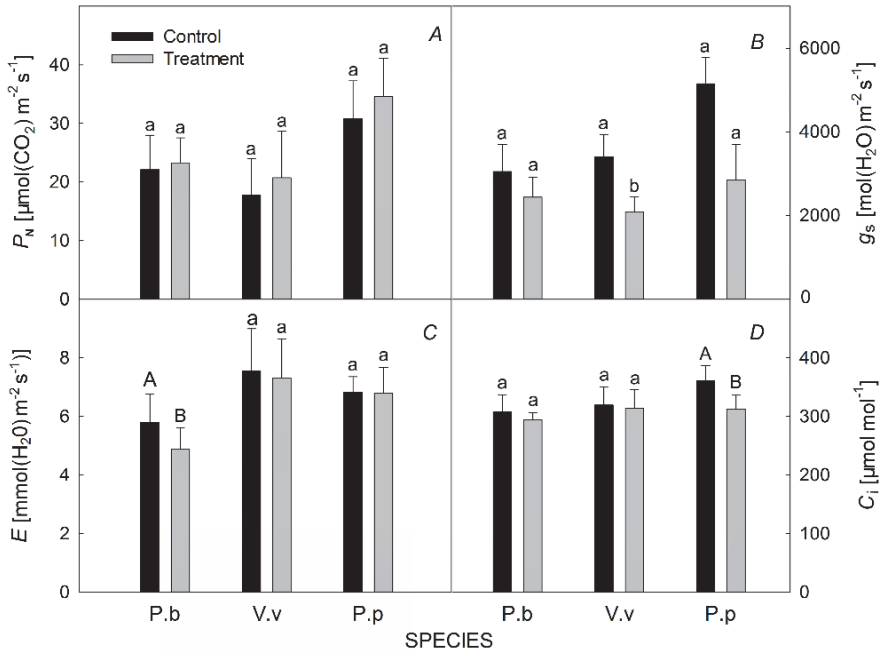

Fig. 1. Effects of foliar spray of amino acid-chelated Se solution on photosynthesis in pear (P.b), grape (V.v), and peach (P.p). Parameters: the net photosynthetic rate (P_N) (*A*), the stomatal conductance (g_s) (*B*), the transpiration rate (*E*) (*C*), and the substomatal CO_2 concentration (C_i) (*D*). Different *lowercase letters* indicate significant differences resulted from *Tukey*'s test (P=0.05) and the *capital* ones indicate extremely significant differences done by the same method (P=0.01). Data are means of three replicates ± SE.

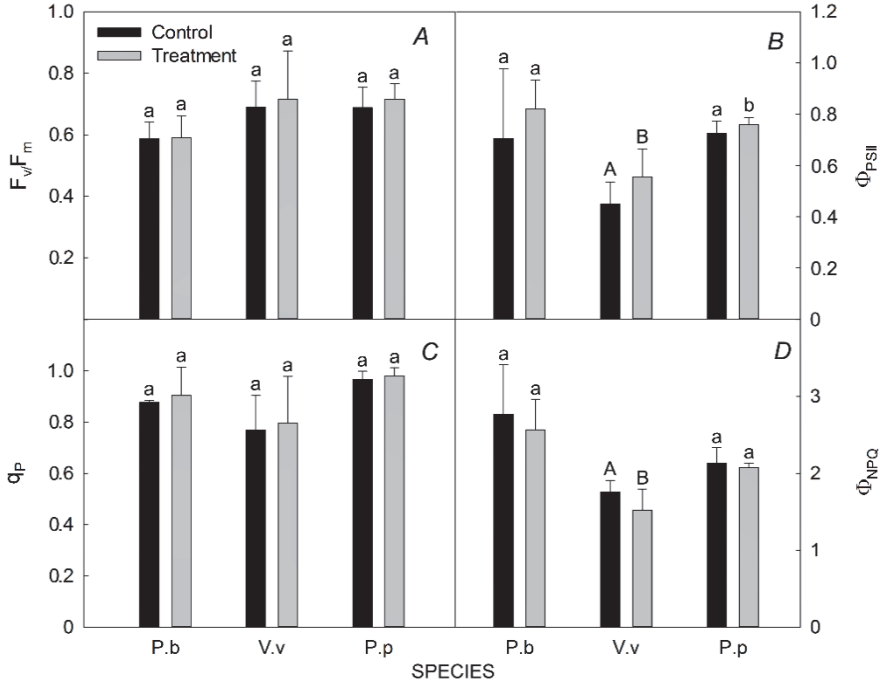

Fig. 2. Effects of foliar spray of amino acid-chelated Se solution on Chl fluorescence in pear (P.b), grape (V.v), and peach (P.p). Parameters: the maximum quantum yield of PSII (F_v/F_m) (*A*), the effective quantum yield of PSII (Φ_{PSII}) (*B*), the photochemical quenching (q_P) (*C*), and the nonphotochemical quenching (NPQ) (*D*). Different *lowercase letters* indicate significant differences resulted from *Tukey*'s test (P=0.05) and the *capital* ones indicate extremely significant differences done by the same method (P=0.01). Data are means of three replicates ± SE.

Similarly, we found that foliar spray of amino acid-chelated selenium improved P_N and Φ_{PSII} in pear, grape, and peach.

Particular protein involved in Hg-Se antagonism had been identified in water hyacinth (*Eichhornia crassipes*) (Pacheco *et al.* 2014). Recently, researchers found that ferredoxin-NADP(+) oxidoreductase in combination with selenium could play an important role in photosynthesis (Szczepaniak *et al.* 2013). Selenium enhanced starch accumulation in alfalfa (*Medicago sativa* L.) leaves and increased fructose-1,6-bisphosphatase activity in the upper leaflets (Owusu-Sekyere *et al.* 2013). We propose that selenium enhances carbohydrate metabolism, which results in promotion effects on photosynthesis in plants. Selenium influenced the expression of genes related to photosynthesis. Selenite transiently repressed genes coding for components of photosynthetic systems and other light-regulated genes in potato leaves (Poggi *et al.* 2008). Proteomic analysis revealed that primary metabolism, photosynthesis, and redox homeostasis were strongly affected by selenium treatments in rice (*Oryza sativa* L.). Low concentration of selenium activated antioxidative system, enhanced photosynthesis, and primary metabolism. However, the higher concentrations damaged photosynthetic apparatus, inhibited photosynthesis, and primary

metabolism (Wang *et al.* 2012). Selenium responsive genes and selenium-binding protein genes were also studied (Hugouvieux *et al.* 2009, Hung *et al.* 2012).

In the present study, we observed that foliar spray of amino acid-chelated selenium solution promoted the net photosynthetic rates in pear, grape, and peach, respectively. The selenium treatments improved the maximum quantum yield of PSII, effective quantum yield of PSII, and photochemical quenching in all the three species. It was suggested that selenium improve photosynthesis and protect PSII by means of enhancing carbohydrate metabolism in fruit crops.

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