Physiological Function of Selenium in Plants

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Abstract The global understanding of selenium (Se) in plant biology mainly comes from the fields of medicine and animal science, while the research on Se in plant biology in the field of plant science lags behind. This paper summarized the physiological functions of Se in plants. These studies indicate that Se can promote plant seed development and growth and plant photosynthesis, increase plant economic yield and quality, and enhance plant antioxidant capacity and resistance to stress. However, its effects have a "dual" character, and its concentration or dosage range is very narrow. At appropriate concentrations, Se has an important impact on the physiological processes of plants and is a beneficial element for many plants to maintain health and good growth and development.

Key words Plant; Selenium; Selenocysteine; Selenoprotein; Selenium biofortification

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The research on selenium (Se) in plant biology in the field of plant science obviously lags behind the research and application of Se in zoology and medicine. Although there is no conclusive evidence that plants are necessary or dependent on Se, many studies and practices have shown that Se has an important influence on the physiological process of plants at a proper concentration and is a beneficial element for many plants to maintain health and good growth and development[1-2]. At present, the worldwide understanding of Se in plant biology mainly comes from the fields of medicine and animal science, but some progress has been made. These studies show that Se can promote plant seed development and plant growth and plant photosynthesis, improve plant economic yield and quality, and enhance plant antioxidant capacity and resistance to adversity stress, but its effects have a "dual" character and its concentration or dosage range is very narrow. This paper summarized the effects of Se on plant physiological functions, providing reference for its research in plant biology.

Se and Plant Growth and Development

Seed germination of *Metasequoia glyptostroboides* was induced by soaking seeds with selenite or selenite solutions at low concentrations (0 – 0.25 mg/L) or applying Se fertilizer as base fertilizer during sowing[3]. Se plays a more significant role in promoting seed germination and seedling growth and development of soybean, green vegetables, eggplant, pepper, tomato and other vegetable plants. The optimal concentration of Se in the solution (Na_2SeO_3) under hydroponic conditions was obviously higher, at 10.0 mg/L[4]. Soaking the seeds of 'Jimai 12' with 0.1 – 0.5 mg/L sodium selenite solution not only improved the seed germination potential, germination rate, germination index and seed vigor index, but also promoted the growth and development of roots, buds and seedlings and increased the grain yield and Se content[5]. Spraying low concentrations of Se increased the thickness of grape leaves by 20.2% and the specific leaf weight by 18.1%, and the maturity of branches increased significantly. After spraying Se fertilizer on walnut trees and persimmon trees, the single leaf weight was increased, the length of spring shoots was increased, and fruit setting was promoted[6].

Se and Economic Yield of Plants

Adding Se fertilizer can promote the absorption of Se by buckwheat and improve the grain yield of buckwheat. Se is mainly distributed in the aleurone layer of grains. Proper application of Se to horticultural plants such as fruit trees, vegetables and edible fungi can increase the yield of these plants[7]. Chinese cabbage and spinach were cultivated in nutrient solutions containing different concentrations of Se, and the results showed that when the Se concentration in the solution was lower than 0.1 mg/L, the growth of Chinese cabbage and spinach was promoted and the plant yield was increased, while when the concentration was higher than 0.5 mg/L, the growth of Chinese cabbage and spinach was inhibited and the plant yield was reduced. When spraying different concentrations of Se on different types of vegetables, the yield of leafy vegetables increased by 8.6% – 11.6% with the Se concentration of 200 mg/kg; and when the concentration of Se sprayed was 250 mg/kg, the yield increase was 6.6% – 9.8%.

Se and Quality of Plant Products

Se application can improve the economic value and edible quality of plant products. Reasonable application of Se could increase Se content and improve the nutritional quality of broad beans, and the low concentration of Se treatment (3.1 mg/kg) was suitable for the development of Se-rich broad beans[8]. Applying

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Se fertilizer to potato in strips one day before planting could significantly increase tuber yield and total protein content, and reduce free amino acid content; when 0.05 mg/L Se was added to the hydroponic nutrient solution of lettuce, the contents of total sugar, reducing sugar and vitamin C in lettuce stems and leaves could be increased and the content of nitrite could be reduced; spraying Se fertilizer on leaves increased the content of total sugar, carotene and crude fiber in carrots; and Se treatment could significantly increase the single fruit weight of grapes, peaches, kiwifruit and other fruits and the soluble solid content and vitamin C content of fruits, improve the appearance quality of fruits, and enhance the consistency of fruit ripening[9].

Se and Growth and Development of Plant Seeds

Adding Se fertilizer can significantly inhibit embryo abortion and improve the quality of seed development. *Pterocarpus santalinus* is a precious redwood tree species, but its embryo is highly abortive[10]. The results of cultivation and testing in our project group showed that applying Se fertilizer, especially Se^{4+}, within one month after harvesting and two months before flowering, significantly reduced the embryo abortion rate, the empty pod rate of samaras and the unfulfilled grain percentage of seeds, significantly increased the single fruit weight, single plant yield and 100-seed weight of samaras, and significantly promoted germination, emergence and seedling growth after sowing, and the fertilizer efficiency could not be achieved by applying N, P, K, Ca, B and S alone, nor by applying N-P-K compound fertilizer alone to improve soil organic matter content. Meanwhile, when Se was combined with N-P-K compound fertilizer, especially EM microbial fertilizer or a combination of both, the aforementioned effects were further enhanced. Table 1 shows the differences in the growth status of seedlings after seed germination of *P. santalinus* with Se application.

Table 1 Differences of seedling growth after seed germination of *P. santalinus* with Se application

Fertilization treatment		Plant height//cm	Ground diameter//cm	Length of taproot//cm	Dry weight of roots//g	Dry weight of stems and leaves//g	Dry weight of whole plant//g
I	Control	14.5 ±1.0 d	0.39 ±0.02 cd	8.8 ±0.6 e	0.31 ±0.02 e	0.76 ±0.05 e	1.07 ±0.07 d
II	N-P-K compound fertilizer	17.5 ±0.5 c	0.43 ±0.03 abc	10.3 ±0.7 cd	0.35 ±0.04 def	0.98 ±0.07 d	1.34 ±0.08 c
III	Na_2SeO_4	18.2 ±0.7 b	0.43 ±0.02 abc	10.7 ±0.6 bc	0.38 ±0.04 cd	1.12 ±0.03 c	1.47 ±0.08 b
IV	Na_2SeO_3	18.6 ±0.6 b	0.43 ±0.04 abc	10.8 ±0.5 bc	0.41 ±0.04 bc	1.15 ±0.05 bc	1.56 ±0.02 b
V	N-P-K compound fertilizer + Na_2SeO_3	20.5 ±0.7 a	0.45 ±0.04 ab	11.5 ±0.6 ab	0.45 ±0.05 ab	1.21 ±0.06 ab	1.66 ±0.06 a

For all treatments, the grass was mowed for covering tree bases once a month. Control: No fertilizer application; N-P-K compound fertilizer: equivalent to fertilization at rates of 180 g N/plant, 180 g P_2O_5/plant and 180 g KCl/plant; Na_2SeO_4: equivalent to fertilization at a rate of 3.6 g Se/plant; Na_2SeO_3: equivalent to fertilization at a rate of 3.6 g Se/plant. In terms of fertilization, 60% of the total fertilizer was applied in early June, and the remaining 40% was applied in early November of that year. Seeds were harvested in early May of the following year and sown in early June. The seedling age was 6 months. Data format: mean ± standard deviation; and different lowercase letters following data in the same column indicate a significant difference ($P < 0.05$).

Se and Antioxidant Capacity of Plants

Moderate Se has a positive regulatory effect, while excessive Se may completely produce a strong negative feedback effect. There are three possible mechanisms by which moderate Se participates in plant antioxidant processes and regulates ROS levels. Firstly, Se-containing compounds mediate the dismutation reaction of $O^{2-}\cdot$ to H_2O_2. Secondly, Se-containing compounds directly react with ROS and participate in the clearance of $O^{2-}\cdot$ and hydroxyl radicals ($OH\cdot$). Thirdly, it is achieved by regulating the antioxidant enzyme system and its activities in plants. In particular, Se can control and clear ROS levels through direct or indirect regulatory effects on antioxidants, which may be a key mechanism for plants to resist environmental stress. Under adverse stress, increasing the application of low doses of Se can reduce the generation of excessive ROS, especially $O^{2-}\cdot$ and H_2O_2, thereby alleviating oxidative stress in plants[11].

Se and Plant Photosynthesis

Treatment with 20 μmol/L selenate on Se hyperaccumulator plants significantly increased their ETR, while under the same conditions, the ETR of non-hyperaccumulator plants significantly decreased. The application of Se (< 50 g/hm^2) in rice increased photosynthetic indicators such as Pn, Ci and ETR, as well as the values of chlorophyll fluorescence parameters Fo, Fv, Fv/Fo and Fv/Fm. The effects of Se on plant photosynthesis may be similar to the mechanism of the antioxidant system. Se directly or indirectly inhibits or induces the accumulation of ROS in plants and the photosynthetic enzyme system. Se may also affect electron transfer and photosynthetic energy conversion by affecting Fe-S protein synthesis[12]. It is currently known that Se can enhance antioxidant capacity by altering the contents of CuZn-SOD and GSH-Px transcripts in chloroplasts. In addition, the assimilation of Se requires the participation of NADPH and GSH in chloroplasts, and Se can alter the redox potential of chloroplasts. The enhancement of the ability to scavenge oxygen free radicals may be one of the mechanisms to alleviate oxidative stress in chloroplasts.

Se and Stress Resistance in Plants

For Se-deficient soil, applying Se can effectively protect plants from biological stress caused by pathogen infection, improve plant cold resistance and salt tolerance, and alleviate abiotic stress such as toxicity of heavy metal ions to plants[13]. There have been many studies on the improvement of plant cold resistance by Se, and it has been found that there are Se-containing proteins in plants that are similar to thioredoxin and Fe-S proteins, which can play a role similar to energy metabolism in electron transfer during photosynthesis and respiration[14]. The mechanism of Se increasing chlorophyll and carotenoid contents in plant leaves under low temperature stress is that Se can stimulate respiratory rate and electron flow in respiratory chain and protect chloroplast enzymes. Meanwhile, Se can regulate chlorophyll synthesis through the interaction of 5-aminoaevulinic acid dehydratase (ALAD) with -SH and porphobilinogen deaminase (PBGD)[15].

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