

Exogenous selenium treatment promoted garlic (*Allium sativum* L.) growth and improved product quality

CHUANGDONG QI¹, JIE ZHOU¹, DAN PENG^{1,2}, QINGQING ZHAO^{1,2}, FANGHUA WU³, JINPING WU¹, FENGLING GUO^{1*}

¹Industrial Crops Institute of Hubei Academy of Agricultural Sciences, Key Laboratory of Vegetable Ecological Cultivation on Highland, Ministry of Agriculture and Rural Affairs, Hubei Key Laboratory of Vegetable Germplasm Enhancement and Genetic Improvement, Wuhan, P.R. China

²Key Laboratory of Horticultural Plant Biology, Ministry of Education, College of Horticulture and Forestry Sciences, Huazhong Agricultural University, Wuhan, P.R. China

³Agricultural Service Center of Lianghe Town, Dangyang City, Yichang, P.R. China

*Corresponding author: guofenglingok@163.com

Citation: Qi C.D., Zhou J., Peng D., Zhao Q.Q., Wu F.H., Wu J.P., Guo F.L. (2026): Exogenous selenium treatment promoted garlic (*Allium sativum* L.) growth and improved product quality. Hort. Sci. (Prague), 53: 70–80.

Abstract: Selenium is an essential trace element in the human body, mainly obtained from the daily diet. Producing selenium-rich agricultural products through selenium-rich cultivation is an important cultivation method. Selenium-rich agricultural products can effectively supplement the selenium element needed by the human body in daily life. In this study, we conducted research on selenium-rich cultivation techniques for garlic, and different concentrations of sodium selenite solutions were used for garlic field treatment. We tested the related agronomic traits, nutritional indicators, and selenium content of garlic sprouts and garlic bulbs. The yield of garlic sprouts (37.08 t/ha) and garlic bulbs (25.31 t/ha) and total selenium content of garlic sprouts (61.00 µg/kg) and garlic bulbs (2 930.00 µg/kg) of T₃ treatment (120 mg/L Na₂SeO₃) were significantly increased, compared with the yield of garlic sprouts (30.66 t/ha) and garlic bulbs (20.90 t/ha) and total selenium content of garlic sprouts (6.33 µg/kg) and garlic bulbs (75.00 µg/kg) of the control (CK). Furthermore, selenium treatment improved the activity of antioxidant enzymes and reduced the accumulation of reactive oxygen species (ROS) in garlic sprouts during winter, and promoted the absorption of soil nutrients by garlic. Taken together, our research indicates that garlic, especially garlic bulbs, has strong selenium-rich ability, and selenium-rich cultivation techniques could significantly improve the yield and quality of garlic products.

Keywords: garlic; ROS accumulation; selenium-rich cultivation; sodium selenite treatment

Garlic (*Allium sativum* L.) originated in the plateau of Western Asia. It has been planted in China for more than 2 000 years. At present, the annual output of garlic in China is about 16 million t, accounting for more than 75% of the world's total output. Garlic is rich in allicin, protein, sugar, ascorbic acid, and many reducing sulphides, and has very

high nutritional value. Medical research shows that garlic has good disinfection and bacteriostatic effects (Subramanian et al. 2020). Daily consumption of an appropriate amount of garlic can prevent and cure basic diseases such as hyperglycaemia (Parvin et al. 2019) and hyperlipidaemia (Ried et al. 2013), and can also reduce the risk of upper respiratory

Supported by the National Featured Vegetable Industry Technology System of China (Grant No. CARS-24-G-17), the Key Research and Development Program Projects in Hubei Province (Grant No. 2022BBA0061) and Hubei Agricultural Science and Technology Innovation Center Project (Project No. 2021-620-000-001-007).

© The authors. This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International (CC BY-NC 4.0).

<https://doi.org/10.17221/79/2024-HORTSCI>

tract cancer (Guercio et al. 2016), gastric cancer (Turati et al. 2014; Li et al. 2018) and colorectal cancer (Turati et al. 2015).

Selenium is one of the essential trace elements in the human body, which has many benefits such as antioxidant activity and maintaining normal physiological functions of the immune system (D'Amato et al. 2020; Zhao et al. 2021). The human body must intake sufficient selenium from external food to maintain physical health (Zhu et al. 2009). Many countries and regions worldwide lack selenium in their natural environment (Winkel et al. 2012). Especially in China, the scope and extent of selenium deficiency in the geographical environment are relatively severe, with about 72% of cities (counties) being in a severe selenium deficiency or low selenium state (Wu et al. 2015). Therefore, it is of great significance to improve the selenium content in crops through selenium-rich cultivation techniques in areas with selenium deficiency.

In recent years, research on plant selenium-rich cultivation techniques has been one of the hot topics. There are relevant reports on the research of selenium-rich cultivation techniques for agricultural products such as grain crops (Wang et al. 2013; Ducsay et al. 2016; Liang et al. 2019; Skalnaya et al. 2019), vegetables (Tian et al. 2016; Hegedúsová et al. 2017; Zhu et al. 2017; Poggi et al. 2000; Jia et al. 2023), fruits (Zahedi et al. 2019), and edible fungi (Falandysz 2008). In plants, selenium contributes to various functions, including promoting growth, enhancing antioxidant capacity, and delaying senescence (Kuznetsov et al. 2003). Rice can absorb selenium in the form of selenite from its roots, and selenium-rich cultivation enhances the antioxidant activity of rice plants, increasing the content of nutrients such as amino acids, phenols, anthocyanins, and sugars (Liang et al. 2019). In lettuce, selenium treatment reduced the nitrate content in the leaves, improved the quality and yield (Hawrylak-Nowak, Matraszek-Gawron 2020). Selenium treatment can delay the ripening of tomato fruits, which is beneficial for their post-harvest preservation and affects the post-harvest shelf life of tomatoes (Zhu et al. 2017). In mung bean sprouts after 72 h of sowing with a temperature cycle of 26 °C (day)/16 °C (night), the growth indices, including plant weight and plant height, were investigated with sodium selenite treatment (Cao et al. 2022).

Garlic is an important fragrant vegetable with health benefits and excellent medicinal value. Cur-

rently, there are limited research reports on the cultivation techniques of selenium-rich garlic. In garlic, leaf spray had a better effect than soil application of selenium enrichment (Shafiq et al. 2019). In this study, we treated garlic plants with exogenous spraying of different concentrations of sodium selenite solution. By observing the growth of garlic plants under different treatments, measuring relevant agronomic traits, physiological indicators, and plant selenium content, this study planned to screen the optimal selenium treatment concentration and comprehensively evaluate the effects of exogenous selenium treatment on garlic growth and nutritional indicators.

MATERIAL AND METHODS

Plant materials. The experimental material for this study is the 'Er Shui Zao' garlic variety, which is the main variety for green garlic production in Hubei Province in China. The garlic variety is provided by the Economic Crop Research Institute of Hubei Academy of Agricultural Sciences.

Site description and experimental design. The field experiment was conducted at the vegetable base of Hubei Academy of Agricultural Sciences in China. The experimental site was located at 30.48°N, 114.32°E, with an altitude of 28 meters. Garlic was planted on September 22, 2021 (22–33 °C), with a spacing of 15 cm between plants and 20 cm between rows. The community area was 20 m², with three replicates and a random block setting. The experiment used a sodium selenite solution for external spraying treatment. Five treatment concentrations were set, namely control (CK) (double-distilled water – ddH₂O), T₁ (40 mg/L Na₂SeO₃), T₂ (80 mg/L Na₂SeO₃), T₃ (120 mg/L Na₂SeO₃), and T₄ (160 mg/L Na₂SeO₃). A total of two treatments were carried out, with 1 L of solution sprayed on each community (20 m²) during each treatment. The first treatment date is November 17, 2021 (6–18 °C), when the garlic plants had three leaves and a plant height of 12–15 cm. The second treatment date is December 2, 2021 (1–15 °C), when the garlic plants had four leaves and a plant height of 18–22 cm.

Observation of agronomic traits of garlic sprouts. A total of nine quantitative trait indicators of garlic sprouts were investigated, including plant height, plant breadth, leaf length, leaf width, number of leaves per plant, cauloid height, cauloid width,

weight per plant, and yield per unit. A field random sampling survey was conducted to measure five biological replicates, and the average value was calculated after measurement. The trait indicators of garlic seedlings were measured during harvesting on January 5, 2022 (4–10 °C), after 105 days of growth.

Observation of agronomic traits of garlic bulbs.

A total of seven quantitative trait indicators of garlic bulbs were investigated, including garlic bulb height, garlic bulb width, scaly bud height, scaly bud width, scaly bud number of garlic bulb, garlic bulb weight, and yield per unit. A field random sampling survey was conducted to measure five biological replicates, and the average value was calculated after measurement. The trait indicators of garlic seedlings were measured during harvesting on May 3, 2022 (13–28 °C), after 223 days of growth.

Analysis of dry matter, vitamin C, soluble protein, and soluble sugar content. The analysis of nutritional quality indicators, including dry matter, vitamin C, soluble protein, and soluble sugar content, was conducted in five mixed fresh samples, with one biological replicate and a total of three replicates (Zhang et al. 2009). The dry matter content (%) was determined by the vacuum drying method. The molybdenum blue colourimetry determined the content of vitamin C (mg/g). The soluble protein content (mg/g) was determined by the Coomassie brilliant blue staining method. The soluble sugar content (%) was measured using the anthrone colourimetric method. These kits for rapid detection of nutritional indicators were produced by Beijing TransGen Biotech, China.

Analysis of selenium content. The total selenium content and organic selenium content of garlic sprouts and garlic bulbs were detected by Hubei Qipu Detection Technology Co., Ltd., Wuhan City, Hubei Province, China. Five mixed samples were used as biological replicates, with a total of three replicates for each treatment. The method of inductively coupled plasma mass spectrometry (ICP-MS, iCAP7400, Thermo Fisher Scientific, USA) was used for detecting selenium content (Romanovskiy et al. 2018; Cao et al. 2022).

Analysis of malondialdehyde (MDA), proline, reactive oxygen species (ROS) accumulation, and antioxidant enzyme activities. The MDA content and proline content were analysed as described previously (Zhang et al. 2014). The content of superoxide (O_2^-) and hydrogen peroxide (H_2O_2), as well as the activities of superoxide dismutase (SOD),

peroxidase (POD), ascorbate peroxidase (APX), and catalase (CAT) were measured as described previously (Li et al. 2020).

Analysis of soil physicochemical indices. The soil pH value was measured using a glass electrode with a 1 : 2.5 (wt/vol) soil/deionised water ratio. Soil electrical conductivity was measured using a conductivity meter (DDS-307, Shanghai Rex, China) with a 1 : 5 (wt/vol) soil/deionised water ratio. The soil available nitrogen, available phosphorus, available potassium, and organic matter content were measured as described previously (Cui et al. 2005; Lall et al. 2018; Lemanowicz et al. 2020; Piotrowska-Dlugosz et al. 2021).

Statistical analysis. All data were analysed by Duncan's multiple range tests ($P < 0.05$) using SPSS version 18.0 software (IBM Corp. Armonk, NY, USA).

RESULTS

A certain concentration of selenium treatment significantly promoted the growth of garlic sprouts. In this study, we sprayed different concentrations of sodium selenite on garlic sprouts grown in the field and determined the related phenotypic and yield characteristics of the garlic sprouts. The results showed that the T_2 (80 mg/L Na_2SeO_3) and T_3 (120 mg/L Na_2SeO_3) treatments significantly promoted the growth of garlic seedlings compared with CK (Figure 1). Furthermore, a higher concentration of selenium, T_4 (160 mg/L Na_2SeO_3) treatment, could inhibit the growth of garlic sprouts. The height, leaf length, leaf width, number of leaves per plant, cauloid width, and plant weight of garlic sprouts were significantly higher than those of the CK. The yield per unit of T_3 treatment was 37.08 t/ha, which increased by 20.9% compared with the 30.66 t/ha of CK (Tables 1 and 2). These results suggest that a specific concentration of selenium treatment significantly promotes the growth of garlic sprouts, with the optimum selenium concentration being 120 mg/L Na_2SeO_3 .

A certain concentration of selenium treatment significantly improved the yield of garlic bulbs. We also determined the related phenotypic and yield characteristics of garlic bulbs under selenium concentration treatment. The results showed that the T_3 (120 mg/L Na_2SeO_3) treatment significantly improved the yield of garlic bulbs com-

<https://doi.org/10.17221/79/2024-HORTSCI>

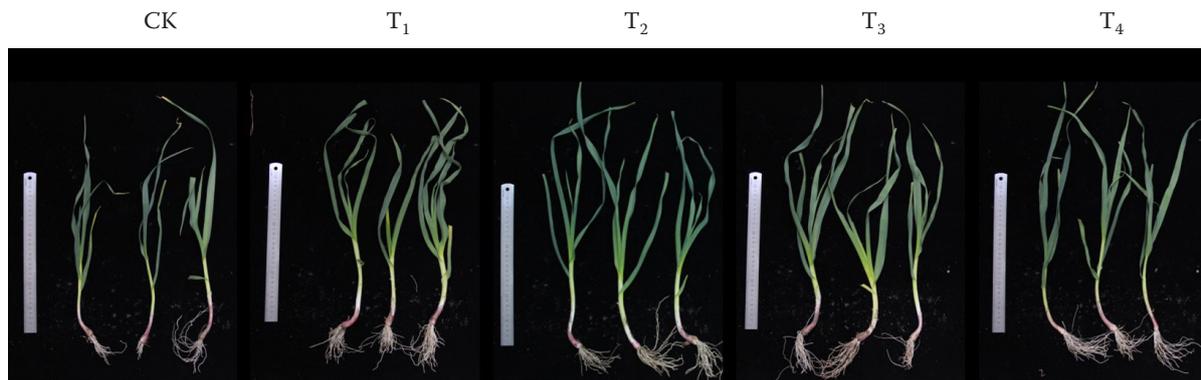


Figure 1. The growth condition of garlic sprouts treated with different concentrations of exogenous selenium (CK–T₄) CK – control (double-distilled water – ddH₂O); T₁ – 40 mg/L Na₂SeO₃; T₂ – 80 mg/L Na₂SeO₃; T₃ – 120 mg/L Na₂SeO₃; T₄ – 160 mg/L Na₂SeO₃

Table 1. The related physiological phenotypes of garlic sprouts

Treatment	Height (cm)	Breadth (cm)	Leaf length (cm)	Leaf width (cm)	Number of leaves per plant
CK	31.6 ± 1.74 ^b	16.0 ± 3.41 ^{ab}	38.6 ± 2.42 ^b	1.52 ± 0.26 ^b	4.4 ± 0.49 ^b
T ₁	31.4 ± 1.85 ^b	15.8 ± 1.72 ^{ab}	42.2 ± 2.32 ^b	1.72 ± 0.15 ^b	4.6 ± 0.49 ^b
T ₂	36.0 ± 2.28 ^a	17.8 ± 1.47 ^a	47.0 ± 4.05 ^a	2.20 ± 0.23 ^a	5.2 ± 0.40 ^{ab}
T ₃	35.0 ± 1.79 ^a	16.2 ± 2.14 ^{ab}	49.6 ± 2.73 ^a	2.18 ± 0.22 ^a	5.4 ± 0.49 ^a
T ₄	30.8 ± 1.47 ^b	15.2 ± 1.17 ^b	41.2 ± 2.32 ^b	1.80 ± 0.20 ^b	4.6 ± 0.49 ^b

Each value is the average of five repetitions; data are means (± SD) of five independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a,b}different letters above the columns indicate significant differences ($P < 0.05$)

Table 2. The related yield indexes of garlic sprouts

Treatment	Cauloid height (cm)	Cauloid width (mm)	Plant weight (g)	Yield per unit (t/ha)
CK	4.9 ± 0.58	7.56 ± 0.84 ^b	12.39 ± 3.07 ^c	30.66 ± 0.67 ^c
T ₁	5.6 ± 0.66	8.41 ± 0.72 ^b	15.10 ± 1.88 ^{bc}	31.58 ± 0.72 ^{bc}
T ₂	5.3 ± 0.51	9.31 ± 1.29 ^{ab}	17.36 ± 1.54 ^{ab}	33.19 ± 0.93 ^b
T ₃	5.3 ± 0.40	9.34 ± 0.21 ^a	17.84 ± 0.54 ^a	37.08 ± 0.85 ^a
T ₄	5.3 ± 0.51	6.61 ± 0.43 ^c	11.68 ± 1.18 ^c	32.22 ± 0.65 ^{bc}

Each value is the average of five repetitions; data are means (± SD) of five independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a,b,c}different letters above the columns indicate significant differences ($P < 0.05$)

pared with CK (Figure 2). The height, width, and weight of garlic bulbs were significantly higher than those of the CK. The yield per unit of T₃ treatment was 25.31 t/ha, which increased by 21.1% compared with the 20.90 t/ha of CK (Tables 3 and 4). These results showed that 120 mg/L Na₂SeO₃ treatment significantly improved the yield of garlic bulbs.

Selenium treatment significantly improved the nutrient content in garlic sprouts and garlic bulbs. To investigate the impact of selenium treat-

ment on the quality of garlic products, we analysed the dry matter, vitamin C, soluble protein, and soluble sugar content in garlic sprouts and garlic bulbs. The results showed that there was no significant difference in dry matter content between different selenium concentration treatments. The vitamin C, soluble protein, and soluble sugar content in garlic sprouts and garlic bulbs of T₃ treatment were significantly higher than those of the CK (Tables 5 and 6). These results indicated that 120 mg/L Na₂SeO₃

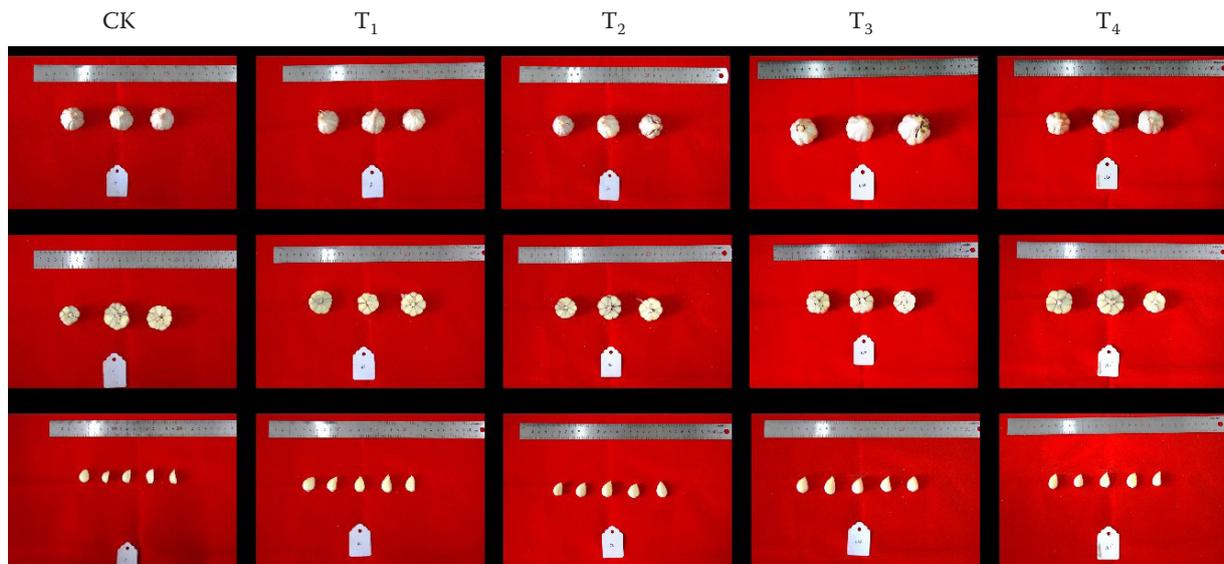


Figure 2. The growth condition of garlic bulbs treated with different concentrations of exogenous selenium For treatment detail (CK–T₄), see Figure 1

Table 3. The related physiological phenotypes of garlic bulbs

Treatment	Garlic bulb height (mm)	Garlic bulb width (mm)	Scaly bud height (mm)	Scaly bud width (mm)
CK	28.66 ± 1.68 ^b	32.02 ± 3.34 ^b	23.83 ± 1.21 ^b	11.79 ± 0.93
T ₁	29.29 ± 1.55 ^{ab}	34.72 ± 0.64 ^b	25.04 ± 2.21 ^{ab}	12.45 ± 1.82
T ₂	30.67 ± 1.13 ^{ab}	35.59 ± 3.32 ^{ab}	24.81 ± 2.50 ^{ab}	12.72 ± 1.04
T ₃	33.20 ± 2.61 ^a	39.12 ± 3.04 ^a	27.81 ± 1.53 ^a	13.52 ± 1.92
T ₄	31.86 ± 2.34 ^{ab}	35.84 ± 2.58 ^{ab}	25.68 ± 0.95 ^{ab}	13.42 ± 2.15

Each value is the average of five repetitions; data are means (± SD) of five independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a,b}different letters above the columns indicate significant differences ($P < 0.05$)

Table 4. Yield-related indices of garlic bulbs

Treatment	Scaly bud number of garlic bulb	Garlic bulb weight (g)	Yield per unit (t/ha)
CK	9.2 ± 1.72	21.48 ± 2.05 ^b	20.90 ± 0.87 ^b
T ₁	8.8 ± 0.98	21.58 ± 2.16 ^b	22.27 ± 1.58 ^b
T ₂	9.2 ± 0.75	23.98 ± 1.05 ^{ab}	25.24 ± 0.83 ^a
T ₃	9.6 ± 0.80	25.30 ± 1.12 ^a	25.31 ± 1.21 ^a
T ₄	8.6 ± 0.49	22.46 ± 1.27 ^{ab}	21.94 ± 0.82 ^b

Each value is the average of five repetitions; data are means (± SD) of five independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a,b}different letters above the columns indicate significant differences ($P < 0.05$)

treatment significantly improved the nutrient content in garlic sprouts and garlic bulbs.

Selenium treatment significantly increased the selenium content in garlic sprouts and garlic bulbs. To study the change in selenium content of different treatment garlic products, the total selenium content and organic selenium content

in garlic sprouts and garlic bulbs were determined. The results showed that selenium treatment could significantly increase the selenium content in garlic sprouts and garlic bulbs. In garlic sprouts, the total selenium content (61.00 µg/kg) and organic selenium content (40.67 µg/kg) of T₃ treatment were the highest, which increased 9.6-fold and

<https://doi.org/10.17221/79/2024-HORTSCI>

Table 5. The nutritional indices of garlic sprouts in fresh matter (FM)

Treatment	Dry matter content (%)	Vitamin C (mg/kg)	Soluble protein (mg/kg)	Soluble sugar (%)
CK	14.59 ± 0.18	695 ± 3 ^d	2 539 ± 59 ^d	2.114 ± 0.034 ^d
T ₁	14.68 ± 0.11	747 ± 27 ^c	3 342 ± 178 ^c	2.309 ± 0.059 ^c
T ₂	14.65 ± 0.13	889 ± 25 ^b	4 017 ± 128 ^a	2.707 ± 0.026 ^b
T ₃	15.06 ± 0.64	1 128 ± 13 ^a	4 242 ± 225 ^a	2.931 ± 0.104 ^a
T ₄	14.66 ± 0.21	872 ± 8 ^b	3 686 ± 53 ^b	2.156 ± 0.198 ^{cd}

Each treatment included three seedlings; data are means (± SD) of three independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a–d}different letters above the columns indicate significant differences ($P < 0.05$)

Table 6. The nutritional indices of garlic bulbs in fresh matter (FM)

Treatment	Dry matter content (%)	Vitamin C (mg/kg)	Soluble protein (mg/kg)	Soluble sugar (%)
CK	39.35 ± 0.36	142 ± 11 ^d	10 152 ± 353 ^e	17.330 ± 0.245 ^{cd}
T ₁	39.90 ± 1.15	193 ± 5 ^c	12 234 ± 66 ^c	17.838 ± 0.332 ^c
T ₂	39.21 ± 0.94	228 ± 31 ^b	12 853 ± 106 ^b	19.390 ± 0.317 ^b
T ₃	39.41 ± 0.64	267 ± 11 ^a	17 446 ± 576 ^a	20.957 ± 0.091 ^a
T ₄	40.23 ± 1.70	184 ± 3 ^c	11 442 ± 181 ^d	16.836 ± 0.197 ^d

Each treatment included three seedlings; data are means (± SD) of three independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a–e}different letters above the columns indicate significant differences ($P < 0.05$)

26.1-fold, respectively, relative to the total selenium content (6.33 µg/kg) and organic selenium content (1.50 µg/kg) of CK (Table 7). In garlic bulbs, the total selenium content (2 930.00 µg/kg) and organic selenium content (1 166.67 µg/kg) of T₃ treatment increased 39.1-fold and 20.6-fold, respectively, relative to the total selenium content (75.00 µg/kg) and organic selenium content (54.00 µg/kg) of CK (Table 8).

Selenium treatment improved the antioxidant enzyme activity and reduced the accumulation of ROS in garlic sprouts. Low temperature stress in winter leads to ROS accumulation in garlic sprouts. The proline content in garlic sprouts was significantly higher in the T₃ treatment compared to CK. The

MDA, O₂^{•−}, and H₂O₂ content of the T₃ treatment was significantly lower than that of the CK (Figure 3). These results indicated that a 120 mg/L Na₂SeO₃ treatment significantly reduced ROS accumulation and damage to the photosynthetic system in garlic sprouts. Additionally, we detected the activity of antioxidant enzymes in garlic sprouts treated with varying concentrations of selenium. The results showed that the enzyme activity of SOD, POD, and CAT of T₃ treatment was significantly improved compared to CK (Figure 4). These results suggested that a 120 mg/L Na₂SeO₃ treatment improved the activity of antioxidant enzymes and reduced ROS accumulation in garlic sprouts.

Table 7. The selenium content of garlic sprouts in fresh matter (FM)

Treatment	Total selenium content (µg/kg)	Organic selenium content (µg/kg)	Proportion of organic selenium (%)
CK	6.33 ± 1.25 ^e	1.50 ± 0.41 ^e	23.33 ± 2.36 ^c
T ₁	25.33 ± 2.05 ^d	13.00 ± 0.82 ^d	51.51 ± 3.64 ^b
T ₂	39.67 ± 2.05 ^c	22.67 ± 0.94 ^c	57.28 ± 3.47 ^b
T ₃	61.00 ± 2.94 ^a	40.67 ± 0.94 ^a	66.81 ± 3.20 ^a
T ₄	48.33 ± 2.62 ^b	31.33 ± 2.87 ^b	64.71 ± 2.77 ^a

Each treatment included three seedlings; data are means (± SD) of three independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a–e}different letters above the columns indicate significant differences ($P < 0.05$)

Table 8. The selenium content of garlic bulbs in fresh matter (FM)

Treatment	Total selenium content (µg/kg)	Organic selenium content (µg/kg)	Proportion of organic selenium (%)
CK	75.00 ± 2.94 ^c	54.00 ± 0.82 ^d	72.08 ± 2.22 ^a
T ₁	1 373.00 ± 20.05 ^d	502.67 ± 15.69 ^c	36.61 ± 0.96 ^c
T ₂	2 161.00 ± 87.19 ^c	764.67 ± 6.60 ^b	35.43 ± 1.21 ^c
T ₃	2 930.00 ± 45.46 ^a	1 166.67 ± 18.86 ^a	39.82 ± 0.23 ^b
T ₄	2 343.33 ± 69.44 ^b	770.00 ± 21.60 ^b	32.87 ± 0.96 ^d

Each treatment included three seedlings; data are means (± SD) of three independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a–e}different letters above the columns indicate significant differences ($P < 0.05$)

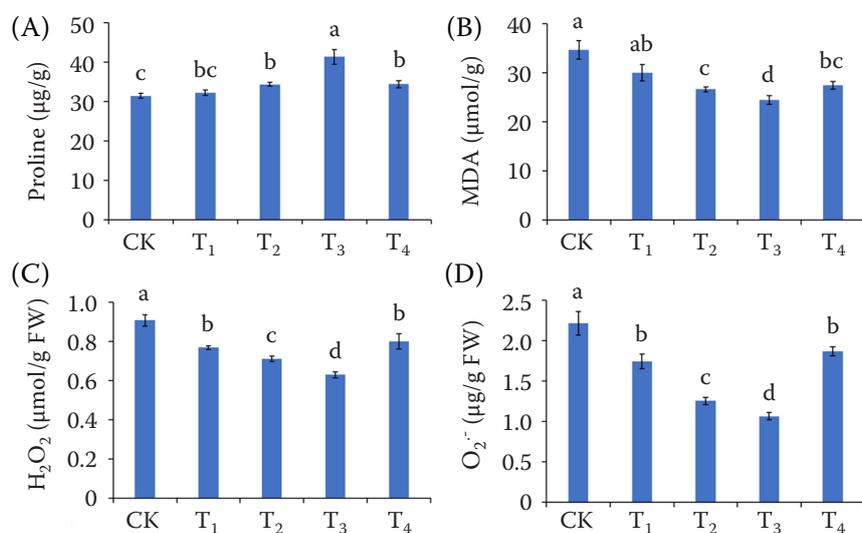


Figure 3. Exogenous selenium treatment positively regulates the resistance of garlic sprouts to cold stress. (A) Proline content, (B) malondialdehyde (MDA) content, (C) hydrogen peroxide (H₂O₂) content and (D) superoxide (O₂⁻) content

Data are the mean (± SD) of three independent biological experiments For treatment detail (CK–T₄), see Figure 1

^{a–d}different letters above each column indicate significant differences ($P < 0.05$)

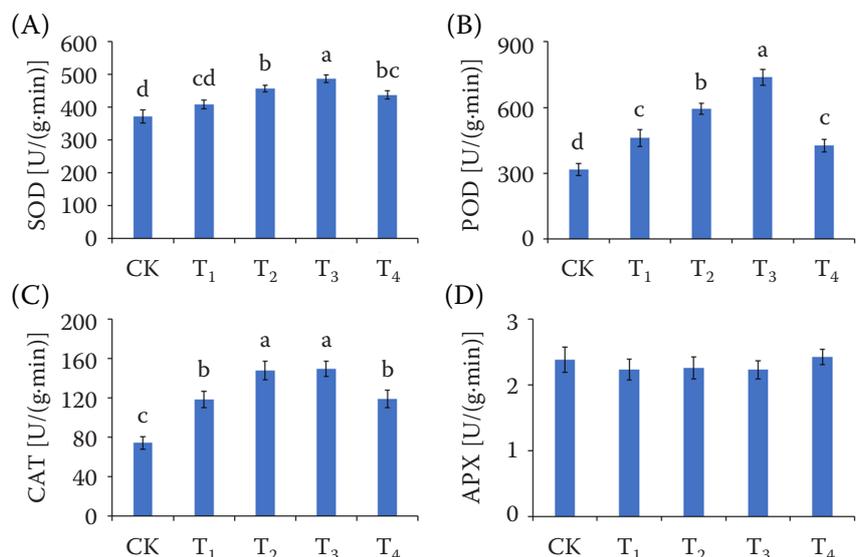


Figure 4. Exogenous selenium treatment activated antioxidant enzymes of garlic sprouts. (A) superoxide dismutase (SOD), (B) peroxidase (POD), (C) catalase (CAT) and (D) ascorbate peroxidase (APX) activities

Data are the mean (± SD) of three independent biological experiments For treatment detail (CK–T₄), see Figure 1

^{a–d}different letters above each column indicate significant differences ($P < 0.05$)

Selenium treatment promoted the absorption of soil nutrients by garlic plants. The soil physicochemical indices were analysed before garlic seeding and after garlic harvest. The results showed that there was no significant difference in the pH value

of soil, soil electrical conductivity, available nitrogen, available phosphorus, available potassium, and organic matter content before garlic seeding. The soil electrical conductivity, available nitrogen, available phosphorus, available potassium, and organic

<https://doi.org/10.17221/79/2024-HORTSCI>

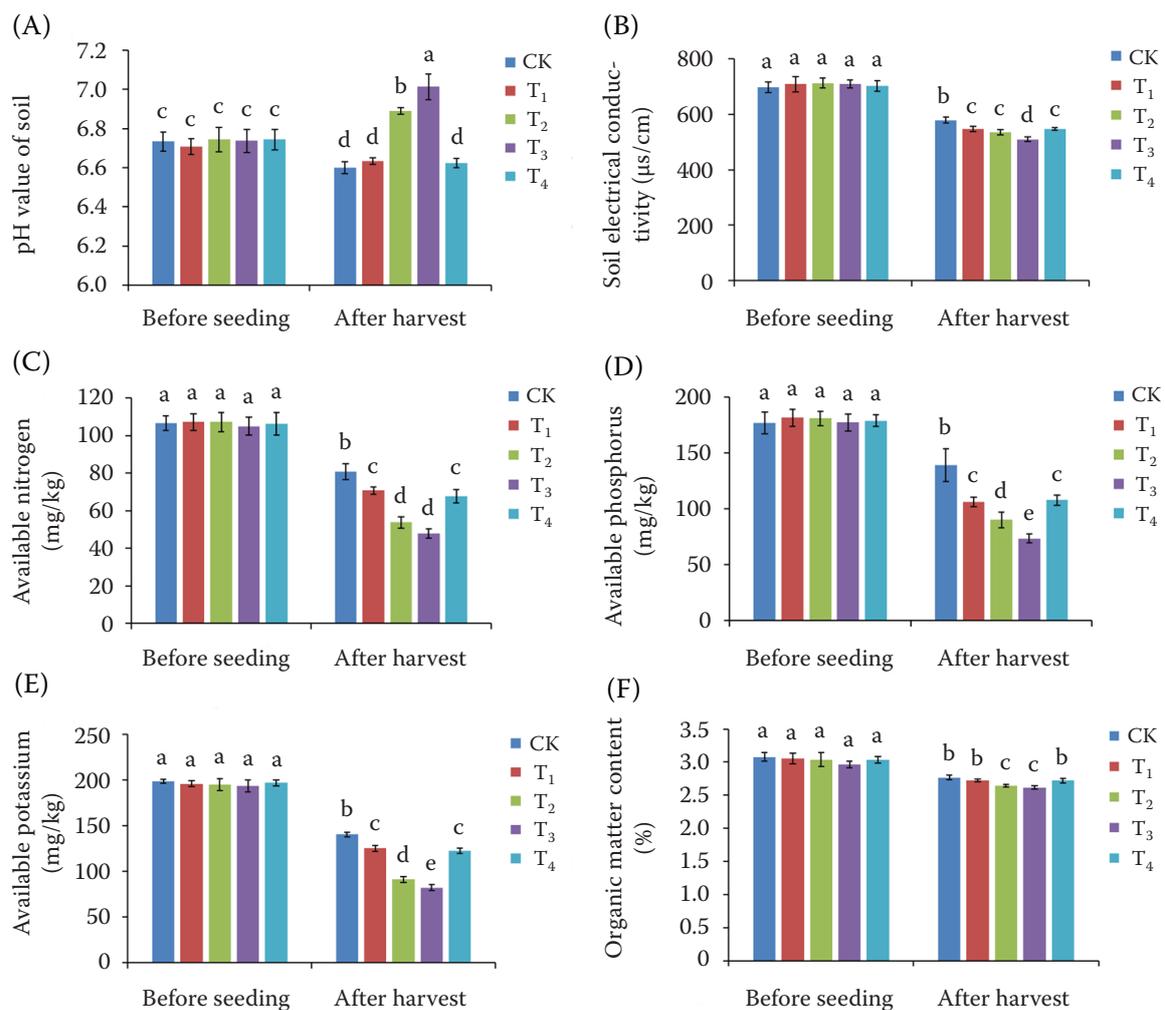


Figure 5. The analysis of soil physicochemical indices before garlic seeding and after garlic harvest. (A) The pH value of soil, (B) soil electrical conductivity, (C) available nitrogen, (D) available phosphorus, (E) available potassium and (F) organic matter content

Each value is the average of three repetitions; data are means (± SD) of three independent experiments

For treatment detail (CK–T₄), see Figure 1

^{a–e}different letters above each column indicate significant differences ($P < 0.05$)

matter content of the T₃ treatment were significantly lower than those of the CK (Figure 5). These results indicated that 120 mg/L Na₂SeO₃ treatment effectively promoted the absorption of nutrients in the soil, thereby increasing garlic yield.

DISCUSSION

Low concentrations of selenium play a crucial role in promoting plant growth, improving quality, enhancing photosynthesis, delaying ageing, and increasing tolerance to various abiotic stresses (Huang et al. 2021; Lanza, Reis 2021; Khanna

et al. 2022). High concentrations of selenium had toxic effects on plants (Pilon-Smits 2019). Soaking rice seeds in sodium selenite solution significantly increased the chlorophyll content, height, spike length, and thousand-grain weight of rice seedlings (Moulick et al. 2018). Under drought stress, exogenous selenium treatment increased the activities of SOD, POD, APX, and CAT in cucumber, reduced the accumulation of ROS in the roots, and enhanced its drought tolerance (Jozwiak, Politycka 2019). This study indicates that low-concentration sodium selenite treatment effectively promotes the growth of garlic plants, improving yield and quality. The optimal treatment concentration is 120 mg/L,

and excessive concentration of sodium selenite had a toxic effect on garlic plants (Tables 1–4). During the low-temperature period in winter, when the air temperature is 0–5 °C, exogenous selenium treatment increased the activity of SOD, POD, and CAT in garlic seedlings, reduced the accumulation of ROS in the body, and enhanced low-temperature resistance (Figures 3 and 4). In addition, the detection results of soil physicochemical indicators before garlic planting and after harvesting also indicated that selenium treatment promotes the absorption of nutrients in the soil, which was closely related to the yield growth of garlic sprouts and garlic bulbs (Figure 5). In summary, the exogenous application of 120 mg/L Na₂SeO₃ treatment effectively promoted garlic growth, improved plant resistance to oxidative stress, and increased product yield and quality, which was consistent with previous research results on other crops.

There were significant differences in selenium enrichment ability among various crops (Beladel et al. 2013; de Vasconcelos et al. 2023). The selenium content in most selenium-rich vegetables is maintained at a relatively low level. The total selenium concentrations were 29.3–48.0 µg/kg for cucumber fruits, 22.7–53.4 µg/kg for lettuce leaves, and 15.2–19.9 µg/kg for tomato fruits (D'Amato et al. 2020). This research showed that the highest total selenium content and organic selenium content in garlic sprouts reached 61.00 µg/kg and 40.67 µg/kg, respectively, which is similar to the selenium content in most selenium-rich fresh vegetables. It was gratifying that garlic bulbs had a very strong selenium-rich ability. The highest total selenium content and organic selenium content in garlic sprouts reached 2 930.00 µg/kg and 1 166.67 µg/kg, respectively (Tables 7 and 8). The Chinese Nutrition Society recommends a daily selenium intake of 50–250 µg for normal adults. Long-term exposure to less than 50 µg is prone to endemic diseases such as Kaschin-Beck disease, as well as tumours, liver diseases, cardiovascular and cerebrovascular diseases (Shi et al. 2017). Garlic, as a type of spicy seasoning, was an essential characteristic vegetable in people's daily diet. The average daily intake of garlic bulbs per person in China is 5–10 grams. The selenium-rich garlic bulbs could supplement the daily selenium intake of the human body by about 15–30 µg. Therefore, conducting research on selenium-rich cultivation techniques for garlic and producing selenium-rich garlic products was of great importance.

CONCLUSION

This study found that exogenous selenium spraying on garlic effectively improved the antioxidant enzyme activity and reduced the accumulation of ROS in the plant under low temperature conditions in winter. In addition, selenium treatment promoted the absorption of nutrients in the soil by garlic, thereby increasing garlic yield. Through selenium-rich cultivation, the total and organic selenium content in garlic sprouts and garlic bulbs increased significantly, thereby improving the quality of garlic products. We will further investigate the selenium enrichment ability of different garlic varieties and study the optimal selenium enrichment treatment conditions and concentrations for different varieties, in order to provide a theoretical basis for the application of selenium enrichment cultivation techniques in garlic.

REFERENCES

- Hegedúsová A., Mezeyová I., Hegedűs O., Andrejiová A., Juríková T. (2017): Increasing of selenium content and qualitative parameters in garden pea (*Pisum sativum* L.) after its foliar application. *Acta Scientiarum Polonorum*, 16: 3–17.
- Beladel B., Nedjimi B., Mansouri A., Tahtat D., Belamri M., Tchanchane A., Khelfaoui F., Benamar M.E. (2013): Selenium content in wheat and estimation of the selenium daily intake in different regions of Algeria. *Applied Radiation and Isotopes*, 71: 7–10.
- Cao L., Zhu J., Li N. (2022): Selenium-agarose hybrid hydrogel as a recyclable natural substrate for selenium-enriched cultivation of mung bean sprouts. *International Journal of Biochemistry*, 194: 17–23.
- Cui X.M., Xu L.S., Wang Q., Chen Z.J. (2005): Analysis on the geologic background and physicochemical properties of soil for the cultivation of *Panax notoginseng* in Yunnan province. *China Journal of Chinese Materia Medica*, 30: 332–335. (in Chinese)
- D'Amato R., Regni L., Falcinelli B., Mattioli S., Benincasa P., Dal Bosco A., Pacheco P., Proietti P., Troni E., Santi C., Businelli D. (2020): Current knowledge on selenium biofortification to improve the nutraceutical profile of food: A comprehensive review. *Journal of Agricultural and Food Chemistry*, 68: 4075–4097.
- de Vasconcelos A.M., Bonfim J.M., de Souza V., Martins T.P., Pompeu R., Facanha D., Ferreira J., Silveira R. (2023): Productive, thermoregulatory, and hormonal responses

<https://doi.org/10.17221/79/2024-HORTSCI>

- of dairy goats supplemented with selenium-enriched yeast in the Brazilian semi-arid region. *Tropical Animal Health and Production*, 55: 365.
- Falandysz J. (2008): Selenium in edible mushrooms. *Journal of Environmental Science and Health, Part C*, 26: 256–299.
- Guercio V., Turati F., La Vecchia C., Galeone C., Tavani A. (2016): Allium vegetables and upper aerodigestive tract cancers: A meta-analysis of observational studies. *Molecular Nutrition & Food Research*, 60: 212–222.
- Hawrylak-Nowak B., Matraszek-Gawron R. (2020): Difference between selenite and selenate in the regulation of growth and physiological parameters of nickel-exposed lettuce. *Biology*, 9: 465.
- Huang H., Li M., Rizwan M., Dai Z., Yuan Y., Hossain M.M., Cao M., Xiong S., Tu S. (2021): Synergistic effect of silicon and selenium on the alleviation of cadmium toxicity in rice plants. *Journal of Hazardous Materials*, 401: 123393.
- Jia Y., Kang L., Wu Y., Zhou C., Cai R., Zhang H., Li J., Chen Z., Kang D., Zhang L., Pan C. (2023): Nano-selenium foliar intervention-induced resistance of cucumber to *Botrytis cinerea* by activating jasmonic acid biosynthesis and regulating phenolic acid and cucurbitacin. *Pest Management Science*, 80: 554–568.
- Jozwiak W., Politycka B. (2019): Effect of selenium on alleviating oxidative stress caused by a water deficit in cucumber roots. *Plants*, 8: 217.
- Khanna K., Kohli S.K., Kumar P., Ohri P., Bhardwaj R., Alam P., Ahmad P. (2022): Arsenic as hazardous pollutant: Perspectives on engineering remediation tools. *Science of the Total Environment*, 838: 155870.
- Kuznetsov V.V., Kholodova V.P., Kuznetsov V.V., Yagodin B.A. (2003): Selenium regulates the water status of plants exposed to drought. *Doklady Biological Sciences*, 390: 266–268.
- Lall C., Vinod K.K., Raj R.V., Vedhagiri K., Sunish I.P., Vijayachari P. (2018): Correlation between physicochemical properties of soil and presence of *Leptospira*. *Ecohealth*, 15: 670–675.
- Lanza M., Reis A. (2021): Roles of selenium in mineral plant nutrition: ROS scavenging responses against abiotic stresses. *Plant Physiology and Biochemistry*, 164: 27–43.
- Ducsay L., Ložek O., Marček M., Varényiová M., Hozlár P., Lošák T. (2016): Possibility of selenium biofortification of winter wheat grain. *Plant, Soil and Environment*, 62: 379–383.
- Lemanowicz J., Haddad S.A., Bartkowiak A., Lamparski R., Wojewodzki P. (2020): The role of an urban park's tree stand in shaping the enzymatic activity, glomalin content and physicochemical properties of soil. *Science of the Total Environment*, 741: 140446.
- Li S., Zhang J., Liu L., Wang Z., Li Y., Guo L., Li Y., Zhang X., Ren S., Zhao B., Zhang N., Guo Y.D. (2020): *SITLFP8* reduces water loss to improve water-use efficiency by modulating cell size and stomatal density via endoreduplication. *Plant Cell and Environment*, 43: 2666–2679.
- Li Z., Ying X., Shan F., Ji J. (2018): The association of garlic with *Helicobacter pylori* infection and gastric cancer risk: A systematic review and meta-analysis. *Helicobacter*, 23: e12532.
- Liang Y., Su Y., Li L., Huang X., Panhwar F.H., Zheng T., Tang Z., Ei H.H., Farooq M.U., Zeng R., Zhang Y., Ye X., Jia X., Zheng L., Zhu J. (2019): Quick selenium accumulation in the selenium-rich rice and its physiological responses in changing selenium environments. *BMC Plant Biology*, 19: 559.
- Moulick D., Santra S.C., Ghosh D. (2018): Effect of selenium induced seed priming on arsenic accumulation in rice plant and subsequent transmission in human food chain. *Ecotoxicology and Environmental Safety*, 152: 67–77.
- Parvin M., Zahra B., Maryam T., Fereidoun A. (2019): Higher consumption of Allium vegetables may modulate insulin homeostasis: A longitudinal follow-up study. *Journal of Herbal Medicine*, 17–18: 100260.
- Pilon-Smits E. (2019): On the ecology of selenium accumulation in plants. *Plants*, 8: 197.
- Piotrowska-Długosz A., Kobierski M., Długosz J. (2021): Enzymatic activity and physicochemical properties of soil profiles of luvisols. *Materials (Basel)*, 14: 6364.
- Poggi V., Arcioni A., Filippini P., Pifferi P.G. (2000): Foliar application of selenite and selenate to potato (*Solanum tuberosum*): Effect of a ligand agent on selenium content of tubers. *Journal of Agricultural and Food Chemistry*, 48: 4749–4751.
- Ried K., Toben C., Fakler P. (2013): Effect of garlic on serum lipids: An updated meta-analysis. *Nutrition Reviews*, 71: 282–299.
- Romanovskiy K.A., Bolshov M.A., Munz A.V., Temerdashev Z.A., Burylin M.Y., Sirota K.A. (2018): A novel photochemical vapor generator for ICP-MS determination of As, Bi, Hg, Sb, Se and Te. *Talanta*, 187: 370–378.
- Shafiq M., Qadir A., Ahmad S.R. (2019): Biofortification: A sustainable agronomic strategy to increase selenium content and antioxidant activity in garlic. *Applied Ecology and Environmental Research*, 17: 1685–1704.
- Shi Z., Pan P., Feng Y., Kan Z., Li Z., Wei F. (2017): Environmental water chemistry and possible correlation with Kaschin-Beck Disease (KBD) in northwestern Sichuan, China. *Environment International*, 99: 282–292.
- Skalnaya M.G., Tinkov A.A., Prakash N.T., Ajsuvakova O.P., Jaiswal S.K., Prakash R., Grabeklis A.R., Kirichuk A.A., Zhuchenko N.A., Regula J., Zhang F., Guo X., Skalny A.V. (2019): Selenium and other elements in wheat (*Triticum aestivum*) and wheat bread from a seleniferous area. *Biological Trace Element Research*, 192: 10–17.

<https://doi.org/10.17221/79/2024-HORTSCI>

- Subramanian M.S., Nandagopal M.G., Amin N.S., Thilakavathy K., Joseph N. (2020): Prevailing knowledge on the bioavailability and biological activities of sulphur compounds from alliums: A potential drug candidate. *Molecules*, 25: 4111.
- Tian M., Xu X., Liu Y., Xie L., Pan S. (2016): Effect of Se treatment on glucosinolate metabolism and health-promoting compounds in the broccoli sprouts of three cultivars. *Food Chemistry*, 190: 374–380.
- Turati F., Guercio V., Pelucchi C., La Vecchia C., Galeone C. (2014): Colorectal cancer and adenomatous polyps in relation to allium vegetables intake: A meta-analysis of observational studies. *Molecular Nutrition & Food Research*, 58: 1907–1914.
- Turati F., Pelucchi C., Guercio V., La Vecchia C., Galeone C. (2015): Allium vegetable intake and gastric cancer: A case-control study and meta-analysis. *Molecular Nutrition & Food Research*, 59: 171–179.
- Wang Y.D., Wang X., Ngai S.M., Wong Y.S. (2013): Comparative proteomics analysis of selenium responses in selenium-enriched rice grains. *Journal of Proteome Research*, 12: 808–820.
- Winkel L.H., Johnson C.A., Lenz M., Grundl T., Leupin O.X., Amini M., Charlet L. (2012): Environmental selenium research: From microscopic processes to global understanding. *Environmental Science & Technology*, 46: 571–579.
- Wu Z., Banuelos G.S., Lin Z.Q., Liu Y., Yuan L., Yin X., Li M. (2015): Biofortification and phytoremediation of selenium in China. *Frontiers in Plant Science*, 6: 136.
- Zahedi S.M., Abdelrahman M., Hosseini M.S., Hoveizeh N.F., Tran L.P. (2019): Alleviation of the effect of salinity on growth and yield of strawberry by foliar spray of selenium-nanoparticles. *Environmental Pollution*, 253: 246–258.
- Zhang H.J., Zhang N., Yang R.C., Wang L., Sun Q.Q., Li D.B., Cao Y.Y., Weeda S., Zhao B., Ren S., Guo Y.D. (2014): Melatonin promotes seed germination under high salinity by regulating antioxidant systems, ABA and GA₄ interaction in cucumber (*Cucumis sativus* L.). *Journal of Pineal Research* 57: 269–279.
- Zhang L., Tian L.H., Zhao J.F., Song Y., Zhang C.J., Guo Y. (2009): Identification of an apoplastic protein involved in the initial phase of salt stress response in rice root by two-dimensional electrophoresis. *Plant Physiology*, 149: 916–928.
- Zhao M., Luo T., Zhao Z., Rong H., Zhao G., Lei L. (2021): Food chemistry of selenium and controversial roles of selenium in affecting blood cholesterol concentrations. *Journal of Agricultural and Food Chemistry*, 69: 4935–4945.
- Zhu Y.G., Pilon-Smits E.A., Zhao F.J., Williams P.N., Meharg A.A. (2009): Selenium in higher plants: Understanding mechanisms for biofortification and phytoremediation. *Trends in Plant Science*, 14: 436–442.
- Zhu Z., Chen Y., Shi G., Zhang X. (2017): Selenium delays tomato fruit ripening by inhibiting ethylene biosynthesis and enhancing the antioxidant defense system. *Food Chemistry*, 219: 179–184.

Received: April 29, 2024

Accepted: June 3, 2025

Published online: January 26, 2026