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RESEARCH ARTICLE

The positive function of selenium supplementation on reducing nitrate accumulation in hydroponic lettuce (*Lactuca sativa* L.)

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Abstract

High nitrate (NO_3^-) in vegetables, especially in leaf vegetables poses threaten to human health. Selenium (Se) is an important element for maintaining human health, and exogenous Se application during vegetable and crop production is an effective way to prevent Se deficiency in human bodies. Exogenous Se shows positive function on plant growth and nutrition uptake under abiotic and/or biotic stresses. However, the influence of exogenous Se on NO_3^- accumulation in hydroponic vegetables is still not clear. In the present study, hydroponic lettuce plants were subjected to six different concentrations (0, 0.1, 0.5, 5, 10 and 50 μmol L^{-1}) of Se as Na_2SeO_3. The effects of Se on NO_3^- content, plant growth, and photosynthetic capacity of lettuce (*Lactuca sativa* L.) were investigated. The results showed that exogenous Se positively decreased NO_3^- content and this effect was concentration-dependent. The lowest NO_3^- content was obtained under 0.5 μmol L^{-1} Se treatment. The application of Se enhanced photosynthetic capacity by increasing the photosynthesis rate (P_n), stomatal conductance (C_s) and the transpiration efficiency (T_r) of lettuce. The transportation and assimilation of NO_3^- and activities of nitrogen metabolism enzymes in lettuce were also analysed. The NO_3^- efflux in the lettuce roots was markedly increased, but the efflux of NO_3^- from the root to the shoot was decreased after treated with exogenous Se. Moreover, Se application stimulated NO_3^- assimilation by enhancing nitrate reductase (NR), nitrite reductase (NiR), glutamine synthetase (GS) and glutamate synthase enzyme (GOGAT) activities. These results provide direct evidence that exogenous Se shows positive function on decreasing NO_3^- accumulation *via* regulating the transport and enhancing activities of nitrogen metabolism enzyme in lettuce. We suggested that 0.5 μmol L^{-1} Se can be used to reduce NO_3^- content and increase hydroponic lettuce yield.

Keywords: selenium, NO_3^-, nitrogen metabolism enzyme, SIET, photosynthetic performance, lettuce

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1. Introduction

Lettuce (*Lactuca sativa* L.) is one of the major greenhouse-grown vegetables and consumed worldwide. Nitrate (NO_3^-) as one of the most important nitrogen sources for plant growth and development, is widely used in vegetable production, especially in hydroponic grow system. Lettuce is a hyperaccumulator of NO_3^- and has a great ability to accumulate NO_3^- in their leaves (Eysinga and Meijs 1985). In the human body, approximately 80% of the daily intake NO_3^- stems from vegetables (Santamaria 2006). Studies have indicated that consumption vegetables with high NO_3^- content poses threaten to human health because besides leading to methemoglobinemia, ingested NO_3^- could be converted to nitrite, a toxic carcinogen, causing cancers and methemoglobinemia (Wright and Davison 1964; Prasad and Chetty 2008). European Commission has imposed a maximum limit on NO_3^- concentration in lettuce for human consumption of 4 500 mg NO_3^- kg^{-1} fresh weight (FW) (UKMAFF 1997).

Since 1957, selenium (Se) has been demonstrated as an essential trace element for maintaining animal and human health (Schwarz and Foltz 1957). Since Se is a vital important component of the glutathione peroxidase, selenoprotein, and tetraiodothyronine 5-deiodinase (Papp *et al*. 2007; Messaoudi *et al*. 2009). Se deficiency not only disturbs metabolism in the human body but also increases the risk of cancers (Diwadkar-Navsariwala *et al*. 2006). However, Se deficiency in the diet is a worldwide problem, especially in China, the UK, Eastern Europe and Australia (Pedrero *et al*. 2006). This is due to the low concentrations of Se in plant tissues as the consequence of low bioavailability of Se in some soils (Hawkesford and Zhao 2007). Previous studies proved that exogenous application of Se could substantially increase Se concentration in crops, vegetables, and fruits (Cartes *et al*. 2005; Hartikainen 2005). Elevating Se content in plant food can effectively avoid and prevent Se deficiency in humans. Thus, increasing Se concentration and reducing NO_3^- content in crops arouse widespread concern for both researchers and farmers (Bian *et al*. 2015, 2016; Cartes *et al*. 2005; Hartikainen 2005).

In plants, the higher uptake rate of NO_3^- than its metabolic rate leads to excessive NO_3^- accumulation. Previous studies found that exogenous Se could affect nitrogen metabolism in plants and this effect depends on the application level of Se (Nowak *et al*. 2004; Rios *et al*. 2010). Exogenous Se affects uptake and translocation of some mineral elements, such as inhibiting cadmium and Na^+ accumulation, and promoting K^+ uptake (Sun *et al*. 2013). However, less is known about the effect of exogenous Se on NO_3^- uptake and translocation in plants.

Exogenous Se application could enhance photosynthetic capacity of plants, especially under different biotic stress, such as cold, drought and salt stress (Feng *et al*. 2013; Zhang *et al*. 2014). In plants, photosynthetic capacity affects NO_3^- metabolism and accumulation. The NO_3^- reduction positively correlates with photosynthetic products, e.g., carbohydrates (Bian *et al*. 2016). Since these products can provide carbon skeleton and energy for nitrogen reduction in plants (Champigny 1995). Therefore, we hypothesize that besides inducing activities of nitrogen metabolism enzymes, exogenous Se may positively promote NO_3^- reduction in plants through maintaining high photosynthetic capacity and concomitantly regulating NO_3^- uptake and translocation in plants. Therefore, the aims of this study are to investigate the effects of exogenous Se on NO_3^- uptake and transport, assimilation enzyme activities and photosynthetic capacity of lettuce grown hydroponically. The results of this study will aid in producing high-quality vegetables in greenhouse.

2. Materials and methods

2.1. Plant materials and treatments

Seeds of lettuce (Rijk Zwaan, De Lier, the Netherlands) were washed and soaked for 4 h using distilled water, then germinated in the dark at 25°C. To avoid root damage during sample preparation, these germinated seeds were sown in sponge dices (3 cm×1.5 cm×1.5 cm) with a density of one seed per disc before grown in a controlled growth chamber. The day/night temperature, light intensity, photoperiod, humidity, and CO_2 levels in the growth chamber was 25°C/(18±1)°C, 200 μmol m^{-1} s^{-1}, 12 h, (75±5)%, 400 μmol mol^{-1}, respectively. Freshly prepared nutrition solution (Hoagland and Arnon 1950) was added daily to maintain the moistness of the substrate and to supply nutrition for plants. After the end of the dark period at 21 d, plants with similar size were randomly transplanted into 25-L containers of Hoagland solution (pH (6.8±0.2), (1.9±0.1) dS m^{-1}) with six concentrations of Se (0, 0.1, 0.5, 5, 10 and 50 μmol L^{-1}) applied as sodium selenium (Na_2SeO_3). There were three replicates with a total 48 plants per treatment. The nutrient solutions were replaced with fresh solution every 5 d throughout this experiment.

2.2. Measurement of plant growth

After Se treatment for 30 d, three plants were randomly harvested from each treatment and cut at the thypocotyls to calculate shoot and root FW. The root length was determined according to the method of Yang *et al*. (2016). Shoots and roots were then dried at 75°C for 3 d in an oven to determine the dry weight (DW) of shoots and roots.

2.3. Measurement of photosynthetic parameters

After Se treatment for 30 d, six plants (two plants per replicate, three replicates per treatment) were randomly selected from each treatment. The second youngest, fully expanded leaf was used to monitor photosynthetic capacity