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RESEARCH ARTICLE

Effects of selenium and sulfur on antioxidants and physiological parameters of garlic plants during senescence

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Abstract

A hydroponic study was conducted to determine the effects of selenium (Se: 0, 3, 6 μmol L^{-1}) on senescence-related oxidative stress in garlic plants grown under two sulfur (S) levels. We evaluated the yields of plants harvested at 160 and 200 days after sowing. Plants grown under a low Se dose (0.3 μmol L^{-1}) at low S level showed higher yields (12.0% increase in fresh weight yield, 13.7% increase in dry weight yield) than the controls, despite a decrease in chlorophyll concentration. Compared with control plants, the Se-treated plants showed lower levels of lipid peroxidation. The Se-treated plants also showed higher activities of glutathione peroxidase and catalase, but lower superoxide dismutase activities. Changes in F_v/F_m values and proline contents were affected more strongly by S than by Se. On the basis of our results, we can conclude that Se plays a key role in the antioxidant systems in garlic seedlings. It delays senescence by alleviating the peroxide stress, but it can be toxic at high levels. A high S level may increase tolerance to high Se concentrations through reducing Se accumulation in plants.

Keywords: selenium, sulfur, garlic, antioxidant activity, oxidative stress, senescence

1. Introduction

Selenium (Se) is an essential micronutrient for animals, microorganisms, and some other eukaryotes. It plays a key role in antioxidant systems and in hormone balance in human and animal cells (Rotruck *et al*. 1973; Berry *et al*. 1991; Pallud *et al*. 1997; Ellis and Salt 2003). The protective role of Se is supported by numerous epidemiological studies conducted in China and abroad, as well as in preclinical and clinical investigations, as reviewed elsewhere (El-Bayoumy 2001, 2004; Medina *et al*. 2001; Ip *et al*. 2002; Sinha and El-Bayoumy 2004). Rotruck *et al*. (1973) identified Se as an essential component of the antioxidant enzyme glutathione peroxidase (GSH-Px), which scavenges hydrogen peroxide and lipid and phospholipid hydroperoxides in human cells. Subsequently, Se has been identified as essential component of more than 30 mammalian selenoproteins or selenoenzymes (Brown and Arthur 2001; Rayman 2002).

There are increasing evidences that Se may also have beneficial effects on higher plants, challenging the opinion that higher plants do not need Se (Hartikainen 2005; Filek

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et al. 2008, 2009; Pedrero *et al*. 2008). Zembala *et al*. (2010) demonstrated that Se promoted the growth of rape and wheat seedlings, and ameliorated stress symptoms in cadmium (Cd)-stressed plants. Se tended to counterbalance the Cd-induced changes in nutrient contents, it also reduced lipid peroxidation and improved cell membrane stability. Selenite application was reported to increase the glucose concentration in leaves of bean plants, to enhance the growth of coffee plants, and to increase the concentration of soluble sugars and caffeine in their leaves (Mazzafera 1998).

Garlic (A*llium sativum* L.) is one of the world's most popular vegetables. It has a high nutritional value, and it is used in Asiatic and Western cultures as a prophylactic and therapeutic medical agent (Song and Milner 2001). As early as 1550 B.C.E., Egyptians had realized the benefits of garlic as a remedy for various diseases (El-Bayoumy *et al*. 2006). Recent research has shown that garlic has anticarcinogenic properties. Many epidemiological studies have supported the protective role of garlic and related species against the development of certain human cancers (Cai *et al*. 1994,1995; Dietz *et al*. 2003, 2004). The sulfur (S) compounds in garlic are responsible for its bioactivity (Ge *et al*. 1996; Francesconi and Sperling 2005). S and Se, which occur in Group VI of the periodic table along with oxygen and tellurium, have related nuclear configurations and electron distributions. Some studies have shown that structurally distinct organo-Se compounds are superior to their corresponding sulfur analogs in cancer chemoprevention (Zembala *et al*. 2010). The antioxidant effect of high Se garlic has been studied extensively (El-Bayoumy *et al*. 2006, 2011; Tsubura *et al*. 2011), but little is known about the effects of Se on the antioxidant system in garlic. The aim of this study was to investigate the effect of Se on the antioxidant system (glutathione peroxidase, GSH-Px; superoxide dismutase, SOD; and lipid peroxidation) in garlic plants grown under different S levels. We also analyzed catalase (CAT) activity, proline content, chlorophyll content, chlorophyll fluorescence, and plant yields to assess the effects of S and Se on the growth of garlic plants.

2. Results

Garlic plants were harvested twice: the first yield (FY) refers to the harvest at 160 days after sowing, and the second yield (SY) refers to the harvest at 200 days after sowing. At the lower S level S_1, the first yield was significantly higher for plants supplemented with the low Se level (Se_1) than for control plants (Table 1). However, at the first yield the higher dosage of Se (Se_2) had a significant negative effect on fresh weight and dry weight. Similar results were obtained at the second yield. Under the high S concentration (S_2), both the fresh weight and dry weight at the first and second yields increased with increasing Se concentrations. The highest fresh and dry weights were obtained in the Se_2 treatments (first yield: fresh weight (FW) yield increase of 16.3%, dry weight (DW) yield increase of 18.6%; second yield: FW yield increase of 41.3%, DW yield increase of 25.5%).

We measured chlorophyll fluorescence to determine the effect of the Se dose on preventing photoinhibition (Table 2). Addition of Se did not affect maximal fluorescence (F_v/F_m) at the first yield. At the second yield, the F_v/F_m value was 20% higher in the S_1Se_1 treatment than in the other treatments. The reduction in the F_v/F_m was monitored in leaves of plants in all treatments at the first and second yields. At the first yield, the F_v/F_m values were higher in the low S treatments than in the high S treatments, but the opposite pattern was observed at the second harvest. The effects of S and Se on photosynthetic pigments differed between the different stages (Table 2). At both the first and second yields, the plants grown under high S dosages showed higher total chlorophyll concentrations than those of plants grown under low S dosages. At the second yield, all plants grown with Se-supplementation showed higher total chlorophyll contents than those of control plants. However, Se could not counteract the decrease in chlorophyll contents in senescing plants.

GSH-Px activity was higher in plants grown with Se

Table 1 Shoot fresh and dry weight of garlic plants grown under different sulfur (S) and selenium (Se) treatments

Treatment	Fresh weight (FW, g plant^{-1})			Dry weight (DW, g plant^{-1})		
	First yield	Second yield	Change (%)[1)]	First yield	Second yield	Change (%)[1)]
S_1Se_0	231.7±0.34 c	204.5±7.4 b	−12	18.8±0.28 b	26.2±0.62 b	+39
S_1Se_1	241.1±5.4 b	229.0±5.5 a	−5	20.3±0.46 a	29.8±1.07 a	+47
S_1Se_2	228.0±8.3 c	188.1±2.2 c	−18	17.6±0.25 c	20.9±0.25 e	+19
S_2Se_0	213.6±5.6 d	167.3±2.9 e	−23	16.7±0.44 d	18.8±0.33 f	+13
S_2Se_1	216.6±2.6 d	177.6±2.2 d	−18	17.1±0.21 cd	22.3±0.27 d	+30
S_2Se_2	248.4±1.0 a	236.4±3.8 a	−5	19.8±0.08 a	23.6±0.38 c	+19

[1)] Change (%)=(Second yield−First yield)/First yield
Values are means±SD (n=3). Means followed by the same letters did not significantly differ at P≤0.05 according to Duncan's multiple range test.
The same as below.