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Silicon alleviates oxidative damage of wheat plants in pots under drought

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Abstract

Drought-induced changes in oxidative damage to photosynthetic pigments, proteins and lipids, some enzyme activities and photosynthesis were investigated in wheat (*Triticum aestivum* L.) plants grown in pots applied with or without silicon under drought stress. Three treatments with three replicates were composed of ''CK'' (control, 2.11 mmol of sodium sulfate Kg^{-1}soil), ''DR'' (drought, 2.11 mmol of sodium sulfate Kg^{-1}soil) and ''DSi'' (drought + silicon, 2.11 mmol of sodium silicate Kg^{-1}soil). Drought stress was applied by maintaining 75% of relative water content in the ''CK'' soil and 50% of relative water content in the drought treatments (''DR'' and ''DSi'') for 12 days from jointing stage, after which the assays were performed on the recent fully expanded leaves. The results showed that application of silicon improved the water status of drought stressed plants. Compared with the non-silicon treatment, application of silicon increased the activities of some antioxidant enzymes: superoxide dismutase (SOD); catalase (CAT) and glutathione reductase (GR), the fatty acid unsaturation of lipids, and the contents of photosynthetic pigments and soluble proteins as well as total thiols under drought, whereas the content of hydrogen peroxide, activity of acid phospholipase (AP) and oxidative stress of proteins were decreased by applying silicon compared with those of non-silicon treatments under drought. The activities of glycolate oxidase (GO), peroxidase (POD) and ascorbate peroxidase (APX) showed no significant difference between ''DR'' and ''DSi''. In addition, application of silicon also increased the net CO_2 assimilation rate of wheat leaves under drought. It was suggested that the improvement of silicon on drought tolerance of wheat plants was associated with the increase of antioxidant defense abilities, therefore alleviating oxidative damage of cellular functional molecules induced by over produced reactive oxygen species (ROS) under drought and maintaining many physiological processes of stressed plants. The present work also suggested that silicon may be involved in metabolic or physiological activities in higher plants under drought, which coincided with previous studies in salt stressed plants.
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Keywords: Wheat (*Triticum aestivum* L.); Drought; Silicon; Oxidative damage

1. Introduction

Drought stress usually causes a decrease in crop production. It inhibits the photosynthesis of plants, causes changes of chlorophyll contents and components and damage of photosynthetic apparatus [1]. It also inhibits the photochemical activities and decreases the activities of enzymes in the Calvin cycle [2]. One of the important

Abbreviations: AP, acid phospholipase; APX, ascorbate peroxidase; CAT, catalase; DTPA, diethylenetriaminepentaacetic acid; EDTA, ethylene diamine tetraacetic acid; GO, glycolate oxidase; GR, glutathione reductase; GSH, reduced glutathione; GSSG, oxidized glutathione; NADP, oxidized nicotinamide adenine dinucleotide phosphate; NADPH, reduced nicotinamide adenine dinucleotide phosphate; NBT, nitroblue tetrazolium; POD, peroxidase; ROS, reactive oxygen species; SOD, superoxide dismutase

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reasons that environmental stress inhibits the growth and photosynthetic abilities of plants is the breakdown of the balance between the production of reactive oxygen species (ROS) and the antioxidant defense [1], causing accumulation of ROS which induces oxidative stress to proteins, membrane lipids and other cellular components [1,3].

The antioxidant defense system in the plant cell includes both enzymatic [superoxide dismutase (SOD, EC 1.15.1.1), catalase (CAT, EC 1.11.1.6), POD peroxidase (POD, EC 1.11.1.7), ascorbate peroxidase (APX, EC 1.11.1.11), glutathione reductase (GR, EC 1.6.4.2), etc.] and non-enzymatic constituents [cystein (Cys), reduced glutathione (GSH), ascorbic acid (Asc), etc.]. SOD removes superoxide anion free radicals accompanying with formation of hydrogen peroxide (H_2O_2), which is then detoxified by CAT and POD [4]. In the ascorbate–glutathione cycle, APX reduces H_2O_2 using ascorbate as an electron donor. Oxidized ascorbate is then reduced by GSH generated from GSSG catalyzed by GR at the expense of NADPH [5]. In environmental stresses conditions such as drought, high activities of antioxidant enzymes and high contents of non-enzymatic constituents are important for plants to tolerate stresses.

Silicon has not yet been considered a generally essential element for higher plants, partly because its roles in plant biology are poorly understood [6–8], and our knowledge of silicon metabolism in higher plants lags behind that in other organisms (such as diatoms) [9]. However, numerous studies have demonstrated that silicon is one of the important elements of plants, and plays an important role in tolerance of plants to environmental stresses [6,10]. Relatively more attention has been paid to roles of silicon in controlling disease [11,12] and pest [13,14], alleviation in toxicity of heavy metal [15,16] and salt stress [7,8,17].

With respect to drought stress, relevant work is limited. Agarie et al. [18] reported that silicon could decrease the transpiration rate and membrane permeability of rice (*Oryza sativa* L.) under water deficit induced by polyethylene glycerol. In sorghum (*Sorghum bicolor* Moench), plants grown in pots applied with silicon had higher relative water content and dry materials [19]. Lux et al. [20] believed that high root endodermal silicification might be related to a higher drought resistance of sorghum. In our previous work, we have also observed that wheat (*Triticum aestivum* L.) plants applied with silicon could maintain better water status and higher content of dry materials compared with non-silicon treatment under drought [21]. These studies show that application of silicon is useful for drought tolerance improvement of plants. However, the mechanism remains unclear, e.g. whether silicon is involved in physiological responses of plants to drought stress and how it is involved, etc. In this work, the effects of silicon on the oxidative stress of wheat plants in pots under drought are investigated, which maybe help elucidate the physiological mechanism of silicon in improvement of drought tolerance of plants.

2. Materials and methods

2.1. Plant materials

After sterilization of the surface with 1% sodium hypochlorite for 10 min and germinated for 24 h, seeds of the wheat (*Triticum aestivum* L. Longchun 8139, provided by the Institute of Agriculture, Dingxi County, Gansu Province, PR China) were sown in plastic pots (45 cm × 32 cm × 13 cm) each filled with 16.95 Kg soil. Before sowing, the soil was mingled sufficiently, divided into several parts each with 16.95 Kg weight, and then sodium silicate or sodium sulfate (in order to supplement Na introduced by application of sodium silicate) was added (Kg^{-1}soil): "CK" (control) and "DR" (drought) treatments, 2.11 mmol of sodium sulfate; "DSi" (drought + Si) treatment, 2.11 mmol of sodium silicate. Each treatment was replicated three times and the experiment was carried out as a complete randomized block design. After emergence, the seedlings were thinned to fifty plants per pot and watered every 3–4 days to maintain 75% of relative water content of the soil until jointing stage. From then on, the seedlings were watered every 1–2 days to maintain 75% of relative water content in the CK soil and 50% of relative water content in the drought treatments ("DR" and "DSi"). Drought treatment lasted 12 days, and the recent fully expanded leaves were collected at about 9 o'clock and frozen in liquid N_2 immediately until analysis. The water status, photosynthesis and pigment content of leaves were assayed on fresh materials. The experiment was conducted in the greenhouse of the campus of Lanzhou University.

2.2. Analyses of soil properties

Soil samples were air dried, ground and passed through a 1 mm mesh stainless steel sieve for properties analysis. The pH of the soils was measured with a glass electrode (soil/water, 1:1), organic matter by the method of Mebius [22], total nitrogen (N) by the Kjeldahl digestion procedure (salicylic acid modification) [23], available phosphorous (P) by the method of Olsen et al. [24], potassium extracted by Li's method [25] and analyzed by atomic absorption spectrophotometry. Deionized water was used to extract soil (1:5 ratio) for available Si and then measured colorimetrically [25]. Some chemical properties of the soil were shown in Table 1.

2.3. Leaf water status

The leaf water potential was measured with the pressure chamber method [26]. The water content was determined by drying the leaves at 80 °C for 48 h and calculated as: water content (%) = (fresh weight − dry weight)/fresh weight × 100.

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