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Potassium silicate alleviates deleterious effects of salinity on two strawberry cultivars grown under soilless pot culture

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ABSTRACT

We aimed to understand the impact of two potassium silicate (K_2O_3Si) levels (1000 and 1500 ppm) on vegetative growth, physiological parameters and fruit yield of two strawberry cultivars under saline (50 mM NaCl) and non-saline conditions during 2014 and 2015. Supplementary Si counteracted the negative effects of salinity on dry matter, leaf area, and root length and volume. Leaf relative water content and chlorophylls content were also improved by application of K_2O_3Si under salinity. NaCl imposed oxidative damages to cell manifested as decreased membrane stability index (MSI) as well as increased malondialdehyde (MDA) and H_2O_2 content. Higher MSI as well as lower MDA and H_2O_2 in Si-supplied plants representing a systemic palliative effect of Si to salinity induced cellular injuries. Salinity led to an increase of proline and soluble carbohydrates suggesting a physiological osmotic strategy to increase salt tolerance. Reduction of proline content further supports the beneficial roles of Si in alleviation of the adverse effects of salt stress. Significant increase in activity of peroxidase (POD) and superoxide dismutase (SOD) enzymes was only observed during 2015 under saline conditions. The induction of antioxidant enzymes coincided with a decrease in concentration of MDA and H_2O_2. Salinity decreased fruit yield in both cultivars with a drastic reduction in Paros. K_2O_3Si nutrition could recover yield loss with almost a 50% increase in fruit weight per plant. Overall, our results suggest that drenching potassium silicate in the nutrient solution of strawberry plants could be considered as a routine strategy to maintain strawberry growth and yield under salinity.

1. Introduction

Strawberry (*Fragaria* × *ananassa* Duch.) is among the most widely cultivated and commercially valuable horticultural crops in the world. The high demand for fresh and processed fruit has led to a considerable increase in production of strawberry with an annual production of 7.73 million tons from 361.662 ha (FAO, 2013) of strawberry fields. Being a nutritionally important crop, strawberry is a relevant source of bioactive compounds and phytochemicals including vitamin C, anthocyanin, flavonoids and other phenolic compounds, which are also powerful natural antioxidants (Giampieri et al., 2012).

Salinity is one of the most critical abiotic stresses impairing the productivity of many horticultural crops. There are over 800 million hectares of salt affected cultivated land worldwide (Munns and Tester, 2008). Soil degradation caused by salinity is major challenge globally and the problems of saline soil and water have serious implications in irrigated agricultural systems (Qadir et al., 2008). Soil salinization is a phenomenon that occurs naturally or through agricultural practices. Among soluble salts, NaCl is the most soluble and dominant salt with adverse effects on various morphological, physiological and microbiological and molecular aspects at cell and whole plant level (Pessarakli and Szabolcs, 2010).

Strawberry is sensitive to NaCl salinity and NaCl-induced salinity adversely affects plant growth and fruit production (Garriga et al., 2015). Salt stress generally impairs the vegetative growth of strawberry and causes leaf necrosis and premature senescence with consequent reduction of the photosynthetic leaf area (Keutgen and Pawelzik, 2009). Depending on period of exposure and degree of salinity, experimental system and plant phenological stage, variation in responses to NaCl have been found in strawberry cultivars (Cardenosa et al., 2015). Other than overall growth

Abbreviations: MDA, malondialdehyde; RWC, relative water content; MSI, membrane stability index; LAI, leaf area index; SOD, superoxide dismutase; POD, peroxidase; STI, salinity tolerance index.

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and development retardants, the major influences of NaCl salinity on strawberry include accelerating leaf necrosis and senescence (Christou et al., 2013), reducing transpiration fluxes (Christou et al., 2013; Orsini et al., 2012), diminishing total chlorophyll content and photosynthetic capability (Kaya et al., 2002; Rahimi et al., 2011), depletion of carbohydrates and protein resources (Keutgen and Keutgen, 2003; Saied et al., 2005) and decreasing leaf relative water content (Garriga et al., 2015; Jamali et al., 2015). Triggered lipid peroxidation and cell membrane permeability (Christou et al., 2013; Kaya et al., 2002), increased proline (Rahimi et al., 2011) and H_2O_2 content (Christou et al., 2013; Jamali et al., 2015), control of stomatal response (Christou et al., 2013; Orsini et al., 2012), unbalanced nutrients uptake (Jamali et al., 2015; Keutgen and Pawelzik, 2009) and impaired nitrogen assimilation (Cardenosa et al., 2015) are other consequences of salinity stress in strawberry. Altogether, these responses impair final fruit productivity and plant performance in strawberry (Awang and Atherton, 1995; Garriga et al., 2015; Kaya et al., 2002; Orsini et al., 2012).

Silicon (Si) is the second most abundant element in the lithosphere which is ubiquitously present in the environment (Broadley et al., 2002). Silicon is still not recognized as an essential element for plant growth and development; however, due to proven effects in improving pest (Han et al., 2015) and disease (Van Bockhaven et al., 2012) controls, enhancing abiotic stress tolerance (Eraslan et al., 2008; Haghighi and Pessarakli, 2013), and increasing photosynthetic capacity and yield (Guntzer et al., 2011) in various plant species, it is usually classified under the beneficial element category. Despite high abundance of silicon, it is never present in a free form in soil and is usually taken up by the plant as monosilicic acid ($Si(OH)_4$) (Ma and Yamaji, 2006). Exact mechanism of Si involvement in metabolic or physiological process of plants has not yet been elucidated (Guntzer et al., 2011). More explored, however, have been the influences of Si in ameliorating adverse effects of salinity and its probable mechanisms of action in some halophyte and glycophyte species including tomato (Haghighi and Pessarakli, 2013), grapevine (Soylemezoglu et al., 2009) zucchini (Savvas et al., 2009), soybean (Lee et al., 2010) and strawberry (Wang and Galletta, 1998). However, there is still a lack of information available regarding the role of hydroponically supplied Si in ameliorating salinity in terms of antioxidant defense system and cell damage of strawberries.

Therefore, the present work framed to study the influence of salinity in the presence or absence of potassium silicate on vegetative growth attributes, chlorophylls content, relative leaf water content, cellular damage effects (MSI, H_2O_2 and MDA), antioxidative enzymes (peroxidase and superoxide dismutase) activities and some other physiological parameters (proline and carbohydrate) in Kurdistan and Paros strawberry cultivars. This can provide a basis for attempting new strategies for diminishing the salinity damages and establishing a functional link between silicon function, morpho-physiological response and salt stress tolerance in strawberry plants.

2. Materials and methods

2.1. Plant growth and treatments

To study the influence of potassium silicate and salinity, a two-year experiment on the same strawberry plants was carried out in the research greenhouse of University of Kurdistan (temperature 14–36 °C, relative humidity 60–70% and photosynthetically active radiation 650–1200 mol m^{-2} s^{-1}) located at 1420 m above MSL, Iran (35°16′51.4“N 46°59′46.5“E). In the first season, the experiment started from March and continued until October 2014. During autumn and winter, the plants were kept in a non-heated green house and plant growth restricted by low temperature. The experiment in the second growing season started from mid-March and continued until mid-June 201. Uniformly well-grown plants of Paros and Kurdistan cultivars were planted individually into 7-L volume plastic pots. All pots were filled with a mixture of commercial perlite and coco peat (in volume proportion of 1:1). For initial establishment, six plants per replication per treatment were used and plants manually received complete Hoagland solution (Hoagland and Arnon, 1950) (EC 1.7 dS m^{-1}, pH 6.0–6.5) for 4 week and were uniformly irrigated on a daily basis. Salinity stress and potassium silicate treatments were initiated 30 days after transplanting when plants had 5–6 fully expanded leaves. Treatments included control: no NaCl and no potassium silicate, SK1: 1000 ppm potassium silicate, SK2: 1500 ppm potassium silicate, NaCL: 50 mM NaCl, NaCl + SK1, NaCl + SK2. For salinity, NaCl was added to the nutrient solution and plants were fed with this solution on an alternate day basis. After one week, stressed strawberry plants received potassium silicate once a week. Two months after experiment initiation, five plants were randomly selected from each treatment for oxidative response and morpho-physiological evaluation. For all analysis requiring leaf material, young fully expanded leaves were used.

2.2. Yield and vegetative parameters assessment

Fruit yield was determined by harvesting all produced fruits from each treatment and given in grams per plant. The root length and volume were measured by Vernier caliper and water-filled beaker methods, respectively. The leaf area per leaf (cm^2 per leaf) and leaf area per plant (cm^2 per plant) were measured by IRGA area meter (Hoddesdon Inc, England). To measure the dry mass, the plants were first separated into leaf, root, petiole and crown parts. Samples were then dried in a programmable oven (UFP800, Memmert, Germany) at 75 °C for 72 h. Thereafter, dry weights and its attributes were measured using a digital balance by unitary method.

2.3. Physiological parameters

Relative water content (RWC) was evaluated on young, fully expanded leaves. It was estimated gravimetrically according to the method of Galmes et al. (2007) based on the following equation: $LRWC\ (\%) = [(FW-DW)/(TW-DW)] \times 100$ where FW, TW and DW represent fresh, turgid and dry weight, respectively. Leaf membrane stability index (MSI) was measured according to the protocol of Sairam (1994). First, small leaf discs were cut, weighed (0.1 g) and kept in 10 mL of double distilled water at 40 °C for 30 min. After incubation, the electrical conductivity (EC) of the water containing the sample was measured (C1) using conductivity bridge (RC-16C Model, Alpha Metals, USA). In the second step, same samples were incubated at 100 °C for 10 min and their second electrical conductivity was measured (C2). MSI was then calculated using the following formula: $MSI\% = [1 - (C1/C2)] \times 100$.

Total soluble proteins was extracted by resuspending 200 mg grinded plant samples in 2 mL of protein extraction buffer containing 50 mM Tris-HCl (pH 8.0), 0.5 M NaCl, 2 mM EDTA, and 4% polyvinylpyrrolidone (PVP). The resulting homogenates were then centrifuged at 10,000 × *g* for 10 min at 4 °C and protein concentration was determined according to Bradford assay (Bradford, 1976). To determine the soluble carbohydrates, 500 mg of leaf tissue was homogenized in 5 mL of 95% ethanol. Then 100 μL of ice-cold ethanolic extract was mixed with 3 mL of anthrone solution (150 mg anthrone dissolved in 100 mL of 72% sulphuric acid, w/w). The samples were then incubated in a water bath for 10 min and the optical density was measured at 625 nm (OD_{625}). Consequently, contents of soluble carbohydrates were measured by using glucose