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Silicon foliar application on nutrition and growth of *Phalaenopsis* and *Dendrobium* orchids

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ABSTRACT

Foliar application of silicon can be beneficial to orchid growth, but it may also impair growth depending on the source and solution concentration. Due to the lack of information on silicon toxicity in long-term orchid nutrition, experiment with two different orchid species, *Phalaenopsis* Golden Peoker and *Dendrobium* Valentine, were performed. The plants were grown in plastic trays with dry *Sphagnum* in a greenhouse, being fed the nutrient solution without silicon in the first six months. After that, the plants were transplanted to individual plastic vessels (0.9 L). The treatments followed a completely randomized design with a 5 × 3 factorial consisting of five Si concentrations (control, 14.3, 28.6, 42.9 and 57.2 mmol L^{-1}) and three sources (monosilicic acid, potassium silicate, and potassium silicate and sodium silicate mixture), with five replicates. After 18 months of Si foliar application, the Si, C, N, P, K, Ca, Mg and S levels, lignin content and biometric variables were determined for both species. The application of 27 and 16 mmol L^{-1} Si (potassium silicate and monosilicic acid) resulted in the highest values for the evaluated biometric parameters for *Phalaenopsis* and *Dendrobium*, respectively. The results suggest that silicon foliar application affected nutrient absorption and green color index of *Phalaenopsis* and *Dendrobium*, and the lignin content of *Phalaenopsis*. Application of concentrations greater than 39 and 18 mmol L^{-1} Si over 18 months was toxic to *Phalaenopsis* and *Dendrobium,* respectively, since the orchid dry matter decreased by 10% (critical level due to toxicity). Applying increasing concentrations of Si sources decreased the C:N:P stoichiometric ratio of orchids.

1. Introduction

There are several studies on orchid nutrition and fertilization in the literature (Naik et al., 2009; Wang and Chang, 2017) because orchid farming represents one of the most economically important activities of the global nursery industry (Teixeira da Silva, 2013). However, to our knowledge, there are no reports on the application of Si during the entire vegetative cycle.

In plant metabolism, silicon (Si) is involved in the synthesis of lignin, increasing tissue stiffness (Epstein, 1999), but, it is not known how excess Si would affect orchid growth.

Recent study in the literature correlated Si to the C:N:P stoichiometric change in grass leaves (Schaller et al., 2012), which may imply that organic compounds are partially replaced by Si compounds in plant tissue when Si is available to the plant, reinforcing the importance of Si. However, this relationship has not been investigated for perennial plants such as orchids.

There are report on *Phalaenopsis* orchids cultivated *in vitro* indicating growth benefit when Si is present in the culture medium (Zhou, 1995). However, Si may decrease plant growth under certain cultivation conditions as reported by Soares et al. (2008) for orchids (*Hadrolaelia*) while using sodium silicate as Si source during the acclimatization phase (8 months).

Also in Maize, Si in excess forms a thick silicate layer below the cuticle on the leaf epidermis (Kochanová et al., 2014) that may reduce plant gas exchange and biomass accumulation without causing oxidative stress. Therefore, unlike other toxicity stresses, excess Si may not trigger an increase of reactive oxygen resulting in oxidation of organic compounds such as proteins and lipids, inducing membrane damage and extravasation of the cytosol to the apparent free space of the cell, causing cell death (Fridovich, 1986; Marschner, 1995).

Other studies on Si are restricted to *in vitro* orchid cultivation (Sivanesan and Park, 2014) or the initial phase during the first month of plant growth (*Phalaenopsis* hybrids) (Vendrame et al., 2010). Furthermore, there are no reports on Si foliar application during the entire vegetative cycle that can last up to 18 months depending on the growth environment.

It is important to study not only the benefits of silicon but also its

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possible detrimental effect on plants that absorb but do not accumulate Si such as orchids to improve the knowledge on the role that foliar Si plays on the growth of ornamental plants.

It has been hypothesized that Si *via* foliar applications can benefit the orchids, but excess can diminish nutrient absorption and plant growth without altering the leakage of cellular electrolytes and lignin contents depending on the Si source and solution concentration.

Therefore, the objective of the present study was to evaluate the response of epiphytic orchids to silicon foliar application from various sources each at several concentrations during the growth phase, from seedlings until pre-flowering.

2. Material and methods

The experiment was carried out in an orchid greenhouse located in Itapolis, São Paulo, Brazil. The used orchids, *Phalaenopsis* Golden Peoker and *Dendrobium* Valentine seedlings, were obtained *via in vitro* propagation and acclimatized in plastic trays filled with dry *Sphagnum* substrate. In the first six months, the plants were fertirrigated with the complete nutrient solution of Sarruge (1975) without Si, biweekly. Then, the seedlings were transplanted individually into black polyethylene vessels (upper diameter: 13 cm, lower diameter: 8.4 cm, height: 10.6 cm) with 0.9 L volume.

The nutrient concentrations (mg L^{-1}) in the solution was: 225 N; 31 P; 234 K; 200 Ca; 48 Mg; 64 S; 0.5 B; 0.5 Mn; 0.05 Zn; 0.02 Cu; 0.01 Mo; 5 Fe (Sarruge, 1975).

The plants were kept in a greenhouse with average Photosynthetic Photon Flux Density of 300 μmol m^{-2}·s^{-1} at noon, and maximum and minimum temperatures of 34 and 15 °C, respectively. The pots were filled with a layer of expanded clay at the bottom (25% of the total volume) and with a 2:1 (v/v) mixture of pinus bark and charcoal medium, and placed on hanging tables at a height of 0.65 m. The position of the pots was randomly changed after each treatment application, every 15 day.

The plants were irrigated twice and three times a week in the winter and summer, respectively, with 100 mL of distilled water (pH = 6.8) per pot. The complete nutrient solution of Sarruge (1975) was applied separately in the substrate *via* fertirrigation, once a week.

The silicon was applied *via* foliar to two orchid species, the *Phalaenopsis* Golden Peoker and *Dendrobium* Valentine, following a 3 × 5 factorial scheme consisting of three sources and five Si concentrations. The treatments were as follows: control (zero), 14.3, 28.6, 42.9 and 57.2 mmol L^{-1} Si from monosilicic acid (Zumsil^{TM} manufactured by TERRATECH CORP. in Miami, Florida, USA); potassium silicate (Sifol® manufactured by Diatom in Mogi das Cruzes, São Paulo, BR) and potassium silicate and sodium silicate mixture. The experiment followed a completely randomized design with five replicates, and the experimental unit consisted of three plants, with one plant per pot.

The characteristics of the Si sources were density = 1.25 and Si = 79.3 g L^{-1} for monossilicic acid (Zumsil^{TM}); density = 1.41, Si = 168 g L^{-1}, and K_2O = 211.5 g L^{-1} for potassium silicate (Sifol®); and density = 1.15; Si = 124 g L^{-1}; K_2O = 42.3 g L^{-1} and Na = 31.6 g L^{-1} for the potassium silicate with sodium silicate mixture. The pH of the Si solution was adjusted to approximately 5.7 and 5.9 for all treatments.

The potassium concentrations were balanced with potassium chloride in all treatments. On the other hand, in the potassium silicate and sodium silicate mixture treatments, the sodium concentrations were balanced with sodium chloride.

Because orchids absorb nutrients and Si *via* foliar and roots, a solution volume sufficient to cover the total leaf area was applied on each plant using a micro-sprayer. This volume increased as plant developed (ranging from 30 to 50 mL per plant) while application frequency depended on the vegetative growth. The Si solution was sprayed every 30 days in the first six months and every 15 days in the last 12 months.

Eighteen months after Si application had started and the plants began flowering (the first stem emerged), the following parameters were measured: stem diameter (mm) measured at 2 cm from the stem base using a digital caliper (Starrett®727-2001 manufactured in Itu, São Paulo, BR); root length (cm) measured the longer of aerial root in each plant; root volume (mL) determined by the volumetric test method (Carrigan and Frey, 1980); leaf area (cm^2) obtained from all plant leaves using a digital meter (Li-Color, model L1-3000®); electrolyte leakage (Dionisio-Sese and Tobita, 1998), and green color index (using the portable OptiScience® chlorophyll meter model CCM-200, in the central part of the adaxial surface of the last fully developed leaf of each plant). The number of pseudobulbs and plant height (cm) were determined only for *Dendrobium* Valentine while the number of leaves and plant width (corresponding to the distance between the apex of the last two fully expanded leaves, cm) were measured only for *Phalaenopsis* Golden Peoker.

The orchids were divided into aerial part/shoot and root and dried in forced circulation oven at 65–70 °C temperature, until constant weight. The dry matter was determined. The plant material was ground to determine the N, P, K, Ca, Mg and S contents following the methodology described by Bataglia et al. (1983) and the C content by the Dumas method using the LECO® CN628 carbon analyzer. The accumulation of C, N, P, K, Ca, Mg and S in the aerial shoot was calculated based on the nutrient concentration and dry matter.

The silicon content in the leaf tissue was determined following the method proposed by Korndörfer et al. (2004), and multiplied by the dry matter to obtain Si levels in the shoot whereas the lignin content was determined by the Klason method (Silva and Queiroz, 2002).

The results were analyzed by the F-test at 1% and 5% probability. The polynomial regression was applied when significant for doses (D) while the means were compared by Tukey at 5%, for sources (F), in which the same letters indicate that the values do differ for the same dosage among the sources (a, b, and c). The calculations were carried using the AgroEstat software (Barbosa and Maldonado, 2014).

3. Results

3.1. Levels of nutrients and silicon

In *Phalaenopsis,* the C levels decreased linearly in relation to monosilicic acid application (Si_Mono); increased quadratically with potassium silicate (Si_K) maximizing at 946.8 mg per plant for 26.7 mmol L^{-1} Si; and, decreased quadratically with the potassium and sodium silicate mixture (Si_K/Na) reaching a minimum at 235.2 mg per plant for 77.3 mmol L^{-1} Si (Fig. 1A). The N, K, Ca and Mg levels increased quadratically with increasing Si from the potassium silicate and the potassium and sodium silicate mixture. However, Si from the monosilicic acid did not affect N, K, Ca and Mg levels (Fig. 1B–F). The K levels were affected by the applied Si, reaching a maximum of 564.5 mg per plant for the 27.6 mmol L^{-1} Si (potassium silicate). The P, S, and Si levels increased quadratically with increasing Si levels, regardless of the source (Fig. 1C, G, and H).

The highest Si levels in *Phalaenopsis* were obtained for the 33.7 mmol L^{-1} Si from the potassium and sodium silicate mixture, followed by 30.9 mmol L^{-1} Si from potassium silicate, and 29.6 mmol L^{-1} Si from monosilicic acid (Fig. 1H).

In *Dendrobium,* the C, N, K and S levels increased quadratically with increasing Si from monosilicic acid, and potassium and sodium silicate mixture while decreasing linearly with increasing Si from silicate potassium (Fig. 2A, B, D, and G). The K level reached up to 244.1 mg per plant for 23.4 mmol L^{-1} Si (Si_K/Na). The highest C levels were 1193.6 and 1155.7 mg per plant recorded for monosilicic acid (14.2 mmol L^{-1} Si) and potassium and sodium silicate mixture (24.2 mmol L^{-1} Si), respectively. The P, Ca and Mg levels increased quadratically with increasing Si from monosilicic acid; decreased linearly with potassium silicate, and remained unchanged for the potassium and sodium silicate mixture (Fig. 2C, E, and F).