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Scientific Article

Effect of silicon on protein and lignin contents of two annual flower species

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Abstract

The beneficial effect of silicon on plants is known, but there are no studies demonstrating the effect of this element on protein and lignin production in ornamental plants.This study aimed to assess the effects of monosilicic acid fertigation at 0, 2, 4, and 8 mmol L^{-1} of Si on protein and lignin production of two ornamental species: *Viola* x *wittrockiana* Gams ex Nauenb. & Buttler 'Majestic Giants II Fire' e *Tagetes erecta* L. 'Hero' (color mix). The experiment was installed in a 4 × 2 factorial arrangement using a completely randomized design with five replications. After 90 days of the sowing, we assessed N and Si contents in shoot system, Si accumulation in shoot system, root, and total, and lignin and protein production. An increase in lignin followed by its reduction was observed from the concentration of 2.0 (4.29) and 4.3 (5.72) mmol L^{-1} of Si for *Viola* and *Tagetes* species, respectively. Silicon application promoted higher lignin content in *T. erecta* and *V.* x *wittrockiana*.
Keywords: ornamental plant nutrition, floriculture, monosilicic acid.

Resumo

Efeito do silício no conteúdo de proteína e lignina em duas especies anuais de flores

É conhecido o efeito benéfico do silício nas plantas, porém não há trabalhos que demonstre qual o efeito deste elemento na produção de proteína e lignina em plantas ornamentais. Este trabalho teve como objetivo avaliar os efeitos da aplicação via fertirrigação de ácido monossilícico nas doses de 0, 2, 4 e 8 mmol L^{-1} de Si, na produção de proteína e lignina, em duas espécies ornamentais: *Viola* x *wittrockiana* Gams ex Nauenb. & Buttler 'Majestic Giants II Fire' e *Tagetes erecta* L. 'Hero' (mistura de cores). O experimento foi instalado em esquema fatorial 4 x 2 em delineamento inteiramente casualizado, com cinco repetições. Após 90 dias da semeadura, foram avaliados o teor de N da parte aérea, acúmulo de Si na parte aérea, raiz e total e produção de lignina e proteína. Houve aumento na lignina seguido de redução, a partir da concentração de 2,0 (4,29) e 4,3 (5,72) mmol L^{-1} de Si em *Viola* e *Tagetes*, respectivamente. Também, promoveu aumento do teor de lignina em *T. erecta* e *V.* x *wittrockiana*.
Palavras-chave: nutrição de plantas ornamentais, floricultura, ácido monossilícico.

Introduction

As a beneficial element, silicon has been contributing to growth and production, improving physical, physicochemical, and chemical conditions unfavorable to the growing environment (Malavolta, 2006). Therefore, silicon role in increasing plant growth under conditions of biotic or abiotic stress is recognized (Campos et al., 2016; Teodoro et al., 2015). However, information about the biological role of silicon in promoting this benefit is very restricted, especially in ornamental plants.

Several studies indicate the structural function of silicon on the cell wall, increasing the contents of hemicellulose and lignin, leading to rigidity (Soares, 2011) and mechanical resistance of cells (Camargo et al., 2007). Lignin is a stable component of the cell wall, acting in defense against pathogens and water stress (Kozlowska and Krzywanski, 1994; Kurup et al., 1994).

Many authors report that Si fertilization provides an increase of lignin production in coffee (Botelho et al., 2005; Amaral et al., 2008), soybean (Moraes, 2009), potato (Gomes, 2005; Gomes et al., 2008), rice (Fleck et al., 2011; Suzuki et al., 2012) and orchid (Mantovani et al., 2018). On the other hand, Fleck et al. (2015) did not find a significant effect of lignin production on Si supply in rice, corn, and onion.

In addition to lignin, Si also increases protein production, as observed for potato (Gomes et al., 2005), coffee (Amaral et al., 2008), and rice (Fleck et al., 2011). Moreover, the silicon concentration available to plants has

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a negative effect on nitrogen uptake (Botelho et al., 2005), which would consequently lead to the same effect on protein production since 16% of the proteins are composed of nitrogen (Galvani and Gaertner, 2006).

Considering that, our hypothesis is that silicon uptake increases lignin content in plant species, but not altering their protein content. Thus, this study aimed to quantify the Si effects on protein and lignin production in *Viola* x *wittrockiana* 'Majestic Giants II Fire' and *Tagetes erecta* - 'Hero' (color mix).

Material and Methods

The experiment was carried out from July to October 2015 in a greenhouse at the Department of Soils and Fertilizers of the Faculty of Agrarian and Veterinary Sciences, Campus of Jaboticabal, SP, Brazil, located at the geographical coordinates of 21°15′22″ S and 48°18′58″ W and an altitude of 610 m. Four plants of *V.* x *wittrockiana* and *T. erecta* were cultivated per pot of 5 L, respectively, with inert substrate (Bioplant®) and daily fertigation with the nutritive solution proposed by Hoagland and Arnon (1950), but using Fe-EDDHMA instead of Fe-EDTA as iron source. Was used the solution at a concentration of 50% up to 45 days after sowing and at 100% up to 90 DAS.

Treatments consisted of the use of monosilicic acid (ZUMSIL®) as Si source at the doses of 0, 2, 4, and 8 mmol L^{-1} of Si and two ornamental species (*V.*x *wittrockiana* and *T. erecta*) that was evaluated at 4 (doses) × 2 (species) factorial arrangement in a completely randomized design, with five replications. Solutions with pH adjusted between 5.5 and 6.5 were applied, via fertigation, each three days.

At 70 days after treatment application and at the end of flowering, plants were separated into shoot system and root system, and washed with running water, detergent solution (0.1%), acid solution (0.3% HCl), and deionized water, and these were put into paper bags, and placed in a forced air circulation oven at 65 to 70 °C, until constant weight. Samples were weighed to determine the dry matter, and shoot and root system, nitrogen and silicon contents, and lignin and protein production. Root, shoot, and total silicon accumulation was calculated.

The analyses of nitrogen, silicon, and lignin contents were carried out following the methodology described by Bataglia et al., (1983), Kraska and Breitenbeck (2010), and Silva and Queiroz (2009), respectively. Protein content was obtained by multiplying nitrogen content by the factor 6.25 (Galvani and Gaertner, 2006). The accumulated Si was obtained by multiplying Si content by the shoot system dry matter of the studied species. An analysis of variance was carried out and when significant values were found, a quantitative analysis of polynomial regression was applied by using the software AGROESTAT (Barbosa and Maldonado Júnior, 2014).

Results and Discussion

Silicon content

Silicon content in shoot system increased until the concentration of 6.75 and 7.01 mmol L^{-1} of Si, reaching 12.11 and 11.16 mg kg^{-1} of Si in *V.*x *wittrockiana* and *T. erecta*, respectively, and stabilizing subsequently at these concentrations. An interaction effect was observed between species up to the concentration of 3 mmol L^{-1}, where *T. erecta* was the species that most absorbed the nutrient at the lowest concentrations whereas, at the highest concentrations, *V.* x *wittrockiana* absorbed about 10% more when both species reached maximum production values (Figure 1A).

When evaluate the effect of silicon at concentrations at 0, 1, and 10 mmol L^{-1} on cucumber plants, Campos et al. (2016) showed an increase in Si content only in relation to the control and at 1 mmol L^{-1} of Si, with no significant effect to other concentrations.

In rose cultivation, a different behavior was observed regarding the Si accumulation, with an increase in leaf Si contents in function of dose of potassium metasilicate applied on substrate (Zanão Júnior et al., 2013).

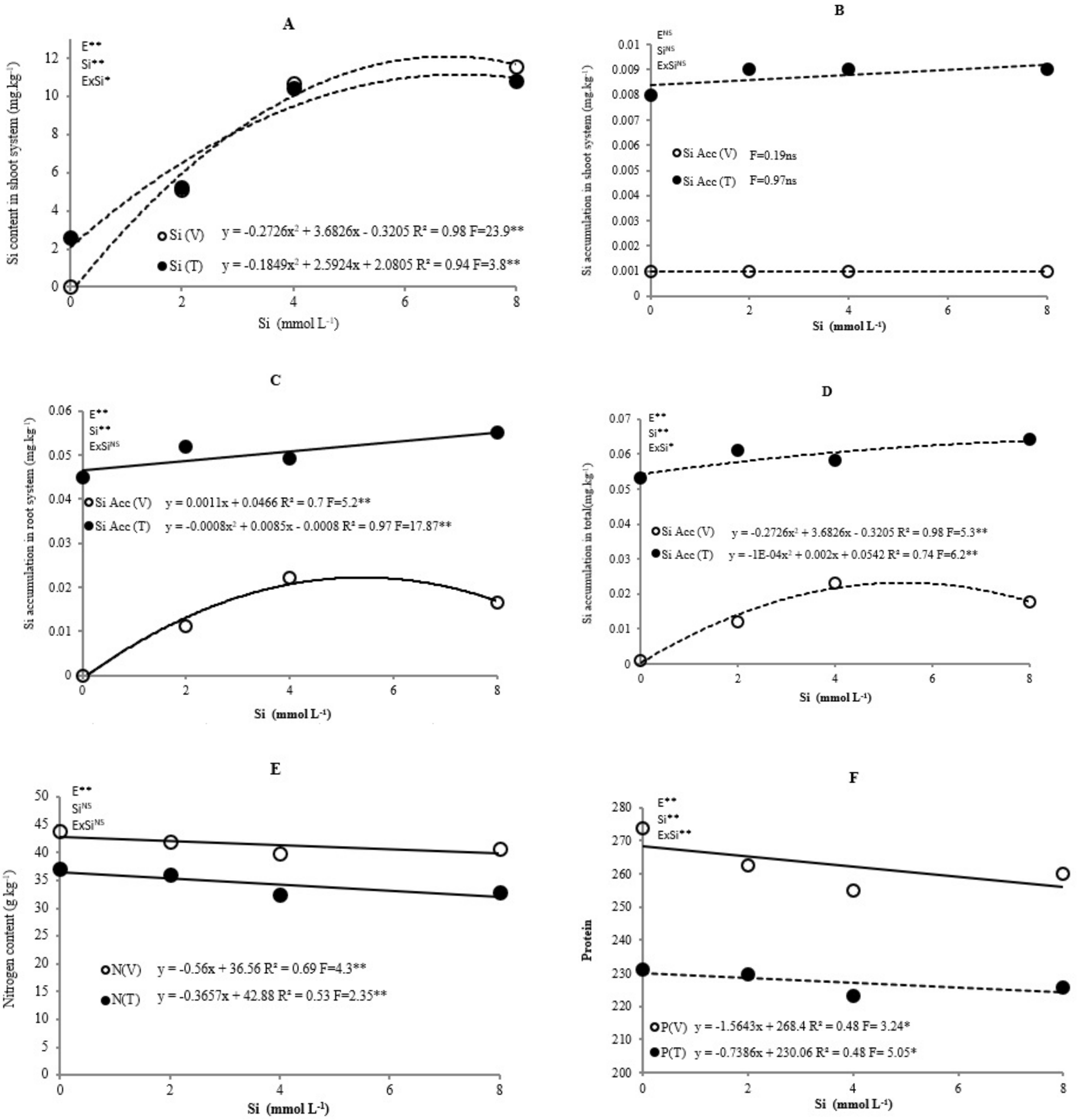
Fleck et al. (2015) observed that Si concentration in the shoot system of rice and corn plants was clearly increased when Si was supplied at a concentration of 1.07 mmol L^{-1} when using silica gel, while in onion plants, Si concentration did not differ between treatments.

Root silicon accumulation showed no significant effect, i.e. it did not differ regarding its amount accumulated in any of the studied species and concentrations. However, a difference was observed between species, with an accumulation of about 90% more for *T. erecta* when compared to *V.* x *wittrockiana*.

Total and shoot system silicon content (Figure 1D) augmented with Si concentration on substrate, increased Si for *T. erecta*, reaching, at 8 mmol L^{-1}, an accumulation of 0.055 and 0.064 mg $plant^{-1}$, respectively. While with a quadratic effect for the other species, it was crescent until the concentration of 5.31 mmol L^{-1}, with maximum accumulated values of 0.022 and 0.0218 mg $plant^{-1}$ for shoot system and total, respectively, presenting a subsequent decreasing behavior. The species *T. erecta* showed an increase of 66% in Si accumulation for both cases when compared to *V.* x *wittrockiana*.

The species *T. erecta* showed the highest Si accumulation (Figures 1B, 1C, and 1D) in shoot system and root and total. Similarly, higher silicon accumulations in *T. patula* (625 mg kg^{-1} Si) was also observed by Hogendorp et al. (2012) when plants were irrigated with water containing more than 2 mmol L^{-1} of Si.

According to the Ma et al. (2001), plants considered as silicon accumulators have a leaf content above 1% and non-silicon accumulators have a content of less than 0.5%. In this study both species can be classified as silicon



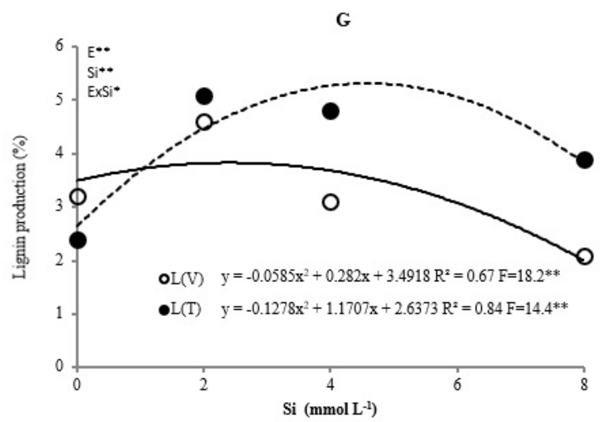


Figure 1. Silicon (Si) content in the shoot system (A); Silicon content in the root system (B), in the shoot (C) in the total (D); Nitrogen content in the shoot system (E); protein content (F) and lignin production (G) in two ornamental species *Viola* x *wittrockiana* (V) and *Tagetes erecta* (T) in function of the doses of silicon at 90 DAS. * ** significant at 1% and 5% probability level, respectively, with the mean significant difference of $p \leq 0.05$ for the F test. (E) species, (Si) concentration of Si (mmol L-1) and (ExSi) interaction.

accumulators since they accumulated more than 1% of silicon in the shoot when submitted to its higher doses.

Nitrogen content

Foliar nitrogen content decreased with increasing Si concentration in the substrate on both species assessed. In our study, the non-application of Si resulted in higher N contents in shoot system, with values from 43.98 and 37.51 gkg^{-1} for *V.* x *wittrockiana* and *T. erecta*, respectively (Figure 1E). Botelho et al. (2005) observed similar result in coffee seedlings, where silicon application (0, 0.32, 0.63, and 1.26 g SiO_2 kg^{-1} substrate) had a negative effect on nitrogen absorption.

Ávila et al. (2010) studied the effect of nitrogen doses in rice plants on the presence (50 mg L^{-1}) and absence of silicon in the medium and found a significant effect on the total nitrogen content only for the tested N doses, with no effects for silicon presence. In addition, increasing nitrogen doses reduces silicon content in plant shoot, showing a strong interaction between both elements, i.e. increasing silicon doses decreases nitrogen content in shoot system (Figure 1E) and increasing nitrogen doses leads to a reduction in silicon content in plant shoot (Ávila et al., 2010).

Protein

Protein production decreased for *V. wittrockiana* and *T. erecta* as substrate Si concentration increased. Thus, the non-application of Si resulted in the maximum protein production of 275.15 and 233.29 for *V. wittrockiana* and *T. erecta*, respectively. This result was already expected due to the negative effect found in this study between substrate silicon concentration and nitrogen content in the shoot of analyzed species since protein was estimated from N content.

Although the species presented the same behavior in the curve, production was not the same. The species *V.* x *wittrockiana* showed 15% more protein when, considering the maximum species production (Figure 1F).

Amaral et al. (2008) working with silicate in coffee, observed that plants sprayed with the product showed a significant increase in peroxidase activity (pathogenesis-related protein) at five days after spraying when compared to the activity of this enzyme in control plants.

Similarly, in a study with wheat resistance induction by silicon and aphids, Gomes et al. (2005) observed an increase of 60% of protein content after silicon application with inoculation when compared to the application without inoculation.

Lignin

Lignin production showed a quadratic effect, increasing at concentrations of 2.0 and 4.3 mmol L^{-1} of Si for *V.*x *wittrockiana* (4.29) and *T. erecta* (5.72), respectively, and decreasing at higher concentrations (Figure 1G). A similar effect was found by Mantovani et al. (2018), who observed that silicon addition via fertigation in *Phalaenopsis* promoted lignin content increased quadratically with increasing Si reaching 0.62, 0.55 and 0.61 g kg^{-1} for the 25, 12.5 and 18.2 mmol L^{-1} Si from monosilicic acid, potassium silicate, and potassium and sodium silicate mixture, respectively.

The species *T. erecta* showed an increase of 25% in lignin production when compared to *V. wittrockiana* and of 54% when compared to the non-silicon application. Amaral et al. (2008) studied potassium silicate in coffee plants and observed that lignin contents of treatments with potassium silicate (1.5 mmol L^{-1}) stood out to treatments without silicate application, with a greater accumulation of this macromolecule. Moraes (2009) observed a significant effect of 10% of the silicon application on soybean crop.

In a study by Zhao et al. (2013) it was observed that silicon application also increased lignin content of inflorescence stem, which might be the result of cooperative action of lignin biosynthesis genes. Additionally, silicon content of inflorescence stem was significantly increased under silicon application, which was mainly distributed in cortex and xylem.

Suzuki et al. (2012) assessed whether silicon deficiency promoted lignin accumulation in wild and 10-64 mutant rice and found that lignin content in wild plants decreased as silicic acid concentration as it was increased in the medium. In contrast, lignin content in the mutant 10-64 was not significantly influenced by silicic acid concentration in the culture medium. These results indicate that silicon deficiency promotes lignin accumulation, which is different from the results obtained by Fleck et al. (2011), who showed that silicon improves lignification in rice roots.

Fleck et al. (2015) did not observe a significant effect of leaf lignin contents on Si supply when assessing the effect of presence (1.07 mmol L^{-1}) or absence of Si on the production of rice, corn, and onion plants.

Whether or not the plant is a silicon accumulator, Si application will increase Casparian band (Fleck et al., 2015) since its fortification may be related to Si availability in the root tissue and if so, Si effect may not be limited to plants that accumulate silicon.

Conclusions

The species *T. erecta* and *V. wittrockiana* are silicon accumulating plants when submitted to doses ranging from 4 to 8 mmol L^{-1} of Si;

Silicon application did not influence protein production in any of the studied species. An application of 2.03 and 4.32 mmol L^{-1} of Si promotes a higher lignin content in *V. wittrockiana* and *T. erecta*, respectively, at 90 days after sowing.

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Author Contribution

E.I.F.T. 0000-0001-8209-4212, **C.M.** 0000-0002-4081-9278 and **R.M.P.** 0000-0003-1998-6343 worked together in all research steps, such as choosing species, planting and managing plants, data collection, analysis and interpretation, and preparation and review of the manuscript.

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