

Use of Silicon in Mitigating Ammonium Toxicity in Maize Plants

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Abstract

Silicon is a beneficial element that can mitigate abiotic stresses, such as ammonium toxicity. The objective herein was to evaluate the effects of silicon (Si) on mitigating toxicity caused by excess ammonium in maize plants grown in nutrient solution. An experiment was conducted with maize plants (cultivar DKB 390 VT Pro II) grown in a greenhouse in pots (8 L) in a hydroponic system. The treatments were arranged in a 2 × 2 factorial, consisting of two ammonium concentrations (30 and 60 mmol·L⁻¹) in the absence and presence of Si (10 mmol·L⁻¹), arranged in a completely randomized design with six repetitions. At 28 days after applying the treatments the dry mass of shoots and roots was evaluated, along with accumulation of silicon and nitrogen in the shoots. The use of silicon resulted in increases in the studied variables, regardless of ammonium concentrations. Silicon reduced the effect of toxicity caused by ammonium excess in maize plants, resulting in greater growth and dry matter accumulation.

Keywords

Zea mays L., Beneficial Element, Nitrogen, Nutritional Disorder, Abiotic Stress

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1. Introduction

Nitrogen absorption by plants predominates in the ammonium and nitric forms, where surplus nitrate levels are tolerable by most cultures [1]. However, high ammonium concentrations cause biochemical and physiological changes in plants, causing toxicity symptoms such as chlorosis and necrosis, and brown coloration of the root system and stem [2].

Toxicity resultant from ammonium causes deleterious effects in various physiological processes in the plant, such as photosynthesis, decreasing the chlorophyll concentration [3], increasing the contents of O_2^- and H_2O_2 which induce oxidative stress [4], and lowering stomatal conductance and transpiration [5].

The plant species are sensitive or tolerant to ammonium excess. In species susceptible to excessive ammonium toxicity symptoms can be severe, resulting in growth suppression [6] or plant death [7]. Cramer and Lewis (1993) [8] reported that the use of ammonium in concentrations exceeding $12 \text{ mmol}\cdot\text{L}^{-1}$ was harmful to maize plants.

The ability of maize plants to tolerate excess nitrogen may be associated with photosynthetic mechanisms. Thus, the greater photosynthetic capacity of maize plants, compared with other cultures, results in decreased deleterious effects caused by ammonium excess [8].

Moreover, when subjected to high ammonium concentrations, tolerant plants present increased activity of enzymes related to the N metabolism [9]. Another explanation is increased activity of the enzymes glutamine synthetase and glutamate dehydrogenase in the roots in relation to the shoots, suggesting that the site of N assimilation is critical in tolerance of ammonium excess [6] [10].

There are some methods to ease stress in plants, highlighting the use of beneficial elements such as silicon. In addition to relieving biotic stresses, conferring increased tolerance of plants against disease and pest attacks, it mitigates abiotic stresses such as nutrient imbalances, like those caused by excessive nitrogen which cause lodging and shading of plants; however, with the use of silicon these effects can be mitigated due to the deposition of silica on stems and leaf blades [11].

The hypothesis thus arises that in stress situations caused by high concentrations of ammonium, plants which accumulate silicon, such as maize [12], may have the stress mitigated. Studies involving silicon and ammonium excess are still incipient, and there is a need to expand research in this area.

Therefore, the objective of the present study was to evaluate the effects of silicon on the toxicity caused by ammonium excess in maize plants grown in a nutrient solution.

2. Material and Methods

The experiment was conducted in a greenhouse at the Universidade Estadual Paulista, FCAV/UNESP, Jaboticabal, SP, Brazil, at the geographic coordinates $21^\circ 15' 22''$ South and $48^\circ 18' 58''$ West. The maize plants (DKB 390 VT Pro II) were grown using a hydroponic system for 28 days.

The experiment was setup in a completely randomized design with six repetitions. The treatments were arranged in a 2×2 factorial, consisting of two ammonium concentrations (30 and $60 \text{ mmol}\cdot\text{L}^{-1}$), in the absence and presence of silicon ($10 \text{ mmol}\cdot\text{L}^{-1}$). Ammonium chloride was used as the N source and potassium silicate as the source of Si. Balancing of the potassium concentrations between treatments was performed so that they were maintained uniform, using potassium chloride as the K source. Each experimental unit consisted of a polypropylene pot with cover, measuring 48 cm long, 16 cm wide and 17 cm deep, containing 8 L of nutrient solution and 4 plants per pot.

Seeds were sown in plastic cups (0.3 dm^3) with substrate composed of vermiculite, irrigated daily. When maize plants presented two pairs of developed leaves (15 days after sowing), they were transplanted to the hydroponic system. From this point the plants were grown in the nutrient solution proposed by Hoagland and Arnon [13], using the N concentrations according to the treatments. The nutrient solution was maintained under continuous aeration by means of a compressed air system.

The nutrient solution was changed weekly and added to the treatments in steps to avoid early ammonium toxicity and impair the effect of silicon in the plants. Thus, in the first week the nutrient solution of Hoagland and Arnon [13] was diluted to half the usual concentration and added to the treatments considering 25% of the N concentrations and 50% of Si concentrations. As of the second week of cultivation the solution of Hoagland and Arnon [13] was used without dilution, and for the treatments the concentrations of 50% and 100% were used for N and Si, respectively. In the third and fourth weeks of cultivation the N concentrations were increased to 100%

and the Si concentrations maintained at 100%.

Water used in the hydroponic system was distilled and deionized, and solution levels were completed daily in each vessel with stock solutions corresponding to each treatment, immediately followed by pH measurements which were taken in order to maintain values between 5.5 and 6.0 using solutions of HCl $1.0 \text{ mol}\cdot\text{L}^{-1}$ or NaOH $1.0 \text{ mol}\cdot\text{L}^{-1}$.

At 28 days after applying the treatments (DAT), corresponding to the stage with 6 developed leaves the plants were separated into roots and shoots, then washed and packed into paper bags which were dried in a forced air circulation oven (65°C) until reaching constant weight. After drying the dry weight of shoots and roots was obtained, followed by grinding in a Willey type mill.

Chemical analyses of the aerial part were performed to determine the nitrogen content according to the methodology proposed by Bataglia *et al.* [14], and silicon according to that of Kraska and Breitenbech [15]. From the contents of nitrogen and silicon and the dry matter accumulation, the accumulation of these elements in the shoots was calculated. The data was submitted to analysis of variance, followed by application of the Tukey test at ($P < 0.05$) for comparison of means using the statistical program SISVAR[®] [16].

3. Results and Discussion

The interaction between N and Si indicates that the accumulation of nitrogen and silicon in the shoots of maize plants depends on the concentration of N and Si in the nutrient solution (Table 1). The highest accumulation of N occurred in treatments with the presence of Si, in both ammonium concentrations. This result indicates the relationship of Si with the N metabolism, as reported by several authors including [17] [18]. According to these authors, Si can improve photosynthesis, the structure of the chloroplasts and increase enzymatic activities responsible for reduction and assimilation of nitrogen.

In the absence of Si, greater accumulation of N occurred with the application of $60 \text{ mmol}\cdot\text{L}^{-1}$ of ammonium; however, with the addition of Si greater N accumulation occurred with use of the lower ammonium concentration ($30 \text{ mmol}\cdot\text{L}^{-1}$). This fact can be explained by the higher efficiency of nitrogen use in plants supplied with Si, implying a greater conversion to dry matter [19].

It was observed that in the presence of Si, greater accumulation of this element occurred with the lowest ammonium concentration ($30 \text{ mmol}\cdot\text{L}^{-1}$). It is possible that the higher ammonium concentration ($60 \text{ mmol}\cdot\text{L}^{-1}$) may have caused damage to the root system, resulting in lower absorption of Si and also N since the ammonium excess causes a reduction in growth and necrosis in the root system [2].

There was a significant interaction between N and Si for the production of dry matter of the shoots and roots

Table 1. Accumulation of nitrogen and silicon in the shoots of maize plants submitted to ammonium concentrations in the absence and presence of silicon.

NH ₄ ⁺ concentration	N accumulation in the shoots		Si accumulation in the shoots	
	Without Silicon	With Silicon	Without Silicon	With Silicon
	----- mg per plant -----			
NH ₄ ⁺ ($30 \text{ mmol}\cdot\text{L}^{-1}$)	52.49 bB	104.08 aA	7.86 bB	19.22 aA
NH ₄ ⁺ ($60 \text{ mmol}\cdot\text{L}^{-1}$)	60.91 aB	86.38 bA	9.31 aB	16.15 bA
F-values				
N		6.25*		4.46 ^{ns}
Si		429.26**		439.30**
NxSi		49.32**		27.17**
MSD ¹		5.49		1.28
CV%		6.0		8.1

Identical upper case letters on the lines do not differ by the Tukey test ($P < 0.05$). Identical lower case letters in the columns do not differ by the Tukey test ($P < 0.05$). *, ** and ^{ns}: significant ($P < 0.05$), ($P < 0.01$) and non-significant, respectively. ¹Minimum significant difference.

Table 2. Dry matter of the shoots and roots of maize plants submitted to ammonium concentrations in the absence and presence of silicon.

NH ₄ ⁺ concentration	Shoot dry matter		Root dry matter	
	Without Silicon	With Silicon	Without Silicon	With Silicon
	----- g por planta -----			
NH ₄ ⁺ (30 mmol·L ⁻¹)	1.667 aB	2.878 aA	0.298 aB	1.057 aA
NH ₄ ⁺ (60 mmol·L ⁻¹)	1.409 bB	2.011 bA	0.265 bB	0.414 bA
F-values				
N		169.06**		753.79**
Si		440.17**		1357.54**
NxSi		49.70**		612.54**
MSD ¹		0.13		0.04
CV%		5.3		5.9

Identical upper case letters on the lines do not differ by the Tukey test ($P < 0.05$). Identical lower case letters in the columns do not differ by the Tukey test ($P < 0.05$). **Significant ($P < 0.01$). ¹Minimum significant difference.

(**Table 2**). Silicon application favored the production of shoot and root dry matter of the maize plants, independent of ammonium concentrations.

The use of Si in maize plants submitted to ammonium concentrations of 30 and 60 mmol·L⁻¹ promoted increases in the production of shoot and root dry matter of 73% and 43%, and 254% and 56%, respectively, in relation to absence of this beneficial element (**Table 2**).

This effect of silicon to mitigate abiotic stresses, such as nutritional excesses, was reported in the review study of Ma [11] in plants submitted to nitrogen excess, where it caused lodging and increased shading; however, with the use of silicon these effects can be mitigated due to deposition of silica in the stems and leaf blades.

The mitigation of this type of stress promoted by silicon may be related to its participation in important plant defense mechanisms, such as antioxidant systems and complexation or immobilization of excess ions [20].

The effect of silicon in mitigating toxicity caused by ammonium excess in maize plants was higher at the concentration of 30 mmol·L⁻¹, since symptoms of toxicity in plants grown in the high ammonium concentrations were severe. This resulted in growth suppression [6] and death of plant tissue [7], even preventing the beneficial action of the silicon element.

In the absence of Si there was greater accumulation of dry matter in the shoots and roots of plants submitted to the lower ammonium concentration (30 mmol·L⁻¹). These results show that the use of high ammonium concentrations cause toxicity in plants, and this effect increases in accordance with the increase in ammonium concentration, confirming results obtained by other authors who observed ammonium toxicity at the concentration of 5 mmol·L⁻¹ in rice plants [21] and 12 mmol·L⁻¹ in maize [8].

The fact that the high concentration of ammonium limited the accumulation of dry matter can be attributed to decreased absorption of cations by plants, since it is known that there occurs competition between these elements for the same transporter sites, as occurs with Ca and Mg [22] and K [23], resulting in lower levels of chlorophyll as well as reduced photosynthesis and plant growth.

4. Conclusion

Silicon reduced the toxicity effect caused by ammonium excess in maize plants, resulting in greater growth and dry matter accumulation.

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