Investigation note

Cucumber and tomato seedlings fortified with silicon and chlorine

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Abstract

The use of silicon (Si) and chlorine (Cl) allows plants to favorably increase growth and development, as they contribute to the increase in dry weight of plants and chlorophyll biosynthesis, as well as resistance to biotic and abiotic factors. The research was carried out to clarify the result caused by the application of Si and Cl in the growth of cucumber and tomato seedlings. For this, cucumber 'Paraiso F1' and tomato F3 were sown in polystyrene trays with 242 cavities filled with peat moss. The experimental design of randomized complete blocks was used, where the treatments were: 20, 30 and 50 mg L^{-1} of Si, 20, 30 and 50 mg L^{-1} of Cl, 20:20, 30:30 and 50:50 mg L^{-1} of Si:Cl, one absolute control and four repetitions per treatment. The response variables were leaf greenness, plant height, leaf area, dry weight of the aerial part and root in cucumber and tomato seedlings. In cucumber seedlings, leaf greenness increased by 18.7% and 4.6% with 20 and 50 mg L^{-1} of Si and Cl, respectively. The combination of 20:20 mg L^{-1} of Si:Cl increased the biomass of the aerial part by 30.2%. While, in tomato seedlings treated with 30 mg L^{-1} of Si and in mixture with Cl at concentration 30:30 mg L^{-1}, their height was 31.9% and 25.1% with respect to the control seedlings. Dry root biomass was significantly increased with the application of Si (20 and 30 mg L^{-1}), Cl (20 and 50 mg L^{-1}) and in combination 30:30 (mg L^{-1}).

Keywords: *Cucumis sativus*, *Solanum lycopersicum*, leaf greenness, seedling height.

Reception date: January 2023
Acceptance date: February 2023

Silicon (Si) accumulation differs between plant species due to differences in Si uptake by roots. Its beneficial effects are mainly related to the increase in growth and quality of seedlings, factors of utmost importance for rapid transplantation and resistance to diseases caused by fungi (Villalón *et al*., 2018). Similarly, it has been reported that, when applying potassium silicate in strawberry crops, an increase in height, fresh weight of the plant, leaf area and photosynthetic rate is caused (Nada, 2020).

Chlorine (Cl) has been reported to be an essential micronutrient, which accumulates at macronutrient levels, as it is normally available in nature and is actively taken up by higher plants (Franco *et al*., 2016). Chloride (Cl^-) plays specific roles in growth, improvement of plant photosynthetic activity and efficient use of water, due to the greater surface of chloroplasts exposed in the aerial part, such findings are due to the nutrition of plants with Cl (Franco *et al*., 2019).

In non-saline conditions (up to 5 mM Cl) and without water limitation, Cl stimulates a larger size of leaf cells, a moderate increase in the fresh and dry biomass of the plant, the above due to the stomatal regulation and turgor of the leaves, which allows the plants to improve the parameters of leaf water balance (Brumós *et al*., 2010). Therefore, the objective of the research was to establish the effect of the application of Si and Cl, as well as the selection of the most efficient dose on greenness, height, leaf area, dry weight of aerial part and root in the production of cucumber and tomato seedlings.

The research was carried out inside a greenhouse (Baticenital®, ACEA SA de CV) of the Faculty of Agronomy of the Autonomous University of Sinaloa (UAS) for its acronym in Spanish, located at coordinates 24° 37' 29" north latitude and 107° 26' 36" west longitude, with an altitude of 38.5 m. With semidry, very hot and extreme climate, where rains in summer predominate, with an average annual temperature of 25.9 °C and 672 mm of rainfall (García, 2004).

Cucumber *cv* Paraiso F1 and tomato F3 were sown in polystyrene trays with 242 cavities filled with peat moss (Berger), in which water and nutrients were supplied by manual decantation with 1 g L^{-1} of N (urea). A randomized complete block design (RCBD) was used, with ten treatments: 20, 30 and 50 mg L^{-1} of Si, 20, 30 and 50 mg L^{-1} of Cl, 20:20, 30:30 and 50:50 mg L^{-1} of Si:Cl, and one absolute control, with four repetitions per treatment.

Silicon dioxide (94% Si, Diatomix) was used as the source of Si and sodium hypochlorite (NaClO, commercial Cloralex) was used as the source of chlorine. When the seedlings had the first true leaf, the treatments were applied only once through one of the irrigations. At 15 days after the application (daa) of the treatments, 20 seedlings per treatment were taken at random, to evaluate: foliar greenness, by means of a chlorophyll meter (Spad-502, Minolta); plant height, measured from the base of the stem to its apical bud, with a tape measure; leaf area, determined by the equations proposed by Blanco and Folegatti (2003): LA= 0.851(LW), for cucumber and LA= $(0.35L^2)-(5.31L)+57.6$, for tomato, weight of dry biomass of root and aerial part of seedlings, obtained after drying for 72 h in an oven (292, Felisa) at 70 °C, using a triple beam balance (CZ 30, Aczet).

The collected data were statistically analyzed with the statistical package Minitab 18, using Anova and Tukey's multiple mean comparison test ($p \leq 0.05$). Silicon and chlorine affected the leaf greenness, with plants treated with Si at 20 mg L^{-1} being statistically higher, with an increase of

19% compared to the control. In terms of height and leaf area, plants treated with 20 mg L^{-1} of Cl increased height by 16%, as well as leaf area by 4% in relation to the control (Table 1), although without statistical differences.

Table 1. Effect of Si and Cl on greenness, height and leaf area of cucumber seedlings.

Treatment	Leaf greenness (spad)	Height (cm)	Leaf area (cm^2)
20 mg L^{-1} of Si	52.25 ±3.97 a*	13.03 ±1.84 abc	10.17 ±0.75 bc
30 mg L^{-1} of Si	47.64 ±4.21 abc	14.00 ±2.43 ab	10.48 ±1.08 abc
50 mg L^{-1} of Si	44.38 ±4.62 c	10.58 ±1.77 d	9.93 ±1.07 bc
20 mg L^{-1} of Cl	48.09 ±5.22 abc	14.96 ±2.18 a	11.44 ±1.21 a
30 mg L^{-1} of Cl	46.92 ±4.81 bc	11.58 ±1.78 cd	9.65 ±0.91 cd
50 mg L^{-1} of Cl	46.07 ±3.77 ab	12.24 ±2.57 bcd	8.62 ±1.13 d
20:20 mg L^{-1} of Si:Cl	45.58 ±4.63 bc	12.90 ±1.4 abc	10.88 ±1.25 abc
30:30 mg L^{-1} of Si:Cl	48.33 ±4.34 abc	10.58 ±1.8 d	9.69 ±1.23 cd
50:50 mg L^{-1} of Si:Cl	44.66 ±5.53 c	12.02 ±1.96 bcd	10.29 ±1.61 abc
0 mg L^{-1} (control)	44.01 ±4.26 c	12.92 ±3.29 abc	10.99 ±1.68 ab

*= means ± standard deviation with the same letter within each column are statistically equal (Tukey, $p \leq 0.05$).

There is scientific evidence on the effect of Si on plants under stress conditions, as Jianpeng *et al*. (2010) found that Si could improve the shape-organization of chloroplasts and thylakoids. Thus, it can keep cucumber leaves in normal photosynthesis situation, including nitrogen utilization and correct the growth-inhibiting effects caused by Cd. The results of this research were consistent with those of Chapagain *et al*. (2011), who indicate that Cl is a micronutrient essential for the growth and development of plants and its role is to help photosynthesis.

The plants treated with Si and Cl did not present statistical differences in dry biomass of root and aerial part (Table 2). However, silicon at doses of 20 mg L^{-1} was effective in inducing greater accumulation at the root, 25% more compared to the control; while the dose of 20:20 mg L^{-1} of Si:Cl increased it in the aerial part by 30% in relation to the control. In this regard, Cabezas *et al*. (2022) mention that silicon has been pointed out as an amendment of great importance for plant growth, absorption and redistribution of nutrients, as well as in the mechanical resistance of cells.

Table 2. Effect of Si and Cl on dry biomass of root and aerial part of cucumber seedlings.

Treatment	Dry root biomass (g)	Dry biomass of aerial part (g)
20 mg L^{-1} of Si	0.055 ±0.001 a*	0.53 ±0.06 ab
30 mg L^{-1} of Si	0.022 ±0.002 cd	0.51 ±0.07 ab
50 mg L^{-1} of Si	0.04 ±0.006 abc	0.41 ±0.05 b
20 mg L^{-1} of Cl	0.032 ±0.015 bcd	0.49 ±0.05 ab
30 mg L^{-1} of Cl	0.032 ±0.013 bcd	0.44 ±0.03 b
50 mg L^{-1} of Cl	0.034 ±0.013 bcd	0.47 ±0.06 ab

Treatment	Dry root biomass (g)	Dry biomass of aerial part (g)
20:20 mg L^{-1} of Si:Cl	0.044 ±0.007 ab	0.56 ±0.08 a
30:30 mg L^{-1} of Si:Cl	0.042 ±0.016 ab	0.44 ±0.05 ab
50:50 mg L^{-1} of Si:Cl	0.02 ±0 d	0.51 ±0.03 ab
0 mg L^{-1} (control)	0.044 ±0.001 ab	0.43 ±0.015 b

*= means ± standard deviation with the same letter within each column are statistically equal (Tukey, $p \leq 0.05$).

Plants treated with 20 mg L^{-1} of Si in tomato seedlings improved leaf greenness by 6% compared to the control (Table 3). At altitude, the greatest increase occurred in plants treated with Si at doses of 30 mg L^{-1} and in those grown with 20:20 mg of Si:Cl, height decreased. In leaf area, plants treated with 20:20 mg of Si:Cl exceeded the control by 1%, the rest of the treatments caused decreases that fluctuated between 3 and 8%, in relation to the control (Table 3).

Table 3. Effect of Si and Cl on greenness, height and leaf area of tomato seedlings.

Treatment	Leaf greenness (spad)	Seedling height (cm)	Leaf area (cm^2)
20 mg L^{-1} of Si	37.11 ±4.74 a*	8.54 ±1.34 bc	37.28 ±2.54 abc
30 mg L^{-1} of Si	36.88 ±5.33 a	10.32 ±1.01 a	35.38 ±2.02 c
50 mg L^{-1} of Si	35.66 ±5.96 a	8.61 ±1.55 bc	35.77 ±2.88 bc
20 mg L^{-1} of Cl	34.66 ±6.43 a	8.6 ±1.67 bc	37.27 ±2.28 abc
30 mg L^{-1} of Cl	36.05 ±5.33 a	8.69 ±1.43 bc	36.38 ±2.65 abc
50 mg L^{-1} of Cl	35.92 ±2.86 a	8.97 ±1.33 abc	35.67 ±2.75 c
20:20 mg L^{-1} of Si:Cl	35.71 ±5.51 a	7.51 ±1.18 c	37.51 ±2.88 abc
30:30 mg L^{-1} of Si:Cl	34.91 ±4.81 a	9.79 ±1.91 ab	36.04 ±2.83 bc
50:50 mg L^{-1} of Si:Cl	35.45 ±5.5 a	8.03 ±1.31 c	38.9 ±3.2 a
0 mg L^{-1} (control)	34.96 ±4.69 a	7.82 ±1.419 c	38.5 ±3.34 ab

*= means ± standard deviation with the same letter within each column are statistically equal (Tukey, $p \leq 0.05$).

The greenness of the seedlings, height, as well as the increase in the weight of dry matter of root and aerial part are aspects that indicate the photosynthetic efficiency of those treated with silicon and consequently, also indicate improvement in the quality of seedlings. In relation to these results, Epstein (1999) explains that plants are structurally weaker when Si is omitted in conventional nutrient solutions and plants can become abnormal in growth, development, viability and reproduction, as plants are treated with Si, the effects of deficiencies or excesses of nutrients such as manganese and aluminum are diminished and the interception of light increases (higher photosynthetic rate).

Regarding Cl, Franco *et al*. (2016) verified that, in tobacco plants subjected to a low concentration of 5 mM, the rates of photosynthesis and leaf cell division were not affected. These results show that Cl in the millimolar range stimulates plant growth, growth of shoot organs (stems and leaves). These results coincide with the above, as well as with Chapagain *et al*. (2011), who mention that Cl is a micronutrient essential for plant growth and development, which is required in small amounts for all crops.

The dry root biomass showed differences ($p \leq 0.05$), with increases that ranged from 89% (50 mg L^{-1} of Si) to 300% (30:30 mg L^{-1} of Si:Cl), in relation to the control (Table 4). In dry weight of aerial part, the seedlings treated with the doses of 20 and 30 mg L^{-1} of Si, 50 mg L^{-1} of Cl and the combination in 30:30 mg L^{-1} of Si:Cl were statistically equal to the control (Table 4), the rest of the treatments caused a decrease that fluctuated between 41 and 3%, in relation to the control.

Table 4. Effect of Si and Cl on dry biomass of root and aerial part of tomato seedlings.

Treatment	Dry root biomass (g)	Dry biomass of aerial part (g)
20 mg L^{-1} of Si	0.23 ±0.04 ab*	0.33 ±0.048 ab
30 mg L^{-1} of Si	0.23 ±0.07 ab	0.37 ±0.019 a
50 mg L^{-1} of Si	0.17 ±0.04 abc	0.26 ±0.013 bc
20 mg L^{-1} of Cl	0.24 ±0.02 ab	0.26 ±0.035 c
30 mg L^{-1} of Cl	0.14 ±0.05 bc	0.22 ±0.028 c
50 mg L^{-1} of Cl	0.24 ±0.08 ab	0.34 ±0.043 a
20:20 mg L^{-1} of Si:Cl	0.15 ±0.02 bc	0.22 ±0.028 c
30:30 mg L^{-1} of Si:Cl	0.27 ±0.02 a	0.36 ±0.017 a
50:50 mg L^{-1} of Si:Cl	0.15 ±0.01 bc	0.24 ±0.017 c
0 mg L^{-1} (control)	0.09 ±0.02 c	0.37 ±0.044 a

*= means ± standard deviation with the same letter within each column are statistically equal (Tukey, $p \leq 0.05$).

It can be inferred that Si and Cl applied to tomato or cucumber seedlings caused effects that improve the quality of the seedlings. Laane (2018) report that Si (salicylic acid) increases growth and decreases biotic and abiotic stress. Abdel *et al*. (2019) found that Si, by potassium silicate at doses of 4 000 ppm, increases height, number of leaves, fresh and dry weight of the plant, stem diameter and chlorophyll.

The increase in the dry root matter of tomato plants confirms what was reported by Ayala *et al*. (2019) about the fact that Cl with a minimum range in irrigation water or nutrition does not affect the fresh weight and production of the hydroponic lettuce crop. Likewise, Causil *et al*. (2017) mention that, when subjecting onion for 72 h in concentrations of 0.2 and 1 mg L^{-1} (sodium hypochlorite) diluted with distilled water, they observed a greater growth in length of the roots of bulbs.

Conclusions

In cucumber seedlings, leaf greenness increased with 20 and 50 mg L^{-1} of Si and Cl, respectively. Only with 20:20 mg L^{-1} of Si:Cl was the biomass of the aerial part significantly increased. In tomato seedlings, only Si was effective in increasing plant height when used at 30 mg L^{-1} and in mixture with Cl at concentration 30:30 mg L^{-1}. Dry root biomass was increased with Si (20 and 30 mg L^{-1}), Cl (20 and 50 mg L^{-1}) and in combination 30:30 (mg L^{-1}).

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