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Silicon And Its Relationship With Germination And Related Indices In Varieties Of *Solanum lycopersicum* L. Under Salinity Conditions
Silicio y su Relación con la Germinación e Índices Relacionados en Variedades de *Solanum lycopersicum* L. en Condiciones de Salinidad

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SUMMARY

Salinity is one of the abiotic stresses that is most affecting the agricultural sector and tomato cultivation in Mexico and the world. Some alternatives are being considered to counteract the effects of salinity, including the use of cation exchangers such as Si (Silicon). The present study aimed to evaluate the response in the germination process to the contribution of three doses of silicon, in different varieties of *Solanum lycopersicum* L. subjected to salt stress with NaCl. The study was carried out at the Seed Laboratory of the Department of Agronomy of the Autonomous University of Baja California Sur, Mexico under laboratory conditions. The variables associated with the germination and seedling morphology of three varieties of *S. lycopersicum* L. were considered, which were evaluated by a completely randomized design in a factorial arrangement with four replications for a total of 27 treatments, resulting from the interaction between varieties. (Cherry, Floradade and Rio Grande), NaCl (0, 25 and 50 mM) and Si (0, 1 and 2 mM). It was obtained that the germination percentage is conditioned by the variety factor and that the fresh biomass and the germination rate (%) are affected by the 3^k interaction ($P \leq 0.001$). The Principal Component Analysis showed that NaCl and Si constitute response modulators in fresh and dry biomass accumulation, and root and stem development in *S. lycopersicum* seedlings under salt stress. It is concluded that there is a differential response in the manifestation of salt stress depending on the phenological state of the plant and variety of *S. lycopersicum*, verifying the mitigating effect of Si in the seedling stage, but not in germination and related variables and indices.

Index words: *biostimulant, seed, stress, tomatoes.*

RESUMEN

La salinidad es uno de los estreses abióticos que más está afectando al sector agrícola y al cultivo de tomate en México y el mundo. Se están considerando algunas alternativas para contrarrestar los efectos de la salinidad, entre ellas el uso de intercambiadores de cationes como el Si (Silicio). El presente estudio tuvo como objetivo evaluar la respuesta en el proceso de germinación al aporte de tres dosis de silicio, en diferentes variedades *Solanum lycopersicum* L. sometidas a estrés salino con NaCl. El estudio se llevó a cabo en el Laboratorio de Semillas del Departamento de Agronomía de la Universidad Autónoma de Baja California Sur, México en condiciones de laboratorio. Se consideraron las variables asociadas a la germinación y morfología de plántulas de tres variedades de *S. lycopersicum* L., las cuales se evaluaron mediante un diseño completamente al azar en arreglo factorial con cuatro

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repeticiones para un total de 27 tratamientos, resultado de la interacción entre variedades. (Cherry, Floradade y Rio Grande), NaCl (0, 25 y 50 mM) y Si (0, 1 y 2 mM). Se obtuvo que el porcentaje de germinación está condicionado por el factor variedad y que la biomasa fresca y la tasa de germinación (%) son afectadas por la interacción 3k ($P \leq 0.001$). El análisis de componentes principales mostró que NaCl y Si constituyen moduladores de respuesta en la acumulación de biomasa fresca y seca, y desarrollo de raíz y tallo en plántulas de *S. lycopersicum* bajo estrés salino. Se concluye que existe una respuesta diferencial en la manifestación del estrés salino en función del estado fenológico de la planta y variedad de *S. lycopersicum*, verificándose el efecto mitigador del Si en la etapa de plántula, pero no en la germinación y variables e índices relacionados.

Palabras clave: *bioestimulante, semilla, estrés, tomate.*

INTRODUCTION

Currently, there are more than 8 billion inhabitants on the planet projected to reach 10 billion in the next 50 years (Batista *et al.,* 2018). As the population increases, so does the demand for agricultural products (Kumar, Reddy, Phogat, and Korav, 2018). Nowadays, the production of agricultural food to cope with the growing population is worrying, agricultural ecosystems are facing the effects of climate change (Nadarajah, 2020) and those induced by the technification of crops that include the excessive use of chemical fertilizers and irrigation, which contribute to accelerate the processes of erosion and salinization of both soils and water sources intended for irrigation.

Of the abiotic stresses mentioned above, salinity has been given special attention due to the effects it causes on crops from the germination process. It is reported globally that around 20% of the total irrigated agricultural areas are affected by salinity (Singh, 2022); the presence of salts in the soil, especially sodium chloride (NaCl), causes changes in growth, development, and productivity in crops due to imbalances in the entry of essential ions such as potassium (K^+) and calcium (Ca^{2+}), causing physiological and biochemical alterations in plant tissues (López-Cuén *et al.,* 2020).

Of Mexico's surface area (1 964 365 km^2), 54% is considered arid, within which one million hectares have excessive salt concentrations, and are mainly located in the northern and northeastern regions of the country (Briones, Búrquez, Martínez, Numa, and Perroni, 2018), right where the main tomato (*Solanum lycopersicum* L.) producing states are located, this Solanacea is very important for Mexico, it is the ninth most consumed horticultural product at the national level with 12.4 kg *per capita* year^{-1} (SIAP, 2023). Among the benefits that promote the consumption and acceptance of tomatoes is the nutritional value of the fruit, based on the presence of significant amounts of carotenoids, ascorbic acid, phenolic compounds, vitamins and minerals (Stoleru *et al.,* 2020; Murariu *et al.,* 2021), however, this crop is sensitive to salt stress, and therefore considered a glycophyte species (Carbajal-Vázquez, Trejo, Alcántar, Herrera, and Gómez, 2023).

Among the alternatives being explored to mitigate salinity stress in plants is the use of Silicon (Si) (Debona, Rodrigues, and Datnoff, 2017; Luyckx, Hausman, Lutts, and Guerriero, 2017), the second most abundant element in the Earth's crust (Kaushik and Saini, 2019) which, although not considered an essential element, has been shown to improve morphological, physiological, biochemical and productive traits in plants that grow under environmental stresses, such as salt stress (Etesami and Jeong, 2018). In addition to its effect on improving the physical and chemical properties of the soil, it is also considered a high-quality fertilizer to promote sustainable agricultural practices (Zargar, Mahajan, Bhat, Nazir, and Deshmukh, 2019).

A bibliometric study developed by Zhu, Gong, and Yin (2019) pointed out that the main current research on Si focuses on combating abiotic stress, including salinity-induced stress, focusing the results on improvements in water absorption from the root and activity of aquaporins (Rios, Martínez, Ruiz, Blasco, and Carvajal, 2017), and from the molecular point of view, its influence on the activity of the salinity sensor (SOS1), and the high-affinity transporter (HKT1), (Bosnic, Bosnic, Jasnic y Nikolic, 2018).

However, the findings are as variable as the plant models in which research has been carried out that include monocotyledons, such as barley (*Hordeum vulgare* L.), wheat (*Triticum aestivum L.*), rice (*Oryza sativa L.*), corn (*Zea mays*), and sorghum (*Sorghum bicolor L.*); dicots, such as cucumber (*Cucumis sativus*), tomato (*S. lycopersicum* L.), tobacco (*Nicotiana tabacum*), pumpkin (*Cucurbita maxima*) and peanut (*Arachis hypogaea* L.); and woody plants e.g., mango (*Mangifera indica* L.) and banana (*Musa spp.*), with accumulating and excluding plants of Si being indicated indistinctly.

Few studies address the effects of Si on seed germination and emergence (Biju, Fuentes y Gupta 2017; Artyszak, 2018); a critical stage for a wide variety of crops (Hubbard, Germida, and Vujanovic, 2012; Sun *et al.*, 2021), in which it is found *S. lycopersicum*, identified as Si excluding. Therefore, the objective of this study to evaluate the response in the germination process to the contribution of three doses of silicon, in different *S. lycopersicum* L. varieties subjected to saline stress with NaCl.

MATERIALS AND METHODS

Location. The research work was carried out at the Autonomous University of Baja California Sur (UABCS, acronym in Spanish), located on Carretera Sur km 5.5, in La Paz, capital of the State of Baja California Sur, Mexico. With 24.102° or 24° 6′ 7″ N and 110.3154° or 110° 18′ 55″ W.

Biological material. Three tomato cultivars were selected: cherry (*S. lycopersicum var*. *Cerasiform*), ball (*S. Lycopersicum var. Floradade*) and saladette (*S. lycopersicum var. Rio Grande*) from the UABCS' Germplasm Laboratory of the Department of Agronomy.

Experimental procedure. Germination tests were performed in sterilized Petri dishes (150 ×15 mm), covered at the bottom with a layer of absorbent filter paper. Each dish was moistened with 5 mL of NaCl concentrations (0, 25, and 50 mM) and silicon levels (0, 1, and 2 mM); Distilled water was used for control treatment. Germination tests were performed for 14 days in germination chambers (Conviron Model CMP 3244) at a temperature of 25 °C ± 0.5 °C and 80% relative humidity. Seeds were considered germinated when the radicle had a minimum length of 2 millimeters (mm). Considering the variables:

Germination percentage. It was recorded daily using the following formula from Al-Mudaris (1998).

$$\%GP = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seeds}\ x\ 100 \qquad (1)$$

Germination rate. It was calculated using Maguire's equation (1962), where n1, n2,...n25 are the number of seeds germinated at times t1, t2,... t14 (in days).

Germination energy. It was calculated using the following formula according to Maguire (1962):

$$\mathrm{GE} = \frac{N1}{D1} + \frac{N2 - N1}{D2} \ldots\ldots \frac{N5 - N4}{D5} \qquad (2)$$

Where "N" indicates the number of seeds germinated on the counting date and "D" is the number of days.

Average germination time. The formula proposed by Orchard (1977) was used:

$$\mathrm{AGT} = \frac{\sum(NxD)}{\sum N} \qquad (3)$$

where "N" indicates the number of seeds germinated on day "D".

Germination rate. The formula proposed by Scott, Bystrom, and Bowler (1962) was used:

$$\mathrm{GR} = \frac{\sum(n, t1)}{N} \qquad (4)$$

Where "n" indicates the number of seeds germinated on day 1, t1: number of days after planting. "N" is the total number of seeds planted.

Germination speed. The formula proposed by Maguire (1962) was used, $\mathrm{M} = \sum(\frac{\mathrm{n1}}{\mathrm{t}})$, where "n" indicates the number of seeds germinated on day 1, and t: is the germination time from planting to the germination of the last seed.

Stem length. It consisted of measuring it from the base of the stem to the apical part, using a conventional metal ruler, graduated in millimeters, expressing this variable in centimeters (cm).

Radicle length. Measurements were taken from the base of the stem to where the taproot ends (coping) expressing the length in centimeters (cm).

Fresh and dry biomass. 14 days after germination, the seedlings were weighed on an analytical balance (Mettler Toledo, model AG204) where fresh and dry biomass was obtained. To obtain the dry biomass, the samples were placed in paper bags and placed in a drying oven (Shel-Lab, model FX-5, series-1000203) at a temperature of 70 *°C for 72 hours.* Units of measurement were expressed in grams (g).

Experimental design. A completely randomized design was used in a factorial arrangement with 4 replications. A total of 27 treatments were obtained resulting from the interaction of tomato variety (Cherry, Floradade and Rio Grande), sodium chloride concentrations (0, 25 and 50 mM) and silicon levels (0, 1 and 2 mM).

Statistical analysis. The Kolmogorov-Smirnov test (Massey, 1951) was used for the normal distribution of the data and the Bartlett test (Bartlett, 1937) was used for the homogeneity of variances. The averages resulting from the interactions were compared using Tukey's least Significance Difference Test at a 95% confidence level. The mathematical model used in each of the ANOVAs was as follows:

$$Y_{ijk} = \mu + Var_i + NaCl_j + Si_k + (Var + NaCl)_{ij} + (Var + Si)_{ik} + (NaCl + Si)_{jk} + (Var + NaCl + Si)_{ijk} + e_{ijk} \quad (5)$$

Where: Y_{ijk} = response variable, μ = constant common to all observations, Var_i = effect of the ith variety (i=1, ...,3), $NaCl_j$ = effect of the jth concentration of sodium chloride (j=1, ..., 3), Sik = effect of the kth level of silicon (k=1,...,3), Var × $NaCl_{ij}$ = combined effect of the ith variety on the jth concentration of NaCl, Var × Si_{ik} = combined effect of the ith manifold at the kth level of Si, NaCl × Si_{jk} = combined effect of the jth concentration of NaCl at the kth level of Si, Var × NaCl × Si_{ijk} = combined effect of ith manifold at the jth concentration of NaCl and the kth level of Si eijk = random error ~ N (0, σ2e).

RESULTS AND DISCUSSION

Germination and associate variables. The combination of sodium chloride levels, silicon, and varieties affected the germination rate percentage (Figure 1). In the control treatment, the Cherry variety, despite showing a superior response ($P \leq 0.01$) in the different salinity levels, compared to the Floradade and Rio Grande varieties, showed a significant decrease ($P \leq 0.01$) with the level of 50 mM of NaCl concerning its values at the levels of 0 and 25 mM of NaCl. This aspect was not observed when Si was included in the concentrations of 1 and 2 mM, in this sense it is important to mention that the Cherry variety had a significantly higher behavior in the expression of the germination rate compared to the rest of the varieties under study ($P \leq 0.01$).

On the other hand, there was an interaction between a variety of factors and salinity levels (Table 1) in the indices associated with germination. However, it was disconcerting to find no interaction or relationship between Si and variables related to the germination process, due to their importance in estimating the germinative power of plant seeds (Zhang, Lei, Zhang, and Sun, 2012).

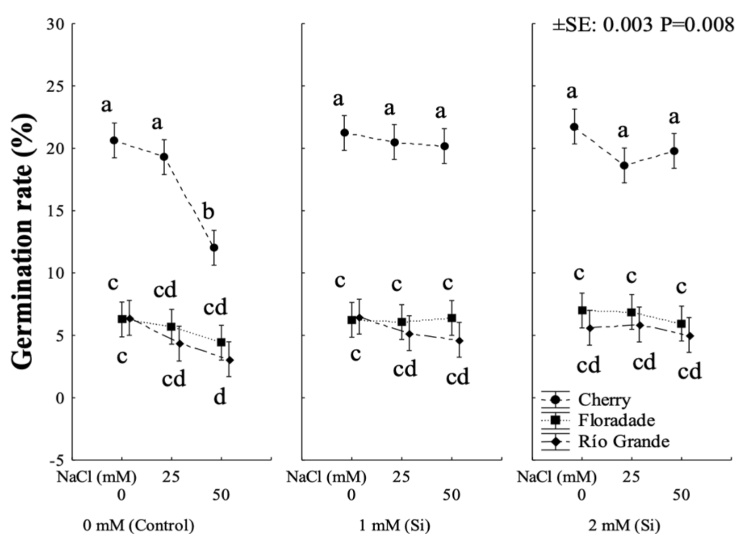

Figure 1. Third-degree (3^k) interaction in germination rate (%) of *S. lycopersicum* seedlings. [a, b, c, d] Averages with equal letters show no significant differences according to Tukey for $P \leq 0.05$. Significance was achieved by the logn(x) transformation. ±SE = Standard error.

Table 1. Interaction effect between S. lycopersicum varieties and sodium chloride (NaCl) levels on variables associated with germination.

Varieties	NaCl	GE	AGR (days)	GR	GS
Cherry	0	11.71±1.22 ab	0.219±0.01a	0.151±0.01ab	0.896±0.07a
Floradade	0	13.40±1.60 a	0.131±0.01b	0.090±0.01c	0.282±0.03b
Rio grande	0	13.25±2.45 a	0.131±0.02b	0.088±0.02c	0.277±0.t05b
Cherry	25	10.72±0.95 b	0.206±0.01 a	0.140±0.01 b	0.826±0.07 a
Floradade	25	13.65±2.03 a	0.133±0.01 b	0.090±0.01 c	0.283±0.04 b
Rio grande	25	12.87±2.46 ab	0.127±0.02 b	0.083±0.02 c	0.261±0.05 b
Cherry	50	13±1.46 ab	0.219±0.01 a	0.161±0.01 a	0.896±0.08 a
Floradade	50	12.92±2.04 ab	0.127±0.01 b	0.085±0.01 c	0.265±0.04 b
Rio grande	50	12.92±2.25 ab	0.115±0.01 b	0.074±0.01 c	0.231±0.05 b
±SE		0.34	0.001	0.001	0.003
p		0.012	0.033	0.001	0.018

GE = germination energy; AGR = average germination time; GR = germination rate; GS = germination speed. Different letters within the same column suggest significant differences according to Tukey para $P \leq 0.05$. The significance for TMG, GI and VG was achieved by the transformation √2.5. ± Represents the standard deviation; ±SE = Standard error.

The results in the GE indicator suggested uniformity between the varieties at the different salinity levels for $P \geq 0.05$, except for Floradade at the 25 mM level which exceeded ($P \leq 0.01$) the Cherry variety was considered the most significantly affected at this same salinity level, however, the Cherry variety exceeded ($P \leq 0.001$) in AGR, GR and GS, without showing any effects on any of the salinity levels under study, regarding the Floradade and Rio Grande varieties (Table 1).

It is possible that the variety effect predisposed an increase in the mechanical pressure for the emission of the first radicle, that depending on the results of the variety interaction with NaCl, the Cherry variety suggested uniformity in the germination process and associated variables without salinity (25, 50 mM) being a limitation, which is congruent with the results of germination percentage (Figure 2) where Cherry outperformed ($P \leq 0.001$) the rest of the varieties, although the germination percentage for any variety was not affected by the saline treatments. In this sense, the development of studies focused on elucidating the mechanisms related to and underlying the germination process in the presence of Si and NaCl-induced abiotic stress is suggested.

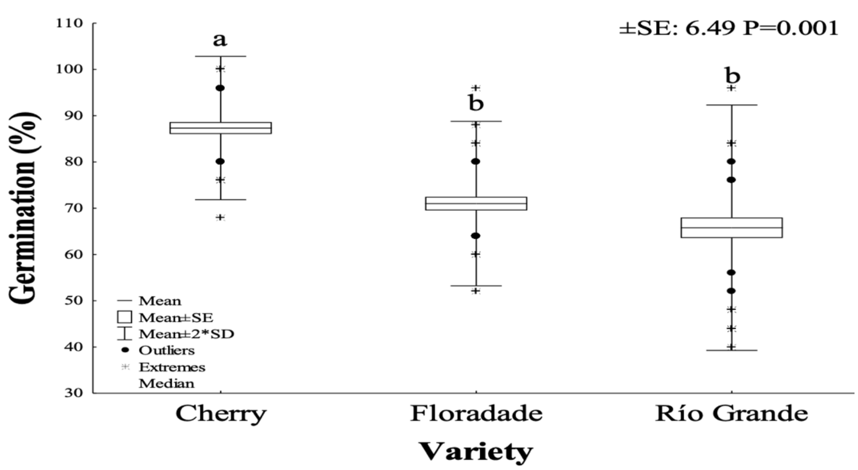

Figure 2. Effect of variety on germination percentage in *S. lycopersicum* varieties.
[a b] Different letters suggest significant differences according to Tukey at a 95% confidence level. ±EE = Standard error. Significance was achieved by the transformation √x+1.

Morphological and biomass accumulation in seedlings of *S. lycopersicum*. a different phenological stage such as the seedling stage, the results were more variable (Figure 3). The accumulation of fresh biomass by the Rio Grande variety was favored by the presence of Si (1 and 2 mM) within a medium-high salinity gradient (25-50 mM) compared to the rest of the varieties under study, own values, and control treatment averages ($P \leq 0.01$). Regarding the morphological development of the plant, it was found that Si interacted with NaCl to improve stem and root length in *S. lycopersicum* seedlings (Table 2).

Root length was increased in the presence of NaCl-enhanced Si, with the largest ($P \leq 0$ .001) lengths focusing on the combination of 50 mM NaCl with 2 mM Si, compared to the control treatment that considered the absence of NaCl, a similar effect occurred for stem length ($P \leq 0.001$). However, silicon did not influence the increase in the dry weight of the biomass (Figure 4). The control treatment exceeded ($P \leq 0.001$) the doses of Si under study in the influence of this variable.

Integration of the effects of Si and NaCl using CPA. Likewise, the relationships between the factors (variety, NaCl and Si) and their contribution to the expression of response variables were confirmed utilizing principal component analysis. The first component explained 45.4% of the variance by relating the varieties under study to the germination rate, which suggests the quality of the germination process; while the second component related the NaCl and Si factors with the accumulation of fresh and dry biomass, stem and root length, suggesting that these variables will be the first to be modified by the effect of both factors; Together, they contributed 22.80% to explain 68.19% of the cumulative variance. The third component, on the other hand, grouped variables related to the germination process, contributing 10.73% to explain 78.92% of the variance of the system (Table 3).

On the other hand, through the graphical analysis of the weight of the components, the variables with the greatest contribution were considered to be those that were located close to the origin, the relationship between variables as a function of the amplitude of the cosine of the angle, variability of the variable as a function of the length of the vector and the dissimilarity between variables as a function of the distance between endpoints of the vector (Figure 5).

The variable closest to the origin was Si but with a wide opening of the cosine of the angle concerning the variables under study, while the variety factor and its closed amplitude of the cosine of the angle with the germination rate was correlated as responsible for the high variability in the response of this variable. Sodium chloride, on the other hand, was correlated with root length, stem, and accumulation of dry and fresh biomass, indicating its direct effect on these variables in the seedling stage; the rest of the variables related to germination did not show a relationship with Si or NaCl (Figure 4). It is perceived that the germination rate will be associated with the variety, while the levels of NaCl and Si will be modulators in the variability of responses in the production of fresh and dry biomass, root, and stem development in S. *lycopersicum* seedlings, but not for the variables related to germination.

Table 2. Interaction effect between sodium chloride (NaCl) levels and Si doses on morphometric variables of seedlings 14 days after emergence.

NaCl	Si	RL	SL
mM	mM	- - - - - - - - - cm	- - - - - - - - -
0	0	5.54±1.78 cd	5.11±1.31 cd
0	1	5.75±1.7 bcd	5.38±1.33 cd
0	2	5.95±1.67 a-d	5.58±1.34 c
25	0	6.72±1.73 ab	6.52±1.36 b
25	1	6.79±1.69 ab	7.26±1.41 a
25	2	6.92±1.75 a	7.17±1.40 ab
50	0	5.01±1.69 d	4.93±1.32 c
50	1	6.32±1.76 ab	6.87±1.35 ab
50	2	6.83±1.84 a	7.20±1.33 ab
±SE		0.15	0.03
p		0.006	0.000

RL = root length; SL = stem length. [a, b, c, d] Different letters within the same row suggest significant differences according to Tukey for $P \leq 0.05$. Significance for SL was achieved by transformation $\sqrt{1.5}$. ± Represents the standard deviation; ±SE = Standard error.

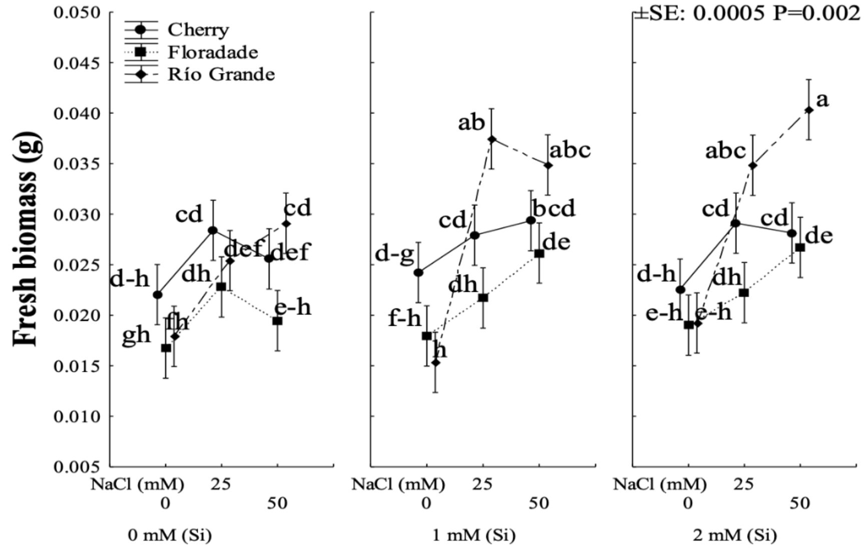

Figure 3. Third-degree (3k) interaction between the factor's variety × levels of NaCl × dose of Si in the accumulation of fresh biomass of S. lycopersicum seedlings. a, b, c, d, e, f, g, h Equal letters in the same column do not show significant differences according to Tukey for $P \leq 0.05$. ±SE = Standard error.

The effects by salinity levels in the percentage of germination rate Floradade and Rio Grande varieties may be related to the "Si excluder" condition of *S. lycopersicum* (Shi *et al.,* 2014), which should condition damage to the cell wall that induces a decrease in the permeability and water conductivity of the plasma membrane with the consequent delay of germination (Katembe, Ungar, and Mitchell, 1998), and prolongation of the latency period (Batista-Sánchez *et al.,* 2017), aspects that are linked to the ionic toxicity generated by sodium chloride salt stress in the embryo (Almodares, Hadi, and Dosti, 2007).
However, the mechanism by which Si alleviates salt stress in germination is not yet elucidated and there are several hypotheses of its influence on the activity of different plant hormones and genes sensitive to them, while others relate it to mechanical modifications of the seed cuticle that is reflected in emergence, germination and variables derived from these two; but without supporting criteria (Zhu *et al.,* 2019).

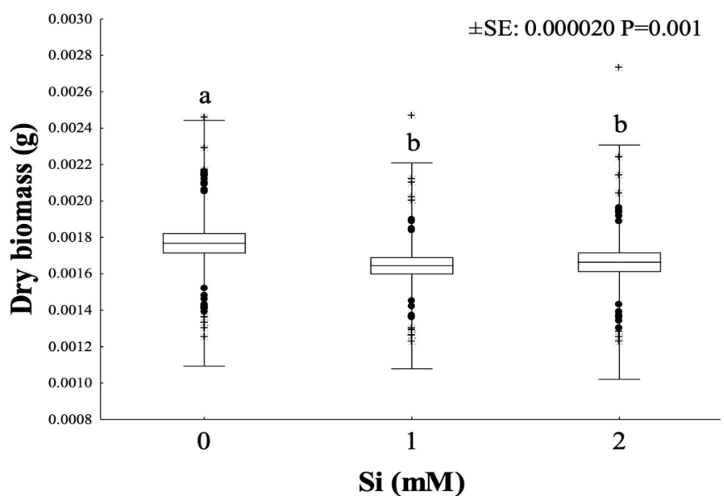

Figure 4. Effect of silicon on the production of dry biomass of *S. lycopersicum* seedlings. a, b Different letters suggest significant differences according to Tukey at a 95% confidence level. ±SE = Standard error.

Table 3. Determinants factors in the germination of and associated variables of S. lycopersicum under salinity and Si conditions as an attenuator of salt stress.

Components	Variables	Weitght Factor	Variance	Accumulated variance explained
			- - - - - - - - - %	- - - - - - - - -
I	Varieties	0.95	45.39	45.3
	Germination rate (%)	0.94		
II	NaCl	0.95	22.80	68.19
	Fresh biomass	0.87		
	Dry biomass	0.80		
	Si	0.92		
	Stem length	0.70		
	Root length	0.70		
III	Germination (%)	0.75	10.73	78.92
	Germination rate	0.75		
	Average germination time (days)	0.70		
	Germination speed	0.75		
	Germination energy	0.70		

Another important factor to consider is the variety, which in the present study clearly shows its determining effect on the plant's response to Si under saline stress conditions. The Cherry variety showed a higher response in the germination rate compared to the Floradade and Rio Grande varieties, which hypothetically may be related to the genetic factor that postulates them as varieties and the condition of extruder of Si by the species *S. lycopersicum* L. Based on the study developed by Deshmukh *et al.,* (2015) on the space between the NPA (asparagine-proline-alanine) domains of aquaporins, in which they obtained that NPA affects the specific length spacing between amino acids (AA) and identified it as an important characteristic for the accumulation of Si, they also compared in their study, different Si accumulating species such as *O. sativa* and *T. aestivum*; and exclusive species such as *S. lycopersicum*; identifying 108 AA for Si accumulator species among the NPA domains, while for *S. lycopersicum 109 AA* were identified among the NPA domains, from which it is inferred that this is one of the aspects that may be influencing the differential response due to the variety effect in terms of the presence of Si to mitigate salt stress.
In the indices or indicators associated with germination considering that GE associates or relates, the energy availability of the cotyledon (carbohydrates and lipids) necessary for germination (Ledea, Benítez, Nuviola, Wrigth, and Rubio, 2022), on the other hand, it could be argued that this variety has a different resistance to germination than Floradade and Río Grande, with the consequent energy cost in the use of energy resources for germination (Amini and Ehsanpour, 2005).

In this sense, they are referred to in studies of various crops as spinach (*Spinacia oleracea*) (Turhan, Kuşçu, and Şeniz, 2011), tomato, (Doğan, Avu, Can, and Aktan, 2008; Ruiz-Espinoza, Villalpando, Murillo, Beltrán, and Hernández, 2014) and eggplant (*Solanum melongena)* (Akinci, Akinci, Yilmaz, and Dikici, 2004), which increased the percentage, energy, index and average germination time at concentrations of 25, 50 and 75 mM NaCl; while other results showed a decrease in germination due to the effect of salinity, while the mean germination time and the time needed for germination (T50) increased significantly proportionally to the increase in NaCl levels (Akram, Zahid, Farooq, Nafees, and Rasool, 2020).

It is debated without consensus that the content, type and quantity of carbohydrates contained in the cotyledon, with emphasis on sugars, have a direct intervention in reducing the effects of salinity stress (Ashraf and Tufail, 1995; Amini and Ehsanpour, 2005), although it could also be related to properties or physical characteristics of the cuticle that condition protection against salinity (Debeaujon, Lepiniec, Pourcel, and Routaboul, 2007).

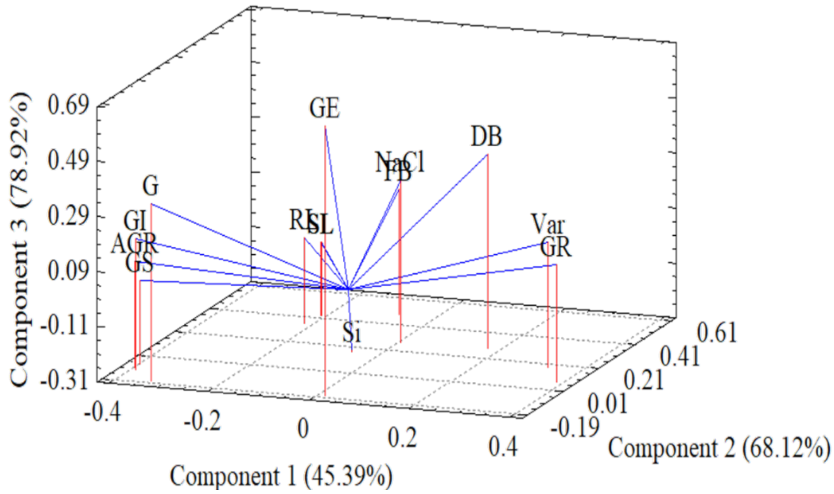

Figure 5. Germination relationship and associated variables of three varieties of *S. lycopersicum* under the effect of NaCl and Si as an attenuating factor. G = germination percentage; GI = gemination index; AGR = average germination time; GS = germination speed; GE = germination energy; RL = root length; SL = stem length; Si = silicon; NaCl = sodium chloride; FB = fresh biomass; DB = dry biomass; Var = variety; GR = germination rate.

The biomass accumulation from physiological homeostasis, is a direct link to the photosynthetic efficiency of the plant and its ability to absorb water and minerals (Ledea-Rodríguez *et al.,* 2022) when this aspect was linked to the effects of silicon, it was identified through the use of chlorophyll fluorescence in *Aloe vera* (Munns and Tester, 2008) and cucumber (Zhu *et al.,* 2019) that favored photosynthetic efficiency by influencing photosystem II (Parihar, Singh, Singh, Singh, and Prasad, 2015), thus protecting its functioning by regulating the accumulation of salt ions, elimination and reduction of ROS (reactive oxygen species) and adjustments in carbohydrate metabolism, the latter is inconclusive (Zhu *et al.,* 2019), so for this study, the increase of fresh biomass to the incidence of Si on the photosynthetic apparatus of seedlings could be considered.

As soon as at morphology development of the plant, the characteristics of the root system the (morphology, anatomy and hormonal activity) are aspects that influence and determine the absorption of Si, together with the location of Si transporters in the cells of the root system, it has been a topic little addressed, also considering the great variability which varies between species (Sah, Reddy, and Li, 2016), and which has been reported in different plant models, such as barley, *Cucurbita spp., C. sativus*, and rice (Zhu *et al.,* 2019); and soybean (*Glycine max* L.), corn, and wheat (Marmiroli, Marmiroli, and Pagano, 2022). However, for *S. lycopersicum* there is a need to develop direct tests that elucidate and contribute to the understanding of the transport of Si from the outside to the cell lumen at the root level (Coskun *et al.,* 2018).

In this sense, Haghighi and Pessarakli (2013) observed that Si mitigated the effects of NaCl salinity by increasing stem and root length in the initial growth stage of cherry tomato and cucumber (Wang *et al.,* 2015), pointing out among the possible manifest routes to mitigate the effects of salt stress at the root level, increased activity of Na^+/H^+ anti-carriers (Numan *et al.,* 2018; Khan *et al.,* 2020), phytolith formation, and caspary band reinforcement (endodermal and exodermal) (Zhu *et al*., 2019).

Regarding the accumulation of biomass, several studies have demonstrated the beneficial effects of Si in improving dry biomass accumulation in crops such as sunflower (*Helianthus annuus*), maize and wheat (Janmohammadi and Sabaghnia, 2015; Sun *et al.* 2021; Chourasiya, Nehra, Shukla, Singh, and Singh, 2021), and *S. lycopersicum* L (Mushinskiy, Aminova, and Korotkova 2018; Khan *et al.,* 2020). Despite the *desunt investigationis* regarding the absorption and transport of Si in tomato plants, it is conceived that it is deposited in the cell walls of the roots and prevents the translocation of salts to the different organs (Liang, Wong, and Wei, 2005), while regulating the loss of water in plants due to the thickening of the cuticle in the cell wall (Wang *et al.,* 2021).

In the present study, the increase in water content in plant tissue was evidenced through the expression of fresh biomass already presented, however, this does not necessarily have to be related to an increase in dry weight; Ali, Nulit, Ibrahim, and Yien (2021) obtained similar results in the cultivation of *O. sativa* when they conditioned the seeds with different stimulants and cation exchangers, including Si; these authors did not refer to the causes that could promote a lower weight of the biomass, however, some basic criteria such as the age of the plant were mentioned, in this case, *S. lycopersicum* at an early age, such as the seedling stage, accumulates a certain amount of water in its tissues similar to a succulent plant, so it could be considered that the mineral deposition, polysaccharides (cellulose and hemicellulose) and phenolic compounds (lignin) in the cell wall, which stimulates the presence of silicon, did not affect the accumulation of dry plant biomass.

CONCLUSIONS

The varieties under study, especially the Cherry variety, played a prominent role independent of Si doses during the germination process even under the effects of experimental NaCl doses. Si only affected the germination rate of seeds of *S. lycopersicum* varieties exposed to doses of NaCl. In the phenological stage of seedling, Si could improve the production of fresh biomass and morphological variables of the plant and root, but not in the dry weight of the plant.

ETHICS STATEMENT

Not applicable.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF SUPPORTING DATA

Not applicable.

COMPETING INTERESTS

All financial and non-financial competing interests must be declared in this section. If you do not have any competing interests, please state "The authors declare that they have no competing interests" in this section.

FINANCING

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AUTHORS' CONTRIBUTIONS

Research, methodology and application writing-original draft: E.A.E.A. Data curation, formal analysis, visualization, writing-original draft: J.L.L.R. Supervision: F.J.C.M. Investigation, conceptualization, validation, project administration, writing - review & editing: F.H.R.E. Methodology: F.A.B.M.

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