Revista Ciência Agronômica, v. 57, e202494602, 2026
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

RESEARCH ARTICLE
ISSN 1806-6690

Silicon seed treatment mitigates salt stress and improves mung bean (*Vigna radiata* L.) growth and development[1]

Natália Barros da Silva[2], Leandra Matos Barrozo[2], Alan Mario Zuffo[2], Francisco Charles dos Santos Silva[2], Tatiane Scilewski da Costa Zanatta[2], Mohammad K. Okla[3], Mohamed Abdel-Mawgoud[4], Charline Zaratin Alves[5]*

ABSTRACT - Mung bean (*Vigna radiata* L.) is tolerant to water deficit. However, a decline in its productivity can occur depending on the salinity stress intensity. Irrigation with low-quality water containing dissolved salts can cause physiological damage to plants. This study aimed to determine the effectiveness of silicon seed treatments as a promising approach for mitigating the adverse effects of saline irrigation water on crops. Five saline water concentrations were used for irrigation: 0.0, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}. Plants with (Si+) and without (Si-) silicon treatment were irrigated for 10, 20, and 30 days after emergence. The analyzed variables included absolute and relative growth rates in terms of shoot height, SPAD index, shoot and root dry mass, shoot and root lengths, stem diameter, number of pods, number of seeds per pod, and overall yield. Irrigation with non-saline water yielded the best outcomes, and increased salinity negatively affected the measured variables. Compared to Si- treatment, Si+ treatment was an effective strategy for mitigating salinity stress, particularly at relatively high salinity levels (4.5 and 6.0 dS m^{-1}), improving the shoot and root lengths, shoot dry mass, and absolute growth rate, and enhancing plant performance. In conclusion, Si application is a practical and effective approach for alleviating the detrimental effects of salinity stress, improving plant growth and productivity under saline stress conditions.

Keywords: Irrigation. Salinity. *Vigna radiata* L.

DOI: 10.5935/1806-6690.v57e202494602
Section Editor: Prof. Bruno França da Trindade Lessa - bruno.ftlessa@univasf.edu.br
*Author for correspondence
Received for publication 02/12/2024; approved on 16/03/2026
[1]Final project of the first author
[2]State University of Maranhão (UEMA), Balsas-MA, Brazil, nataliabrros9@gmail.com. (ORCID ID 0009-0009-3045-5704); leandrabarrozo1@gmail.com (ORCID ID 0000-0003-4956-4555); alan_zuffo@hotmail.com (ORCID ID 0000-0001-9704-5325); franciscocharlessilva@professor.uema.br (ORCID ID 0000-0001-9917-6863); sctatiane@gmail.com (ORCID ID 0000-0002-5103-605X)
[3]Botany and Microbiology Department, College of Science, King Saud University, P.O. Box, 2455, Riyadh 11451, Saudi Arabia. malokla@ksu.edu.sa (ORCID ID 0000-0002-4420-0587)
[4]National Center for Natural Product Research, University of Mississippi, USA, mahassa1@olemiss.edu (ORCID ID 0000-0003-0327-9345)
[5]Federal University of Mato Grosso do Sul (UFMS), Chapadão do Sul-MS, Brazil, charline.alves@ufms.br (ORCID ID 0000-0001-6228-078X)

INTRODUCTION

A low water quality with high salinity significantly hampers plant development by disrupting biochemical and physiological processes. Thus, salinity stress is a major challenge in agricultural systems, especially in arid and semiarid regions where high salt concentrations in soil and water adversely affect plant growth and yield (Zörb *et al*., 2019). It reduces the osmotic potential of the soil solution, hindering the absorption of water and minerals, such as potassium (K), calcium (Ca), and magnesium (Mg), and mitigating the toxic effects of sodium (Na) (Fernandes *et al*., 2022; Zörb *et al*., 2019). It also affects the soil–plant system by reducing the osmotic potential due to high dissolved salt concentrations in the substrate solution, limiting water availability to plants (Pinheiro *et al*., 2019).

It is crucial to improve plant tolerance to salinity stress via innovative strategies and sustainable practices. Recent studies have highlighted silicon (Si) as a promising tool for mitigating the detrimental effects of salinity stress. Although it is not an essential nutrient, Si significantly contributes to plant resilience by enhancing biochemical, physiological, and structural attributes (Santos *et al*., 2020). In this context, the salinity tolerance of plants is associated with the use of chemical elements, including Si (Santos *et al*., 2020). It strengthens cell walls, reduces oxidative damage, improves water-use efficiency, and modulates antioxidant enzyme activity. These benefits collectively increase the ability of plants to cope with saline environments (Rodrigues *et al*., 2018). Thus, Si can be used as a tool in more sustainable food systems, potentially promoting food security for populations, especially in regions with extreme environmental conditions for agricultural production (Mir *et al*., 2022).

Mung beans (*Vigna radiata* L.), known for their adaptability, are valuable crops for these regions. Considering that mung bean is a good alternative for second crops, it has the potential to become increasingly cultivated in the southern region of Maranhão, as it develops well even under water stress conditions (Favero *et al*., 2021). Mung bean growth and productivity are significantly reduced under salinity stress conditions. Si application enhances plant resilience, resulting in better growth and development under saline conditions, and maintains agricultural productivity and food security in regions affected by salinity. Thus, studies on the ability of seed treatments to attenuate salinity stress and provide vigor in mung bean production, which is characterized by water scarcity and, consequently, saline stress in the soil, contribute to cultivation in Northeast Brazil.

MATERIAL AND METHODS

Experimental location

The experiment was conducted at Maranhão State University, in Balsas, State of Maranhão, Brazil, under a protected environment from February to May 2024. Mung bean seeds were obtained from production properties in the region of Balsas, MA. The soil used in the experiment was a dystrophic yellow LATOSSOL (Santos *et al*., 2018) and was collected from the experimental area of the State University of Maranhão, Balsas Campus. Eight-liter plastic seedling pots filled with sifted soil were used to promote root development.

Si treatment

The Si source used was potassium silicate fertilizer (Protect Silifol®) containing 12% Si and 12% K. Si fertilizer was applied to the soil at a rate of 1.5 mL/kg soil (equivalent to 180 mg/kg Si and 150 mg/kg K). Coating was performed following the methodology described by Nunes (2005), which consisted of manual application in plastic bags. After treatment, the seeds were dried at room temperature for 24 h. The control seeds were treated with water free of Si (150 mL/100 kg). After seed treatment, four seeds were sown in each pot, and thinning was performed at four days after emergence, prioritizing the maintenance of the most vigorous seedlings.

Salinity treatment

Saline irrigation solutions were prepared with NaCl at electrical conductivities ranging from 0.0 to 6.0 dS m^{-1}, in which 3 saline irrigations were performed at 10, 20, and 30 days after emergence. The saline water concentrations were determined based on the electrical conductivity of the water (0.0, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}). The relationship between the electrical conductivity of the solution and the NaCl concentration was determined to calculate the amount of NaCl to be added to the volume of water (Souza *et al*., 2017). According to measurements taken with a conductivity meter, an equation was derived and utilized to prepare irrigation solutions in the field. The following equation was used was: $EC = A + BX$, where EC represents the electrical conductivity of the solution (dS m^{-1}) and X denotes the amount of NaCl (mg L^{-1}). This equation provides a practical method for calculating the required NaCl concentration to achieve the desired electrical conductivity in irrigation solutions.

Growth analyses

The following variables were analyzed throughout the cycle: absolute and relative growth rates in terms of shoot height (in cm day^{-1}), SPAD index (vegetative stage, flowering and maturation), and stem diameter (in each phenological stage). At the end of the crop cycle, the plants were taken to the laboratory, and the following variables were analyzed: shoot and root dry mass, shoot and root lengths, number of pods, number of seeds per pod, and yield (t h^{-1}).

The study was conducted in randomized blocks in a 2 × 5 factorial design (seed treatment with the presence (Si+) or absence (Si-) of Si and 5 salt concentrations in irrigation water: 0.0, 1.5, 3.0, 4.5, and 6.0 dS m^{-1}). There were 3 replicates, with 3 plants per plot, totaling 90 experimental plots.

Statistical analyses

The data were subjected to analysis of variance (ANOVA). The means of the qualitative factors (with and without Si) were compared using the Tukey test at a confidence level of 0.05. Regression analysis was used to determine the salt concentrations of the irrigation water (quantitative factor), and the significance equations (F test, $p < 0.05$) were adjusted according to the highest coefficients of determination. These analyses were performed using Sisvar software, version 5.6, for Windows (Statistical Analysis Software, UFLA, Lavras, MG, BRA).

RESULTS AND DISCUSSION

ANOVA revealed that most of the variables significantly differed under salt stress (Table 1). Si was only significant for stem diameter at pod formation and maturation, shoot length, root length, and root dry mass. The interaction effects of both salinity and Si were significant for stem diameter at flowering, pod formation, maturation, length of part of the area, root length, dry mass of the part of the area, and absolute growth rate.

For stem diameter, at the significant stages analyzed (flowering, pod formation, and maturation), the same behavior was observed, in which Si was effective against stress at 6.0 dS m^{-1}, ensuring larger diameters than those of plants without treatment (Figures 1–3).

Si application has been used as a strategy to minimize the deleterious effects of salt stress on plants (Nóbrega *et al*., 2020). Si functions as an enzymatic antioxidant agent, activating defense mechanisms in plants under both biotic and abiotic stressors. It is involved in processes, such as nitrogen and proline metabolism, glycine betaine production, the antioxidant defense system, and the regulation of the water–plant–atmosphere ratio (Rocha *et al*., 2022).

Table 1 - Summary analysis of variance (ANOVA) of the variables analyzed in the growth and development of mung bean under different salt concentrations in water with silicon

Variables	Salinity (SA)	Silicon (SI)	SA × SI	Mean	CV (%)
SD (V)	0.05	0.06	0.07	2.14	12.07
SD (F)	0.13	0.20	0.21*	2.53	9.19
SD (FV)	0.17	0.44*	0.22*	2.61	9.37
CD (M)	0.19*	0.47*	0.21*	2.64	9.41
Index Spade (V)	77.55**	27.55	7.84	27.07	13.96
Index Spade (F)	98.48**	13.27	5.95	29.99	12.06
Index Spade (M)	54.88**	2.46	19.57	23.03	12.86
LPA	277.72**	286.26**	62.71*	43.03	9.52
RL	44.97**	13.15**	9.08**	6.66	18.67
DMPA	5.17**	0.005	0.36**	1.61	6.90
RDM	0.17**	0.003*	0.01**	0.27	8.00
NPP	4.76**	0	0.15	2.00	18.71
NSPP	23.53**	0.16	0.72	6.12	8.09
AGR	0.12**	0.003	0.02**	0.46	12.65
RGR	0.004**	0.01	0.003	0.02	25.00
Y	81.967**	0.07	0.353	4.39	20.15

Abbreviations: Stem diameter (SD) - vegetative (V), flowering (F), pod formation (PF), maturation (M); Spad index (Spad Index) - vegetative (V), flowering (F), maturation (M)**;** length of part area (LPA); root length (RL); dry mass of the part area (DMPA); root dry mass (RDM); number of pods per plant (NPP); number of seeds per pod (NSPP); absolute growth rate (AGR); relative growth rate (RGR); yield (Y). * ($p < 0.05$) and ** ($p < 0.01$) indicate significance according to the F test. CV (%): Coefficient of variation. Source: Research data

Figure 1 - Stem diameter (SD) at flowering of mung bean subjected to different saline irrigation and silicon treatments with (Si+) and without silicon (Si-)

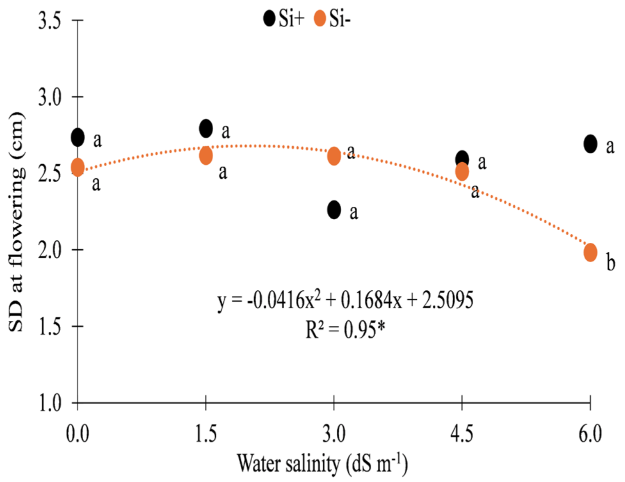
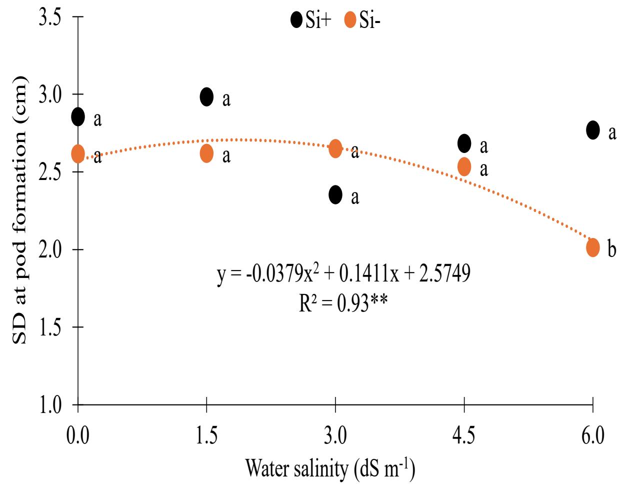


Figure 2 - Stem diameter (SD) during pod formation of mung bean subjected to different levels of saline irrigation and silicon treatments with (Si+) and without silicon (Si-)



Even under Si treatment, the stem diameter decreased, indicating that increased salinity significantly reduced the stem diameter. Additionally, compared to the control, Si further reduced the stem diameter at 6.0 dS m^{-1} salinity. Salinity stress affects water uptake depending on the species and interferes with mineral nutrition and, consequently, the absolute increase in shoot diameter (Mesquita *et al*., 2012). Prazeres *et al*. (2015) reported that cowpea had a reduced stem length starting at a salinity of 1.55 dS $m^{-1,}$ and the maximum reduction observed between extremes (0.8 – 5 dS m^{-1}) was 10.33%. A more significant reduction was reported by Andrade *et al*. (2019), who evaluated the initial growth of cowpea genotypes and reported that the stem reduction reached 21.46% at 20 days after emergence, with salinity levels ranging from 0.6 to 5.1 dS m^{-1}.

The increase in salinity decreased the length of the aerial plant parts, regardless of the amount of Si (Figure 4). Therefore, at a salinity of 6 dS m^{-1}, the use of Si promoted a greater shoot length than the control treatment. Plant responses to saline stress are typically characterized by growth inhibition, which can occur within minutes or days. This results in stomatal closure and cell expansion inhibition, particularly in the aerial parts of the plant (Isayenkov; Maathuis, 2019). Andrade *et al*. (2019) and Sá *et al*. (2018) reported that the height of cowpea decreased as the salinity of the irrigation water increased.

Compared to the control plants, plants treated with Si presented higher values, with the maximum potential at the maximum Si dose under 6.0 dS m^{-1} salinity. Similar results to those of the present study have been reported by Tatagiba *et al*. (2024), who found that plants not supplied with Si and exposed to stress presented significant reductions in the average height by up to 32% compared to those treated with Si. This confirms that Si enhances the plant height under stress conditions.

As the salinity increased, the root length decreased (Figure 5). At a salinity of 1.5 dS m^{-1}, the use of Si promoted a greater root length than the treatment without this element. The stress effects caused by salinity disrupt cellular and metabolic activities, including stomatal closure, photosynthesis inhibition, leaf abscission, and plant growth cessation (Taiz *et al*., 2017).

Si can only be used as an attenuator of salinity stress at 1.5 dS m^{-1} (mild stress), as there was a significant difference between the root length and stabilization of the negative effects of salinity, ensuring a decrease compared to that of plants without Si. Si application is known to regulate the local and systemic defense responses of plants against abiotic stress, stimulating plant growth and development (Silva, Anderson *et al*., 2020).

The dry mass of the aerial plant parts decreased with increasing saline irrigation concentrations, indicating that salt negatively affects the physiological processes of plants (Figure 6). In this context, Mesquita *et al*. (2012) reported that the stem diameter and root and aerial part biomass decreased with the increasing salinity of the irrigation water.

Si did not have significant effects in the early stages, when salt stress was not yet pronounced. However, it demonstrated its potential in the stages with 4.5 and 6.0 dS m^{-1} salinity, as the plants experienced severe stress. Under these conditions, Si reduced the negative effects caused by saline irrigation. According to Moreira *et al*. (2010), Si application increased the dry weight and growth rate of soybean. Estaji and Niknam (2020) reported that the increase in leaf area growth observed in plants subjected to concentrations up to 2.0 mM was attributed to the ability of salicylic acid to prevent the reduction of cytokinin and auxin, stimulating cell division and promoting plant growth. These results agree with those of Oliveira *et al*. (2009), who reported significant increases in aerial dry matter in rice and common bean after Si application. Araújo *et al*. (2022), who studied foliar Si application in maize, reported increases in shoot fresh matter under soil water deficit conditions, indicating the positive effects of Si on plant development. According to Souza *et al*. (2013), the efficiency of Si application in increasing biomass can be attributed to the ability of Si to accumulate in leaf tissues and reduce plant transpiration, increasing water accumulation.

Saltwater depth had negative effects, reducing the root dry mass, and Si had no effect on this damage; thus, it was not possible to ensure these decreases. As shown in Figure 7, these results of increasing salinity are consistent with those observed by Mesquita *et al*. (2012), who reported that the phytomass yield accumulation decreased with the increasing saline content of irrigation water. At a saline irrigation level with an electrical conductivity of 1.5 dS m^{-1}, the treatment without Si application resulted in a greater root dry mass.

Figure 3 - Stem diameter (SD) at maturation of mung bean subjected to different saline irrigation and silicon treatments with (Si+) and without silicon (Si-)

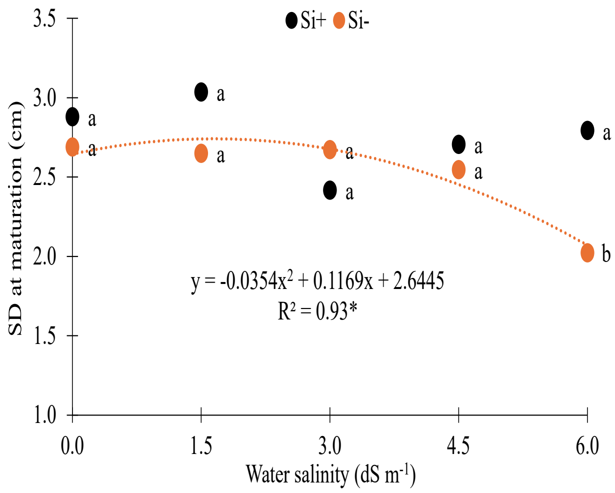


Figure 4 - Length of part area (LPA) of mung bean subjected to different levels of saline irrigation and silicon treatments with (Si+) and without silicon (Si-)

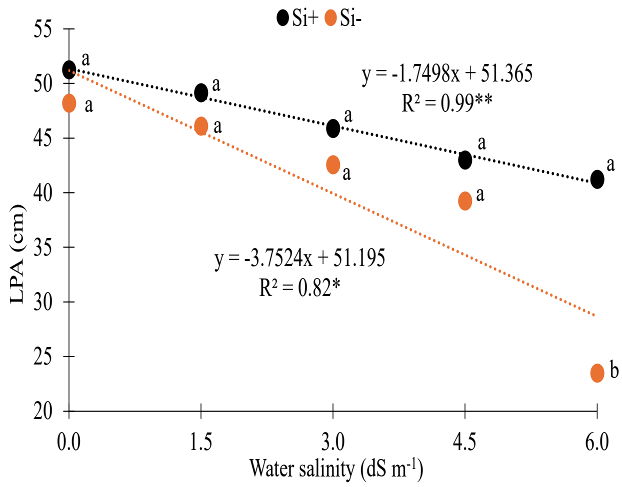


Figure 5 - Root length (RL) of mung bean subjected to different levels of saline irrigation and silicon treatments with (Si+) and without silicon (Si-)

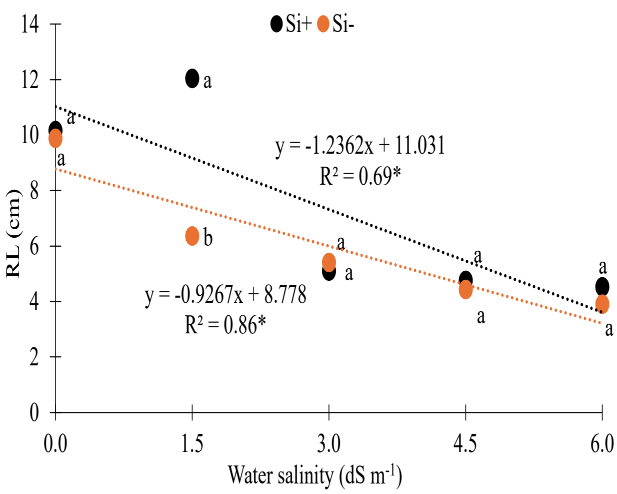
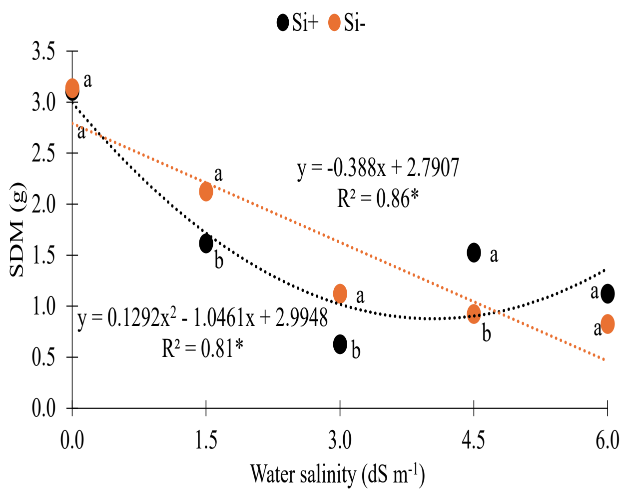


Figure 6 - Shoot dry mass (SDM) of mung bean subjected to different levels of saline irrigation and silicon treatments with (Si+) and without silicon (Si-)



The absolute growth rate is an indicator of the average growth rate of a given plant over an evaluation period. For this variable, a reduction in growth was observed as the salt concentration in the water increased; reductions were also observed in the other variables analyzed (Figure 8). This behavior was also observed by Mesquita *et al*. (2014), who reported that the absolute height growth was affected by the degenerative action of the salts present in the irrigation water. Salinity stress inhibits plant growth by restricting water absorption. In addition, the partial closure of stomata caused by osmotic and ionic effects causes changes in the photosynthetic rate and plant metabolism, reducing turgor pressure, cell elongation, and cell wall elasticity and inhibiting their growth (Charfeddine *et al*., 2019; Rodrigues *et al*., 2018).

Si did not exhibit potential in the first salinity levels, as the effect of salt was not yet significant, but showed an effect at 4.5 and 6.0 dS m^{-1}, as the plant was under severe stress, reducing the decrease caused by saline irrigation. According to Moreira *et al*. (2010), Si application increased the dry weight and growth rate of soybean. The increase in the leaf area growth rate observed in plants subjected to concentrations up to 2.0 mM reflects the ability of salicylic acid to prevent the reduction of cytokinin and auxin, which stimulates cell division and plant growth (Estaji; Niknam, 2020).

To analyze many factors and their interactions, the use of multivariate techniques is a viable option, as it allows multiple combinations of variables within the experimental unit (Moreira, 2009). The analysis of canonical variables can serve as a tool of great importance because it determines the best linear combination of two groups of variables that are highly correlated by measuring the existence and intensity of the relationships between groups (Silva, André *et al*., 2020).

Based on canonical correlation analysis (Figure 9), saline irrigation had a negative effect on the variables. The lowest irrigation depths, which yielded the best results, showed similar values, whereas an increase in the salt content corresponded to a greater distance from the negative axis. According to Dias and Blanco (2010), the reductions in plant growth parameters, such as those observed, resulted from the indirect effects caused by salinity, such as difficulty in water absorption, toxicity of specific ions, and interference in physiological processes.

For the salt concentrations at 0.0 and 1.5 dS m^{-1}, the treated and untreated plants presented the highest means, as they were closer to all variables, indicating that there were no significant differences for salt or Si under less severe stress. The lowest values were observed at 4.5 and 6.0 dS m^{-1} when there was no Si, and Si attenuated against the deleterious effects of salinity at 4.5 dS m^{-1}. The main mechanisms by which Si mitigates the effects of water stress, as outlined by Wang *et al*. (2021), include the enhancement of water uptake and transport, regulation of stomatal behavior and water loss through transpiration, accumulation of solutes and osmoregulatory substances, and activation of plant defense responses associated with signaling. These processes help maintain the overall integrity and balance within the plant, ensuring a proper water content and supporting its healthy development. In the analysis of the canonical variables, the first and second canonical axes accounted for 87.1% of the variation in the agronomic characteristics of mung bean under different salt concentrations in the irrigation water in combination with Si treatment. Future studies should investigate the mechanisms by which Si mediates stress tolerance and its effectiveness across crops and environments to promote sustainable agriculture.

Figure 7 - Root dry mass (RDM) of mung bean subjected to different saline irrigation and silicon treatments with (Si+) and without silicon (Si-)

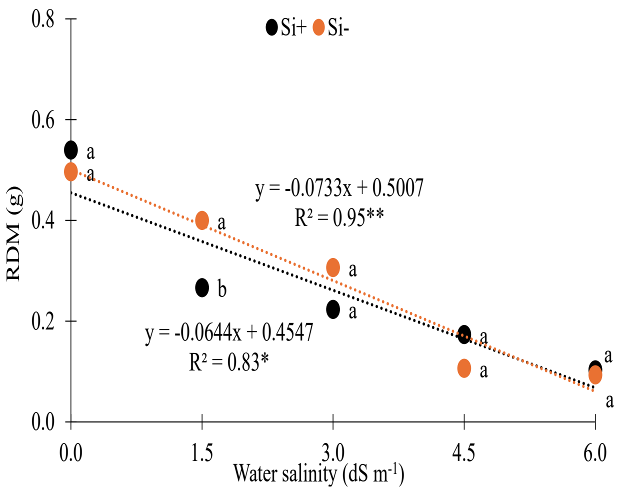


Figure 8 - Absolute growth rate (AGR) of mung bean subjected to different levels of saline irrigation and silicon treatments with (Si+) and without silicon (Si-)

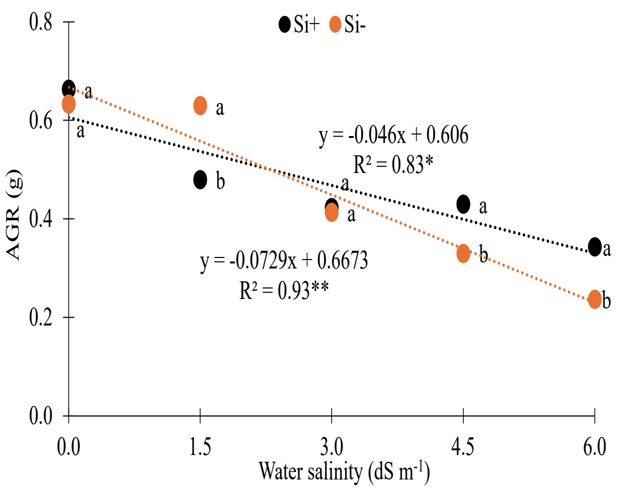
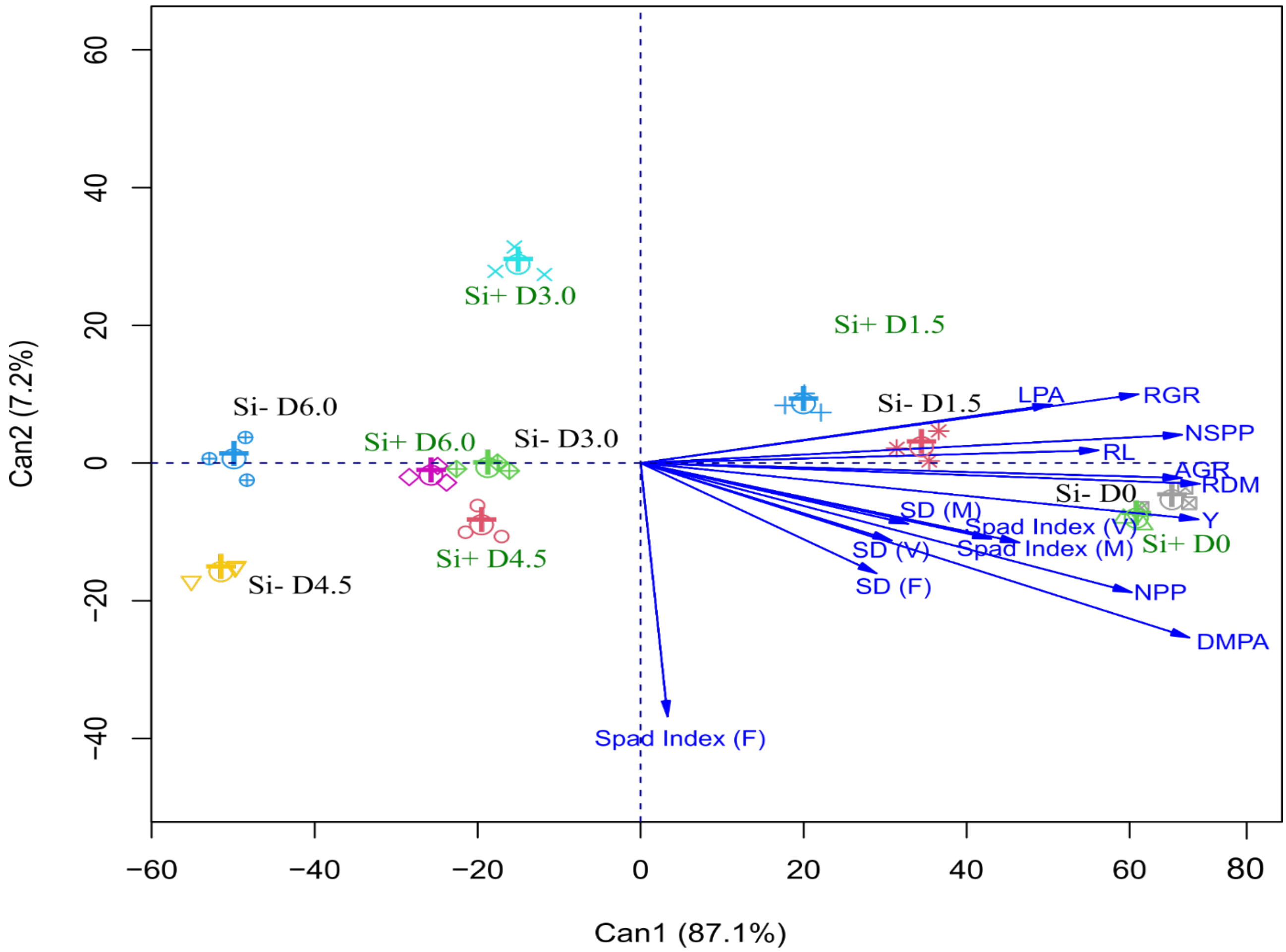


Figure 9 - Stem diameter (SD) at the vegetative stage (V), flowering (F), pod formation (PF), and maturation (M); spike index (Spad Index) at the vegetative stage (V), flowering (F), and maturation (M)**;** length of part area (LPA); root length (RL); dry mass of the part area (DMP); root dry mass (RDM); number of pods per plant (NPP); number of seeds per pod (NSPP); absolute growth rate (AGR); relative growth rate (RGR); yield (Y); and growth and development of mung bean under different saltwater concentrations applied in water with silicon. Seed treatment with the presence (Si+) and absence of silicon (Si-); salt concentrations of irrigation water: 0.0 dS m^{-1} (D1); 1.5 dS m^{-1} (D2); 3.0 dS m^{-1} (D3); 4.5 dS m^{-1} (D4); and 6.0 dS m^{-1} (D5)



CONCLUSIONS

Non-saline irrigation water (0.0 dS m^{-1}) resulted in the highest mung bean quality and productivity, and increasing salinity levels negatively affected these attributes. Compared to Si, Si increased the stem diameter, shoot and root lengths, shoot dry mass, and absolute growth rate, significantly enhancing plant performance. These findings highlight the value of incorporating Si into crop management under saline conditions.

DATA AVAILABILITY STATEMENT

The research data is available only upon request to the corresponding author.

REFERENCES

ANDRADE, J. R. *et al*. Chlorophyll fluorescence as a tool to select salinity-tolerant cowpea genotypes. **Comunicata Scientiae**, v. 10, n. 2, p. 319-324, 2019.

ARAÚJO, V. S. *et al*. Influência da aplicação foliar de silício no desenvolvimento e produtividade do milho sob deficit hídrico no semiárido piauiense. **Research Society and Development**, v. 11, p. 1-10, 2022.

CHARFEDDINE, S. *et al*. Ectopic expression of a grape vine vacuolar NHX antiporter enhances transgenic potato plant tolerance to salinity. **Journal of Plant Biochemistry and Biotecnology**, v. 28 p. 50-62, 2019.

DIAS, N. S.; BLANCO, F. F. Efeitos dos sais no solo e na planta. *In*: GHEYI, H. R.; DIAS, N. S.; LACERDA, C. F. (ed.). **Manejo da salinidade na agricultura**: estudos básicos e aplicados. Fortaleza: Instituto Nacional de Ciência e Tecnologia em Salinidade, 2010. p. 129-140.

ESTAJI, A.; NIKNAM, F. Foliar salicylic acid spraying effects on growth, seed oil content, and physiology of drought-stressed *Silybum marianum* L. plant. **Agricultural Water Management**, v. 234, e106116, 2020.

FAVERO, V. O. *et al*. Bradyrhizobium as the only rhizobial inhabitant of mung bean (*Vigna radiata*) nodules in tropical soils: a strategy based on microbiome for improving biological nitrogen fixation using bioproducts. **Journal Frontiers in Plant Science**, v. 11, n. 1, p. 602-645, 2021.

FERNANDES, C. S. *et al*. Ionic homeostasis, biochemical components and yield of Italian zucchini under nitrogen forms and salt stress. **Brazilian Journal of Biology**, v. 82, n. 1, p. 233-567, 2022.

ISAYENKOV, S. V.; MAATHUIS, F. J. M. Plant salinity stress: many unanswered questions remain. **Frontiers in Plant Science**, v. 10, p. 1-11, 2019.

MESQUITA, F. O. *et al*. Crescimento absoluto e relativo de mudas de maracujazeiro sob biofertilizante e águas salinas. **Revista de Ciências Agrárias**, v. 35, n. 1, p. 229-239, 2014.

MESQUITA, F. O. *et al*. Crescimento inicial de Carica papaya sob irrigação com águas salinas em solo com biofertilizante bovino. **Revista Semina: Ciências Agrárias**, v. 33, p. 2689-2704, 2012.

MIR, R. A. *et al*. Multidimensional role of silicon to activate resilient plant growth and to mitigate abiotic stress. **Frontiers in Plant Science**, v. 13, 2022.

MOREIRA, A. R. *et al*. Resposta da cultura de soja a aplicação de silício foliar. **Bioscience Journal**, v. 26, n. 3, p. 413-423, 2010.

MOREIRA, R. M. P. Potencial agronômico e divergência genética entre genótipos de feijão-vagem de crescimento determinado. **Semina: Ciências Agrárias**, v. 30, p. 1051-1060, 2009.

NÓBREGA, J. S. *et al*. Potencial fisiológico de sementes de melão pepino submetidas a salinidade. **Research, Society and Development**, v. 9, n. 7, e31973735, 2020.

NUNES, J. C. **Tratamento de sementes**: qualidade e fatores que podem afetar a sua performance em laboratório. Syngenta Proteção de Cultivos, 2005. 16 p.

OLIVEIRA, L. L. P. *et al*. Efeito da água residuária de dessalinizadores na germinação de feijão mungo-verde. **Agropecuária Científica no Semiárido**, v. 9, n. 2, p. 37-41, 2009.

PINHEIRO, G. G. *et al*. Efeito do estresse salino em sementes e plântulas de feijão-guandu. **Enciclopédia Biosfera**, v. 9, n. 16, p. 901-912, 2019.

PRAZERES, S. S. *et al*. Crescimento e trocas gasosas de plantas de feijão-caupi sob irrigação salina e doses de potássio. **Revista Agro@mbiente On-line**, v. 9, n. 2, p. 111-118, 2015.

ROCHA, M. E. L. *et al*. Morphophysiological changes in seedlings of two wood species after application of salicylic acid. **Revista Ceres**, v. 69, p. 158-166, 2022.

RODRIGUES, A. J. O. *et al*. Efeito da adubação silicatada no cultivo de tomateiro sob estresse salino. **Revista Agropecuária Científica no Semiárido**, v. 14, n. 2, p. 141-148, 2018.

SÁ, F. V. S. *et al*. Growth, gas exchange and photochemical efficiency of the cowpea bean under salt stress and phosphorus fertilization. **Comunicata Scientiae**, v. 9, n. 4, p. 668-679, 2018.

SANTOS, C. M. G. *et al*. Efeito da aplicação de silício na germinação de sementes de pimenta sob estresse salino. **Revista Pesquisa, Sociedade e Desenvolvimento**, v. 9, n. 8, p. 1-14, 2020.

SANTOS, H. G. *et al*. **Sistema brasileiro de classificação de solos**. 5. ed. rev. e ampl. Brasília, DF: Embrapa, 2018. 352 p.

SILVA, A. A. R. da *et al*. Salicylic acid as an attenuator of salt stress in soursop. **Revista Caatinga**, v. 33, p. 1092-1101, 2020.

SILVA, A. S. *et al*. Análise multivariada da palma forrageira: características morfoprodutivas sob correlações canônicas. **Revista Agrarian**, v. 13, n. 47, p. 100-106, 2020.

SOUZA, L. C. *et al*. Osmorreguladores em plantas de sorgo sob suspensão hídrica e diferentes níveis de silício. **Revista Brasileira de Milho e Sorgo**, v. 12, n. 3, p. 240-249, 2013.

SOUZA, R. S. *et al*. Concentração de macronutrientes e de sódio em mudas de mogno submetidas ao estresse salino. **Revista Nativa**, v. 5, n. 2, p. 127-132, 2017.

TAIZ, L. *et al*. **Fisiologia e desenvolvimento vegetal**. 6. ed. Porto Alegre: Artmed, 2017.

TATAGIBA, S. D. *et al*. Uso do silício no crescimento e produção do feijoeiro submetido a diferentes condições hídricas. **Scientific Electronic Archives**, v. 17, n. 3, p. 1-13, 2024.

WANG, M. *et al*. Functions of silicon in plant drought stress responses. **Hortic Research**, n. 8, p. 254, 2021.

ZÖRB, C. *et al*. Salinity and crop yield. **Plant Biology**, v. 21, n. 1, p. 31-38, 2019.