Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Potassium silicate on the productivity of *Opuntia stricta* Haw and the infestation by *Diaspis echinocacti*

Silicato de potássio na produtividade de *Opuntia stricta* Haw e na infestação por *Diaspis echinocacti*

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Abstract

Forage cactus has gradually gained economic importance and is a potential alternative for producers in the semiarid region, as it can be used for various purposes for both humans and animals. However, its cultivation is affected by several types of insect pests that affect its production, especially the scale insect. Thus, this study aimed to test the influence of potassium silicate on forage cactus productivity and scale insect infestation. The experimental design used was randomized blocks in a factorial scheme with repeated measurements over time of 4 x 4 + 1, corresponding to four concentrations of potassium silicate (0, 5, 9, 18, 28 ml L-1) and four application times (0, 90, 180, 270 days) and an additional control treatment (without silicate application) with four blocks, containing five plants as the experimental unit. At 365 days after the start of the experiment, the plants of the experimental plot were used to perform biometric and infestation analyses. Morphoagronomic variables of the palm were considered, and the level of scale mealybug infestation was also evaluated. There was no significant difference between the different times of product application. The applications of potassium silicate benefited the forage palms, especially at a concentration of 28 mL L^1, which provided greater dry matter productivity (84.78 t ha^1) and lower scale mealybug infestation (55.4%). It is concluded that there is evidence that the application of potassium silicate induces resistance to scale mealybug with a lower level of infestation in the cladodes.

Keywords: *Opunti*a spp., *Diapis echinocacti*, K_2SiO_3, forage cactus management, pest control.

Resumo

A palma forrageira vem gradualmente adquirindo importância econômica, sendo uma alternativa em potencial para produtores do semiárido, pois pode ser usada para diversos fins tanto para humanos como animais. No entanto, seu cultivo é acometido por vários tipos de insetos-praga que afetam sua produção, em especial a cochonilha de escama. Dessa forma, objetivou-se testar a influência do silicato de potássio na produtividade de palma-forrageira e na infestação por Cochonilha de Escama. O delineamento experimental utilizado foi em blocos casualizados em esquema fatorial com medida repetida no tempo de 4 x 4 +1, correspondente a quatro concentrações de silicato de potássio (0, 5, 9, 18, 28 ml L^{-1}) e quatro épocas de aplicação (0, 90, 180, 270 dias) e um tratamento adicional testemunha (sem aplicação do silicato) com 4 blocos, contendo 5 plantas como unidade experimental. Aos 365 dias após o ínicio do experimento, as plantas da parcela experimental foram usadas para a realização das análises biométricas e de infestação. Foram levados em consideração variáveis morfoagronômicas da palma e também foi avaliado o nível de infestação da cochonilha da escama. Não houve diferença significativa entre as diferentes épocas de aplicação do produto. As aplicações de silicato de potássio beneficiaram as palmas-forrageiras, especialmente na concentração de 28 ml L^{-1}, que proporcionou maior produtividade de matéria seca (84,78 t ha^{-1}) e com menor infestação por cochonilha da escama (55,4%). Conclui-se que existem evidências que a aplicação de silicato de potássio induz resistência a cochonilha da escama com menor nível de infestação nos cladódios.

Palavras-Chave: *Opuntia* spp., *Diapis echinocacti*, K_2SiO_3, manejo da palma forrageira, controle de pragas.

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Received: June 19, 2025 – Accepted: August 04, 2025
Editor: Takako Matsumura Tundisi

1. Introduction

The genera *Opuntia* and *Nopalea* are responsible for the most commercially cultivated forage palms and the primary food source for ruminants in the semiarid region of northeastern Brazil (Bayar et al., 2018; Albuquerque Junior et al., 2023a). Forage palm has gradually acquired economic importance, generally cultivated in arid areas to protect the soil against erosion (Batista et al., 2022; Albuquerque Junior et al., 2023a). It is an alternative that can be used for several purposes, and humans and animals consume its fresh fruit. The rich chemical composition of the cladodes suggests that they can be exploited to extract pectin (Kumar et al., 2017). In addition, its industrial and medicinal products are in high demand in the market (Bayar et al., 2018; Ramdani et al., 2021; Kumar et al., 2017. However, like any agricultural crop, forage palm is damaged by several types of insect pests that can affect its production, such as ants, caterpillars and grasshoppers, but the scale insect *Diaspis echinocacti* (Bouché, 1833) (Hemiptera; Diaspididae) is the primary harmful agent to the crop, causing the most significant losses to these plants in the central producing regions of Brazil (Albuquerque Junior et al., 2023a; Albuquerque Junior et al., 2023b).

The genera *Opuntia* and *Nopalea* are responsible for the most commercially cultivated forage palms and the main food source for ruminants in the semiarid region of northeastern Brazil (Bayar et al., 2018; Albuquerque Junior et al., 2023a). Forage palm, cultivated in arid environments to protect the soil, has gradually acquired economic importance, as it constitutes an agricultural alternative that can be used for human and animal consumption (Batista et al., 2022). The rich chemical composition of the cladodes suggests that they can be exploited to extract pectin. In addition, its industrial and medicinal products are in high demand in the market (Bayar et al., 2018; Ramdani et al., 2021; Kumar et al., 2017). However, like any agricultural crop, forage palm is affected by several insect pests that harm its production, with the scale insect *Diaspis echinocacti* (Bouché, 1833) (Hemiptera; Diaspididae) standing out among these organisms in the main producing regions of Brazil (Albuquerque Junior et al., 2023b). *Diapis echinocacti* causes direct (sap suction and toxin injections) and indirect (sooty mold growth on honeydew, reducing photosynthesis) damage. Its preference for mature cladodes is associated with lower production of defense metabolites in these tissues (Lopes et al., 2018; El Aalaoui and Sbaghi, 2023a). In addition, its high reproductive rate and propensity to spread rapidly through natural supports (wind, water, etc.) make the establishment and propagation of the scale insect much easier than many other species (El Aalaoui and Sbaghi, 2023b). In conventional agriculture, scale insect control has been carried out mainly with the use of chemical insecticides (Gonçalves et al., 2020).

However, it is known that chemical insecticides are often dangerous to many forms of life in the environment and to humans. To preserve plant productivity and maintain ecological and sustainable balance, it is vital to understand the host plant's resistance and its use in pest management (Nagaratna et al., 2021). In addition, it is also known that chemical insecticides applied to forage cactus plants can select resistant populations of *D. echinocacti*, and can contaminate meat and milk from cattle, goats, and sheep fed with cladodes of this plant (Ramdani et al., 2021). Therefore, alternatives to traditional insecticides are desirable, especially for small-scale forage cactus producers.

Silicon (Si) accounts for ~28% of the Earth's crust, but its availability to plants depends on the solubilization of minerals such as silicates (Zamojska et al., 2018). In agriculture, the application of soluble Si (e.g., potassium silicate) has gained relevance due to its dual effects: improving cellular architecture (via phytolith deposition) and activating defense pathways against herbivores (Nagaratna et al., 2021). Silicon, although not essential for all plants, acts as a beneficial element by: (i) strengthening the cell wall via phytolith deposition, (ii) modulating biochemical defense pathways, and (iii) improving tolerance to water stress (Ma, 2004; Nagaratna et al., 2021).

Silicon increases plant resistance and reduces plant damage caused by biotic and abiotic factors (Ma, 2004). Nagaratna et al. (2021) reported that silicon can increase plant resistance in two ways, the first through physical resistance and the second through chemical defense. Some studies demonstrate its effects in pest control in some species, such as pest and disease control in rice (Buck et al., 2008; Rezende et al., 2009; Stout et al., 2009), soybean (Rodrigues et al., 2009; Cruz et al., 2013), coffee (Lopes et al., 2013), cucumber (Liang et al., 2005a) and tomato (Kedarnath et al., 2016) and induce resistance to abiotic stress in crops such as wheat (Sattar et al., 2019) and potato (Pilon et al., 2014). Although silicon has been studied in crops such as rice and soybean, its potential in managing *D. echinocacti* in forage cactus remains little explored, especially regarding ideal doses and application times. Therefore, this study aimed to test the influence of potassium silicate on forage cactus productivity and scale insect infestation.

2. Material and Methods

The experiment was carried out at Fazenda Riachão, located in the municipality of Boa Vista (7º18'25.7"S and 36º18'1.03"W), situated in the Mesorregion of Agreste Paraibano and Microregion of Campina Grande and the Paraíba do Norte River Basin. The property's headquarters are approximately 475.0 meters and are 152.6509 km from the capital. Access is from Campina Grande via highways BR 230/BR 412.

The climate of the region is 'Bsh' hot semiarid, with rain from January to April, with average annual temperatures around 24 ºC, relative humidity of around 68%, and an average rainfall of 400 mm per year, with a water deficit almost all year round (SUDENE, 1996). The work was implemented in field conditions, the area presents a Litholic Neosol, presenting low depth, sequenced by horizons A – C – R, with absence of horizon B, high fertility when derived from bare or limestone rocks, low water storage capacity, general stoniness and rockiness and high susceptibility to erosion (EMBRAPA, 1999).

2.1. Assay

The scale insect infestation was carried out naturally in the field. The palm used in the experiment was Orelha de Elefante Mexicana (*Opuntia stricta* Haw), the most widely cultivated in Paraíba. The plantation chosen for the experiment was 2 years old with a double row system, with the following measurements (150 cm between double rows, 30 cm between single rows, and 20 cm between plants - racks in the planting row), totaling approximately 55 thousand plants/ha. The experiment was conducted under field conditions, with the following chemical attributes: pH of 7.5; 132.02 mg dm-3 of P; 392.05 mg dm-3 of K+; 10.90 cmolc dm-3 of Ca2+; 5.83 cmolc dm-3 of Mg2+; 0.23 cmolc dm-3 of Na+; 0.10 cmolc dm-3 of H+ + Al3+; 0.05 cmolc dm-3 of Al3+; sum of bases of 18.96 cmolc dm-3; 19.06 cmolc dm-3 of cation exchange capacity and 36.64 g kg-1 of organic matter. Mineral fertilization was not applied in this experiment to reflect the traditional cultivation practices of forage cactus (*Opuntia* spp.) in the Brazilian semiarid region, where the crop is typically grown in low-input systems on soils with naturally limited fertility. To evaluate the influence of silicon on forage cactus, the source potassium silicate (K2 SiO3) was used in 4 doses with four applications during the year (the product was applied every quarter, 90 days) plus the absolute control. The concentrations used in the experiment (Table 1) were determined based on the product recommendation for plants with the acid metabolism of Crassulaceans (CAM), to which *O. stricta* belongs. The experimental design used was randomized blocks in a factorial scheme with repeated measurements in time 4 × 4 +1, corresponding to four concentrations of potassium silicate (0, 5, 9, 18, 28 ml L-1) and four application times (0 - start of the experiment, 90, 180, 270 days) and an additional control treatment (without silicate application) with four blocks, containing five plants as an experimental unit.

The experimental unit corresponded to one linear meter of the plantation, which had 10 plants, of which only five were evaluated. The treatments were applied throughout the experimental unit with a manual sprayer with a capacity of 2 liters.

2.2. Variables

At 365 days after the installation of the experiment, the plants of the experimental plot were used to perform biometric and infestation analyses. The total number of infested cladodes was evaluated. Five random rackets from the experimental plot were used to measure the cladodes' width, length, and thickness. The fresh biomass of the cladodes was determined on a digital scale. Subsequently, the cladodes were fragmented, packed in paper bags, and kept in a forced circulation oven at 65 ºC until constant dry weight was reached, thus obtaining the dry biomass of the cladode, these variables were used exclusively to calculate dry matter productivity, in t ha^{-1}, which was obtained by multiplying the average dry mass weight of cladodes by the total number of cladodes per plant and by the number of plants per hectare.

2.3. Data analysis

Different generalized models were programmed taking into account a factorial structure with the inclusion of an additional factor. The data on length, width, and thickness of the rackets were treated with a Gaussian model with an identity link function. At the same time, the productivity variable was analyzed with a Gamma model. The R means function (R Core Team, 2025) was used to calculate the estimated marginal means (EMMs) for factors specified in the model and the generated combinations of the factors. Additionally, comparisons were made through contrasts between the possible combinations, including the additional control factor.

A Supervised Decision Tree Machine Learning model was adopted to classify the Silicon application levels based on morphological characteristics, productivity and infestation of the rackets. 70% of the data were reserved for model training, while 30% of the data were reserved for validation. The following initial numbers of nodes (called classes here) were used: 2 classes (Presence and Absence of Silicon), 5 classes (Control and Silicon Doses) and 21 classes (Control, Silicon Doses within each application epoch). To compare the best number of nodes for classification of this data set, the following metrics were used: Accuracy, Misinformation Rate and Kappa.

3. Results

The factors Application Time (P_{length} = 0.2131; P_{Width} = 0.5843; $P_{Thickness}$ = 0.5106) or Dose (P_{length} = 0.8828; P_{Width} = 0.8471; $P_{Thickness}$ = 0.1671), interaction Application Time vs Dose (P_{length} = 0.4626; P_{Width} = 0.8841; $P_{Thickness}$ = 0.9625), and the contrasts applied taking into account the combination of the interaction of the combined treatments vs additional factor revealed no significant difference (P_{length} = 0.9982; P_{Width} = 0.5746; $P_{Thickness}$ = 0.06485) for the variables Length, Width and Thickness of the Racket (Figures 1, 2 and 3). For the dry matter productivity variable (Figure 4), there was an effect of the dose ($P_{productivity}$ = 0.001013) and no effect of the application time ($P_{productivity}$ = 0.944291).

Table 1. Concentrations of fertilizer used in the experiment.

	Concentrations (ml L^{-1})				
Potassium silicate	0	5	9	18	28
	Concentrations (L ha^{-1})				
Potassium silicate	0	1	1.8	3.6	5.6

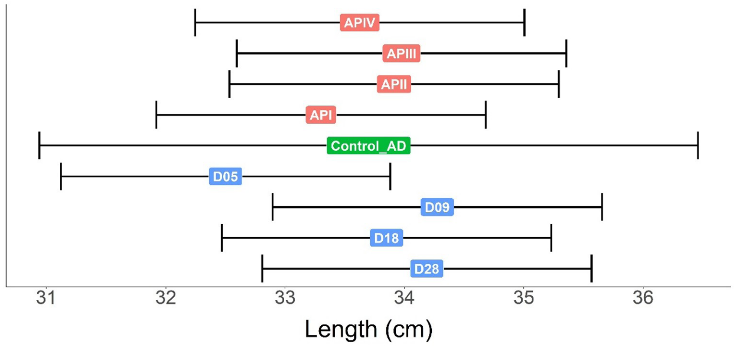

Figure 1. Contrasts for the variable palm racket length as a function of different doses of Potassium Silicate: D05, D09, D18 and D28 and the application period: API, APII, APIII and APIV and the additional factor Control. Means do not differ from each other due to the overlap of the Confidence Intervals (95% CI) generated by the Gaussian generalized linear model with identity link function.

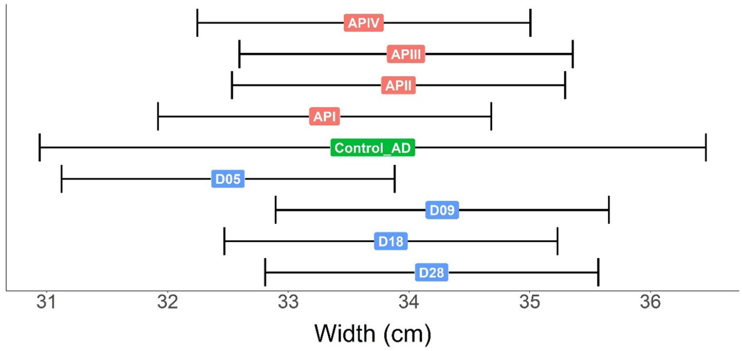

Figure 2. Contrasts for the width of the palm racket as a function of different doses of Potassium Silicate: D05, D09, D18, and D28, and the application period: API, APII, APIII, and APIV, and the additional factor Control. Means do not differ due to the overlap of the Confidence Intervals (95% CI) generated by the generalized linear Gaussian model with identity link function.

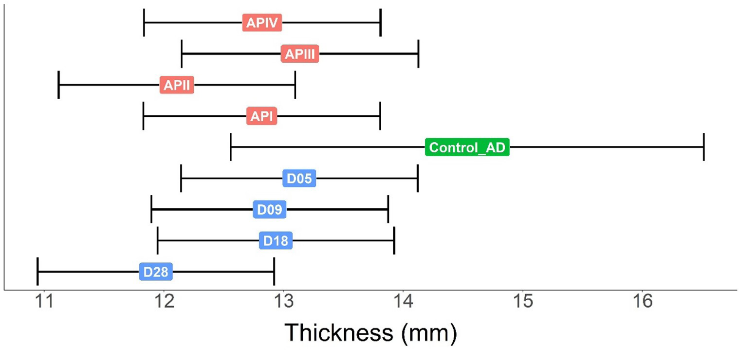

Figure 3. Contrasts for palm racket thickness as a function of different doses of Potassium Silicate: D05, D09, D18 and D28 and application time: API, APII, APIII and APIV and the additional control factor. Means do not differ from each other due to the overlap of the Confidence Intervals (95% CI) generated by the Gaussian generalized linear model with identity link function.

Furthermore, there was an increase in productivity of the adopted treatments, regardless of the application time and dose, in relation to the control ($P_{productivity} = 0.01623$). The behavior that best describes the relationship between silicon dose and dry matter productivity is given by the following cubic function y = exp ($-0.0054x^3 - 0.0019x^2 -$

0.0177x + 0.0154). A sigmoidal response clearly describes dry matter productivity, presenting stabilization points between 5 and 18 mL/L doses, and an increasing trend in this variable between 18 and 28 mL/L.

For the variable scale infestation in palm rackets (Figure 5), there was an effect of the dose ($P_{infestation} = 0.03366$) and no effect of the application time ($P_{infestation} = 0.93934$). In addition, there was an increase in productivity of the adopted treatments, regardless of the application time and dose, in relation to the control ($P_{infestation} = 0.000645$). There was a growing reduction in the silicon dose versus palm racket infestation relationship, described by the quasibinomial logistic model y = exp(-0.43055+-0.09613x)/1+exp(-0.43055+-0.09613x). The variability in this variable for practically all doses was also clearly expressed, which justified adopting the binomial model with overdispersion. Regarding the Decision Tree model, which aimed to classify the different classes of silicon application based on morphoagronomic characteristics and scale insect infestation, the confusion matrix revealed an accuracy above 90% and a non-information rate index above 95%, demonstrating good overall performance and high agreement between predictions and observations (Table 2). The analysis by class showed high sensitivity and specificity, only when the silicon application and control classes were categorized, there was a very low performance

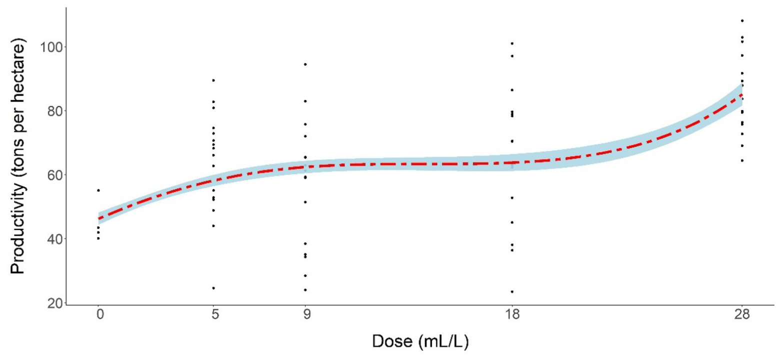

Figure 4. Relationship between Potassium Silicate Dose (mL/L) and Dry Matter Productivity (tons per hectare) of palm. Points reflect the original data, while the dashed and colored lines represent the mean data, and Confidence Intervals (95% CI) are generated by the generalized linear model of the Gamma type with a log link function.

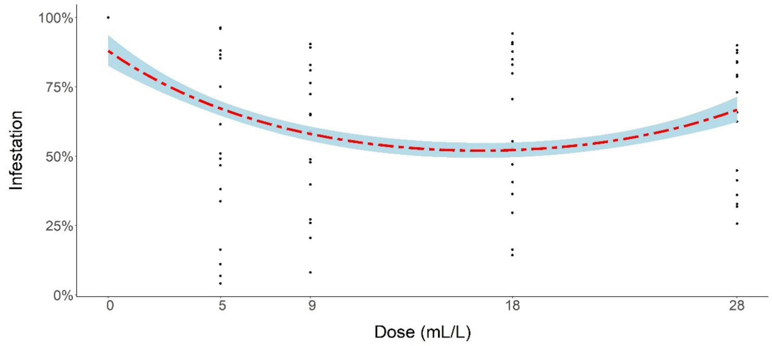

Figure 5. Relationship between Potassium Silicate Dose (mL/L) and Scale Insect Infestation on Palm Racket. Points reflect the original data, while the dashed and colored lines are the mean probability and Confidence Intervals (95% CI) generated by the generalized linear model of the quasibinomial type with logit link function.

Table 2. Performance metrics of the decision tree model for categorizing different numbers of initial classes.

Performance metrics	2 Classes	5 Classes	21 Classes
Accuracy	0.9524	0.1429	0.0476
95% CI	0.7618 - 0.9988	0.0305 - 0.3634	0.0012 - 0.2382
Non information rate	0.9524	0.381	0.1429

in the classification of doses or when the classes were separated within the doses and application times.

4. Discussion

Potassium silicate applications benefited forage palms, especially at a concentration of 28 mL L^1, which provided higher dry matter productivity (84.78 t ha^1) and lower scale insect infestation (55.4%). After absorption by the plant, silicon is deposited mainly at the border of the cell membrane and cell wall (i.e., the apoplast), which is the site of interactions between receptors and effectors of pests and pathogens. Once deposited in the apoplast of plants, silicon polymerizes in the extracellular spaces of the walls of epidermal cells of plant tissues and xylem vessels, forming a double cuticle-silica layer (Kaur and Greger, 2019; Islam et al., 2020). In addition to silicon, adequate potassium (K) levels supplied by potassium silicate play a crucial role in enhancing plant resistance to pests. Potassium regulates enzymatic functions and overall metabolism, promotes the synthesis of high-molecular-weight structural compounds (proteins, starch, and cellulose), and reduces soluble sugars and other low-molecular-weight compounds that favor infections and infestations. Moreover, K increases the production of phenols and other defensive compounds, decreases pest attractiveness, and can enhance pest mortality, strengthening the plant's natural defense mechanisms (Wang et al., 2013).

This leads to hardening of plant tissues, delaying insect penetration into host tissues and thus increasing the duration of insect exposure to natural enemies (Alhousari and Greger, 2018). Therefore, silicon accumulated in the apoplastic space can disrupt insect feeding styles and released effectors, since the effectors are trapped in the silicon matrix and therefore insects are unable to recognize the plant as a suitable host, thus reducing infestations in different plant species and different insect pests (Coskun et al., 2019; Singh et al., 2020). Furthermore, it is known that silicon addition can increase plant defense through physical, molecular and/or biochemical mechanisms.

This study observed that forage cacti benefited from applying potassium silicate, especially at a dose of 28 ml L^{-1}, which was mainly reflected in increased dry matter productivity and reduced scale insect infestation. Some studies have proven this mechanism, as demonstrated by Kim et al. (2002), who reported that the penetration of *Pyricularia grisea* into rice leaves is hindered and delayed due to this double layer. Similarly, spraying potassium silicate (K_2SiO_3) at a rate of 17 mmol L^{-1} Si on grapevine seedlings resulted in a significant reduction in the penetration rate of Uncinula necator due to the formation of a Si layer on the leaf cuticle. The polymerization of K_2SiO_3 on the surfaces of melon, cucumber, and pumpkin leaves was also studied by Liang et al. (2005b), and Menzies et al. (1992), who found that the penetration of *Sphaerotheca fuliginea* was reduced due to this physical barrier. In addition to hardening of plant tissues, silicon also causes the formation of phytoliths (deposition of SiO2 as biogenic opals) that promote the strengthening of the cell wall. The abrasiveness of silicified plant tissues causes wear on the mouthparts of insects and reduces palatability and digestibility, causing a reduction in the growth and development of herbivores (Alhousari and Greger, 2018; Islam et al., 2020).

Similar to scale insects, silicon accumulation in plants decreased the performance of other herbivores such as leaf beetles, bees, weevils, stem borers, and true bugs (Barnes and Giliomee, 1992; King et al., 1998; Roitberg et al., 2005; Kvedaras et al., 2009). Si-supplemented plants show the formation of silicified microstructures that present different patterns and are distributed in various plant tissues (Cooke and Leishman, 2011; Kumar et al., 2017). The role of mechanical defense in plants against damage caused by insects is reinforced in other more recent studies (Dorairaj and Ismail, 2017; Yang et al., 2017; Alhousari and Greger, 2018).

Our results confirm some studies that obtained increased yield with applications of different forms of silicon in other species, such as apple trees (Wang et al., 2016; Soppelsa et al., 2018; Świerczyński et al., 2022), fig trees (Hussien and Kassem, 2021), pumpkin (Salim et al., 2021), peach trees (Abidi et al., 2023), sorghum (Abdeen and Mancy, 2018) and corn (Gomaa et al., 2021). However, it is essential to emphasize that the effect of potassium silicate on plant productivity may vary according to abiotic conditions and the different susceptibilities of each species to the supply of this element in the form of spraying on the aerial part (Świerczyński et al., 2022). Information on how this element acts to increase plant productivity is still uncertain. It is speculated that gains in productivity are associated with subtle changes in metabolic activity such as photosynthesis and respiration, as well as the optimization of the supply, use and absorption of nutrients by plants, resulting in increases in mass, whether under normal conditions or biotic or abiotic stress conditions (Gomaa et al., 2021; Świerczyński et al., 2022).

The increase in dry biomass caused by potassium silicate can be attributed to several reasons, since silicon acts at various points in the plant, one of which may be related to improved nitrogen assimilation, since plants that received applications of potassium silicate at a higher dosage of 28 ml L^{-1} may have accumulated a greater amount of this nutrient, providing a synergistic effect, leading to the accumulation of biomass in the palms and consequently increasing both green and dry productivity (Garg et al., 2020).

5. Conclusions

The timing of potassium silicate application does not affect plant growth or insect infestation.

A potassium silicate concentration of 28 ml L^{-1} provides higher dry matter productivity (t/ha) and lower insect infestation rates.

There is evidence that the application of potassium silicate induces resistance to scale insects with a lower level of infestation in the cladodes.

Data Availability Statement

The research data analyzed in this study are not publicly available by any means.

References

ABDEEN, S.A. and MANCY, A.G.A., 2018. Ameliorelação SS/ATn of water stress effect on sorghum plant growth and water use efficiency by application of potassium silicate and salicylic acid. *Egyptian Journal of Agricultural Sciences*, vol. 69, no. 1, pp. 43-52. http://doi.org/10.21608/ejarc.2018.211480.

ABIDI, W., AKRIMI, R., HAJLAOUI, H., REJEB, H. and GOGORCENA, Y., 2023. Foliar fertilization of potassium silicon improved postharvest fruit quality of peach and nectarine [*Prunus persica* (L.) Batsch] cultivars. *Agriculture*, vol. 13, no. 1, pp. 1-16. http://doi.org/10.3390/agriculture13010195.

ALBUQUERQUE JUNIOR, P.S., SILVA, C.A.D., MEDEIROS, E.P.D. and ZANUNCIO, J.C., 2023a. Effectiveness of Agave genotype extracts applied alone or mixed with mineral oil against the cactus scale mealybug *Diaspis echinocacti* (Hemiptera: diaspididae). *Bragantia*, vol. 82, pp. e20230024. http://doi.org/10.1590/1678-4499.20230024.

ALBUQUERQUE JUNIOR, P.S., SILVA, C.A.D., RAMOS, R.S., ZANUNCIO, J.C. and CASTELLANI, M.A., 2023b. *Diaspis echinocacti* (Hemiptera: Diaspididae) on cactus pear cladodes: biological aspects at different temperatures. *Brazilian Journal of Biology*, vol. 83, pp. e274016. http://doi.org/10.1590/1519-6984.274016. PMid:37610947.

ALHOUSARI, F. and GREGER, M., 2018. Silicon and mechanisms of plant resistance to insect pests. *Plants*, vol. 7, no. 2, pp. 33. http://doi.org/10.3390/plants7020033. PMid:29652790.

BARNES, B.N. and GILIOMEE, J.H., 1992. Fruit-feeding behaviour of banded fruit weevil, *Phlyctinus callosus* (Schönherr)(Col., Curculionidae), in apple orchards. *Journal of Applied Entomology*, vol. 113, no. 1-5, pp. 407-415. http://doi.org/10.1111/j.1439-0418.1992.tb00681.x.

BATISTA, M.C., NASCIMENTO, R., ALMEIDA, I.V.B., MEDEIROS, L.T.V., SOUZA, J.T.A., SANTOS, J.P.O., CARTAXO, P.H.A. and ARAÚJO, J.R.E.S., 2022. Production and selection of accessions of *Opuntia* spp. with resistance to false carmine cochineal. *Comunicata Scientiae*, vol. 13, pp. e3869. http://doi.org/10.14295/cs.v13.3869.

BAYAR, N., FRIJI, M. and KAMMOUN, R., 2018. Optimization of enzymatic extraction of pectin from *Opuntia ficus indica* cladodes after mucilage removal. *Food Chemistry*, vol. 241, pp. 127-134. http://doi.org/10.1016/j.foodchem.2017.08.051. PMid:28958509.

BUCK, G.B., KORNDÖRFER, G.H., NOLLA, A. and COELHO, L., 2008. Potassium silicate as foliar spray and rice blast control. *Journal of Plant Nutrition*, vol. 31, no. 2, pp. 231-237. http://doi.org/10.1080/01904160701853704.

COOKE, J. and LEISHMAN, M.R., 2011. Silicon concentration and leaf longevity: is silicon a player in the leaf dry mass spectrum? *Functional Ecology*, vol. 25, no. 6, pp. 1181-1188. http://doi.org/10.1111/j.1365-2435.2011.01880.x.

COSKUN, D., DESHMUKH, R., SONAH, H., MENZIES, J.G., REYNOLDS, O., MA, J.F., KRONZUCKER, H.J. and BÉLANGER, R.R., 2019. The controversies of silicon's role in plant biology. *The New Phytologist*, vol. 221, no. 1, pp. 67-85. http://doi.org/10.1111/nph.15343. PMid:30007071.

CRUZ, M.F.A.D., RODRIGUES, F.Á., POLANCO, L.R., CURVÊLO, C.R.D.S., NASCIMENTO, K.J.T., MOREIRA, M.A. and BARROS, E.G., 2013. Inducers of resistance and silicon on the activity of defense enzymes in the soybean-Phakopsora pachyrhizi interaction. *Bragantia*, vol. 72, pp. 162-172. https://doi.org/10.1590/S0006-87052013005000025.

DORAIRAJ, D. and ISMAIL, M.R., 2017. Distribution of silicified microstructures, regulation of cinnamyl alcohol dehydrogenase and lodging resistance in silicon and paclobutrazol mediated *Oryza sativa. Frontiers in Physiology*, vol. 8, pp. 491. http://doi.org/10.3389/fphys.2017.00491. PMid:28747889.

EL AALAOUI, M. and SBAGHI, M., 2023a. Efficacy of some biorational insecticides against the cactus scale pest *Diaspis echinocacti* (Bouché, 1833)(Hemiptera: Diaspididae) in Morocco. *African and Mediterraneam Agricultural Journal*, vol. 139, pp. 21-36. http://doi.org/10.34874/IMIST.PRSM/afrimed-i139.41149.

EL AALAOUI, M. and SBAGHI, M., 2023b. Potential of parasitoids to control *Diaspis echinocacti* (Bouché) (Hemiptera: Diaspididae) on *Opuntia* spp. cactus pear. *Egyptian Journal of Biological Pest Control*, vol. 33, no. 1, pp. 57. http://doi.org/10.1186/s41938-023-00704-0.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA – EMBRAPA, 1999. *Sistema Brasileiro de Classificação de Solos*. Brasília: Embrapa/SPI. 412 p.

GARG, K., DHAR, S. and JINGER, D., 2020. Silicon nutrition in rice (*Oryza sativa* L.) – A review. *Ann Agric Res*, vol. 41, no. 3, pp. 221-229.

GOMAA, M.A., KANDIL, E.E., EL-DEIN, A.A.Z., ABOU-DONIA, M.E., ALI, H.M. and ABDELSALAM, N.R., 2021. Increase maize productivity and water use efficiency through application of potassium silicate under water stress. *Scientific Reports*, vol. 11, no. 1, pp. 224. http://doi.org/10.1038/s41598-020-80656-9. PMid:33420308.

GONÇALVES, G.B., VASCONCELOS, J.F., GRAÇA, G.A., DIAS, K.L.L., ARAÚJO, C.T., JESUS, T.A. and SANTANA, S.F., 2020. Óleo de dendê: alternativa para o manejo agroecológico da cochonilha de escamas da palma forrageira *Diaspis echinocacti* (Hemiptera: Diaspididae). *Cadernos de Agroecologia*, vol. 15, no. 2, pp. 1-8.

HUSSIEN, M.A. and KASSEM, M.S., 2021. Influence of spraying kaolin, silicon and calcium on productivity and quality of Sultani Fig. *Egyptian Journal of Horticulture*, vol. 48, no. 1, pp. 9-18. http://doi.org/10.21608/ejoh.2020.52431.1153.

ISLAM, W., TAYYAB, M., KHALIL, F., HUA, Z., HUANG, Z. and CHEN, H.Y., 2020. Silicon-mediated plant defense against pathogens and insect pests. *Pesticide Biochemistry and Physiology*, vol. 168, pp. 104641. http://doi.org/10.1016/j.pestbp.2020.104641. PMid:32711774.

KAUR, H. and GREGER, M., 2019. A review on Si uptake and transport system. *Plants*, vol. 8, no. 4, pp. 1-8. http://doi.org/10.3390/plants8040081. PMid:30934978.

KEDARNATH, K.T., RANGASWAMY, N.B., PRAKASH, N., NAGARAJU, C.N., REDDY, L. and NARASEGOWDA, N.C., 2016. In vitro evaluation of silicon sources against late blight (*Phytophthora infestans*) of tomato. *International Journal of Science and Nature*, vol. 7, no. 4, pp. 881-884.

KIM, S.G., KIM, K.W., PARK, E.W. and CHOI, D., 2002. Silicon-induced cell wall fortification of rice leaves: a possible cellular mechanism of enhanced host resistance to blast. *Phytopathology*, vol. 92, no. 10, pp. 1095-1103. http://doi.org/10.1094/PHYTO.2002.92.10.1095. PMid:18944220.

KING, B.H., CROWE, M.L. and BLACKMORE, M.D., 1998. Effects of leaf age on oviposition and on offspring fitness in the imported willow leaf beetle *Plagiodera versicolora* (Coleoptera: chrysomelidae). *Journal of Insect Behavior*, vol. 11, no. 1, pp. 23-36. http://doi.org/10.1023/A:1020810415249.

KUMAR, S., MILSTEIN, Y., BRAMI, Y., ELBAUM, M. and ELBAUM, R., 2017. Mechanism of silica deposition in sorghum silica cells. *The New Phytologist*, vol. 213, no. 2, pp. 791-798. http://doi.org/10.1111/nph.14173. PMid:27621091.

KVEDARAS, O.L., BYRNE, M.J., COOMBES, N.E. and KEEPING, M.G., 2009. Influence of plant silicon and sugarcane cultivar on mandibular wear in the stalk borer *Eldana saccharina. Agricultural and Forest Entomology*, vol. 11, no. 3, pp. 301-306. http://doi.org/10.1111/j.1461-9563.2009.00430.x.

LIANG, Y., SUN, W.C., SI, J. and RÖMHELD, V., 2005b. Effects of foliar-and root-applied silicon on the enhancement of induced resistance to powdery mildew in *Cucumis sativus. Plant Pathology*, vol. 54, no. 5, pp. 678-685. http://doi.org/10.1111/j.1365-3059.2005.01246.x.

LIANG, Y.C., SI, J. and RÖMHELD, V., 2005a. Silicon uptake and transport is an active process in *Cucumis sativus. The New Phytologist*, vol. 167, no. 3, pp. 797-804. http://doi.org/10.1111/j.1469-8137.2005.01463.x. PMid:16101916.

LOPES, R.S., OLIVEIRA, L.G., COSTA, A.F., CORREIA, M.T., LIMA, E.A.L.A. and LIMA, V.L., 2018. Efficacy of *Libidibia ferrea* var. ferrea and *Agave sisalana* extracts against *Dactylopius opuntiae* (Hemiptera: coccoidea). *Journal of Agricultural Science*, vol. 10, no. 4, pp. 255-267. http://doi.org/10.5539/jas.v10n4p255.

LOPES, U.P., ZAMBOLIM, L., SOUZA NETO, P.N., SOUZA, A.F., CAPUCHO, A.S. and RODRIGUES, F.D.Á., 2013. Effect of foliar application of potassium silicate on the progress of coffee leaf rust. *Tropical Plant Pathology*, vol. 38, no. 6, pp. 547-551. http://doi.org/10.1590/S1982-56762013000600012.

MA, J.F., 2004. Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Science and Plant Nutrition*, vol. 50, no. 1, pp. 11-18. http://doi.org/10.1080/00380768.2004.10408447.

MENZIES, J., BOWEN, P., EHRET, D. and GLASS, A.D., 1992. Foliar applications of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon, and zucchini squash. *Journal of the American Society for Horticultural Science*, vol. 117, no. 6, pp. 902-905. http://doi.org/10.21273/JASHS.117.6.902.

NAGARATNA, W., KALLESHWARASWAMY, C.M., DHANANJAYA, B.C., SHARANABASAPPA and PRAKASH, N.B., 2021. Effect of silicon and plant growth regulators on the biology and fitness of fall armyworm, *Spodoptera frugiperda*, a recently invaded pest of Maize in India. *Silicon*, vol. 14, pp. 783-793. http://doi.org/10.1007/s12633-020-00901-8.

PILON, C., SORATTO, R.P., BROETTO, F. and FERNANDES, A.M., 2014. Foliar or soil applications of silicon alleviate water-deficit stress of potato plants. *Agronomy Journal*, vol. 106, no. 6, pp. 2325-2334. http://doi.org/10.2134/agronj14.0176.

R CORE TEAM, 2025 [viewed 5 April 2025]. *R: A language and environment for statistical computing* [online]. Vienna, Austria: R Foundation for Statistical Computing. Available from: https://www.R-project.org/.

RAMDANI, C., BOUHARROUD, R., SBAGHI, M., MESFIOUI, A. and EL BOUHSSINI, M., 2021. Field and laboratory evaluations of different botanical insecticides for the control of *Dactylopius opuntiae* (Cockerell) on cactus pear in Morocco. *International Journal of Tropical Insect Science*, vol. 41, no. 2, pp. 1623-1632. http://doi.org/10.1007/s42690-020-00363-w.

REZENDE, D.C., RODRIGUES, F.A., CARRÉ-MISSIO, V., SCHURT, D.A., KAWAMURA, I.K. and KORNDÖRFER, G.H., 2009. Effect of root and foliar applications of silicon on brown spot development in rice. *Australasian Plant Pathology*, vol. 38, no. 1, pp. 67-73. http://doi.org/10.1071/AP08080.

RODRIGUES, F.A., DUARTE, H.S.S., DOMICIANO, G.P., SOUZA, C.A., KORNDÖRFER, G.H. and ZAMBOLIM, L., 2009. Foliar application of potassium silicate reduces the intensity of soybean rust. *Australasian Plant Pathology*, vol. 38, no. 4, pp. 366-372. http://doi.org/10.1071/AP09010.

ROITBERG, B.D., GILLESPIE, D.R., QUIRING, D.M.J., ALMA, C.R., JENNER, W.H., PERRY, J., PETERSON, H.J., SALOMON, M. and VANLAERHOVEN, S., 2005. The cost of being an omnivore: mandible wear from plant feeding in a true bug. *Naturwissenschaften*, vol. 92, no. 9, pp. 431-434. http://doi.org/10.1007/s00114-005-0013-x. PMid:16086188.

SALIM, B.B.M., ABOU EL-YAZIED, A., SALAMA, Y.A.M., RAZA, A. and OSMAN, H.S., 2021. Impact of silicon foliar application in enhancing antioxidants, growth, flowering and yield of squash plants under deficit irrigation condition. *Annals of Agricultural Science*, vol. 66, no. 2, pp. 176-183. http://doi.org/10.1016/j.aoas.2021.12.003.

SATTAR, A., CHEEMA, M.A., SHER, A., IJAZ, M., UL-ALLAH, S., NAWAZ, A., ABBAS, T. and ALI, Q., 2019. Physiological and biochemical attributes of bread wheat (*Triticum aestivum* L.) seedlings are influenced by foliar application of silicon and selenium under water deficit. *Acta Physiologiae Plantarum*, vol. 41, pp. 146. http://doi.org/10.1007/s11738-019-2938-2.

SINGH, A., KUMAR, A., HARTLEY, S. and SINGH, I.K., 2020. Silicon: its ameliorative effect on plant defense against herbivory. *Journal of Experimental Botany*, vol. 71, no. 21, pp. 6730-6743. http://doi.org/10.1093/jxb/eraa300. PMid:32591824.

SOPPELSA, S., KELDERER, M., CASERA, C., BASSI, M., ROBATSCHER, P. and ANDREOTTI, C., 2018. Use of biostimulants for organic apple production: effects on tree growth, yield, and fruit quality at harvest and during storage. *Frontiers in Plant Science*, vol. 9, pp. 1342. http://doi.org/10.3389/fpls.2018.01342. PMid:30298077.

STOUT, M.J., RIGGIO, M.R. and YANG, Y., 2009. Direct induced resistance in *Oryza sativa* to *Spodoptera frugiperda. Environmental Entomology*, vol. 38, no. 4, pp. 1174-1181. http://doi.org/10.1603/022.038.0426. PMid:19689897.

SUPERINTENDÊNCIA DO DESENVOLVIMENTO DO NORDESTE – SUDENE, 1996. Pacto Nordeste: ações estratégicas para um salto do desenvolvimento regional. Recife: SUDENE, 77 p.

ŚWIERCZYŃSKI, S., ZYDLIK, Z. and KLEIBER, T., 2022. The influence of foliar nutrition of apple trees with silicon on growth and yield as well as mineral content in leaves and fruits. *Agronomy*, vol. 12, no. 7, pp. 1680. http://doi.org/10.3390/agronomy12071680.

WANG, M., ZHENG, Q., SHEN, Q. and GUO, S., 2013. The critical role of potassium in plant stress response. *International Journal of Molecular Sciences*, vol. 14, no. 4, pp. 7370-7390. http://doi.org/10.3390/ijms14047370. PMid:23549270.

WANG, Y., CHAI, L., YANG, Z., MUBARAK, H. and TANG, C., 2016. Chlorophyll fluorescence in leaves of *Ficus tikoua* under arsenic stress. *Bulletin of Environmental Contamination and Toxicology*, vol. 97, no. 4, pp. 576-581. http://doi.org/10.1007/s00128-016-1905-5. PMid:27541274.

YANG, L., HAN, Y., LI, P., LI, F., ALI, S. and HOU, M., 2017. Silicon amendment is involved in the induction of plant defense responses to a phloem feeder. *Scientific Reports*, vol. 7, no. 1, pp. 4232. http://doi.org/10.1038/s41598-017-04571-2. PMid:28652621.

ZAMOJSKA, J., DANIELEWICZ, J., JAJOR, E., WILK, R., HOROSZKIEWICZ-JANKA, J., DWORZAŃSKA, D. and NARKIEWICZ-JODKO, J., 2018. The influence of foliar application of silicon on insect damage and disease occurrence in field trials. *Fresenius Environmental Bulletin*, vol. 27, pp. 3300-3305.