Potassium silicate as a new micronutrient agent in the initial development of sunflower (*Helianthus annuus* L.)

Felipe da Silva Malta[1], Porshia Sharma[2], Antonio Carlos Pereira de Menezes Filho[3,4], Carlos Frederico de Souza Castro[4], Marconi Batista Teixeira[4], Frederico Antônio Loureiro Soares[4], Aurélio Ferreira Melo[1] & Matheus Vinícius Abadia Ventura[1,4]

[1] Centro Universitário UniBRAS Rio Verde, Rio Verde, Goiás State, Brazil

[2] University of Hohenheim, Stuttgart, Germany

[3] Menezes Agricultural Research, Rio Verde, Goiás State, Brazil

[4] Goiano Federal Institute, Rio Verde, Goiás State, Brazil

Correspondence: Felipe da Silva Malta, Centro Universitário UniBRAS Rio Verde, Rio Verde, Goiás State, Brazil. E-mail: felipemalta78@gmail.com

Received: February 27, 2024 DOI: 10.14295/bjs.v3i5.561

Accepted: April 08, 2024 URL: https://doi.org/10.14295/bjs.v3i1.561

Abstract

Silicon (Si) is considered a non-essential micronutrient for vegetables, although it has important functions during vegetative development in some large crops of agricultural interest. This study aimed to evaluate the action of Silicon on vegetative development in a sunflower cultivar ‘Multissol’. The experiment was carried out in full sun in February 2024, with five dosages (0; 150; 300; 600 and 900 kg ha^{-1}) using potassium silicate as a source of Si. The vigor variables for humidity, germination, accelerated aging, weight of 100 grains, electrical conductivity, cold test and emergence in sand and soil were analyzed. Vegetative parameters for plant height, root size, number of leaves, aerial and root fresh mass and aerial and root dry mass were also evaluated. The germination rate was greater than 90%, the electrical conductivity was 100 µS cm^{-1}.g^{-1}, emergence in sand and soil was greater than 90%, regarding the variables of the vegetative phase, there were substantial gains ($p < 0.05$) in all parameters analyzed, especially for the highest dosage of 900 kg ha^{-1} when compared between the control. Si has a positive effect on the evaluated parameters and is a non-essential element that has positive effects on sunflower crops, especially on the Multissol cultivar.

Keywords: potassium silicate, sunflower crop, sunflower cultivar, effects of Silicon, micronutrients.

Silicato de potássio como novo agente micronutriente no desenvolvimento inicial de girassol (*Helianthus annuus* L.)

Resumo

Silício (Si) é considerado um micronutriente não essencial para os vegetais, embora apresente funções importantes durante o desenvolvimento vegetativo em algumas grandes culturas de interesse agrícola. Este estudo teve por objetivo, avaliar a ação do Silício no desenvolvimento vegetativo em um cultivar de girassol ‘Multissol’. O experimento foi realizado a pleno sol em Fevereiro de 2024, com cinco dosagens (0; 150; 300; 600 e 900 kg ha^{-1}) utilizando silicato de potássio como fonte de Si. Foram analisadas as variáveis de vigor para umidade, germinação, envelhecimento acelerado, peso de 100 grãos, condutividade elétrica, teste de frio e emergência em areia e solo. Foram avaliados também os parâmetros vegetativos para altura de planta, tamanho de raízes, número de folhas, massa fresca aérea e de raízes e massa seca aérea e de raízes. A taxa de germinação foi superior a 90%, a condutividade elétrica foi de 100 µS cm^{-1}.g^{-1}, emergência em areia e solo superior a 90%, quanto as variáveis da fase vegetativa, houve ganhos substanciais ($p < 0,05$) em todos os parâmetros analisados em especial para a maior dosagem de 900 kg ha^{-1} quando comparados entre a testemunha. O Si possui efeito positivo nos parâmetros avaliados e é um elemento não essencial que apresenta efeitos positivos na cultura do girassol em especial na cultivar Multissol.

Palavras-chave: silicato de potássio, cultura de girassol, cultivar de girassol, efeitos do Silício, micronutrientes.

1. Introduction

Among the major crops of global agricultural and economic interest is the sunflower (*Helianthus annuus* L.) (Figure 1), belonging to the Asteraceae family, annual and with plant behavior known as heliotropism (Carvalho et al., 2009), presenting species that do not emit pollen , high diversity of tones and shapes (Schoellhorn et al., 2003). The center of origin of this culture is remote from areas of Southwest Mexico in North America. Sunflower is an important source of oil in the world, being considered among the five main oil-producing plant species (Nobre et al., 2010; Dias et al., 2022). It is cultivated on all continents, being widely diversified in South American countries. Its socioeconomic importance stands out for its multiple uses, in human and animal nutrition due to the nutrients, vitamins and fatty acids of importance in the diet, in the production of medicines and as a basis for biodiesel production (Harris et al., 2016).

As for fertilization, sunflower cultivation is demanding, demonstrating drastic reduction visually and in production rates when subjected to adverse conditions such as lack of macro and micronutrients, water deficit resulting in less transpiration; increased efficiency in photosynthesis, resistance against cold; effects of sailinization and out-of-correction pH (Biscaro et al., 2008). Silicon (Si) is the second most abundant element in the Earth's crust, where the majority of soil classes that have already undergone the desilicate process, such as Oxisols, organic and sandy soils such as Quartzarene Neosols, have low soluble levels of this element (Juo; Sanchez, 1986; Savant et al., 1997), which is considered a non-essential micronutrient for crops, also involving sunflower cultivation.

Sunflower plants are considered non-Si accumulators; however, they benefit from the application of this element. The effects of Si have been studied in sunflower crops, as research has demonstrated good results from this element, minimizing various stress factors suffered by sunflower plants, both biotic and abiotic throughout their vegetative and reproductive cycle (Carvalho et al., 2009; Dias et al., 2022). Rodrigues (2010) discuss plants that develop in Si-rich soil where there are differences from other plants with deficiency conditions for this element. Since, Si influences the chemical composition, mechanical resistance of cells, characteristics of the leaf surface, tolerance to various abiotic stresses and attacks by pests and phytopathogens.

Ma & Yamaji (2016) adds that plants where there is a rich source of Si, have greater tolerance to toxic metals such as Aluminum (Al), Manganese (Mn) and Iron (Fe) and heavy Cadmium (Cd) and Lead (Pb) and gains in quality and productivity in agricultural crops. Carvalho et al. (2009) and Zanão Júnior et al. (2017) further discusses that Si considerably influences sunflower plants grown in pots for floristic or experimental interest where they report gains in production and quality of flowering and seed production.

The mechanisms of action on Si absorption are still poorly elucidated, but what we know is that the defense mode of the plant that goes through biotic or abiotic stress tends to absorb more Si, and therefore, resists this disorder better (Dallagnol et al., 2014). Among major crops, the ability to absorb Si differs; for rice, barley and wheat, absorption occurs through the active process (Rains et al., 2006). In sunflower, absorption processes mainly of H_4SiO_4 or another labile source of Si such as K_2SiO_4 present transport from the root to the shoot through the xylem occurring in both active and passive forms.

These types of forms of transport are determined by the concentration of this mineral, where at low concentration it leads to mass flow transport as discussed by Gunes et al. (2008). Plants belonging to the families Poaceae, Equisetaceae and Ciperaceae have a greater absorption capacity and consequently, the Si contents are higher, this difference occurs due to the type of physiological mechanism by which Si is absorbed (Ma et al., 2001).

Thus, for there to be accumulation, like any essential element, Si must be in its labile form, capable of absorption by sunflower plants, and not be precipitated, adsorbed or polymerized. Considering the benefits of Si for plants, this study verified the action of different dosages of K_2SiO_4 in the sunflower (*Helianthus annuus* L.) crop where attributes were verified in the vegetative period in a ‘Multissol’ cultivar regarding their effects during the evaluated period.

Figure 1. Sunflower plant (*Helianthus annuus* L.) cultivar Multissol in flowering period. Source: Authors, 2024.

2. Materials and Methods

2.1 Experimental location

The experiment was conducted in a rural area (Fazenda Antônio Menezes & Filho) in the municipality of Rio Verde, Goiás, Brazil, at coordinates (17º43'06.6''S and 50º53'06.8W) between November 2023 and January 2024. The average altitude of the region is 748 m; the region's climate is classified according to Köppen as humid mesothermal, with two well-defined seasons: a rainy season between October and April, and a dry season between May and September; the average temperature is 25.5 ºC.

2.2 Sunflower cultivar

The sunflower cultivar was Multissol (*rajado muido aguara 6*), an erect shrub, with a height between 1.3 and 1.7 m, an average flower diameter of 22 cm. Characteristics: without branches and with rough hairs, annual vegetative cycle between 60 and 130 days, resistance to diseases moderately susceptible to *Alternaria* sp., and *Sclerotinia* sp.

2.3 Seed analyzes

2.3.1 Moisture content

The water content was determined from the percentage difference in initial and final mass of 5 samples with 5 g of seeds, after drying in an oven with forced air circulation at 105 ºC for 24 h. The result was expressed as a percentage (%) as described by Hilgert et al. (2021).

2.3.2 Germination test

Germination was performed on germitest paper sheets rolled into a roulade and moistened with distilled water in an ratio of 2.5 x the weight of the paper. The seeds were stored in plastic bags inside the BOD greenhouse at 25 °C for 10 days (Brasil, 2009), and the number of seeds were counted every day. Germinated seeds were those which showed development of the essential embryo structures (root system and aerial part). The germination assay was expressed in (%) (Oliveira et al., 2023).

2.3.3 Accelerated aging

Sunflower seeds were exposed to a temperature of 42 ºC for 72 h in a B.O.D chamber. In this test, a germination box with metal mesh was used. 100 mL of distilled water was added and then the seed screen described by Ducatti et al. (2014). After this time, the seeds were germinated according to subtopic 2.3.2.

2.3.4 Weight 100 seeds

The weight of 100 seeds (W100) was evaluated with four subsamples, according to the methodology for the weight of a thousand seeds recommended in the Rules for Seed Analysis (Brasil, 2009). The result was expressed in grams (g).

2.3.5 Electrical conductivity (EC)

Approximately 10 g of seeds were soaked in distilled and deionized water at 25 ºC for 24 h and then electrical conductivity was determined using a digital conductivity meter. The result was expressed in (µS $cm^{-1}.g^{-1}$) as proposed by Oliveira et al. (2012).

2.3.6 Cold test

The cold test was conducted on a germitest paper substrate for seven days at a temperature of 10 ºC, in the absence of light (Murcia et al., 2001). Subsequently, the rolls were kept at 25 ºC. Assessments were carried out after 10 days (Brasil, 1992), and the result was expressed as a percentage (%).

2.3.7 Seeding emergence assay

The seedling emergence test was conducted in plastic boxes containing sterilized washed sand and/or soil moistened with distilled water, aiming to reach 60% of retention capacity. The boxes were kept in ambient conditions, and evaluations were carried out four and 10 days after the test was installed (Nakagawa, 1999). The result was expressed as a percentage (%).

2.4 Soil type and parameters

The soil in the region is classified as a typical dystroferric red latosol. The physicochemical characteristics of the soil sampled from the experimental area at a depth of 0-20 cm. Calcium (Ca) 2.13, Magnesium (Mg 1.43, Ca + Mg 3.56, Aluminum (Al) 0.0, H + Al 8.09 and Potassium (K) 0.3 $cmol_c$ dm^{-3}; K 117, Sulfur (S) 9, Phosphorus (P) 3.0 mg dm^{-3} and pH 4.9; Sodium (Na) 1.0 mg dm^{-3}; organic matter (OM) 61.1 g dm^{-3}; clay 30.3, silt 25.2 and sand 44.4 (%). In the area where soil was collected, the previous crop was soybeans with a direct planting system.

2.4 Experiment design

The experimental design used was a randomized block design with six replications, four treatments (150; 300; 600 and 900 kg ha^{-1}) + a control (6x4+1). The experiment was installed in full sun in 5.5 L black flexible polyethylene pots. Potassium silicate was applied to the soil 10 days before sowing with the following composition of K_2SiO_4 with 25% Si, 10% K, 3% Mg and 0.01% Ca. The soil after application was previously disturbed and on alternate days watering was carried out with water from a natural lagoon.

Sowing was carried out at a depth of 2 cm. A uniform and vigorous emergence was observed six days after sowing. Fifteen days after emergence, uniform thinning was carried out with just two plants per pot. At 30 days after plant emergence (DPE), Nitrogen (N) fertilization was carried out together with Boron (B), following the recommendations for sunflower cultivation. The harvest took place at 50 DPE, with 50% of the plants on the stand in studio R4 (initial flowering). Irrigation was performed in one period (morning) daily according to the needs of the culture and the measurement of temperature and relative humidity monitored by a thermo-hygrometer.

2.5 Variables analyzed (vegetative period)

The variables plant lenght (PL), root length (RL) were determined using a measuring tape and the results expressed in centimeters (cm), the number of leaves was determined by visually counting developed petioles, the aerial fresh mass (AFM) and root fresh mass (RFM) were determined on an analytical balance and the results expressed in grams (g), for aerial dry mass (ADM) and root dry mass (RDM) after fresh determination , the material was dried in an oven with forced air circulation for 48 h at 65 ºC and the results expressed in (g) (Guedes et al., 2023).

2.6 Statistical analysis

The results obtained were subjected to regression analysis using the F test and the means were grouped using the Tukey test with 5% probability using the SISVAR statistical program (Ferreira, 2019).

3. Results

In our results, the moisture content was 7%, the germination rate was 92%, accelerated aging was 52%, weight of 100 grains was 6 g, electrical conductivity was 100 µS $cm^{-1}.g^{-1}$ and cold test with 71% germination (Table 1). The seedling emergence rate in sand was 94.6% ± 1.14 with (CV% = 0.01) and seedling emergence in soil with

94.4% ± 1.51 and (CV% = 0.01).

Table 1. Average parameters of moisture, germination, accelerated aging, weight of 100 grains, electrical conductivity and cold test in sunflower seeds cultivar 'Multissol'.

Moisture (%)	Germination (%)	Accelerate aging (%)	W100 (g)	Electrical conductivity (μS $cm^{-1}.g^{-1}$)	Cold test (%)
7.59 ± 0.38	92.8 ± 2.58	52.6 ± 3.20	6.90 ± 0.49	100.12 ± 0.98	71.2 ± 1.30
*0.05	*0.02	*0.05	*1.24	*0.88	*0.01

Note: *coefficient variation in (CV%).

Table 2 presents the results of the ANOVA of the 'Multissol' cultivar based on the effects of the K_2SiO_4 dosages evaluated. All variables AL, RL, AFM, RFM, ADM, RDM and Number of Leaves showed significant effects depending on the KSi doses. Second order polynomial regression was performed.

Table 2. Mean squares (M.S.) obtained in the analysis of variance of the application of doses of K_2SiO_4 via soil in the 'Multissol' cultivar. AL = aerial length; RL = root length; AFM = aerial fresh mass; RFM = root fresh mass; ADM = aerial dry mass; RDM = root dry mass, and Nº Leaves = number leaves.

SV	MS						
	AL	RL	AFM	RFM	ADM	RDM	Nº Leaves
Doses	510.06*	863.42*	838.41*	37.19*	18.29*	1.39*	19.44*
Residue	53.21	57.22	154.85	6.66	1.79	0.14	1.38
CV%	14.30	17.98	44.89	41.34	32.27	37.33	9.80

Note: SV = Source of variation. MS = Mean squares. CV% = coefficient of variation. *Significative a 5%. Source: Authors, 2024.

In Figure 2 (**A**) increasing doses of K_2SiO_4 provided a significant change for AL with greater length for the dose of 900 kg ha^{-1} with 56.33 cm and in (Figure 2 **B**) the RL with the highest value of 51.88 cm for the dose of 300 kg ha^{-1}, higher doses had a negative effect. Both positive effects for the variables analyzed.

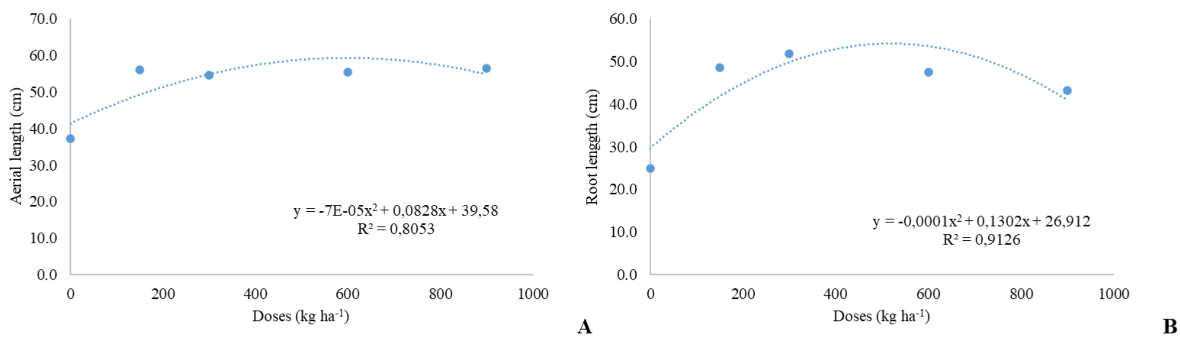

Figure 2. Parameters aerial length (**A**) and root length (**B**) of sunflower plants in different doses of potassium silicate. Source: Authors, 2024.

The number of leaves was significant where at the highest dose of 900 kg ha^{-1} (K_2SiO_4) sunflower plants in R4 presented an average of 13.67 leaves versus control with 9.50 (0 kg ha^{-1}) leaves (Figure 3).

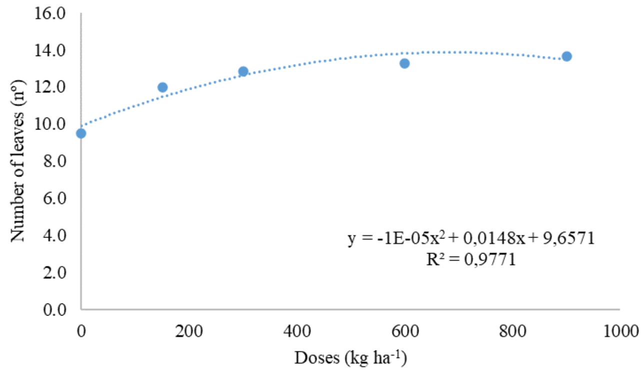

Figure 3. Number of leaves per sunflower plant at different doses of potassium silicate. Source: Authors, 2024.

Regarding the parameters of AFM and RFM our results, the production of fresh matter demonstrated incremental gains at the dose of 150 kg ha^{-1} with 38.52 g compared to the control 0 kg ha^{-1} with 11.45 g ($p < 0.05$) (Figure 4, **A**). Gains in the RFM increment were also observed at the highest dose of 900 kg ha^{-1} with an average value of 7.90 g compared to the control with 2.54 g for dose 0 kg ha^{-1} ($p < 0.05$) (Figure 4, **B**).

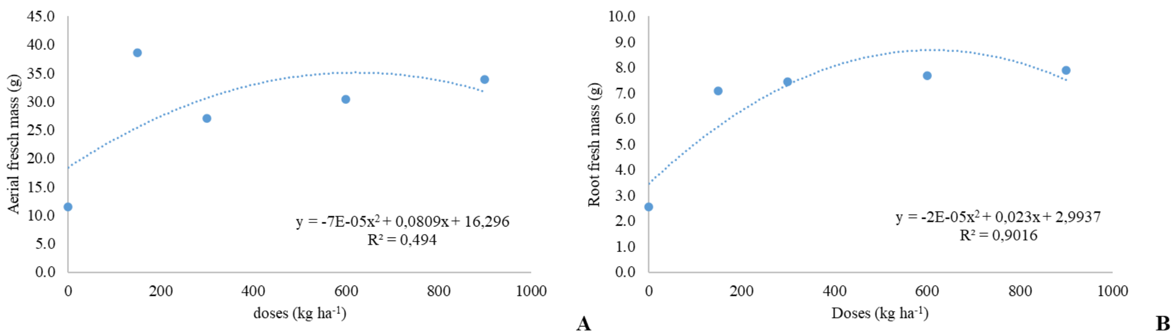

Figure 4. Parameters of aerial dry mass (**A**) and root dry mass (**B**) of sunflower plants in different doses of potassium silicate. Source: Authors, 2024.

The production of dry matter (straw) of ADM and RDM showed a significant increase ($p < 0.05$) both, at the highest dose of K_2SiO_4. For ADM (Figure 5, **A**) a dry mass yield of 5.97 was obtained and for RDM with 1.47 g for a dose of 900 kg ha^{-1} (Figure 5, **B**).

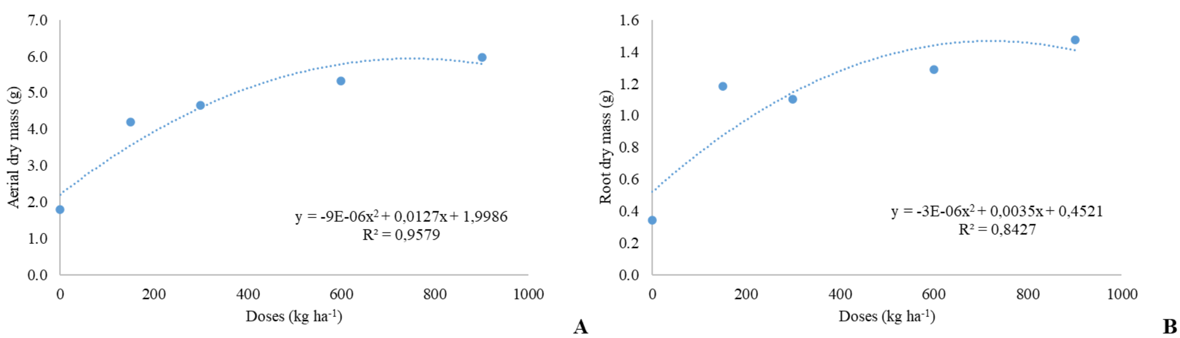

Figure 5. Parameters of aerial dry mass (**A**) and root dry mass (**B**) of sunflower plants in different concentrations of potassium silicate. Source: Authors, 2024.

4. Discussion

The average vigor parameters for humidity, germination, accelerated aging, weight of 100 grains, electrical conductivity and cold test presented similar and also higher averages for the parameters evaluated in other studies with the same cultivar and compared with different sunflower cultivars. The percentage of germination and seedling emergence (sand and soil) were above 90%, indicating satisfactory physiological quality.

In other studies, Oliveira et al. (2012) studied the same cultivar as in this study where they obtained results for seedling emergence above 81%, humidity between 6.2-6.7%, germination between 90-99% and for another cultivar 'Catissol' humidity between 5.0-5.9% and germination between 92-97%. As for EC Oliveira and collaborators, they found lower results than this study between 48.7-75.6 and 45.3-94.3 µS $cm^{-1}.g^{-1}$ for the ‘Multissol’ and ‘Catissol’ cultivars. Braz & Rossetto (2006) verified germination, accelerated aging, cold test and seedling emergence in sand values between 82-87% for different lots of the ‘Embrapa 122V2000’ cultivar; 50-70%; 90-97% and between 72-80%, respectively.

Our EC result was higher than that obtained in the study by Braz & Rossetto where there was a variation between 28.7-41.93 µS $cm^{-1}.g^{-1}$ for sunflower seeds. According to Araújo et al. (2011) electrical conductivity is one of the vigor tests recommended for other countries, mainly for pea seeds, and is suggested for soybeans according to the Association of Official Seed Analysts (AOSA) Canadian Food Inspection Agency (CFIA, 2023), in Brazil, it is used as a vigor test with results promising seeds for peanuts, soybeans, cowpeas, snap beans, okra, pumpkin and peppers. However, several other variables can interfere negatively in EC tests, this is presented and discussed by Vieira (1994) where in his study he comments that there are several factors that negatively affect the results such as seed age, genotypes, water quality, temperature, duration of the imbibition period, degree of humidity and number of seeds.

Our results were satisfactory using K_2SiO_4 in the Multissol cultivar in the large sunflower crop. The effects were positive for all variables analyzed ($p < 0.05$). Encouraging results were also obtained by other authors, such as Carvalho et al. (2009) where they studied the ornamental sunflower cultivar 'hybrid F1 Pollenless Sunbright' where they found that doses of Si had a positive influence on AL and when checking the Si content in the roots, they showed that there was an increase in the percentage of this element in them. Still in this study, the researchers did not notice changes in the concentration of Si in the leaves, inflorescences, leaf litter and stem diameter with split application. For this, there is a justification, where the Si content is higher in young leaves, this is easily explained, as Si, after being absorbed and deposited, becomes immobile forming hydrated amorphous silica ($SiO_2.nH_2O$) or biogenic silica (Balastra et al., 1989). When the Si element was applied to the substrate, the results were positive and encouraging as they found that different doses of Si improved the production of dry matter in inflorescences, roots and aerial parts.

In addition to these studies, our results corroborate other research, Gunes and collaborators (2008) found positive results when they applied Si to the soil in sunflower crops, verifying an increase in the production of ADM and RDM. In the study by Hussain et al. (2018) researchers demonstrated beneficial effects with the use of Si in sunflower plants irrigated with saline solution and Sodium water where they measured increases in diameter between 22-30% of the sunflower flower and consecutively an increase in achene yield between 15-25% . These authors add that the incorporation of Si in soil fertilization is a potential strategy to increase productivity against brackish water stress.

Si also has an effect when applied by air, Abd El-Gwad & Salem (2013), tested a Si solution by spraying and biofertilization where they described in their results, positive effects on improving the parameters plant height, number of leaves, leaf surface area, fresh and dry mass of leaves and plants, stem and inflorescence diameter and weight of 100 sunflower seeds (W100). The use of K_2SiO_4 also has positive effects on other crops, as discussed by Souza and collaborators (2015), where they found satisfactory results evaluating different doses of K_2SiO_4 in transgenic corn for plant height, stalk diameter, leaf area, root dry matter, in However, for aerial part dry matter, researchers found negative effects obtained at all dosages of K_2SiO_4. Zanão Júnior et al. (2009), studying the effects of Si doses on rice crops, found encouraging results for the production of straw from shoots and roots.

Some studies present negative results regarding the use of Si as a micronutrient, these results can be strongly influenced due to the low concentration of the doses that were applied, in this theory, Zanão Júnior (2007) also emphasizes this fact, in addition, complement that very high doses high may also present false negative results. Birchall (1995) says that Si can polymerize and produce colloidal particles of hydrated silica ($SiO_2.H_2O$). Furthermore, the low solubility Si source interferes with the results (Kamenidou et al., 2008; Hurtado et al., 2020).

Si in large and small crops, in addition to its positive aspects of plant productivity already discussed, also indirectly influences pest control. This was verified by Assis et al. (2012) where the use of Si in sunflower plants induced resistance to aphids (*Myzus persicae*) through the mechanism of non-preference for feeding and/or reproduction. Antunes et al. (2010) where they evaluated doses of Si that did not directly affect the infestation of *Spodoptera frugiperda* in corn cultivar ‘hybrid Dow Agrosciences 2301’, however, it favored the occurrence of the predator *Dorus* spp., consecutively, there was a reduction of *Chlosyne lacinia saumdersii* (largate -do-sunflower) in sunflower plants cultivar ‘HF 358’. The number of ladybugs being significantly higher is found on sunflower plants.

5. Conclusions

The application of potassium silicate improved vegetative growth in the sunflower cultivar ‘Multissol’, especially at a dose of 900 kg ha^{-1}. Further studies should be carried out checking the Si content in different parts of sunflower plants in the vegetative and reproductive phases to know what the final deposits of this element are in this crop.

6. Acknowledgments

We thank the Fundação de Amparo à Pesquisa do Estado de Goiás – FAPEG, Brazil e Conselho Nacional de Desenvolvimento Científico e Tecnológico, Brazil.

7. Authors’ Contributions

Felipe da Silva Malta: development, planting, crop monitoring, analysis, article writing. *Porshia Sharma*: translation corrections and idea complements. *Antonio Carlos Pereira de Menezes Filho*: planting, harvesting, analysis, writing and translation. *Carlos Frederico de Souza Castro*: funding and laboratory maintenance. *Marconi Batista Teixeira*: funds, laboratory maintenance and analysis of ideas. *Frederico Antônio Loureiro Soares*: funds, laboratory maintenance and statistical analysis. *Aurélio Ferreira Melo*: data analysis, writing and corrections. *Matheus Vinícius Abadia Ventura*: advisor, data interaction, statistical evaluation, submission and publication.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Not applicable.

10. References

Abd El-Gwad, A. M., & Salem, E. M. M. (2013). Effect of biofertilization and silicon foliar application on productivity of sunflower (*Helianthus annuus* L.) under New Valey conditions. *Egyptian Journal of Soil Science*, 53(4), 509-536. https://doi.org/10.21608/ejss.2013.189

Antunes, C. S., Moraes, J. C., Antônio, A., & Silva, V. F. (). Influência da aplicação de silício na ocorrência de lagartas (Leptoptera) e de seus inimigos naturais chaves em milho (*Zea mays* L.) e em girassol (*Helianthus annuus* L.). *Bioscience Journal*, 26(4), 619-625.

Araújo, R. F., Zonta, J. B., Araújo, E. F., Heberle, E., & Zonta, F. M. G. (2011). Teste de condutividade elétrica para sementes de feijão-mungo-verde. *Revista Brasileira de Sementes*, 33(1), 123-130. https://doi.org/10.1590/S0101-31222011000100014

Assis, F. A., Nascimento, A. M., Moraes, J. C., Coelho, M., Parolin, F. T. (2012). Não-preferência ao pulgão *Myzus persicae* em girassol induzida por silício. *In*: VI Workshop Agroenergia, 27 e 28 de Junho de 2012, Ribeirão Preto, São Paulo, Brasil, 1-7 p.

Balastra, M.L.F., Perez, C. M., Juliano, B. O., Villareal, C. P., Lott, J. N. A. & Roxas, D. B. (1989). Effects of silica level on some properties of *Oriza sativa* straw and hult. *Canadian Journal of Botany*, 67(8), 2356-2363. https://doi.org/10.1139/b89-301

Biscaro, G. A., Machado, J. R., Tosta, M. S., Mendonça, V., Soratto, R. P., & Carvalho, L. A. (2008). Adubação nitrogenada em cobertura no girassol irrigado nas condições de Cassilândia-MS. *Ciência e Agrotecnologia*, 32(5), 1366-1373. https://doi.org/10.1590/S1413-70542008000500002

Birchall, J. D. (1995). The essentiality of silicon in biology. Chemical. *Society Reviews*, 24(5), 351-357. https://doi.org/10.1039/CS9952400351

Braz, M. R. S., & Rossetto, C. A. V. (2009). Correlação entre testes para avaliação da qualidade de sementes de girassol e emergência das plântulas em campo. *Ciência Rural*, 39(7), 2004-2009. https://doi.org/10.1590/S0103-84782009005000146

Carvalho, M. P., Zanão Júnior, L. A., Grossi, J. A. S., & Barbosa, J. G. (2009). Silício melhora produção e qualidade do girassol ornamental em vaso. *Ciência Rural*, 39(8), 2394-2399. https://doi.org/10.1590/S0103-84782009005000194

Cassel, J. L., Gysi, T., Rother, G. M., Pimenta, B. D., Ludwig, R. L., & Santos, D. B. (2021). Benefícios da aplicação de silício em plantas. *Brazilian Journal of Animal and Environmental Research*, 6601-6615. https://doi.org/10.34188/bjaerv4n4-140

CFIA. (2023). Canadian methods and procedures for testing seed. *In*: Canadian Food Inspection Agency, Edition, version 1.1, Effective 1 July 2023, RDIM 19261425, 171 p. https://analyzeseeds.com/publications/

Dallagnol, L. J., Rodrigues, F. A., Mielli, M. V. B., & Ma, J. (2014). Rice grain resistance to brown spot and yield are increased by silicon. *Tropical Plant Pathology*, 39(1), 056-063. https://doi.org/10.1590/S1982-56762014005000003

Dias, G. M. G., Ferreira, D. G. B., Anjos, D. C., Mendes, I. P. B., & Guimarães, M. A. (2022). Silicon accumulation in bioenergetic sunflower germination. *Scientia Agraria Paranaensis*, 21(2), 151-157. https://doi.org/10.18188/sap.v21i2.28947

Ducatti, K. R. (2014). Accelerated aging test in determining the vigor of sunflower seeds with and without pericarp. *Scientific Electronic Archives*, 7, 39-43.

Ferreira, D. F. (2019). SISVAR: A computer analysis system to fixed effects split plot type designs. *Brazilian Journal of Biometrics*, 37(4), 529-535. https://doi.org/10.28951/rbb.v37i4.450

Guedes, R. M., Nogueira, R. A., Martins, W. V., Silva, H. A. R., Mota, S. B. O., & Sales, H. R. (2023). Avaliação agronômica de plantas de girassol, cultivar BRS323, em função de diferentes doses de agrosilício. IF Integra. *In*: XI Seminário de Iniciação Científica, III Seminário de Pós-Graduação, Semana Integrada da Extensão e Vi Encontro do Ensino, 21 a 24 de Novembro, 3 p.

Gunes, A., David, J., Pilbeam, A. I., & Sencan, C. (2008). Influence of silicon on sunflower cultivars under drought stress, I: Growth, antioxidant mechanisms, and lipid peroxidation. *Communications in Soil Science and Plant Analysis*, 39(13-14), 1885-1903. https://doi.org/10.1080/00103620802134651

Harris, T. M., Hottle, T. A., Soratana, K., Klane, J., Landis, A. E. (2016). Life cycleassessment of sunflower cultivation on abandoned mine land for biodiesel production. *Journal of Cleaner Production*, 112(1), 182-195. https://doi.org/10.1016/j.jclepro.2015.09.057

Hilgert, M. A., Sá, L. C., Júnior, J. J. M., Lazarotto, M., & Souza, P. V. D. (2021). Luminosidade e temperatura na germinação de sementes de nogueira-pecã. *Pesquisa Agropecuária Gaúcha*, 27(1), 74-89. https://doi.org/10.36812/pag.202127174-89

Hurtado, A. C., Chiconato, D. A., Prado, R. M., Júnior, G. S. S., Gratão, P. L., Felisberto, G., Viciedo, D. O., & Santos, D. M. M. (2020). Different methods of silicon application attenuate salt stress in sorghum and sunflower by modifying the antioxidative defense mechanism. *Ecotoxicology and Environmental Safety*, 203, 110964. https://doi.org/10.1016/j.ecoenv.2020.110964

Hussain, S. A., Farooq, M. A., Akhtar, J., Saqib, Z. A. (2018). Silicon – mediated growth and yield improvement of sunflower (*Helianthus annus* L.) subjected to brackish water stress. *Acta Physiologiae Plantarum*, 40. https://doi.org/10.1007/s11738-018-2755-z

Júnior, P. P., Rezende, P. M., Malfitano, S. C., Lima, R. K., Corrêa, L. V. T., & Carvalho, E. R. (2010). Efeito de doses de silício sobre a produtividade e características agronômicas da soja [*Glycine max* (L.) Merrill]. *Ciência e Agrotecnologia*, 34(4), 908-913.

Juo, A. S. R., & Sanchez, P. A. (1986). Soil nutritional aspects with a view to characterize upland rice environment. *In*: International Rice Research Institute. Upland Rice Research, Los Banos: IRRI, 81-95 p.

Kamenidou, S., Cavins, T. J., & Marek, S. (2008). Silicon supplements affect horticultural traits of greenhouse-produced ornamental sunflowers. *HortScience*, 43(1), 236-239. https://doi.org/10.21273/HORTSCI.43.1.236

Kohl, S., Capelaro, S., Milanesi, P. M., & Silva, V. N. (2021). Tratamento de sementes de girassol ornamental com silício: efeitos fisiológicos e sanitários. *In*: XI Jornada de Iniciação Científica e Tecnológica, Universidade Federal da Fronteira Sul, Brasil, 23 a 26 de Novembro, 5 p.

Ma, J. F. (2004). Role of silicon in enhancing the resistance of plants to biotic and abiotic stresses. *Soil Science and Plant Nutrition*, 50(1), 11-18. https://doi.org/10.1080/00380768.2004.10408447

Ma, J. F., & Yamaji, N. (2006). Silicon uptake and accumulation in higher plants. *Trends in Plant Science*, 11(8), 392-397. https://doi.org/10.1016/j.tplants.2006.06.007

Nobre, R. G., Gheyi, H. R., Soares, F. A. L., Andrade, L. O., Nascimento, E. C. S. (2010). Produção do girassol sob diferentes lâminas com efluentes domésticos e adubação orgânica. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 14(7), 747-754. https://doi.org/10.1590/S1415-43662010000700010

Oliveira, F. N. (2012). Qualidade fisiológica de sementes de girassol avaliadas por condutividade elétrica. *Pesquisa Agropecuária Tropical*, 42(3), 279-287.

Oliveria, J. T. L., Campos, V. B., Chaves, L. H. G., & Filho, D. H. G. (2013). Crescimento de cultivares de girassol ornamental influenciado por doses de silício no solo. *Revista Brasileira de Engenharia Agrícola e Ambiental*, 17(2), 123-128. https://doi.org/10.1590/S1415-43662013000200002

Oliveira, R. R., Silva, D. F., & Monzani, R. M. (2023). Germination of yellow passui fruit (*Passiflora edulis*) seeds subjected to different dormancy overcoming methods. *Agropecuária Catarinense*, 36(3), 26-28. https://doi.org /10.52945/rac.v36i3.1720

Rains, D. W., Epstein, E., Zasoski, R. J., & Aslam, M. (2006). Active silicon uptake by wheat. *Plant and Soil*, 280(1-2), 223-228. https://doi.org/10.1007/s11104-005-3082-x

Rodrigues, F. A. (2010). Silício na agricultura. Viçosa, UFV, DFP, 385 p.

Santos, L. G., Meira, A. L., Públio, A. P. P. B., Mendes, H. T. A., Souza, U. O., & Amaral, C. L. F. (2017). Parâmetros genéticos da germinação de sementes e emergência de plântulas em girassol. *Magistra*, 29(2), 47-55. https://periodicos.ufrb.edu.br/index.php/magistra/article/view/3840

Savant, N. K., Snyder, G. H., & Datnoff, L. E. (1997). Silicon management and sustainable rice production. *Advances in Agronomy*, 58(1), 151-199. https://doi.org/10.1016/S0065-2113(08)60255-2

Schoellhorn, R., Emino, E., & Alvarez, E. (2003). Specialty cut flower production guides for florida: Sunflower. University of Florida, Ifas Extension, ENH885, 3p. https://hort.ifas.ufl.edu/floriculture/pdfs/crop_production/Sunflower_EP1421.pdf

Souza, J. P. F., Martins G. L. M., Pereira, A. C., Binotti, F. F. S., & Maruyama, W. I. Efeito de silicato de cálcio e magn´seio no crescimento inicial de milho transgênico. *Revista de Agricultura Neotropical*, 2(3), 13-17. https://doi.org/10.32404/rean.v2i3.280

Vieira, R. D. (1994). Teste de condutividade elétrica. *In*: Vieira, R. D., Carvalho, N. M. (Ed.). Testes de vigor em sementes, Jaboticabal: FUNEP, 103-132 p.

Zanão Júnior, L.A. (2007). Resistência do arroz à mancha parda mediada por silício e manganês. Dissertação (Mestrado em Solos e Nutrição de Plantas), Programa de Pós-graduação em Solos e Nutrição de Plantas, Universidade Federal de Viçosa, Minas Gerais, Brasil, 125 p.

Zanão Júnior, L.A., Rodrigues, Á. R., Fontes, R. L. F., Korndöfer, G. H., & Neves, J. C. L. (2009). Rice resistance to brow spot mediated by silicon and its interaction whit manganese. *Journal of Phytopathology*, 157(2), 73-78. https://doi.org/10.1111/j.1439-0434.2008.01447.x

Zanão Júnior, L. A., Alvarez Venegas, V. H., Fonte, R. L. F., Carvalho-Zanão, M. P., Dias-Pereira, J., Maranho, L. T., & Pereira, N. (2017). Leaf anatomy and gas exchange of ornamental sunflower in response to silicon application. *Bioscience Journal*, 33(4), 833-842. https://seer.ufu.br/index.php/biosciencejournal/article/view/36559/20647

Zelin, E., Bussolaro, I., & Simonetti, A. P. M. M. (2011). Aplicação de silício no controle de largatas e produtividade da cultura da soja. *Cultivando o Saber*, 4(1), 171-180.

Funding

Not applicable.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.