Journal of Applied Horticulture, 27(1): 126-131, 2025

https://doi.org/10.37855/jah.2025.v27i01.24

Journal of Applied Horticulture
ISSN: 0972-1045

Silicon supplementation affects floricultural traits and leaf nutrient content in gladiolus (*Gladiolus grandiflorus* Hort.)

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Abstract

This study was conducted to evaluate five basal doses of silicon (0, 25, 50, 75 and 100 kg ha^{-1} as SiO_2) along with four foliar sprays at 3rd and 6th leaf stages (water spray, 1, 2 and 3% as SiO_2) on floricultural traits and leaf nutrient content in gladiolus *cv.* White Prosperity. The synergetic effect of silicon on the vegetative growth and floricultural traits was noticed as the dose was increased under both methods of application; however, more beneficial effect was recorded under the basal method of application. Basal silicon application at 100 kg ha^{-1} recorded the earliest spike emergence and flowering (101.68 and 122.42 days) along with maximum plant height (103.91 cm), spike length (79.88 cm), spike weight (15.51 g), vase life (8.75 days) and silicon content (2.04%). Foliar spray at 3% resulted in early spike emergence and flowering (101.53 and 122.28 days) along with maximum plant height (99.33 cm), spike length (82.18 cm), floret size (9.73 cm), spike weight (15.51 g) and silicon content (1.88%). Despite the positive effect of the singular application of silicon, the combined application of soil and foliar method exhibited the most inductive effect on all observed parameters. Silicon application at lower rates improved Cu, Mn, Fe and Zn content in leaves and vice-versa. Hence, it was concluded that silicon fertilization at 100 kg ha^{-1} along with foliar spray of 3% at 3rd and 6th leaf stage in gladiolus can be considered a production technology of great importance for promoting floricultural traits and nutrient content in gladiolus.

Key words: Gladiolus, silicon, soil analysis, plant nutrition, foliar spray

Introduction

Gladiolus (*Gladiolus grandiflorus* Hort.) is a commercial bulbous cut flower used in landscaping, gardening, floral arrangements and bouquets (Kumari *et al.*, 2014). It belongs to the family Iridaceae and is native to South Africa. Commonly known as Queen of bulbous flowers due to their elegant attractive spikes of different hues, varying sizes and long vase life.

Chemical fertilizers are essential for overall growth and development improving flower quality and propagule production in gladiolus. Silicon (Si) is the most abundant element in earth crust with many beneficial effects for crops. Despite its abundance, it exists mostly as silica (SiO_2) that is not available for plant uptake. Silicon is absorbed through the xylem in the form of mono silica acids ($Si(OH)_4$) and is mostly accumulated in leaves, trichomes and spines in the form of hydrated amorphous silica ($SiO_2.nH_2O$), which prevents its mobility in the phloem (Taiz and Zeiger, 2013).

Silicon is required during the vegetative and reproductive growth of the plant to attain healthy and maximum yield from the plant. The role of silicon is important in plant growth, production; metabolism and enhanced resistance to abiotic and biotic stress as well as increased efficiency of NPK fertilizers and stimulates uptake of macronutrients and micronutrients from the soil (Greger *et al.,* 2018). Silicon has been reported to strengthen the epidermal cell wall by increasing lignin accumulation and maintaining the cell shape (Yavas and Unay, 2017).

Subtropical and tropical agriculture are typically low in available silicon and rational Si fertilization could enhance the crop yield. However, inadequate quantities and brands of silicon based fertilizers are available in the market and are often unaffordable to many farmers due to their high prices which restrict their utilization at the global level (Yeshe *et al.*, 2022).

Several studies have reported with positive effects of silicon on different plant crops such as cucumber (Alsaeedi *et al.*, 2018), soybean (Hamayun *et al.,* 2010), etc. Despite the positive effect of silicon on plant development in several field crops, there is a lack of such investigation in ornamental plants, which has generated interest for research with horticultural crops as well. Farooq *et al.* (2020) reported improved vegetative, floral and corm characteristics in gladiolus with application of silicon either as a soil drench or foliar application.

The farmers have inadequate knowledge about these nutrient elements and their significant impact in increasing output and production, thus leading to deficient soils which further hinder the plant's ability to produce optimal corm, spike and cormel size for commercial flower production. Unfortunately, no work on silicon has been done so far in gladiolus crop under Punjab conditions with respect to its method of application as well as dose, especially without biotic and abiotic stresses. Therefore, in this study, we investigated the effects of different methods of application as well as doses of silicon on the growth, flowering and nutrient content in gladiolus under non-stress conditions.

Materials and methods

Experimental setup: The present study was conducted at Research Farm, Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana, Punjab, India (30º54'N latitude, 75º48'E longitude) from October 2022 to April 2023.

The soil of the experimental plot was sandy loam and alkaline with pH 8.07. The available N, P, and K in soil were 123.35, 66.84 and 171.81 kg ha^{-1}, respectively. The experimental field was uniformly leveled and was brought to a fine tilth by ploughing twice. The raised beds of 90 cm width and 15 cm height were prepared with 40 cm spacing between the two beds. The experimental plots were prepared with a split plot randomized block design with three replications each. The recommended dose of NPK fertilizers @ 200:100:100 kg ha^{-1} was applied in the form of Urea (half as basal dose and half as top dressing at 3rd and 6th leaf stage) whereas, Single Superphosphate and Muriate of Potash entire dose was applied as basal before planting. All treatments of silicon were applied treatment-wise before and after planting of corms. The corms of gladiolus cv. 'White Prosperity' of uniform 3- 4 cm diameter was selected and treated with 0.2% Bavistin solution for 30 minutes. Then corms were planted at spacing of 30 × 20 cm under open field conditions on October 21st, 2022. From October to February, irrigation was given at an interval of 7-10 days whereas, 4-6 weeks before lifting of corms irrigation was withheld. Earthing up was done at 4-6 leaf stage to avoid crop lodging. Three manual hoeing were done *i.e.* first two during the vegetative phase and the third after the flowering was over at the time of corm development. Weeding and plant protection measures were done regularly from time to time. The corms were lifted from the ground 4-6 weeks after spike harvesting when leaves turned yellow. These corms were cleaned and dried in the shade for 4-5 days and packed in gunny bags for cold storage at 4°C. The data for growth and floral traits along with nutrient analysis were collected, compiled and statistically analyzed.

Silicon treatments: Gladiolus cv. 'White Prosperity' with different levels of silicon concentrations as basal (soil) and foliar applications was accommodated in the experiment in a split-plot randomized block design. The commercial product silicon dioxide was used as a source of silicon. The powdered active silicon was broadcasted at five different rates *i.e.* 0, 25, 50, 75, 100 kg ha^{-1}as basal application on the prepared beds before planting of corms (as most fertilizers are applied before planting to provide nutrition for sprouting of corms). After corm sprouting, at 3rd and 6th leaf stage (critical stages of corm development), foliar spray of powdered silicon dissolved in water at four doses *i.e.* control, 1%, 2% and 3% was done with a pressurized portable sprayer of 1 L covering the entire plant. The control of foliar application was sprayed with deionized water at the same time. The doses were taken concerning silicon application on other ornamental crops.

Sampling and laboratory analysis of plant: The plants were sampled at the flowering stage when two basal florets on the spike were opened. The leaves and spikes were collected together from the plant and then separated into above-ground biomass and spike biomass. All the separated parts were washed, air dried for 1-2 days and then placed in butter paper for oven drying at 60°C for 72 h till they reached a constant dry weight. After drying, the above-ground biomass and the spike biomass samples were weighed and ground into fine powder using a 40-mesh screen Willey mill. The powdered leaf samples were then analyzed for the key nutritional elements (N, P, K, and Si) by using the standard methods. The nitrogen content (%) in leaf samples was analyzed by Kjeldahl's micro distillation process as described by Piper (1966). Using a nitric acid system and the vanadomolybdo phosphoric yellow colour technique described by Chapman and Pratt (1961), the phosphorus content was ascertained. The amount of potassium was measured using the Flame Photometer technique (AOAC, 1970). The silicon content was determined by the dry ashing method by Fox *et al.* (1969). For micronutrient analysis (Zn, Mn, Fe and Cu in mg/kg), digested leaf material was fed into an atomic absorption spectrophotometer (Page *et al.*, 1982).

Statistical Analysis: The multivariate analysis was done for all the observations recorded by using OP-STAT computer software. The split-plot two-way analysis of variance was used to test the effect of silicon as basal, foliar and their interaction. The mean difference between a pair of treatments was evaluated by CD at 5% level of significance.

Results

Effect of silicon on vegetative growth and floricultural traits: ANOVA indicated that silicon application as basal and foliar had a significant effect on plant height, leaf length, days to spike emergence, flowering, spike length, rachis length, floret size and total dry spike matter yield/ plant in gladiolus, whereas silicon

Table 1. Individual effect of silicon as basal fertilization and foliar spray on growth and flowering of gladiolus cv. White Prosperity

Treatments	Plant height (cm)	Leaf length (cm)	SPAD index	Total dry leaf matter yield/ plant (g)	Days to spike emergence	Days to flowering	Spike length (cm)	Rachis length (cm)	No. of florets/ spike	Floret size (cm)	Total dry spike matter yield/ plant (g)
Factor A: Basal (SiO_2)											
S_1	94.67	47.56	23.61	2.07	103.77	125.02	72.97	34.14	8.40	8.88	2.29
S_2	94.83	52.47	38.05	2.08	103.78	123.99	78.16	37.53	8.50	9.48	2.43
S_3	97.41	53.14	38.40	2.24	103.50	122.62	78.68	38.36	8.56	9.56	2.44
S_4	98.83	54.97	46.85	3.02	102.89	122.43	79.43	38.96	8.56	10.16	2.80
S_5	103.91	54.20	50.17	4.23	101.68	122.42	79.88	39.19	8.65	9.60	2.76
C.D. (5%)	0.71	1.09	10.76	NS	0.73	0.10	0.22	0.26	NS	0.05	0.04
Factor B: Foliar (SiO_2)											
F_1	94.67	47.56	23.61	2.46	103.77	125.02	73.35	35.41	8.29	9.18	
F_2	97.13	52.48	40.85	2.45	103.68	124.29	77.57[c]	36.51	8.42	9.61	2.11
F_3	98.80	52.65	42.58	2.77	103.37	122.62	78.19[b]	38.92	8.76	9.63	2.38
F_4	99.33	54.43	43.86	3.23	101.53	122.28	82.18[a]	39.71	8.67	9.73	2.56
C.D. (5%)	0.71	0.89	NS	NS	0.43	0.23	0.21	0.24	0.11	0.03	3.12

S_1= 0 kg ha^{-1} (control), S_2=25 kg ha^{-1}, S_3=50 kg ha^{-1}, S_4=75 kg ha-1, S_5=100kg ha^{-1} SiO_2 as basal fertilization before planting of corms. F_1= water spray (control), F_2= 1%, F_3=2%, F_4=3% SiO_2 foliar spray at 3rd and 6th leaf stage

Table 2. Combined effect of silicon as basal fertilization and foliar spray on growth and flowering of gladiolus cv. White Prosperity

Treatments	Plant height (cm)	Leaf length (cm)	SPAD index	Total dry leaf matter yield per plant (g)	Days taken to spike emergence	Days taken to flowering	Spike length (cm)	Rachis length (cm)	Number of florets per spike	Floret size (cm)	Total dry spike matter yield per plant (g)
S_1F_1	94.67	47.56	23.61	1.47	103.77	125.02	77.34	38.24	8.20	9.00	2.16
S_1F_2	100.00	50.20	33.86	1.06	104.10	126.5	72.34	36.56	8.10	8.67	2.02
S_1F_3	90.00	49.67	39.85	1.92	103.48	125.45	72.10	31.56	9.05	8.42	2.17
S_1F_4	90.33	50.60	31.71	3.80	104.23	126.40	70.10	30.23	8.25	9.42	2.81
S_2F_1	98.67	51.80	35.53	1.33	104.67	125.83	71.12	34.12	8.35	8.75	1.92
S_2F_2	91.33	51.20	42.30	1.72	105.00	123.83	70.89	31.29	8.30	9.92	2.04
S_2F_3	92.67	53.10	42.30	2.39	103.40	122.78	83.76	42.07	8.80	9.67	3.06
S_2F_4	96.67	53.80	37.78	2.88	102.07	123.54	86.89	42.67	8.55	9.58	2.70
S_3F_1	96.33	52.50	35.60	3.47	105.67	125.49	74.07	36.93	8.45	9.08	2.42
S_3F_2	94.00	51.00	40.76	2.08	102.64	123.67	78.56	37.98	8.45	9.62	1.98
S_3F_3	102.67	51.20	38.86	1.70	103.89	122.00	80.65	37.34	8.55	9.80	3.04
S_3F_4	96.67	57.89	38.36	1.73	101.83	119.34	81.45	41.20	8.80	9.75	2.32
S_4F_1	92.67	53.90	37.63	2.02	103.82	122.6	70.78	33.60	8.25	10.25	2.11
S_4F_2	95.33	55.10	54.41	3.32	103.50	123.33	84.10	41.23	9.25	10.00	3.12
S_4F_3	103.67	55.20	41.33	3.55	104.20	122.59	78.87	42.49	8.25	10.25	1.43
S_4F_4	103.67	55.70	54.03	3.22	100.06	121.23	84.00	38.54	8.50	10.17	4.55
S_5F_1	96.33	53.60	54.10	4.02	102.17	124.3	73.45	34.19	8.20	8.83	1.95
S_5F_2	105.00	54.90	37.45	4.07	103.17	124.17	81.98	35.50	8.00	9.83	2.74
S_5F_3	105.00	54.10	50.56	4.31	101.89	120.33	75.60	41.17	9.15	10.00	3.10
S_5F_4	109.33	54.20	58.58	4.53	99.50	120.89	88.50	45.93	9.25	9.75	3.26
C.D. (5%) F at same level of S	0.86	2.059	NS	NS	1.02	0.52	0.49	0.55	0.27	0.07	0.13
C.D. (5%) S at same level of F	0.99	2.039	NS	NS	1.11	0.46	0.46	0.53	0.28	0.08	0.12

fertilization did not have any significant effect on total dry leaf matter yield per plant irrespective of the application method (Table 1, 2).

The synergetic effect of Si on the vegetative growth was noticed in plant height, leaf length and SPAD index under both methods of application as compared to the control (without Si application); however more beneficial effect was recorded under the basal method of application. The control plants had the shortest plant height and leaf length among all the treatments (90 and 47.56 cm). The plant height and leaf length were significantly increased by increasing Si application from the dose of 25 kg ha^{-1} (94.83 and 52.47 cm) to 100 kg ha^{-1} (103.91 and 54.20 cm) as basal and 1% (97.13 and 52.48 cm) to 3% (99.33 and 54.43 cm) as a foliar spray (Fig. 1). Despite the positive effect of the singular application of silicon, the combined application of soil and foliar method exhibited the most inductive effect recording the tallest plants (109.33 cm in S_5F_4) with the longest leaves (57.89 cm in S_3F_4).

The values of SPAD in leaves of plants increased upon the exogenous application of Si either through foliar, soil, or dual application; however effect of foliar and dual application was non-significant. The control plants had the lowest SPAD value (23.61) which increased by 112.50% when plants received the soil application 100 kg ha^{-1} Si (50.17). The combined application of Si through soil and foliar had a non-significant effect, however, the highest SPAD value corresponds to S_5F_4 (58.58).

The exogenous application of Si, regardless of the application method, improved the characteristics of the flowering period and floricultural traits of gladiolus compared to control plants. The results detected that with the increase of Si dose, there was an increase in all the studied characters *i.e.* spike length, rachis length, and number of florets per spike, floret size and total dry spike matter yield/plant (Table 1, 2). All treated plants with Si, regardless of the concentration and application way, needed shorter periods to spike emergence and flowering. The higher doses, applied as a singular basal dose (100 kg ha^{-1}) and foliar spray (3%), resulted in spike emergence and flowering after 101.68 and 122.42 days, and 101.53 and 122.28 days, respectively. The control plants needed 103.89 and 125.02 days to spike emergence and flowering, which were at par to lower doses of Si as basal (25.50 kg ha^{-1}) as well as foliar application (1, 2%). However, combined application of Si *i.e.* S_5F_4 and S_3F_4 corresponded to earliest spike emergence (99.50 days) and flowering (119.34 days), respectively, with almost 4.11 and 4.54% reduction in days as compared to control.

The spike length and rachis length directly proportioned to the addition of Si regardless of the method of application, as all the treated plants had more spike and rachis length (Table 2). Plants that received 3% Si through the foliar application had more spike length and rachis length (82.18 and 39.71 cm) than those that received 100 kg ha^{-1} Si through the soil application (79.88 and 39.19 cm); this gives slight priority to the foliar application over the soil application. The 3% foliar spray of Si resulted in 12.62% and 16.31% increase in spike and rachis length over the control (72.97 and 34.14 cm). Despite the positive effect of the singular application of soil and foliar, the combined application (S_5F_4) resulted in the highest values for spike and rachis length (88.50 and 45.93 cm) with 21.28 and 34.53% increase over the control plants.

The high Si concentration resulted in a higher number of florets regardless of application method; however foliar application had a significant advantage over the soil application. Upon treating plants with 3% Si through foliar technique, number of florets showed an increase of 5.73% over the control plants. However, combined application at S_4F_4 and S_4F_2 resulted in the highest number of florets per plant (9.25). The floret size was directly proportional to the supplementation of Si regardless of the application method, as all the treated plants had a larger floret size than the control. The plants that received 75 kg ha^{-1} Si through soil had larger floret size (10.16 cm) than those received 3% through foliar spray (9.73 cm), this gives slight preference to soil application than foliar spray. The dual application of Si exhibited the largest floret size (10.25 cm) with S_4F_1 and S_4F_3 treatments.

The total dry spike matter yield/plant increased upon increasing the dose of Si regardless of the application method. The foliar application of 3% showed priority over soil application of 100 kg ha^{-1} Si with total dry spike matter yield/plant of 3.12 and 2.76 g, respectively. However, the highest value (3.26 g) was observed under combined application at S_5F_4 which is almost 127.97% higher than the lowest value (1.43 g) at S_4F_3.

Effect of silicon on leaf nutrient content: Except for nitrogen and silicon, the singular addition of Si either through foliar or soil application had a non-significant effect on phosphorus, potassium and micronutrients (Zn, Mn, Fe and Cu) (Table 3).

Table 3. Individual effect of silicon as basal fertilization and foliar spray on leaf nutrient content of gladiolus cv. White Prosperity

Treatments	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Silicon (%)	Zinc (ppm)	Manganese (ppm)	Iron (ppm)	Copper (ppm)
Factor A: Basal (SiO_2)								
S_1	0.92^b	0.12	0.35	1.42^e	13.92	34.93	269.53	6.08
S_2	1.00^b	0.14	0.42	1.65^d	16.33	32.54	270.12	5.76
S_3	1.11^a	0.14	0.43	1.86^c	12.54	40.29	250.05	7.21
S_4	1.23^a	0.16	0.46	1.96^b	11.52	34.46	232.49	5.97
S_5	1.18^a	0.14	0.54	2.04^a	12.16	38.38	234.48	5.96
C.D. (5%)	0.20	NS	NS	0.06	NS	NS	NS	NS
Factor B: Foliar (SiO_2)								
F_1	1.03^b	0.12	0.42	1.71^c	13.72	36.25	245.87	6.18
F_2	1.11^a	0.13	0.43	1.76^b	12.54	35.73	245.67	6.74
F_3	1.16^a	0.15	0.44	1.78^b	14.28	33.59	260.56	6.38
F_4	1.04^b	0.15	0.46	1.88^a	12.63	36.91	253.23	5.49
C.D. (5%)	0.08	NS	NS	0.02	NS	NS	NS	NS

S_1= 0 kg ha^{-1} (control), S_2=25 kg ha^{-1}, S_3=50 kg ha^{-1}, S_4=75 kg ha-1, S_5=100kg ha^{-1} SiO_2 as basal fertilization before planting of corms. F_1= water spray (control), F_2= 1%, F_3=2%, F_4=3% SiO_2 foliar spray at 3rd and 6th leaf stage

Table 4. Combined effect of silicon as basal fertilization and foliar spray on leaf nutrient content of Gladiolus cv. White Prosperity

Treatments	Nitrogen content (%)	Phosphorus Content (%)	Potassium content(%)	Silicon content (%)	Zinc content (ppm)	Manganese content (ppm)	Iron content (ppm)	Copper content (ppm)
S_1F_1	0.87	0.12	0.41	0.98	13.77	26.35	268.87	6.18
S_1F_2	0.75	0.12	0.36	1.52	13.87	36.38	269.12	6.05
S_1F_3	0.90	0.13	0.33	1.82	13.97	35.87	269.37	6.13
S_1F_4	1.16	0.13	0.33	1.34	14.05	41.13	270.75	5.98
S_2F_1	1.08	0.12	0.39	1.77	16.02	32.35	276.19	5.34
S_2F_2	1.01	0.15	0.41	1.80	11.44	32.50	234.53	6.83
S_2F_3	0.89	0.14	0.30	1.43	18.52	32.57	264.15	5.10
S_2F_4	1.01	0.15	0.57	1.60	19.33	32.72	305.59	5.78
S_3F_1	0.76	0.10	0.42	1.55	13.77	51.47	229.90	7.80
S_3F_2	1.28	0.10	0.37	2.10	16.92	33.97	271.95	8.33
S_3F_3	1.42	0.17	0.60	1.69	12.05	41.17	248.02	7.08
S_3F_4	0.97	0.20	0.33	2.09	7.42	34.55	250.32	5.65
S_4F_1	1.25	0.18	0.33	2.15	14.02	37.92	241.62	6.82
S_4F_2	1.23	0.13	0.50	1.60	10.47	29.95	223.64	6.17
S_4F_3	1.22	0.16	0.47	1.96	14.32	34.77	253.32	5.15
S_4F_4	1.22	0.19	0.53	2.13	7.25	35.20	211.37	5.75
S_5F_1	1.20	0.12	0.54	2.11	11.02	33.17	212.77	4.78
S_5F_2	1.26	0.18	0.53	1.80	9.97	45.85	229.10	6.33
S_5F_3	1.39	0.17	0.54	2.02	12.52	33.55	267.92	8.46
S_5F_4	0.85	0.10	0.54	2.23	15.10	40.95	253.23	4.28
C.D. (5%) F at same level of S	0.20	NS	0.16	0.06	NS	NS	NS	NS
C.D. (5%) S at same level of F	0.25	NS	0.27	0.07	NS	NS	NS	NS

However, the combined application had a significant effect on nitrogen, potassium and silicon, whereas other nutrients were non-significantly affected (Table 4). The silicon application affected the nitrogen content in the leaf but it was not unidirectional (Table 3). The effect of soil application was more pronounced than the foliar application with the highest nitrogen content (1.23%) reported with 75 kg ha^{-1} Si application. However, the highest leaf nitrogen content (1.42%) was measured with a combined application at S_3F_3.

The silicon content in leaves increased upon treating plants with Si, irrespective of application method, with control plants recording the lowest value (0.98%). Silicon content follows a dose-response relationship, *i.e.* as much as 2.04% at basal application of 100 kg ha^{-1} Si to as little as 1.65 % at 25 kg ha^{-1} Si. A greater response to the soil application of Si than foliar application was observed. However, the highest value of Si (2.23%) was measured in the leaves of plants that received Si through the combined application of soil and foliar (S_5F_4).

The potassium content in leaves was not affected significantly by single application of soil or foliar method but showed a noticeable effect by combined application of Si through soil and foliar without following any pattern. The highest potassium content (0.60%) was measured in S_3F_3.

Discussion

In the present study, gladiolus plants significantly responded to the exogenous application of silicon regardless of the application method and concentration, however, combined application resulted in better vegetative growth, flowering and corm production. This synergetic effect of silicon may be attributed to improved uptake and transport of water and nutrients in xylem sap, upregulation of antioxidant activity and hormones, cell elongation, maintaining membrane integrity and enhancing the chloroplast structure and photo-assimilate translocation. The enhanced plant height and leaf length might be due to the precipitation of silica in the cell wall which gives a more erect appearance to the leaves, thus resulting in better light interception and improving photosynthetic apparatus (Isa *et al.*, 2010). The linear increase in SPAD content of leaves with the application of Si might be due to the direct involvement of Si in the synthesis of new chlorophyll as well as protecting the existing chlorophyll from stress (Shikari *et al.*, 2022). Moreover, silicon addition increases the nitrogen content in leaves which leads to an increase in leaf area thereby increasing the chlorophyll content of plants. The results of Ahmad *et al.* (2013) and Khenizy *et al.* (2015) in gladiolus are compatible with the present findings.

The early spike emergence and flowering with silicon supplementation might be due to silicon's positive effects in uptake, translocation, and availability of nutrients like nitrogen which stimulates cell proliferation and improves floral primordial differentiation inside the flower bud, thus resulting in earlier flowering than usual. Moreover, it might be attributed to an increase in endogenous levels of GA_3 by exogenous application of silicon (Lang *et al.*, 2018).

The floral traits of plants treated with silicon noticed a proportional increase in the spike length, rachis length, number of florets, and floret size with increasing the dose of applied silicon irrespective of method. This might be due to enhanced availability of nutrients (nitrogen) and improved nitrogen use efficiency, which further improved plant development with taller plants, long spike length with more florets. The increase in spike and rachis length might be due to the role of silicon in cell wall expansion and cell enlargement. Moreover, silicon enhances phenylalanine ammonia-lyase enzyme which further ameliorates the cellulose and lignin production in spike, resulting in spike reinforcement and lignification. The above results are in confirmative with Alikhani *et al.* (2021) in gerbera. The large-sized florets might be the result of cell enlargement in the flowers due to increased turgor pressure with silicon supplementation. The present findings conform with Hajipour *et al.* (2019).

The alleviated dry spike matter yield (biomass) with silicon supplementation might be due to enhanced production of carbohydrates as a result of more phosphorylation of sugars in response to silicon application. Moreover, silicon ameliorates water use efficiency and cell elongation which further promotes growth and biomass production (Isa *et al.*, 2010).

The increased nitrogen content in leaves with the application of silicon might be due to its potential to raise available soil nitrogen and improve nitrogen use efficiency as the plants fertilized with silicon gain the maximum benefit of ample nitrogen availability (Laine *et al.,* 2019).

The silicon supplementation increases the available silicon in the soil which further enhances the root growth and stimulates the plants to absorb more silicon from the soil and further increases the silicon content in leaves as well. The above results are in conformity with Gayed (2019) in zinnia.

The nutrients like phosphorus, potassium, iron, manganese, zinc and copper showed a slight increase in leaves with supplementation of lower doses of silicon irrespective of method, whereas decreased at higher doses. This might be attributed to the fact that silicon promotes the binding of these nutrients in roots but not in shoots, thus preventing their uptake and translocation to leaves at higher concentrations (Vaculík *et al.*, 2012).

The present study can be conducted in different areas of the country as the concentration of silicon in the soil varies according to the regions, therefore the effect of different concentrations and application methods of silicon on crops can vary.

Overall this study revealed that although the singular application of silicon either soil or foliar, had a positive effect on plant growth and flowering traits, the combined supplementation of silicon (soil+foliar@100 kg ha^{-1} @3%) resulted in maximum plant height, spike length, rachis length, and silicon content in leaves with the earliest spike emergence and flowering. Moreover, plants were more responsive to the basal application of silicon for vegetative and flowering as compared to foliar application. Hence, it could be recommended to farmers that the basal fertilization of silicon dioxide @100kg ha^{-1} along with the foliar spray @ 3% at 3^{rd} and 6^{th} leaf stages would enhance flower production along with the improvement of corm and cormel traits in gladiolus.

Acknowledgments

For technical support during the experiment, thanks are due to Punjab Agricultural University, Ludhiana, Punjab, India.

Conflict of Interest: The authors report no conflicts of interest in this work.

References

Ahmad, I., R.U. Saquib, M. Qasim, M. Saleem, K.A . Sattar and M. Yaseen, 2013. Humic acid and cultivar effects on growth, yield, vase life, and corm characteristics of gladiolus. *Chilean J. Agric. Res*., 73: 339-44.

Alikhani, T.T., S.J. Tabatabaei, A.M Torkashvand and D. Talei, 2021. Silica nanoparticles and calcium on the histological characteristics and stem bending in gerbera cut flower. *J. Orn. Hortic.*, 27: 334-43.

Alsaeedi, A., H. El-Ramady, T. Alshaal, M. El-Garawani, N. Elhawat and A. Al-Otaibi, 2018. Exogenous nanosilica improves germination and growth of cucumber by maintaining K^+/Na^+ ratio under elevated Na^+ stress. *Plant Physiol. Biochem.,* 125: 164-171.

AOAC, 1970. *Official method of analysis 10th edition*, Association of Official Agriculture Chemicals. Washington. DC

Chapman, H.D. and P.F. Pratt, 1961. *Methods of Analysis of Soils, Plants And Waters*. University of California Division of Agric. Sciences.

Farooq, M.U., K.M. Ahmad, M.A. Sadique, F. Shabbir, M.M.W. Khalid and M. Shahzad, 2020. Effect of silicon and gibberellic acid on growth and flowering of gladiolus. *World J. Biol. Biotechnol.,* 5: 19-24.

Fox, R.L., J.A. Silva, D.L. Plucknett and D.Y. Teranishi, 1969. Soluble and total silicon in sugar cane. *Plant Soil,* 30: 81-92.

Gayed, M.E.A.E., 2019. Effect of silicon levels and methods of application on vegetative growth and flowering of zinnia (*Zinnia elegans* L.). *Int. J. Productive Dev.,* 24: 929-44.

Greger, M., T. Landberg and M. Vaculík, 2018. Silicon influences soil availability and accumulation of mineral nutrients in various plant species. *Plants,* 7: 41.

Hajipour, H., Z. Jabbarzadeh and M.H. Rasouli, 2019. Effect of foliar application of silica on some growth, biochemical and reproductive characteristics and leaf elements of chrysanthemum (*Dendranthema x grandiflorum* cv. Fellbacher Wein). *J. Plant Interact.,* 10: 29-46.

Hamayun, M., E.Y. Sohan, S.A. Khan and Z.K. Shinwari, 2010. Silicon alleviates the adverse effects of salinity and drought stress on growth and endogenous plant growth hormones of soybean (*Glycine max* L.). *Pak. J. Bot.*, 42: 1713-1722.

Isa, M., S. Bai, T. Yokoyama, J.F. Ma, Y. Ishibashi, T. Yuasa and M. Iwaya-Inoue, 2010. Silicon enhances growth independent of silica deposition in a low-silica rice mutant, lsi1. *Plant Soil,* 331**:** 361-75.

Khenizy, S.A.M. and H.E. Ibrahim, 2015. Effect of silicon and/ or NPK treatments on growth, flowering and corm production in gladiolus. *Egypt J. Hortic.,* 42*:* 839-51.

Kumari, R.V., D.P. Kumar, B. Arunkumar and M. Mahadevamma, 2014. Effect of integrated nutrient management on floral and cormel parameters in gladiolus (*Gladiolus hybridus* Hort.). *Int. J. Agric. Sci.,* 10: 15-22.

Laine, P., C. Haddad, M. Arkoun, J.C. Yvin and P. Etienne, 2019. Silicon promotes agronomic performance in *Brassica napus* cultivated under field conditions with two nitrogen fertilizer inputs. *Plants,* 8: 137.

Lang, D., P. Fei, G. Cao, X. Jia, Y. Li and X. Zhang, 2018. Silicon promotes seedling growth and alters endogenous IAA, GA_3 and ABA concentrations in *Glycyrrhiza uralensis* under 100 mM NaCl stress. *J. Hortic. Sci. Biotechnol*., 94: 1-7.

Page, A.L., R.H. Miller and D.R. Keeney, 1982. *Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties*. 2nd Edition. ASA and SSSA, Madison, Wisconsin

Piper, C.S., 1966. *Soil and Plant Analysis.* Inter Sci Pub Inc, New York.

Shikari, A.B., M. Dikilitas, E. Simsek, M.E. Guldur, U. Simsek, S. Karakas and A.A.H. Abdel Latef, 2022. Sustainable remedies for abiotic stress in cereals. Pp. 675-87. Springer Nature, Singapore.

Taiz, L. and E. Zeiger, 2013. *Fisiologia, Vegetal. Techbooks.* 5th ed. Dados eletrônicos. Porto Alegre: Artmed;. p. 918.

Vaculík, M., T. Landberg, M.Greger, M. Luxová, M. Stoláriková and A. Lux, 2012. Silicon modifies root anatomy, and uptake and subcellular distribution of cadmium in young maize plants. *Ann. Bot*., 110: 433-443.

Yavas, İ. and A. Unay, 2017. The role of silicon under biotic and abiotic stress conditions. *Türkiye Tarımsal Araştırmalar Dergisi,* 4: 204-09.

Yeshe, A., P. Gourkhede and P. Vaidya, 2022. Role and application of silicon in agriculture. *Curr. Res. Soil Fert.*, 66: 55-78.

Received: June, 2024; Revised: July, 2024; Accepted: August, 2024