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Impact of Plant Spacing and Foliar Spraying with Potassium Silicate, Salicylic Acid and Glycine Betaine on Bottle Gourd Tolerance to High Temperature

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Abstract: This experiments were carried out during the two summer seasons of 2022/2023 and 2023/2024 at the Horticulture Research Farm of El- Baramoon, Horticultural Research Institute, Agriculture Research Centre, Dakahlia Governorate, Egypt. The study examined the effects of two plant spacing's (75 and 100 cm) and foliar spraying with potassium silicate, salicylic acid, and glycine betaine, each at 100 and 200 ppm on bottle gourd under high temperature stress. The results showed that the plant spacing 75 cm gave the highest fruit length, number of fruits and total yield, due to increased plant density. While, plant spacing 100 cm gave the highest vine length, number of branches and leaves, fruit diameter and fruit weight. The results indicated that potassium silicate, at 200 ppm, enhanced length and diameter of fruits, total yield, potassium and silicon content, while glycine betaine at 200 ppm improved vine length, number of branches and leaves, nitrogen and phosphorus concentrations. The study showed that sowing bottle gourd seeds at 75 cm spacing with foliar spraying with potassium silicate at 200 ppm maximized the total yield, while spraying with glycine betaine at the same rate improved the vegetative traits and fruit nutritional value. Wider plant spacing 100 cm combined with potassium silicate at 200 ppm maximized seed yield/plant, while salicylic acid at 200 ppm was most effective in improving 100 seed weight. Interaction effects suggest that optimal plant spacing can enhance the efficacy of certain foliar treatments. These findings highlight the potential of integrating optimized plant spacing with specific foliar application to enhance both productivity and nutritional value of bottle gourd under high temperature.

Key words: Bottle gourd, plant spacing, potassium silicate, salicylic acid and glycine betaine.

1. Introduction

Global warming is one of the most dramatic consequences of climate change, with long-term implications for agriculture; particularly vegetable crops. *Cucurbitaceae* are warm-season vegetables that are sensitive to high temperature stress. High temperatures impact various physiological processes in plants, including cell growth, cell division, water loss, cell wall synthesis, stomatal regulation, hormonal interactions, protein amalgamation, biomass reduction, root growth inhibition, and decreased flowering. Furthermore, a diminished photosynthetic rate under high temperature stress correlated with a decrease in plant growth, fruit length, diameter and weight, and overall total yield (**Parvathi *et al.*, 2022; Oyebamiji *et al.*, 2024**). Under heat stress conditions, reactive oxygen species levels increase in plant tissues, causing oxidative stress, reducing enzyme activity, and affecting the function of protein, RNA, and DNA. Another technique for preventing osmotic damage induced by high temperatures is to accumulate several suitable solute molecules such as glycine betaine and salicylic acid (**Yusuf *et al.* 2024).**

Bottle gourd (*Lagenaria siceraria* Mol. Standl.) belongs to the *Cucurbitaceae* family and is a popular vegetable in Asia and Africa. It originated in Africa and is today farmed mostly throughout the tropics and subtropics of the world (**Bisognin, 2022**). Worldwide, bottle gourd is grown for young fruits, which are used as a vegetable while in Egypt; it is grown in Egypt for its seeds, which are used to make salad oil (**Hegazy and El Kinawy, 2011**). Bottle gourd has been utilized medically from ancient times, as well as in pharmaceutical formulations and nutritional supplements (**Atef *et al.*, 2022).** The fruits show high variation in size and shape varied from discoid and flattened form, long club shaped and can be round (**Tiwari, and Ram, 2009**). One hundred grams of fruit may include 2000 mg of protein, 2500 mg of carbohydrates, and 0.7 mg of iron (**Naafe *et al.* 2022**).

It is obvious that density dependent impacts on yield are caused by competition for natural resources between nearby plants. Plant spacing of 50 cm between bottle gourd plants resulted in the best quantity of fruits and production **(Nek, *et al.* 2020)**. The tightest spacing, such as 60 cm, resulted in a greater overall yield than plant spacing of 75 or 100 cm. On bottle gourd, **Mousa *et al.* (2022)** discovered that plant spacing of 45 cm resulted in the maximum yield. **Arora and Mallik (1990)** found that ridge gourd was grown in 2x4 m raised beds with 6, 9, or 12 plants/ bed. The high weight, quantity of fruits, and yields were recorded with a spacing of 9 plants/ bed.

Potassium silicate (K_2SiO_3), salicylic acid (SA), and glycine betaine (GB) are promising substances used to mitigate environmental stresses, especially heat stress, in various plants (**Alotaibi, 2023)**. Silicon (Si) has a major role in reducing abiotic stress such as high temperatures by strengthening the cell walls of hulls, culms, leaves, and roots (**Kumar *et al.*, 2021**). **Shalaby *et al.* (2021)** demonstrated that, under high temperature stress, adding Si boosted cucumber photosynthetic rates, reduced water loss, and increased yields. **Abd-Elaziz *et al.* (2019)** also suggested that spraying squash plants with potassium silicate boosted fruit yield per plant. It also enhances fruit quality by increasing its weight and firmness, spraying plants with potassium silicate increased production and its components as well as fruit quality (**Shehata *et al.*, 2018; Nada and Metwaly, 2020)**. Furthermore, salicylic acid and glycine betaine are solute molecules accumulated under high temperature stress preventing oxidative damage in plants (**Yusuf *et al.*, 2024).**

Salicylic acid (SA) is a naturally occurring plant hormone that is classified as phenolic acid; it’s known to influence biochemical and physiological activities such as nutritional absorption, photosynthetic capability, transport, and membrane permeability during high temperature stress (**Sayed *et al.*, 2023 and Yan *et al.*, 2023**). **Carneiro *et al.* (2019)** demonstrated that SA is an endogenous regulator in plants and plays a major role in many biological and physiological processes under environmental pressure; it adjusts membrane permeability, ion uptake, stomatal conductivity, transport, and growth development, as well as regulating the synthesis and signaling of other hormones such as jasmonic acid, ethylene, and auxin. As a result, it contributes significantly to plant resistance to biotic and abiotic challenges, as well as increased water usage efficiency, flower induction, and growth development (**Venegas-Molina *et al.*, 2020 and Khan *et al.*, 2021**).

Glycine betaine (GB) is an amino acid derivative, which works as a compatible solute and controls the osmotic equilibrium inside cells. It works as a compatible solute that controls intracellular osmotic equilibrium and prevents climate change. GB can be absorbed by the leaves and transported to other organs, improving the plant's resistance to high temperature stress **(Nada, 2020**). It has been demonstrated that the usage of glycine betaine benefits plants by maintaining osmotic equilibrium and stabilizing photosynthetic pigments. According to **Shooshtari *et al.* (2020**), glycine betaine foliar treatments at 250 ppm significantly boosted plant height and total yield when compared to untreated plants. In squash, **El Shoura (2020)** showed that foliar treatment of glycine betaine at 75 ppm improved plant height, leaf number, and total chlorophyll under heat stress conditions.

The current study was undertaken to determine the appropriate plant spacing between plants and foliar treatments increase the productivity of the bottle gourd crop under heat stress conditions.

2. Materials and Methods

2.1. Experimental site and design

Two field experiments were carried out at El-Baramon Research Station (310 25' 16.1" E, 310 03' 07.8" N.), Dakahlia governorate, Horticulture Research Institute, Agriculture Research Center, Egypt, during two growing seasons of 2022/2023 and 2023/2024.

2.2. Soil sampling:

Before beginning the experiments, soil samples were obtained from depths ranging from 0 to 30 cm to determine the soil's basic physicochemical parameters according to the method described by (**Dane and Topp, 2020**). The predominant weather conditions at the meteorological station for the two bottle gourd growing seasons in Dakahlia Governorate are shown in table 1.

The physical and chemical properties of the experimental soil during the two seasons 2022/2023 and 2023 / 2024 are displayed in Table 2.

Table (1). Meteorological recorded of Dakahlia Governorate* during the seasons 2022/2023 and 2023/2024.

Months	2022/2023			2023/2024		
	Maximum Air Temperature [°C]	Minimum air temperature [°C]	Average relative humidity (%)	Maximum Air Temperature [°C]	Minimum air temperature [°C]	Average relative humidity (%)
June	36.91	21.66	49.66	38.13	22.85	51.59
July	38.86	23.17	51.16	40.00	23.96	50.82
August	40.34	24.45	52.93	42.09	25.12	55.43
September	36.48	21.89	56.29	36.90	24.06	56.10
October	32.33	21.18	60.66	32.36	21.35	60.05
November	29.09	17.39	67.80	27.52	17.15	62.77

* Source: Meteorology data from Central Lab. for Agricultural Climate, A. R. C., Egypt.

Table (2). Physical and chemical properties of the experimental soil during the two seasons 2022/2023 and 2023 / 2024.

Season	Particle size distribution (%)			Texture class	Available nutrients, mg kg^{-1}			Organic matter,%	EC dS m-1	pH value
	Sand	Silt	Clay		N	P	K			
1st	27.1	30.88	42.02	**Clay loam**	35.0	7.02	202.20	1.31	0.89	8.05
2nd	25.6	31.2	43.2	**Clay loam**	35.9	7.04	202.50	1.45	0.96	8.09

2.3. Plant material, treatments and cultivation

Seed of local cultivar of bottle gourd (*Lagenaria siceraria*) were sowed manually in morning time at a depth of 2-2.5 cm in the field during the first week of July for both seasons. Bottle gourd seeds were received from the Horticulture Research Institute in Egypt. The experimental design is split-plot system in a randomized complete block design with three replicates. The experiments included 14 treatments, main plots consist of two plant spacing (75 and 100 cm), whereas the sub-plots contained of seven foliar treatments (potassium silicate, salicylic acid and glycine betaine each at 100 and 200 ppm in addition to control. The plot area was 45 m^2 and consisted of three ridges (5 meters long and 3-meter-wide), with 0.75 and 1.00 meter spacing between plants in each row. After germination, the seedlings were thinned to one plant per hill. Bottle gourd plants were treated with bespoke treatments twice during the growth season. The 14 treatments were as follows: potassium silicate (K_2SiO_3) (at 100 and 200 ppm per liter), salicylic acid at (100 and 200 ppm per liter), glycine betaine at (100 and 200 ppm per liter), and control (water only) were applied foliar to all plants three times beginning 20 days after planting and repeated every 15 days interval for both planting seasons. The control plants sprayed with tap water. The components were purchased from the Egyptian commercial sector for practical application in local farming settings. The appropriate agricultural procedures (fertilizers, irrigation, pest and disease management, etc.) for bottle gourd plants for commercial crop production in the region were followed as advised by Egypt's Ministry of Agriculture.

2.4. The recorded data

A random sample of 5 plants from each plot was collected after 3 months from sowing to estimate the studied traits: Vegetative growth traits: vine length (cm), number of branches per plant, number of leaves per plant. Flowering traits: days to first male flower (days), days to first female flower (days), days to maturity (days). Fruit yield traits: fruit length (cm), fruit diameter (cm), number of fruits per plant, average fruit weight (kg) and fruit yield per feddan (ton). Seed traits: At harvest, a random of 5 plants from each plot was collected to estimate seed yield per fruit (g), 100 seed weight (g) and seed yield per plant (g).

2.5. Chemical constituents

The N, P, K, and Si contents of fruits were measured according to the procedures given by **Okalebo *et al.* (2002), Pregl (1945), Murphy and Riely (1962) and APHA (1992).**

2.6. Statistical Analysis

The data acquired were statistically analyzed in accordance with the technique outlined by **Snedecore and Cochran (1982)**, and the treatment averages were compared using the least significant differences at the 0.01% and 0.05% levels of probability (L.S.D) **Gomez and Gomez (1984**). The statistical analysis was carried out using the co-stat software.

3. Results and Discussion

3.1. Vegetative growth

The data in Table 3 illustrate sowing bottle gourd seeds with a plant spacing at 100 cm exhibited slightly longest vine length, more branches and higher leaf number compared with those at 75 cm during the first and second growing seasons, respectively. Wider spacing reduces competition for light, nutrients and water, allowing better vegetative growth and canopy expansion. Similar observations have been reported in cucurbits, where increased spacing enhanced light interception and improved vegetative traits. Similar results were obtained by (**Ding *et al.*, 2022; Mousa *et al.*, 2022 and Huang, 2025**). The same results were reached by (**Hossain *et al.*, 2015**), who determined that optimal plant spacing is required for crop production owing to the plants' efficient use of nutrients, water, and light. Similarly, (**Kumar *et al.*, 2023**) showed that increasing the spacing between plants boosted vegetative growth.

Table (3). Influence of plant spacing and foliar spray with potassium silicate, salicylic acid, glycine betaine on vine length, number of branches and number of leaves of bottle gourd during the seasons of 2022/2023 and 2023/2024

Treatments		Vine length (m)		Number of branches plant $^{-1}$		Number of leaves plant -1	
		1st	2nd	1st	2nd	1st	2nd
Plant spacing							
75 cm		2.40	2.42	9.26	9.42	99.24	99.60
100 cm		3.32	3.53	10.53	9.67	103.95	97.29
LSD 5 %		0.71	0.54	0.71	0.01	1.41	0.12
Foliar spraying							
K_2SiO_3 100ppm		2.97	2.47	9.45	9.45	99.67	100.57
K_2SiO_3 200ppm		3.17	2.81	11.78	9.86	106.36	91.67
SA 100ppm		2.75	2.30	8.59	8.58	82.33	82.00
SA 200ppm		2.77	2.31	8.69	9.19	82.67	91.67
GB 100 ppm		3.30	2.80	11.68	11.76	119.67	119.27
GB 200 ppm		3.41	2.92	11.87	11.87	123.67	123.46
Control		1.65	1.73	9.22	6.16	96.84	64.33
LSD 5 %		1.27	1.25	1.27	1.16	1.10	1.17
Interaction							
75	**K_2SiO_3 100ppm**	2.44	2.45	9.23	9.20	98.33	98.87
	K_2SiO_3 200ppm	2.66	2.60	9.60	9.64	106.40	107.00
	SA 100ppm	2.20	2.23	8.50	8.54	91.67	92.00
	SA 200ppm	2.25	2.30	8.66	9.70	93.00	93.66
	GB 100 ppm	2.79	2.78	11.35	11.39	118.33	117.67
	GB 200 ppm	2.86	2.88	11.40	11.47	120.33	121.00
	Control	1.60	1.68	6.11	6.06	66.67	67.00
100	**K_2SiO_3 100ppm**	3.50	2.49	9.67	9.70	101.00	102.07
	K_2SiO_3 200ppm	3.68	2.69	10.00	10.07	106.33	108.67
	SA 100ppm	3.30	2.36	8.67	8.62	73.00	72.00
	SA 200ppm	3.28	2.31	8.71	8.67	72.33	89.67
	GB 100 ppm	3.81	2.82	12.00	12.13	121.00	120.87
	GB 200 ppm	**3.95**	**2.96**	**12.33**	**12.26**	**127.00**	**125.91**
	Control	1.70	1.78	6.33	6.26	62.67	61.67
LSD 5 %		1.80	1.76	1.80	1.64	1.56	1.65

As shown in Table 3, all studied foliar spraying treatments improved bottle gourd vegetative development in both seasons when compared to untreated plants. Foliar spraying with glycine betaine (at 100 and 200 ppm) achieved the longest vine length, one probable cause for this acceleration of vine length with glycine betaine might be the amount of glycine betaine of nitrogen, proteins, and growth promoting hormones (**Qassem *et al.*, 2022**), highest branching, and maximum leaf number production) for both growing seasons, followed by potassium silicate foliar spraying. GB is a potent osmoprotectant that stabilizes membranes, enzymes, and chloroplast function under varying stress conditions, thus enhancing vegetative vigor (**Basit, 2025**). The increase in bottle gourd plant growth caused by glycine betaine foliar spray might be attributed to increased tissue simplified and flexibility water volume, both of which are connected with all expansion and plant growth (**Küçükyumuk *et al.*, 2024**). Potassium silicate(K_2SiO_3) at 200 ppm, enhanced vine length, branches, and number of leaves, the enhancements in vine length, number of branches and number of leaves traits may be related to the fact that potassium silicate is a high source of soluble potassium and silicon. Its main functions in agricultural production systems are to regulate silicon and give plants trace amounts of potassium. Furthermore, potassium which is the cation found in plants, K plays a crucial part in controlling plant cells' osmotic potential. Additionally, improving photosynthesis, enhancing stress resilience and increased total root length, plant height, and plant roots (**Savvas and Ntatsi, 2022**). Salicylic acid at 100 and 200 ppm, moderately increased vegetative growth compared with the untreated plants, likely due to its role in activating antioxidant systems and improving water relations (**Biareh *et al.*, 2022)**. The results in Table 3 show that spraying plants with all concentrations of glycine betaine followed by spraying potassium silicate resulted in the highest significant magnitudes of vegetative parameters, whereas untreated plants had the lowest magnitudes of growth parameters in both seasons. In contrast, untreated plants exhibited the lowest results for all vegetative development characteristics in this regard.

In terms of the interaction between plant spacing and foliar spraying treatments, there is a substantial difference between the different treatments. Sowing bottle gourd seeds at 100 cm spacing and spraying the plants with glycine betaine increased growth, and boosted its magnitude above the control. The interaction between plant spacing and foliar spraying demonstrated that the combination of 100 cm spacing with glycine betaine at 200 ppm produced the most vigorous vegetative growth. In contrast, the lowest values were reported for 75 cm spacing with no treatment. This highlights a synergistic effect between optimal spacing and osmoprotectant foliar application. Our findings are agreement with those of **Abd-Elaziz *et al.* (2019) and El Shoura (2020)** who observed that foliar spraying with glycine betaine enhanced vine length, number of branches, and number of leaves/plant. Increasing glycine betaine, potassium silicate, and SA concentrations resulted in substantial increases in vegetative growth in both seasons compared to the control group. The current findings match the findings of **Salim *et al.* (2021)**, who reported improved results for squash growth metrics with the exogenous application of silicon based. Moreover, the results indicated the importance of silicate in increasing cell wall rigidity, strength, and elasticity, which might be attributed to potassium's involvement in plant nutrition and boosting assimilate translocation and protein synthesis. These silicon deposition results were consistent over both growth seasons and agreed with those of (**Alotaibi, 2023**).

3.2. Flowering traits

The data in Table 4 illustrate that plants grown at wider spacing (100 cm) recorded earlier flowering and maturity compared to those grown at a closer spacing 75 cm (Table 4). Specifically, the days to first male flower, days to first female flower were reduced by approximately 2 - 3 days under wider spacing, leading to earlier maturity by about 3 - 4 days. This can be attributed to reduced intra-specific competition for light, nutrients, and water, enhancing vegetative growth and accelerating reproductive development. Similar results were reported by **Kumar *et al.* (2023),** who emphasized that optimum plant density enhances photosynthetic efficiency and reproductive transition in bottle gourd.

Among the foliar spraying treatments, potassium silicate (K_2SiO_3) particularly at 200 ppm exhibited the earliest flowering days to first male flower, days to first female flower and the shortest days to maturity (Table 4). This may be attributed to the role of Si in enhancing stress tolerance, plant vigor and hormonal balance, which promote earlier flowering (**Savvas and Ntatsi, 2022**). Si is increasingly recognized as a beneficial element that enhances water status, antioxidant capacity, and phytohormone homeostasis, thereby supporting floral induction and shortening time to maturity. Multiple recent studies in cucurbits reported improved growth and stress tolerance, increased yield components and pronounced earliness due to potassium silicate. Salicylic acid at 100 or 200 ppm exhibited moderate improvement in flowering time compared to the untreated plants (control) but was less effective than (K_2SiO_3). In contrast, glycine betaine 100 or 200 ppm delayed flowering and maturity, indicating its role in osmoprotection under stress, which may delay reproductive stages under the studied conditions. SA is a key signaling molecule that modulates antioxidant systems and stress responses; in cucurbits, it has improved physiological performance and quality, particularly under abiotic stress (high temperature). While SA did not surpass K_2SiO_3 for earliness here, its moderate improvement versus the control is consistent with its role in priming reproductive development through hormonal crosstalk and enhanced photosynthetic stability. It is a classic osmo-protectnt that most strongly benefits plants under high temperature stress; GB can improve vegetative vigor without necessarily accelerating phenology consistent with the delayed days to first male flower, days to first female flower, and days to maturity noticed here (**Chen, 2025)**.

Table (4). Influence of plant spacing and foliar spray with potassium silicate, salicylic acid, glycine betaine on days to first male flower, days to first female flowers and days to maturity traits of bottle gourd during the seasons of 2022/2023 and 2023/2024

Treatments		**Days to first male flower**		**Days to first female flower**		**Days to maturity**	
		1st	**2nd**	**1st**	**2nd**	**1st**	**2nd**
Plant spacing							
75		45.91	46.29	59.33	59.38	68.76	69.52
100		43.85	44.28	56.71	57.14	65.33	67.10
LSD 5 %		0.70	0.61	0.70	0.71	0.70	0.89
Foliar spraying							
K_2SiO_3 100ppm		42.00	42.50	50.00	50.67	57.00	59.50
K_2SiO_3 200ppm		40.67	40.83	48.50	47.83	54.33	57.17
SA 100ppm		45.50	46.17	60.67	61.00	71.50	71.67
SA 200ppm		43.67	44.17	58.00	58.16	68.67	69.84
GB 100 ppm		46.67	46.83	62.67	62.66	71.33	73.17
GB 200 ppm		47.84	48.17	62.33	63.00	70.33	71.67
Control		47.84	48.33	64.00	64.50	76.17	75.34
LSD 5 %		**1.22**	1.26	1.21	**1.04**	1.21	1.12
Interaction							
75	**K_2SiO_3 100ppm**	43.67	44.00	51.33	52.00	60.67	61.67
	K_2SiO_3 200ppm	41.33	42.33	50.33	49.67	57.00	58.67
	SA 100ppm	46.00	46.67	62.33	62.00	72.00	72.67
	SA 200ppm	45.00	45.33	59.00	58.33	70.33	70.67
	GB 100 ppm	47.67	48.33	63.67	64.33	72.33	74.00
	GB 200 ppm	48.67	48.67	63.67	64.00	71.33	72.67
	Control	49.00	49.33	65.00	65.33	77.67	76.67
100	**K_2SiO_3 100ppm**	40.33	41.00	48.67	49.33	53.33	57.33
	K_2SiO_3 200ppm	40.00	39.33	46.67	46.00	51.67	55.67
	SA 100ppm	45.00	45.67	59.00	60.00	71.00	70.67
	SA 200ppm	42.33	43.00	57.00	58.00	67.00	69.00
	GB 100 ppm	45.67	45.67	61.67	61.00	70.33	72.33
	GB 200 ppm	47.00	47.67	61.00	62.00	69.33	71.00
	Control	46.67	47.33	63.00	63.67	74.67	74.00
LSD 5 %		1.72	1.77	1.72	1.47	1.72	1.60

The combination of wider spacing 100 cm with K_2SiO_3 at 200 ppm recorded the most pronounced earliness days to first male flower, days to first female flower and days to maturity, suggesting a synergistic effect between optimal plant spacing and silicon mediated physiological enhancement. Conversely, the untreated plants at closer spacing resulted in the latest flowering and maturity days to first male flower, days to first female flower and days to maturity. These results are congruent with those of **Oyebamiji *et al.* (2024**). Generally, the interaction between plant spacing and foliar spraying was agronomical meaningful: combining spacing 100 cm with K_2SiO_3 at 200 ppm produced the earliest profile across traits (lowest days to first male flower, days to first female flower, and days to maturity), outperforming the same foliar at 75 cm and far surpassing untreated plants at either spacing. This suggests a synergism where reduced crowding enhances silicon's physiological benefits collectively hastening reproductive transition (**Wadas, 2025**).

SA at 100 or 200 ppm remains a viable option where stress buffering is desired, albeit with lesser earliness than K_2SiO_3. GB should be reserved for stress prone settings, where its benefits are more pronounced than under favorable conditions.

3.3. Fruit yield traits

The obtained results in table 5 showed that plant spacing and foliar spray significantly influenced fruit length, fruit diameter, number of fruits per plant, average fruit weight, and total yield per feddan of bottle gourd throughout both growing seasons compared with untreated plants. The results showed that plant spacing had a substantial impact on the number of fruits per plant. 75 cm plant spacing produced the most fruits per plant, followed by 100 cm plant spacing. Total yield increased in low plant spacing, most likely due to environmental factors and the decrease in number of fruit at low population could be attributed to a reduction in the number of plants, which, in turn, reduces the number of fruitful branches (**Hossain *et al.*, 2015**). Similar findings were reported by **Jan *et al.* (2000**) on bottle gourd, who found that the quantity of fruits and overall production rose linearly as plant spacing decreased. This result is similar to those of **Barot *et al.* (2022**), who found that plant spacing affects the amount of fruits per plant in bottle gourd. The high fruit weight was attained at 75 cm, while the low fruit weight was recorded at 100 cm plant spacing. According to the results, increasing plant spacing led to an increase in average fruit weight. The results are comparable to those of **El Shatoury and Mahmoud (2014) and Nek *et al.* (2020)**; they found that greater spacing resulted in the heaviest fruits of bottle gourd. Plants of bottle gourd grown at 75 cm spacing produced significantly higher total yield compared to 100 cm spacing in both seasons. This is attributed to the higher plant density at closer spacing, which compensates for the slight reduction in fruit diameter and number of fruits per plant. The loss in average fruit weight caused by increased plant population was offset by an increase in the number of fruits per plant, resulting in an overall increase in yield. These findings were in harmony with those reported by (**El-Seifi *et al.*, 2015**) on bottle gourd, who found that increasing plant population reduced fruit weight. Similar findings were reported by **El-Mogy *et al.* (2025),** who demonstrated that moderate plant density enhances total yield of cucumber by optimizing light interception and photosynthetic activity.

The same table shows that bottle gourd plants sprayed with all doses of potassium silicate produced considerably values of fruits per plant, average fruit weight, and total yield/feddan features than untreated plants throughout the first and second seasons. Foliar spraying of potassium silicate at 200 ppm recorded the highest values for fruit length, fruit diameter and total yield, followed by K_2SiO_3 at 100 ppm. The foliar spraying with potassium silicate, salicylic acid, and glycine betaine also had a substantial influence on the quantity of fruits per plant, compared to the control group, which had the fewest fruits per vine. Salicylic acid treatments, particularly at 200 ppm, moderately improved fruit characteristics, whereas glycine betaine at both concentrations and the control treatments recorded the lowest values for all parameters. The results revealed that spraying plants with all doses of potassium silicate considerably boosted fruit quality as measured by physical attributes (fruit length and diameter) as compared to fruits from untreated plants. In this regard, potassium silicate at 200 ppm was the most effective therapy for increasing fruit quality, followed by potassium silicate at 100 ppm. Untreated plants had the lowest values for these characteristics. Plants sprayed with greater doses of potassium silicate (100 or 200 ppm) were the most effective treatments for increasing fruit length and diameter, fruit weight, and overall yield/feddan. These results are consistent with those of **Shehata and Abdelgawad (2019) and Naafe *et al.* (2022**) on squash plants. These photo assimilates can be translocated to fruits, which are powerful metabolic drains; leading to increased plant production (**Mohamed and Reda 2024**). Moreover, silicon may increase cell division, increased nutritional and water intake, and the development of a greater quantity of fruits (**Alkharpotly *et al.*, 2019**). The acquired results are consistent with those reported by **Elwan and El-Shatoury (2014) and Doklega (2018**), who reported that applying potassium silicate (K_2SiO_3) improved the greatest bottle gourd

Table (5). Influence of plant spacing and foliar spray with potassium silicate, salicylic acid, glycine betaine on fruit length, fruit diameter, number of fruits per plant, average fruit weight and total yield per feddan traits of bottle gourd during the seasons of 2022/2023 and 2023/2024

Treatments		Fruit length (cm)		Fruit diameter (cm)		Number of fruits plant $^{-1}$		Average fruit weight (kg)		Total yield feddan $^{-1}$ (ton)	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Plant spacing											
75		39.95	40.95	10.33	10.33	4.26	4.34	0.589	0.582	4.88	4.91
100		41.57	42.47	11.33	11.24	4.06	4.09	0.628	0.618	3.69	3.69
LSD 5 %		2.50	0.71	0.70	2.12	0.03	0.04	0.002	0.008	0.04	0.03
Foliar spraying											
K_2SiO_3 100ppm		44.34	45.50	12.67	12.5	4.95	5.03	0.769	0.761	6.22	6.26
K_2SiO_3 200ppm		45.50	46.84	13.83	13.17	5.58	5.65	0.804	0.798	7.36	7.39
SA 100ppm		40.00	41.16	10.50	11.17	3.64	3.68	0.635	0.599	3.60	3.59
SA 200ppm		39.83	40.15	11.83	11.50	4.39	4.46	0.607	0.627	4.55	4.60
GB 100 ppm		39.17	40.16	9.17	10.00	3.71	3.79	0.474	0.465	2.87	2.93
GB 200 ppm		38.84	39.50	9.67	9.34	3.84	3.88	0.507	0.495	3.18	3.14
Control		37.67	38.66	8.17	7.83	2.97	3.01	0.462	0.456	2.23	2.21
LSD 5 %		1.02	1.27	1.27	0.90	0.08	0.06	0.010	0.008	0.10	0.08
Interaction											
75	**K_2SiO_3 100ppm**	44.00	46.00	12.33	11.33	5.05	5.15	0.758	0.750	7.14	7.20
	K_2SiO_3 200ppm	45.33	46.67	13.33	12.33	5.79	5.89	0.794	0.787	8.58	8.64
	SA 100ppm	39.00	40.33	10.00	10.67	3.68	3.74	0.585	0.578	4.01	4.03
	SA 200ppm	38.33	39.00	11.33	11.67	4.50	4.57	0.615	0.607	5.16	5.17
	GB 100 ppm	37.67	38.33	8.67	9.33	3.80	3.94	0.458	0.452	3.25	3.32
	GB 200 ppm	38.67	38.00	9.00	9.67	3.94	4.00	0.496	0.485	3.64	3.62
	Control	36.33	38.33	7.67	7.33	3.03	3.06	0.420	0.414	2.39	2.36
100	**K_2SiO_3 100ppm**	44.67	45.00	13.00	13.67	4.85	4.92	0.780	0.771	5.29	5.31
	K_2SiO_3 200ppm	45.67	47.00	14.33	14.00	5.38	5.42	0.814	0.808	6.13	6.12
	SA 100ppm	40.67	42.00	11.00	11.67	3.61	3.62	0.630	0.620	3.18	3.14
	SA 200ppm	41.33	41.30	12.33	11.33	4.29	4.34	0.657	0.647	3.95	4.02
	GB 100 ppm	40.67	42.00	9.67	10.67	3.62	3.63	0.490	0.479	2.48	2.53
	GB 200 ppm	39.00	41.00	10.33	9.00	3.74	3.75	0.518	0.504	2.71	2.65
	Control	39.00	39.00	8.67	8.33	2.92	2.95	0.505	0.497	2.06	2.06
LSD 5 %		1.44	1.80	1.80	1.27	0.11	0.09	0.010	0.011	0.14	0.12

yield per feddan compared to untreated plants. Moreover, the beneficial impact of K_2SiO_3 on crop plants appears to result from cell wall strengthening caused by silicon deposition in the form of amorphous silica (**Epstein, 2001**). Also, foliar spraying cucumber plants with potassium silicate improved output, which was proportional to the quantity of fruits per plant. The data on average fruit weight revealed that plant spacing and foliar spray with potassium silicate, salicylic acid, and glycine betaine had a substantial influence on fruit weight. Potassium silicate has a good impact on growth and yield; enhanced yield might be ascribed to enhanced photosynthetic activity of the plant, water metabolism, chlorophyll content, carbohydrate synthesis, membrane lipid peroxidation, nutrient absorption and protective enzymes under high temperature conditions. Similar findings were noticed by (**Al-Ahmad and Al-Jubouri, 2022**) on squash. Potassium silicate is a source of highly soluble potassium and silicon, so it is used in agricultural production systems primarily as a silicon amendment source, with the added benefit of providing small amounts of potassium to improve yield quality. These results agree with **Zhang *et al.* (2022**), who indicated that silicon application enhances cell wall rigidity, water-use efficiency, and stress tolerance, leading to improved fruit quality. These findings are agreement with those reported by (**Sapt *et al.*, 2019**), who found that foliar treatment of either SA at 200 ppm or potassium silicate at 100 ppm resulted in a considerable increase in fruit length and diameter relative to untreated plants. Foliar potassium silicate treatment considerably increased the synthesis of enzymatic and non-enzymatic anti-oxidants. It has been widely reported that Si supply reduces oxidative damage by increasing the antioxidant enzyme (SOD, APX, CAT, and POD) activities under heat stress (**Salim *et al.*, 2021**). The superiority of potassium silicate treatments can be attributed to their role in enhancing photosynthetic activity, strengthening plant tissues, and reducing abiotic stress, while salicylic acid improved fruit quality parameters through its role in regulating plant defense mechanisms and hormonal balance (**Hasanuzzaman *et al.*, 2023**). On the other hand, glycine betaine, though known for its osmoprotective effect, showed limited improvement under the current experimental conditions.

In the current study, the increase in bottle gourd fruit production seen after foliar spraying with K_2SiO_3 and SA, as well as their combination with plant spacing, might be attributed to the previously reported improvement in vegetative development characteristics. It is also clear from the data that the fruit weight trait, the obtained results exhibited that plants sprayed with 200 ppm potassium silicate in combination with plant spacing 100 cm resulted in the highest mean magnitudes during the first and second seasons. The interaction between plant spacing (75 cm) and K_2SiO_3 at 200 ppm resulted in the highest total yield followed by plants treated with 100 ppm potassium silicate in combination with plant spacing 75 cm, indicating a synergistic effect between adequate plant density and silicon supplementation. This is consistent with previous studies of **Kumar *et al.* (2023**) that emphasized the combined role of optimal spacing and biostimulant foliar sprays in improving nutrient assimilation and reproductive efficiency in bottle gourd. These results were consistent with those obtained by **El-Sayed *et al.* (2022) and Gad *et al.* (2023).**

3.4. Fruits nutrient content

Table 6 shows plants grown at a wider spacing of 100 cm recorded slightly higher nitrogen and phosphorus contents compared to 75 cm spacing. This could be attributed to reduced inter-plant competition for nutrients under wider spacing, allowing better root expansion and nutrient uptake. These results are in agreement with **El-Mogy *et al.* (2025**), who reported enhanced nutrient partitioning in cucumber under moderate to wide spacing conditions.

Table 6 shows that foliar spraying of glycine betaine improved nitrogen content in both seasons compared to the other evaluated combination treatments. **Nada and Metwaly (2020)** showed similar findings on squash. Data given in the same table reveal that foliar spraying with glycine betaine resulted in the greatest phosphorus content values in both seasons when compared to the other tested treatments. Potassium silicate, particularly at 200 ppm, increased K and Si contents compared to untreated plants, reflecting the direct role of silicate in enhancing potassium and silicon accumulation within plant tissues. Salicylic acid at 200 ppm enhanced N and P concentrations, likely due to its involvement in nutrient mobilization and enzymatic activation. Glycine betaine at higher concentrations (200 ppm) resulted in the highest N and P levels, which may be attributed to its role as an osmoprotectant that enhances nutrient uptake under varying environmental conditions (**Hasanuzzaman *et al.*, 2023**). **Chaudhary *et al.* (2019**) on bottle gourd, who found considerably higher silicon in fruits of plants treated with silicon than fruits obtained from untreated plants. The increase in silicon content following potassium silicate treatments may contribute to improved structural integrity, stress tolerance, and fruit quality. Enhanced N and P fruits under GB treatments indicate its potential in improving metabolic activity and fruit nutritional value. Similar trends have been documented in other cucurbit species under biostimulant application (**Jalali *et al.*, 2022**).

Table (6). Percentages of bottle gourd fruits nutrient contents as affected by plant spacing and foliar spray with potassium silicate, salicylic acid, glycine betaine during the seasons of 2022/2023 and 2023/2024

Treatments		N %		P %		K %		Si %	
		1st	2nd	1st	2nd	1st	2nd	1st	2nd
Plant spacing									
75		1.78	1.79	0.27	0.26	3.04	3.02	0.67	0.66
100		1.86	1.87	0.29	0.28	3.08	3.05	0.70	0.70
LSD 5 %		0.17	0.02	0.02	0.01	0.04	0.03	0.07	0.12
Foliar spraying									
K_2SiO_3 100ppm		1.60	1.63	0.24	0.23	3.20	3.18	0.92	0.93
K_2SiO_3 200ppm		1.66	1.66	0.26	0.25	3.24	3.20	0.97	0.97
SA 100ppm		1.85	1.86	0.28	0.27	2.91	2.89	0.68	0.70
SA 200ppm		1.88	1.89	0.31	0.34	2.96	2.93	0.65	0.64
GB 100 ppm		2.14	2.08	0.32	0.31	3.14	3.12	0.53	0.52
GB 200 ppm		2.23	2.17	0.35	0.34	3.17	3.13	0.54	0.50
Control		1.53	1.54	0.23	0.21	2.72	2.69	0.51	0.49
LSD 5 %		0.18	0.02	0.01	0.01	0.03	0.02	0.11	0.09
Interaction									
75	**K_2SiO_3 100ppm**	1.57	1.58	0.22	0.21	3.18	3.16	0.90	0.89
	K_2SiO_3 200ppm	1.63	1.63	0.25	0.24	3.22	3.19	0.93	0.92
	SA 100ppm	1.80	1.81	0.26	0.25	2.89	2.88	0.66	0.67
	SA 200ppm	1.82	1.84	0.30	0.29	2.95	2.92	0.65	0.62
	GB 100 ppm	2.02	2.03	0.31	0.30	3.13	3.11	0.52	0.53
	GB 200 ppm	2.11	2.13	0.34	0.33	3.15	3.12	0.55	0.51
	Control	1.51	1.54	0.19	0.20	2.80	2.78	0.50	0.48
100	**K_2SiO_3 100ppm**	1.65	1.67	0.25	0.24	3.22	3.19	0.95	0.97
	K_2SiO_3 200ppm	1.68	1.69	0.28	0.26	3.25	3.22	1.00	1.02
	SA 100ppm	1.90	1.91	0.29	0.28	2.93	2.91	0.70	0.72
	SA 200ppm	1.93	1.94	0.32	0.30	2.98	2.94	0.66	0.67
	GB 100 ppm	2.10	2.12	0.33	0.32	3.15	3.13	0.55	0.51
	GB 200 ppm	2.18	2.20	0.36	0.35	3.18	3.15	0.52	0.50
	Control	1.59	1.57	0.20	0.19	2.85	2.81	0.52	0.50
LSD 5 %		0.25	0.03	0.02	0.01	0.03	0.02	0.16	0.13

The interaction between plant spacing at 100 cm and foliar spraying with K_2SiO_3 at 200 ppm showed the highest Si content, while GB at 200 ppm treatments tended to enhance N and P contents irrespective of plant spacing. The results are accord with those of (**Hu *et al.*, 2022**). This suggests that combining wider spacing with silicon supplementation may optimize Si accumulation, while glycine betaine is more effective in enhancing N metabolism under both spacing (**Kumar *et al.*, 2023**).

3.5. Seed traits

The results in Table 7 showed that, wider spacing (100 cm) generally resulted in slightly higher seed weight per fruit, 100 seed weight, and seed yield per plant compared with narrow spacing (75 cm). This trend can be attributed to reduced intra plant competition for nutrients, water and light allowing plants to develop larger canopies and allocate more assimilates to seed filling. Similar findings have been reported in cucurbits, where wider spacing improved seed size and overall yield due to enhanced photosynthetic efficiency (**Tartoura *et al.*, 2013**).

Table (7). Influence of plant spacing and foliar spray with potassium silicate, salicylic acid, glycine betaine on seed weight per fruit, 100 seed weight and seed yield per plant traits of bottle gourd during the seasons of 2022/2023 and 2023/2024

Treatments		Seed weight fruit $^{-1}$ (g)		100 seed weight (g)		Seed yield plant $^{-1}$ (g)	
		1st	2nd	1st	2nd	1st	2nd
Plant spacing							
75 cm		99.14	101.26	16.31	16.49	422.98	446.51
100 cm		103.47	105.29	17.70	17.92	428.74	449.03
LSD 5 %		3.26	2.78	0.05	0.07	2.08	1.75
Foliar spraying							
K_2SiO_3 100ppm		102.66	107.45	16.26	16.54	507.72	540.66
K_2SiO_3 200ppm		108.17	111.50	17.10	17.21	603.20	629.24
SA 100ppm		123.83	126.83	20.33	20.64	451.27	466.52
SA 200ppm		132.33	132.00	22.42	22.58	581.44	587.95
GB 100 ppm		79.16	80.84	14.39	14.57	293.81	305.98
GB 200 ppm		79.16	95.34	15.43	15.55	354.50	369.38
Control		70.67	69.00	13.11	13.33	210.13	220.69
LSD 5 %		1.16	1.03	0.06	0.12	1.27	1.37
Interaction							
75	**K_2SiO_3 100ppm**	98.00	102.33	15.26	15.45	494.90	526.99
	K_2SiO_3 200ppm	103.67	106.00	16.08	16.16	600.24	624.34
	SA 100ppm	121.00	123.33	20.08	20.47	445.28	461.25
	SA 200ppm	130.67	131.00	21.07	21.36	588.01	598.67
	GB 100 ppm	80.33	81.00	13.87	13.96	305.25	319.14
	GB 200 ppm	91.67	95.00	14.84	14.95	361.17	380.00
	Control	68.67	70.33	12.97	13.06	208.07	215.20
100	**K_2SiO_3 100ppm**	107.33	112.67	17.26	17.63	520.55	554.33
	K_2SiO_3 200ppm	112.67	117.00	18.11	18.25	606.16	634.14
	SA 100ppm	126.67	130.33	20.57	20.80	457.27	471.79
	SA 200ppm	134.00	133.00	23.75	23.79	574.86	577.22
	GB 100 ppm	78.00	80.67	14.92	15.18	282.36	292.83
	GB 200 ppm	93.00	95.67	16.03	16.15	347.82	358.76
	Control	72.67	76.67	13.25	13.60	212.19	226.17
LSD 5 %		1.64	1.45	0.14	0.19	1.85	1.80

Among the foliar treatments, potassium silicate at 200 ppm recorded the highest seed yield per plant in both seasons followed by potassium silicate at 100 ppm. This improvement is likely due to the combined role of potassium and silicon in enhancing cell wall strength, improving nutrient translocation, and mitigating abiotic stresses (**Mostafa *et al.*, 2021**). Salicylic acid at 200 ppm, resulted in the greatest 100 seed weight, suggesting its major role in promoting seed filling and hormonal regulation during reproductive development (**Agriculture, 2023**). Glycine betaine at 100 and 200 ppm exhibited relatively minor improvements in seed characters compared with the untreated plants and other treatments, which may be due to the absence of pronounced environmental stress during the experimental seasons. GB is well documented as an osmoprotectant with higher efficiency under drought or heat stress (**Azab *et al.*, 2022; Chen, 2025 and Salama *et al.*, 2025).**

The interaction between plant spacing and foliar sprays is an important factor that can modulate the response of seed traits. The result trends indicate that wider spacing (100 cm) tended to enhance the positive effects of potassium silicate and SA more than narrow spacing. Potassium silicate at 200 ppm produced its highest seed yield /plant under wider spacing, likely due to increased light interception and more efficient foliar spray deposition per plant. Also, SA at 200 ppm exhibited consistent improvement in 100 seed weight across both spacing's, indicating that its effect is relatively independent of plant density. GB exhibited no clear interactive benefit, reinforcing that its effectiveness may be context dependent, primarily under stress conditions. These findings align with recent reports suggesting that the efficiency of foliar sprays is often influenced by canopy density and microclimate conditions (**Khan *et al.*, 2021**). A wider spacing reduces canopy overlap, nutrient absorption, and photosynthate allocation, thereby amplifying the benefits of growth promoting sprays such as SA and potassium silicate.

4. Conclusion

Based on the results of this study, it is recommended to adopt plant spacing of 75 cm with foliar spraying with potassium silicate at 200 ppm in combination to maximize the total yield of bottle gourd, as this treatment demonstrated the highest productivity across both seasons. For growers aiming to enhance the nutritional composition of the fruits, particularly nitrogen and phosphorus contents, the use of glycine betaine at 200 ppm under a wider spacing of 100 cm is suggested, especially in moderately fertile soils. Wider plant spacing 100 cm combined with Potassium silicate at 200 ppm maximized seed yield per plant, while Salicylic acid at 200 ppm was most effective in improving 100-seed weight. Interaction effects suggest that optimal plant spacing can enhance the efficacy of certain foliar treatments.

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