Effect of foliar nano-minerals (zinc sulfate) and ground biofertilizers (rhizobacteria) on vegetative growth and flowers yied in *Matthiola incana* L.

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Abstract

This study was conducted during the 2025–2026 growing season in a greenhouse covered with 75% shade at the University of Kufa nursery to investigate the effect of foliar application of nano zinc sulfate and soil inoculation with plant growth-promoting rhizobacteria (PGPR) on the vegetative growth and flowering characteristics of stock (*Matthiola incana* L.) cv. Cinderella Purple. The experiment was arranged as a factorial experiment RCBD with three replicates. Four concentrations of nano zinc sulfate (0, 3, 6, and 9 mg L^{-1}) were combined with four bacterial treatments including an uninoculated control, *Bacillus subtilis*, *Pseudomonas fluorescens*, and *Azotobacter chroococcum*. The results demonstrated significant improvements in both vegetative growth and flowering traits due to the application of nano-fertilizers and beneficial bacteria. Foliar spraying with 9 mg L^{-1} nano zinc sulfate increased plant height to 27.67 cm compared with 24.58 cm in the control treatment. The same concentration also enhanced leaf area to 30.32 cm^2 compared with 25.52 cm^2 in untreated plants. Inoculation with *P. fluorescens* produced the highest plant height (27.50 cm), whereas the greatest number of leaves (33.00 leaves $plant^{-1}$) was also obtained with the same bacterial treatment. Flowering was significantly accelerated by nano-fertilization, reducing the number of days to flowering from 125.42 days in the control treatment to 120.96 days at 9 mg L^{-1}. Furthermore, the number of florets increased from 54.50 florets $plant^{-1}$ in the control to 75.75 florets $plant^{-1}$ at the highest nano-fertilizer concentration. Inflorescence length was similarly improved, reaching 12.14 cm compared with 10.61 cm in untreated plants, while flowering duration increased from 8.08 to 9.98 days. The interaction between nano zinc sulfate and PGPR inoculation produced the most favorable responses. The combination of 9 mg L^{-1} nano-fertilizer and *P. fluorescens* achieved the highest plant height (30.67 cm) and inflorescence length (13.89 cm), whereas 9 mg L^{-1} combined with *A. chroococcum* produced the highest number of florets (84.00 florets $plant^{-1}$). These findings indicate that integrating nano-fertilization with beneficial rhizobacteria can effectively enhance vegetative growth, flowering performance, and ornamental quality of stock plants, providing a sustainable approach for improving commercial cut-flower production.

Keywords: cut flowers, PGPR bacteria, foliar fertilization, sulfur, xanthophyll, zinc sulfate

Introduction

The genus *Matthiola* comprises numerous species in Europe, particularly in Sicily and

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the Mediterranean, including widespread endemic and highly endemic species (17, 11). Notable species include *Matthiola incana*, *M. fructicolaza*, *M. tricospidata*, and *M. sennoata* (17, 26). *Matthiola* species exhibit considerable morphological diversity in leaves, flowers, fruits, and seeds. Their flowers are typically fragrant, ranging in color from white to pink to purple, and are arranged in terminal clusters (1).

Matthiola species are characterized by their high morphological diversity in leaves, flowers, fruits, and seeds. Mattheula species are characterized by their richness in bioactive compounds, including phenols, volatile substances, and essential oils, with antioxidant activity and low toxicity (26). These properties make them promising for food, pharmaceutical, and cosmetic applications (5, 25). Mattheula incana is a globally popular ornamental plant, prized for its bright, fragrant flowers and its adaptability to cold seasons. Optimal cultivation practices have been developed for this plant to produce cut flowers (2). *M. incana* is a herbaceous plant that can be annual, biennial, or perennial, depending on the subspecies and growing conditions. It typically reaches a medium height and spread, producing flowers in shades of purple, lavender, and white. These flowers are particularly popular for cut flower production due to their fragrance and longevity (16). The plant exhibits moderate drought tolerance and is suitable for large-scale cultivation. Recommended planting times vary depending on the USDA hardiness zone. This plant is available from nurseries, and varieties are adapted to different climates, including those suitable for Florida (20).

Recent studies indicate the effectiveness of nano-fertilizers in improving photosynthesis, reducing the use of chemical fertilizers due to their high efficiency, and minimizing soil and water damage caused by chemical fertilizers. Furthermore, nano-fertilizers contribute to increased plant resistance to diseases and harsh environmental conditions, strengthening plant immunity and helping plants withstand extreme environmental conditions such as drought and heat. Consequently, nano-fertilizers contribute to improving the quality and market value of cut flowers, particularly by enhancing their growth and extending their flowering period (4).

Biofertilizers can also be used to improve soil fertility and stimulate plant life processes, especially plant growth-promoting bacteria (PGPR) that colonize plant roots and directly improve plant growth and yield by enhancing root development and thus improving water and nutrient absorption (16). They also produce plant hormones that stimulate plant growth, or indirectly by altering the biotic balance in the root zone through stimulating beneficial soil microbes, or by suppressing bacterial, fungal, nematode, and viral diseases present in the soil. Their use has become a common practice in many parts of the world (25). Therefore, this study was conducted to evaluate the effect of spraying with zinc sulfate and nano-sulfur and injecting biofertilizers on the growth and flowering of broadleaf plants, with the aim of identifying the optimal treatments that contribute to improving production quality and increasing productivity.

Materials and Methods

Experimental general procedure

The experiment was conducted during the 2025–2026 growing season in a greenhouse with 75% shade at the University of Kufa nursery. The aim was to study the effect of

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spraying with nano-fertilizer containing zinc sulfate, and soil injection of plant growth-stimulating bacteria (PGPR), on the vegetative and flowering characteristics of the winter annual stock (*Matthiola incana* L.). Seeds of the stock variety Cinderella Purple, produced by the Japanese company TAKII SEED, were sown on October 7, 2025, in 55 x 28 cm plastic trays containing peat moss. After germination and the emergence of true leaves, uniform seedlings were selected and transplanted on November 4, 2025, into 19 cm diameter plastic pots containing a growing media consisting of a peat moss and sandy loam (1:3). All necessary agricultural practices were carried out according to plant requirements and suitable environmental conditions. A layer of polyethylene was used under the pots to prevent weeds and salinity effects. Potting soil was subjected to analysis of the physical and chemical properties (Table 1).

The experimental units were distributed in a two factorial experiment based on randomized complete block design (RCBD) of 240 plants divide on 16 treatments three replications each. The first factor is Nano-zinc sulfate (0, 3, 6, and 9 mg L^{-1}), while the second factor is biofertilizer included the control, soil injection with *Bacillus subtilis*, *Pseudomonas fluorescens*, or *Azotobacter chroococcum*.

Table 1. Some of the physical and chemical properties of the potting soil used in this study

Value	Unites	Properties
6.8	---	H
4.20	ds m^{-1}	EC
	%	Organic maters
14.5	mg Kg^{-1}	N
12.9	mg Kg^{-1}	P
13.5	mg Kg^{-1}	K
10.9	%	$CaCO_3$
2.5	%	Organic matter
Soil texture		
22	%	Clay
6	%	Silt
70	%	Sand
Sandy	Soil texture	

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Preparation of Bacteria Inoculation

Bacterial strains (*Bacillus subtilis*, *Pseudomonas fluorescens*, and *Azotobacter chroococcum*) were obtained from Al-Amin Laboratory and cultured in suitable nutrient media at 28°C for 72 hours. On November 19, 2025, bacterial suspensions were prepared by adding 10 ml of sterile distilled water to the culture plates. The suspensions were left to stand for 15 minutes and then collected using sterile pipettes into Falcon tubes. The bacterial density was estimated by measuring the turbidity of the solution using a spectrophotometer at a wavelength of 600 nm. The amount of bacteria added to the culture medium was then calculated to obtain a final optical density of 0.07, which is approximately equivalent to 10^8 CFU ml^{-1} of the culture medium. The plants were then injected with the required amount of bacterial suspension.

Zinc sulfate nano-solution

Conversion of Micro- Zinc sulfate Sulfate to Nanoparticle Size

Micro-Zinc sulfate fertilizer powder was supplied by Al-Reef Al-Khadra Company (Iraq/Baghdad). The micro-sized zinc sulfate powder was converted to nanoparticle size using a planetary ball mill (MSK-SFM-1, MTI Corporation, USA). The pure powder was mechanically mixed in a dry ball mill for approximately 20 hours at a speed of 500 rpm. During mixing, the weight of the stainless-steel balls exceeded the weight of the powder by a factor of ten. The nanoscale size of the powder was confirmed by electron microscopy (SEM) imaging at 120,000 times fixed (7), with zinc sulfate particles ranging in size from 25-30 nm (Figure 1).

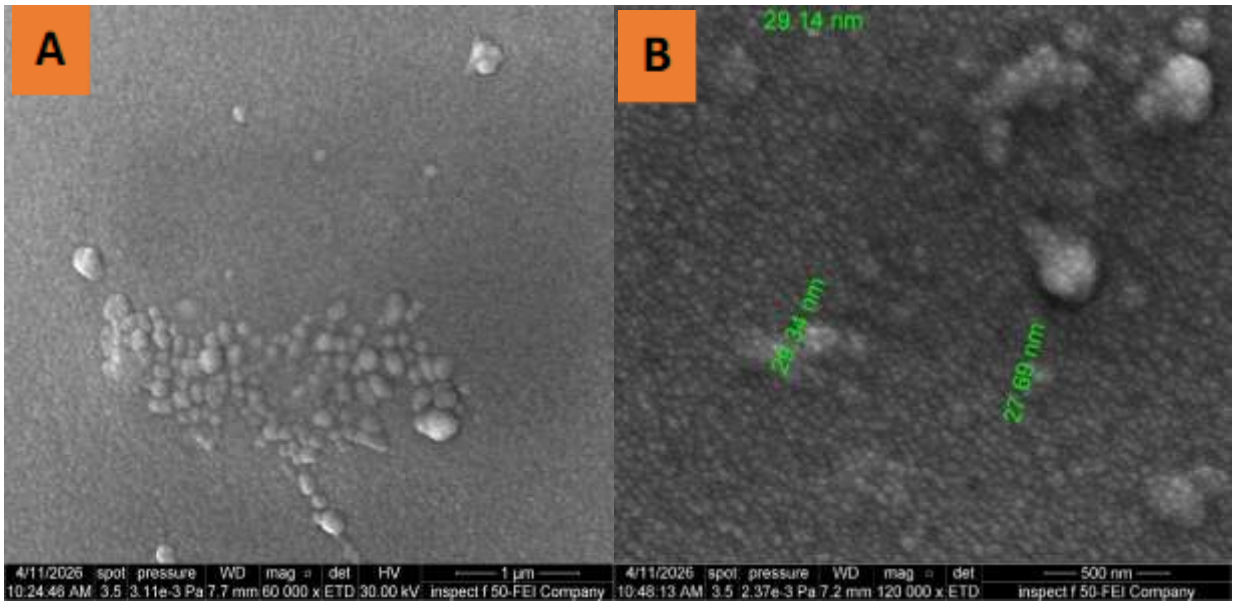


Figure1. The scanning electron microscope SEM images illustrating zinc sulfate, (A) particles at 60000X and (B) particles at 120000X magnification.

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The plants were sprayed with a combination of zinc sulfate nano-fertilizers at concentrations of 0, 3, 6, and 9 mg L^{-1} using a hand sprayer. Three sprays were applied at three-week intervals, on December 2, 2025, December 22, 2025, and January 12, 2026. The foliar spray was carried out in the early morning, immediately after irrigation. A surfactant was added to increase the efficiency of the spray solution. The control plants were sprayed with distilled water until fully moisten, and treatments were separated with polythene barriers during spraying to prevent overlap interference.

Study Indicators

The study indicators included some of the vegetative growth indicators and flowering traits. Plant height (cm) was measured using a measuring tape from the soil surface of the pots to the highest point of the flower buds for five plants of each experimental unit. The total number of leaves (leaf $plant^{-1}$) for each experimental unit was also calculated. Leaf area (cm^2) was estimated among the experimental treatments, and the digital image was analyzed using ImageJ software. Leaf images were imported into ImageJ, and the image scales were converted to square centimeters using a calibration scale (15). floral growth indicators such as flowering time (number of days from sowing to flower bud coloration), number of florets per plant, inflorescence length and duration of flowering.

Data analysis

Data were collected on October 1, 2025 at the end of the experiment and were statistically analyzed as ANOVA tables were performed using the GenStat 12.1 VSN International statistical software (21). Differences between means were compared using the least significant difference (LSD) test at a probability level of 0.05 (10).

Results and Discussion

The results presented in table (2) showed that foliar application of the nano-zinc sulfate mixture significantly increased plant height of stock (*Matthiola incana* L.) compared with the control treatment sprayed with distilled water. Plants treated with 3, 6, and 9 mg L^{-1} recorded mean plant heights of 25.833, 26.667, and 27.667 cm, respectively, whereas the control treatment produced a mean height of 24.583cm. A significant enhancement in plant height was also observed following inoculation of the growing medium with plant growth-promoting bacteria. The bacterial treatments recorded mean values of 26.000, 27.083, and 27.500cm, compared with 24.167 cm in the uninoculated control treatment. The interaction between the nano-zinc sulfate and bacterial inoculation further improved plant height. Foliar application at 9 mg L^{-1}, either in the presence or absence of bacterial inoculation, produced significant increases in plant height, with interaction means reaching 25.000, 26.667, 28.333, and 30.667 cm. The highest plant height (30.667cm) was achieved when plants were sprayed with the nano mixture at 9 mg L^{-1} and inoculated with Pseudomonas fluorescens, significantly surpassing the control treatment, which recorded the lowest value of 23.667cm.

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Table 2. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on plant height in *Matthiola incana*

Nano-zinc sulfate-sulfur mixture (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
24.167	25	24	24	23.667	Control
26	26.667	26.333	25	26	*Azotobacter chroococcum*
27.083	28.333	28.333	27.333	24.333	*Bacillus subtilis*
27.5	30.667	28	27	24.333	*Pseudomonas fluorescens*
	27.667	26.667	25.833	24.583	Average
Interaction= 2.5766		Bactria or Nano mix= 1.2883			LSD 0.05

The results also indicated that foliar application of the nano-zinc sulfate mixture had a positive effect on increasing the number of leaf $plant^{-1}$ compared with the control treatment (Table 3). Plants sprayed with 3, 6, and 9 mg L^{-1} recorded averages of 31.833, 31.000, and 30.250 leaves $plant^{-1}$, respectively, whereas the control treatment produced only 26.833 leaves $plant^{-1}$. Similarly, inoculation of the growing medium with plant growth-promoting bacteria significantly enhanced leaf production. The bacterial treatments recorded mean values of 28.333, 30.917, and 33.000 leaf $plant^{-1}$, compared with 27.667 leaf $plant^{-1}$ in the uninoculated control treatment. The interaction between the nano-zinc sulfate and bacterial inoculation further improved this characteristic. The combination of foliar application at 9 mg L^{-1} and inoculation with *Pseudomonas fluorescens* resulted in the highest number of leaves, reaching 38.00 leaves $plant^{-1}$, significantly exceeding the control treatment, which recorded the lowest value of 25.33 leaf $plant^{-1}$.

Table 3. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on number of leaves (leaf $plant^{-1}$) in *Matthiola incana*

Nano-zinc sulfate (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
27.667	29.333	27.667	28.333	25.333	Control
28.333	26	30.667	29	27.667	*Azotobacter chroococcum*
30.917	27.667	32	35.333	28.667	*Bacillus subtilis*
33	38	33.667	34.667	25.667	*Pseudomonas fluorescens*
	30.25	31	31.833	26.833	Average

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Interaction= 4.3585	Bactria or Nano mix= 2.1793	LSD 0.05

Findings revealed that foliar application of the nano-zinc sulfate significantly increased leaf area compared to untreated control treatment (Table 4). Plants treated with 3, 6, and 9 mg L^{-1} recorded leaf area values of 28.557, 30.519, and 30.323 cm^2, respectively, whereas the control treatment recorded the lowest value of 25.522 cm^2. A significant increase in leaf area was also observed following inoculation with plant growth-promoting bacteria. Mean leaf area values reached 29.488, 29.378, and 29.945 cm^2 for the bacterial treatments, compared with 26.110 cm^2 in the uninoculated control treatment. The interaction between foliar application of the nano-zinc sulfate and bacterial inoculation further enhanced leaf area development. The combination of 6 mg L^{-1} nano solution and *P. fluorescens* inoculation produced the highest leaf area value (33.077 cm^2), significantly surpassing the control treatment, which recorded 25.333 cm^2. These results suggest that the combined application of nano-nutrients and beneficial bacteria provided more favorable conditions for leaf expansion and vegetative growth.

Table 4. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on leaf area (cm^3) in *Matthiola incana*

Nano-zinc sulfate (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
26.11	27.64	26.82	24.763	24.763	Control
29.488	31.893	30.39	29.37	26.3	*Azotobacter chroococcum*
29.378	30.97	31.79	30.203	24.763	*Bacillus subtilis*
29.945	30.787	33.077	29.44	26.477	*Pseudomonas fluorescens*
	30.323	30.519	28.557	25.522	Average
Interaction= 1.6813		Bactria or Nano mix= 0.8406			LSD 0.05

Regarding the treatments effect on flowering traits, the results show that foliar spraying with nano-zinc sulfate led to earlier flowering compared to the control treatment (Table 5). The number of days required for the first flowering bud decreased at concentrations of 3, 6, and 9 mg L^{-1} to 123.59, 122.37, and 120.96 days, respectively, compared to 125.42 days for plants sprayed with distilled water. Growth-promoting bacteria also significantly reduced the flowering period. Treatments with *B. subtilis*, *P. fluorescens*, and *A. chroococcum* recorded averages of 122.97, 120.26, and 121.12 days, respectively, compared to 127.98 days in the control treatment. The interaction between the two factors showed that the concentration of 9 mg L^{-1}, especially when combined with *B. subtilis* bacteria, was superior in reducing

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the number of days required for flowering, reflecting the efficiency of this bacterium in activating the physiological processes associated with early flowering (Table 5).

Table 5. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on number of days to flowering in *Matthiola incana*

Nano-zinc sulfate (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
127.98	125.67	127.2	128.77	130.3	Control
122.97	120.97	122.3	123.3	125.3	*Azotobacter chroococcum*
120.26	118.1	119.1	120.87	122.97	*Bacillus subtilis*
121.12	119.1	120.87	121.43	123.1	*Pseudomonas fluorescens*
	120.96	122.37	123.59	125.42	Average
Interaction= 0.9219		Bactria or Nano mix= 0.4609			LSD 0.05

Number of florets (floret/plant^{-1})

Table 6 shows that spraying with nano-zinc sulfate significantly increased the number of florets compared to untreated plants. The average number gradually increased at concentrations of 3, 6, and 9 mg/L^{-1}, reaching 57.083, 62.667, and 75.75 florets/plant^{-1}, respectively, compared to 54.5 florets/plant^{-1} in the control treatment. Inoculation with growth-promoting bacteria also significantly increased the number of florets. Treatments with *B. subtilis*, *P. fluorescens*, and *A. chroococcum* resulted in averages of 69.833, 66.833, and 68.083 florets plant^{-1}, respectively, compared to 45.25 florets plant^{-1} for uninoculated plants. The interaction between the two factors further enhanced this increase, particularly at a concentration of 9 mg L^{-1} with A. chroococcum bacteria, which achieved the highest average number of florets. These results indicate that nano-treatment and bacterial inoculation provided more favorable conditions for supporting flower growth and increasing the efficiency of flower formation in the plant.

Table 6. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on the number of flowers (flower plant^{-1}) in *Matthiola incana*

Nano-zinc sulfate (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
45.25	56	44.333	42	38.667	Control
69.833	84	70.333	63.667	61.333	*Azotobacter chroococcum*
66.833	81	67.333	60.667	58.333	*Bacillus subtilis*

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68.083	82	68.667	62	59.667	*Pseudomonas fluorescens*
	75.75	62.667	57.083	54.5	Average
Interaction= 2.4172		Bactria or Nano mix= 1.2086			LSD 0.05

Inflorescences' length (cm)

Plants treated with nano-zinc sulfate exhibited longer inflorescences than untreated plants, with average lengths of 10.970, 11.636, and 12.136 cm at concentrations of 3, 6, and 9 mg L^{-1}, respectively, whereas the control treatment produced an average length of 10.607cm (Table 6). The beneficial effect was also evident following inoculation with plant growth-promoting bacteria. The average inflorescence length increased to 10.858, 11.774, and 12.386 cm in the bacterial treatments, while untreated plants recorded only 10.331cm. Examination of the interaction effect revealed that combining nano-fertilization with bacterial inoculation provided additional stimulation for inflorescence development. In general, increasing the concentration of the nano sulfur-zinc sulfate mixture enhanced inflorescence length across all bacterial treatments. The most pronounced response was associated with the application of 9 mg L^{-1} in combination with *P. fluorescens*, which produced a significant increase in inflorescence length compared with the control treatment (Table 6).

Table 6. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on inflorescence length (cm) in *Matthiola incana*

Nano-zinc sulfate-sulfur mixture (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
10.331	10.663	10.553	10.11	9.997	Control
10.858	11.33	10.997	10.777	10.33	*Azotobacter chroococcum*
11.774	12.663	12.33	11.33	10.773	*Bacillus subtilis*
12.386	13.887	12.663	11.663	11.33	*Pseudomonas fluorescens*
	12.136	11.636	10.97	10.607	Average
Interaction= 0.902		Bactria or Nano mix= 0.414			LSD 0.05

Field flowering period (days)

A clear improvement in field flowering period was observed when plants were treated with foliar nano-zinc sulfate (Table 7). The duration reached 8.4583, 8.4583, and 9.975 days at concentrations of 3, 6, and 9 mg L^{-1}, respectively, compared to 8.075

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days in the control treatment (Table 7). Growth-promoting bacteria also contributed to extending the flowering period. Treatments with Bacillus subtilis, Pseudomonas fluorescens, and Azotobacter chroococcum recorded averages of 9.075, 9.4917, and 9.325 days, respectively, while the duration did not exceed 7.6333 days in unpollinated plants. The interaction between nano-spray and bacterial inoculation also gave a significant response, especially at a concentration of 9 mg L^{-1} with the three bacterial species, as these treatments achieved the longest flowering period in the field, which reflects the effectiveness of the interaction in supporting continuous flowering and improving the flowering performance of the plant (Table 7).

Table 7. Effect of foliar Nano-zinc sulfate and soil injection with three bio-fertilizing bacteria on field flowering period in *Matthiola incana*

Nano-zinc sulfate (mg L^{-1})					Bacterial treatments
Average	9	6	3	0	(Soil injection)
7.6333	8.1	7.733	7.5	7.2	Control
9.075	10.3	9.3	8.5	8.2	*Azotobacter chroococcum*
9.4917	10.867	9.633	9.3	8.5	*Bacillus subtilis*
9.325	10.633	9.4	8.867	8.4	*Pseudomonas fluorescens*
	9.975	8.4583	8.4583	8.075	Average
Interaction= 0.4032		Bactria or Nano mix= 0.2016			LSD 0.05

These results are consistent with those reported by Sahu, et al. (23) in gladiolus, where the interaction between Azotobacter and phosphate-solubilizing bacteria increased spike length and number of florets. It was also demonstrated (18) that Azotobacter, Bacillus, and Pseudomonas strains improved growth and biomass in ornamental plants. Other studies on carnation, jasmine, and safflower have shown that nano-zinc sulfate and sulfur improved flower number, diameter, and flowering time, while Prasanna et al. (22) showed that supplementing cyanobacteria with Azotobacter or Pseudomonas fluorescens reduced bud formation time and increased flower diameter in chrysanthemums. Similarly, it was confirmed that combining biofertilizers with nano-nutrients enhances growth and flowering efficiency and improves the qualitative characteristics of ornamental plants (9, 19).

In the same vein, *Pseudomonas* and *Bacillus* spp. have demonstrated a clear ability to increase the number of flowers and plant size in geraniums, chrysanthemums, dahlias, and marigolds, especially under stress conditions or low soil fertility (19). These bacteria can also promote the production of secondary compounds and essential oils in aromatic ornamental plants such as basil and rose bushes, which positively impacts the marketability of the flowers (3). In general, the use of *A. chroococcum*, *B. subtilis*, and

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P. fluorescens as biofertilizers is associated with improved flowering timing, increased flower abundance, enhanced flower quality, and extended market lifespan, as well as increased inflorescence number and flower size in many ornamental plants.

Spraying with a nano-sulfur and zinc sulfate mixture enhanced the chemical composition of stock plants. Leaf chlorophyll, carbohydrate, and nutrient content increased, as did the carotene and xanthophyll pigments in the flowers compared to the control treatment. This is attributed to the role of sulfur and zinc sulfate in activating photosynthesis, improving nutrient uptake, and promoting the formation of organic compounds within the plant. Zinc sulfate is an essential element in the formation of enzymes and proteins involved in chlorophyll synthesis, while sulfur contributes to the synthesis of amino acids and proteins, resulting in increased photosynthetic efficiency and the accumulation of carbohydrates and plant pigments (27). Nanoparticles also enhance nutrient availability and absorption due to their small size and high effective surface area. These findings align with those in a previous study were demonstrating that zinc sulfate nanoparticles combined with Bacillus subtilis or Pseudomonas fluorescens increased chlorophyll, carotenoids, and other nutrients in maize (12). The response was even greater when nanoparticles were combined with growth-promoting bacteria. Another study (13) also showed that zinc sulfate-containing nano-biofilms increased chlorophyll content in wheat compared to nanoparticles alone. Furthermore, other studies have shown that combining sulfur and zinc sulfate nanoparticles with *Azotobacter*, *Bacillus*, and *Pseudomonas* improves nutrient and pigment absorption in plants and enhances their tolerance to environmental stresses. A study by García-López, et al. (8) also showed that zinc sulfate nanoparticles increased photosynthetic pigments and carotenoids in maize and other crops. In general, the combination of nano-fertilizers and growth-promoting bacteria offers greater efficiency than traditional fertilization in improving plant chemical and physiological indicators.

higher plant height and inflorescence height and formation efficiency. These results indicate that combining biofertilizers and Nano-nutrients not only improves plant morphological growth but also activates physiological processes related to photosynthesis and carbohydrate

Conclusion

The findings revealed that spraying with zinc sulfate nanoparticles, especially at the highest concentration, was the most effective in increasing plant vegetative growth, advancing flower maturity, reducing the number of days required for flowering, increasing the number of florets and inflorescences, and extending the flowering period and flower viability compared to plants treated with lower concentrations and the control group. The use of *Bacillus subtilis* resulted in earlier flowering and a longer flowering period in the field, while *Agrobacterium chroococcum* inoculation exhibited the highest number of florets. *Pseudomonas fluorescens* bacteria also contributed to improved overall growth, accumulation, leading to higher and better-quality flower production indicators to meet market demands. This could be a practical and promising approach to improving the growth and flowering of mother plants, and raising their physiological and qualitative efficiency, with the possibility of adopting it

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within sustainable production programs for ornamental plants.

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