

Original Article

INFLUENCE OF FOLIAR APPLICATION OF ZINC SULFATE AND 6-BENZYLADENINE ON THE CHEMICAL PROPERTIES OF ZINNIA CULTIVARS (*Zinnia elegans*)

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ABSTRACT

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This study was conducted in the lath house of the Horticulture Department, College of Agricultural Engineering Sciences, University of Duhok, Kurdistan Region, Iraq, during 2024. The study investigated the effects of different levels of zinc sulfate (0, 0.50, and 0.75% Zn) and 6-benzyladenine (BA) concentrations (0, 50, and 100 mg L⁻¹) on selected chemical characteristics and leaf pigments of two *Zinnia* cultivars, Lavanda and Rosso Scarlatta. Anthocyanin content, however, was determined only in the flower petals. The results showed that Lavanda recorded significantly higher values of N, P, K, and Zn contents, reaching (3.65, 0.077, 3.707, and 0.063)%, respectively, compared with Rosso Scarlatta. Lavanda cultivar also showed significantly higher photosynthetic pigments and carbohydrate content, recording 22.287 mg g⁻¹, 12.435 mg g⁻¹, and 5.964%, respectively. Regarding BA concentration, spraying with 100 mg L⁻¹ resulted in the highest values of N, P, K, Zn, anthocyanin, photosynthetic pigments, and carbohydrate, reaching 3.95%, 0.096%, 4.130%, 0.077%, 205.372, 27.422 mg g⁻¹, 12.726 mg g⁻¹, and 5.753%, respectively. Similarly, spraying with Zn at 75% produced the highest values, reaching 3.78%, 0.089%, 3.951%, 0.071%, 192.925, 25.421 mg g⁻¹, 13.453 mg g⁻¹, and 5.913%, respectively. The triple interaction showed that Lavanda treated with BA at 100 mg L⁻¹ and Zn at 75% produced significantly superior results for all measured parameters except anthocyanin. The highest anthocyanin content was recorded in Rosso Scarlatta under BA100 mg L⁻¹ and Zn at 100%, reaching 236.233, compared with the lowest value of 116.250 in Lavanda without BA and Zn application.

Keywords: *Zinnia elegans*, essential micronutrients, benzyl adenine (BA) levels, and foliar spraying.

1. INTRODUCTION

Zinnia plants are commonly known as *Zinnia elegans*, and it is an annual plant in the Asteraceae family of flowering plants, which comprises over 1,600 genera along with 24,000 species of herbaceous plants, shrubs, and trees (Gomaa *et al.*, 2019). It is an annual bloomer during the summer season; it is a plant belonging to Mexico. The growth habit is upright and bushy, carrying leaves that are lightly hairy, ovate to lance-shaped, and approximately 8 cm long. *Zinnia elegans* is a summer-flowering annual plant that bears daisy-like flower heads with broad petals, reaching approximately 4.5 cm in diameter, with flowering occurring during the summer season (Noor El-Deen *et al.*, 2018). *Zinnias* rise to about 60 to 75 cm tall, spreading about 30 cm wide; these plants develop rapidly (Bandurska *et al.*, 2023). These plants are grown for their lone, long-stemmed, daisy-like terminal flowers (some with different-colored centers). Flowers come in white, yellow, orange, red, purple, and lilac and other varied colors. Such plants find their application in annual or mixed borders and happen to be one of the top ten in appeal for cutting. The short kinds of *zinnia* are best for edging, window boxes, or containers (Smolin *et*

al., 2023). The flowers of *Zinnia elegans* may occur in single, semi-double, and double forms, with flower heads exhibiting a wide range of colors, including purple, lilac, red, and red-purple hues. *Zinnia* is commonly cultivated as an annual ornamental plant and is primarily propagated by seeds for commercial and experimental production (Suzuki *et al.*, 2026). *Zinnia* is often utilized in cut flowers, bedding plants, or pot-plants. The reason behind its commercial value is its ability to have a long vase life while still offering different shapes in vibrant colors (Yigiter & Coskun, 2024).

BA (6-Benzyladenine), also known as 6-Benzylaminopurine (6-BAP), is a synthetic cytokinin-type plant growth regulator that primarily stimulates cell division and promotes shoot development, lateral bud growth, and other aspects of plant growth and development. It can also influence flowering and delay senescence depending on the plant species and concentration used (Bai, *et al.*, 2026). Benzyl adenine (BA) exhibits a rapid short-term response without causing any harmful effects on the plant. Consequently, multiple applications of BA can have a beneficial impact on crop development. To ensure effective translocation within the plant, BA coverage is necessary (Zhang *et al.*, 2022). When applied externally, cytokinin's like BA imitate the

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effects of pinching in plants. Numerous studies suggest that auxins and cytokinin's often work antagonistically to regulate apical dominance. BA, a type of cytokinin and an aromatic compound, promotes the formation of lateral branches, giving the plant a bushier appearance. Its antagonistic relationship with auxin allows BA to counteract apical dominance while reducing overall plant height (Kumawat *et al.*, 2019). Direct application of BA can stimulate growth and cell division in dormant buds, thereby enhancing the overall vigor of the plant (Pavlů *et al.*, 2018).

Zinc is important micronutrient required for improved production of flowers. The role of Zinc is established in the production of auxin and RNA. It regulates the metabolic process and enhances growth in plants (Denre *et al.*, 2025). It is required in sugar regulation and different enzymological aspects of growth in plants (Zhang *et al.*, 2021). However, application of fertilizers in the form of spray may prove useful in such cases to avoid fixation of micronutrients in the soil (Renuka *et al.*, 2024). Micronutrients which are essential for all higher plants are boron (B), chlorine (Cl), copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), Zn, Cu, Fe and Mn are associated with various enzymatic activities and Boron is associated with the carbohydrate metabolism and reproductive phase of the plants along with photosynthesis or enzymatic activities (Sahu *et al.*, 2020). Zinc is a very important micronutrient required for internodes' elongation and hormone production in plants. They play an important role as they hold immense connotation in association with enzyme metabolism in plants (Umair Hassan *et al.*, 2020).

Plants usually receive their nutrients from the soil through their roots, but plants can also be given nutrients through foliar sprays. Foliar feeding is one of the newer and controversial methods in which liquid fertilizers are applied directly onto the foliage of plants (Zahed *et al.*, 2021). In general, trace elements like Fe, Zn, Mn, and Cu are added to foliar fertilizers in many parts of the world to control their deficiencies, especially in arid and semi-arid regions (Renuka *et al.*, 2024). Micronutrients, mainly Fe and Zn, are either a component of many enzymes or acting as a functional, structural, or regulatory co-factor. Considering the importance of the flower zinnia in worldwide cut flower production, an outdoor pot experiment has been conducted. The aims of this present study were to evaluate the individual effects of each treatment on the nutrient content and chemical properties of plants. It also seeks to assess how these treatments influence flower pigmentation, which is essential for ornamental value. Additionally, the study investigates whether the combined application of Zn and BA results in additive, synergistic, or inhibitory effects on nutrient uptake, chemical composition, and pigmentation.

2. MATERIALS AND METHOD

The research was conducted in the lath house of the Department of Horticulture, College of Agriculture Engineering Sciences, University of Duhok, Kurdistan Region, Iraq, which was on April 20, 2024. The experiment was arranged in a factorial Randomized Complete Block Design (RCBD) involving three factors. The first factor was 6-benzyladenine (BA) applied at three concentrations (0, 50, and 100 mg L⁻¹). The second factor consisted of three levels of ZnSO₄ (0.00, 0.50, and 0.75% Zn). The third factor comprised two *Zinnia* cultivars, Lavanda and Rosso Scarlatta. A total of 216 plants were used for the experiment, all based on an experimental design consisting of (3*3*2*3*4= 216 plants). *Zinnia elegans* seeds, imported from Italy by Pagano Costantino, were delivered to Kurdistan Region via Duhok offices of the Agricultural Offices, where the seeds were first sowing in a growing medium consisting of peat moss. After the seeds were germinated, the plants were then transferred into a growing medium consisting of a combination of river soil and peat moss, in a ratio of (1:2 v/v). These were then placed in a lath house. Once the plants reached the 'four leaves' stage, different concentrations of BA and ZnSO₄ were sprayed on the leaves. Three different treatments were applied every 15 days. Samples were collected at the pre-flowering stage for the determination of the biochemical and mineral constituents. In contrast, floral samples for anthocyanin quantification were collected at the full-bloom stage. Biochemical contents:

1. Nitrogen contents%: the nitrogen percentage started with selecting the leaves and green parts of the plants. After washing, they were dried by putting them in the electrical oven with

70°C for 72 hours and then crushed. The amount 0.2 gm of the powder had been digested by using 10 ml of Sulfuric acid and adding 10 ml of H₂O₂. Lastly, Nitrogen was estimated by using the Micro Kjeldahl's device according to (Black, 1965).

2. Phosphors contents%: the phosphorus was estimated according to Mattingly (1975) by using spectrophotometer instrument.
3. Potassium contents%: the potassium was estimated according to Richards (1954) by using Flame photometer instrument.
4. Zinc contents%: Chromatography according to the method described by Vogel (1975). In dry matter of leaves Fe, Mn, Zn and Cu were determinate. Digestion of plant materials was carried out using sulphuric and perchloric acids as described by Piper (1947). Determination of micronutrients (Zn) concentrations were determined by the atomic absorption spectrophotometer (Thermo Jarrellas H, AASCANI).
5. Total anthocyanins were evaluated by the pH differential method (Lee *et al.*, 2005). The TMA in 25 mM potassium chloride solution (pH 4.5) and 400 mM sodium acetate buffer (pH 1.0) were measured simultaneously at 520 nm and 700 nm, respectively. The content of total anthocyanins was expressed as mg cyanidin-3-glucoside equivalents per 100 g of dry weight (mg C3-G E/100g DW).
6. Total carbohydrates (% d. w): The concentration of total carbohydrates was determined according to Herbert *et al.* (1971).
7. Total chlorophylls contents were determined in fresh samples of leaves according to Saric *et al.* (1967), as mg/g fresh matter.
8. Total carotenoid content was determined spectrophotometrically at 450 nm and expressed as milligrams of β -carotene equivalents per 100 g of dry weight (mg β -CE/100 g DW), following the method described by Rodriguez-Amaya (2001).

Statistical Analysis

The experimental design used was the factorial Randomized Complete Block Design (RCBD). The experiment was conducted with three factors, with three replications of four plants per replicate. The analysis of the collected data was done through analysis of variance (ANOVA). The means were separated using Duncan's Multiple Range Test with a minimum value at significance level $p \leq 0.05$, done through the SAS software.

3. RESULTS AND DISCUSSION

Nitrogen percentage (N%):

Data from Table 1 show that the cultivar significantly influenced the nitrogen percentage in leaves. *Zinnia Lavanda* cultivar recorded a significantly higher N (3.65 %) compared to *Zinnia Rosso Scarlatta* cultivar, with an N of 3.18%. The concentration of BA also proved to have a significant effect on N%, with the increase in BA promoting the increase in N. Application of 100 mgL⁻¹ BA had 3.95% N, followed by 3.44 % for 50 mgL⁻¹ BA and 2.85% for the control. Level of Zn significantly influenced N, with 0.75 % Zn increasing the N to 3.78 %, while 0.50 % Zn and the control were 3.37% and 3.10%, respectively.

Regarding the interaction between cultivar and BA, significant results were obtained with the spraying of *Zinnia Lavanda* cultivar with 100 mgL⁻¹ BA, reaching a maximum N of 4.348%, while minimum in the same cultivar without BA application was 3.23%. The interaction between cultivar and Zn also indicated that *Zinnia Lavanda* cultivar at 0.75 % Zn had the maximum N at 4.128%, while a minimum of 2.997% was recorded in *Zinnia Rosso Scarlatta* cultivar without Zn application.

Among the combinations of three factors, the following were observed to have the highest N, *Zinnia Lavanda* cultivar that was sprayed with 100 mgL⁻¹ BA and 0.75% Zn had the highest N of 4.790%, while the N of the *Zinnia Lavanda* cultivar that did not receive BA and Zn treatment had a significantly lower N of 2.493%.

Table 1: Effect of foliar application of BA concentrations and Zn% on nitrogen percentage in leaf of two cultivars of zinnia plants.

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	2.49 ^j	2.70 ^{ji}	3.33 ^{efg}	2.84 ^c	3.65 ^a
	50	3.30 ^{efg}	3.74 ^{def}	4.26 ^{bc}	3.77 ^b	
	100	3.81 ^{cde}	4.45 ^{ab}	4.79 ^a	4.35 ^a	
Z. rosso scarlatta	0	2.76 ^{hij}	2.74 ^{hij}	3.11 ^{ghi}	2.87 ^c	3.18 ^b
	50	2.96 ^{g-j}	3.13 ^{ghi}	3.26 ^{fgh}	3.12 ^c	
	100	3.27 ^{fgh}	3.47 ^{d-g}	3.93 ^{cd}	3.56 ^b	
Interaction of Cultivar X Zn %		3.20 ^{cd}	3.63 ^b	4.13 ^a	Effect of BA	0
		3.00 ^d	3.11 ^d	3.43 ^{bc}	Conce. MgL ⁻¹	50
Effect of Zn%		3.10 ^c	3.37 ^b	3.78 ^a	100	3.95 ^a

Phosphorus percentage (P%):

In Table 2, data illustrated that the cultivars had a significant effect on the phosphorus content in the leaves. The Zinnia Lavanda cultivar recorded a significantly higher P (0.077%) compared to the Zinnia Rosso Scarlatta cultivar, with a P of 0.063%. While the concentration of BA also proved to have a significant effect on P, with the increase in BA promoting the increase in P. The application of 100 mgL⁻¹ BA resulted in a P concentration of 0.096%, which is significantly higher than the 0.069% observed for 50 mgL⁻¹ BA and the 0.045% for the control group. The level of Zn significantly influenced P percent, with 0.75% Zn increasing the P to 0.089%, significantly, 0.50% Zn and the control were 0.066% and 0.055%, respectively.

In addition, the interaction between cultivar and BA, significant results were obtained with the spraying of the Zinnia Lavanda culti-

var with 100 mgL⁻¹ BA, reaching a maximum P of 0.104%, which was significantly compared with all treatments, while the minimum in the Zinnia Rosso Scarlatta cultivar without BA application was 0.042%. The interaction between cultivar and Zn also indicated that the Zinnia Lavanda cultivar at 0.75% Zn had a significant effect, with a maximum P percentage of 0.105%, while a minimum of 0.054% was recorded in the same cultivar without Zn application.

However, in terms of the combinations of three factors, the following were observed to have the highest P: the Zinnia Lavanda cultivar that was sprayed with 100 mgL⁻¹ BA and 0.75% Zn had the highest P of 0.147%, which was significantly affected compared with all treatments, while the P percent of the Zinnia Rosso Scarlatta cultivar that did not receive BA and Zn treatment had a significantly lower P of 0.035%.

Table 2: Effect of foliar application of BA concentrations and Zn% on Phosphor percentage in leaf of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	0.038 ^{hi}	0.044 ^{ghi}	0.060 ^{e-h}	0.047 ^{cd}	0.077 ^a
	50	0.053 ^{e-i}	0.087 ^{cde}	0.109 ^b	0.080 ^b	
	100	0.070 ^{def}	0.094 ^{bc}	0.147 ^a	0.104 ^a	
Z. rosso scarlatta	0	0.035 ⁱ	0.040 ^{hi}	0.052 ^{f-i}	0.042 ^d	0.063 ^b
	50	0.047 ^{ghi}	0.060 ^{e-h}	0.066 ^{d-g}	0.058 ^c	
	100	0.087 ^{bcd}	0.078 ^{cde}	0.098 ^{bc}	0.088 ^b	
Interaction of Cultivar X Zn %		0.054 ^c	0.072 ^b	0.105 ^a	Effect of BA	0.045 ^c
		0.056 ^c	0.059 ^c	0.072 ^b	Conce. MgL ⁻¹	0.069 ^b
Effect of Zn%		0.055 ^c	0.066 ^b	0.089 ^a		0.096 ^a

Potassium percentage (K%):

Data from Table 3 show that the two cultivars had a significant effect on the percentage of K in the leaf tissues. Zinnia Lavanda had a significantly higher percentage of K, reaching 3.707%, than the Zinnia Rosso Scarlatta cultivar, with a K percentage of 3.491%. On the other hand, the concentration of BA had a significant effect on the percentage of K; thus, the higher the BA concentration, the higher the increase in the percentage of K than the rest. Concentration of BA at 100 mgL⁻¹ had a K percentage of 4.130%, followed by 3.659% for the 50 mgL⁻¹ BA concentration and 3.007% for the control. The levels of Zn had a significant effect on the percentage of K; thus, the concentration of 0.75% had a significantly higher effect on the increase in the percentage of K to 3.951%, which is significantly higher than the concentration of 0.50% with a value of 3.327% and the control with a value of 3.519%.

Concerning the interaction of cultivar and BA, it was significant for the spraying of cultivar Zinnia Lavanda with a concentration of 100 mgL⁻¹ BA, where a maximum K value of 4.209% was reached, compared to all treatments, and the minimum value was found in cultivar Zinnia Rosso Scarlatta without BA treatment, reaching 2.972%. On the other hand, the interaction between cultivar and Zn recorded significant results: the Zinnia Lavanda cultivar with 0.75% Zn had a significant value compared to all treatments, so the maximum result, reaching 4.179% compared to the minimum of 3.318%, was recorded for the same cultivar without Zn application.

Additionally, the combination of these three factors significantly changed the potassium (K) content. The Zinnia Lavanda variety achieved its highest K content (4.621%) when sprayed with 100 mgL⁻¹ BA and 0.75% Zn. Conversely, K content for the same variety dropped dramatically to 2.614% when the zinc concentration was reduced to 0.50%, and when BA controlled.

Table 3: Effect of foliar application of BA concentrations and Zn% on Potassium percentage in leaf of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	2.918 ^{hij}	2.614 ^j	3.598 ^{def}	3.043 ^d	3.707 ^a
	50	3.318 ^{figh}	3.968 ^{bcd}	4.318 ^{ab}	3.868 ^b	
	100	3.718 ^{def}	4.288 ^{ab}	4.621 ^a	4.209 ^a	
Z. rosso scarlatta	0	2.728 ^{ij}	2.898 ^{hij}	3.289 ^{figh}	2.972 ^d	3.491 ^b
	50	3.135 ^{hij}	3.508 ^{efg}	3.708 ^{def}	3.450 ^c	
	100	4.143 ^{bc}	3.838 ^{cde}	4.173 ^{bc}	4.051 ^{ab}	
Interaction of Cultivar X Zn %		3.318 ^d	3.623 ^{bc}	4.179 ^a	Effect of BA Conce. MgL ⁻¹	3.007 ^c
		3.335 ^d	3.415 ^{cd}	3.723 ^b		3.659 ^b
Effect of Zn%		3.327 ^c	3.519 ^b	3.951 ^a		4.130 ^a

Zinc percentage (Zn%):

Data from Table 4 indicated that the cultivar significantly influenced the Zinc percentage of leaves. Zinnia Lavanda cultivar recorded a significantly higher Zinc reaching (0.063%) compared to Zinnia Rosso Scarlatta cultivar, with 0.046 % Zinc. BA was also significantly affected by Zn%, with the increasing BA concentration zinc was increased. Application of 100 mgL⁻¹ BA had 0.077^a % of Zn, followed by 0.054% for 50 mgL⁻¹ BA and 0.033% for the control treatment. Additionally, adding Zn caused the increase in zinc percent in leaves. Adding Zn at the rate of 0.75% produced Zinc (0.071%), while it dropped to (0.053 and 0.040) %, respectively, which were in the treatments of 0.50% and control.

Regarding the interaction between cultivar and BA, significant re-

sults were obtained with the spraying of the Zinnia Lavanda cultivar by 100 mgL⁻¹ BA, reaching a maximum Zinc of 0.090%, while minimum results show in the Zinnia Rosso Scarlatta cultivar without BA application at 0.028%. The interaction between cultivars and Zn also recorded significant results; the Zinnia Lavanda cultivar at 0.75% Zn had the maximum Zinc at 0.086%, while a minimum result of 0.037% was recorded in Zinnia Rosso Scarlatta cultivar without Zn application.

Moreover, the interaction between three factors was observed to have recorded the highest Zinc percentage in the Zinnia Lavanda cultivar that was sprayed with 100 mgL⁻¹ BA, and 0.75% Zn, reaching 0.122%, while the lower percentage of Zinc recorded in the Zinnia Rosso Scarlatta cultivar that did not receive BA and Zn treatment reached 0.020%.

Table 4: Effect of foliar application of BA concentrations and Zn% on Zn percentage in leaf of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	0.026 ^{gh}	0.035 ^{figh}	0.052 ^{d-g}	0.038 ^{cd}	0.063 ^a
	50	0.039 ^{e-h}	0.064 ^{b-c}	0.085 ^b	0.063 ^b	
	100	0.064 ^{b-e}	0.084 ^{bcd}	0.122 ^a	0.090 ^a	
Z. rosso scarlatta	0	0.020 ^h	0.025 ^{gh}	0.038 ^{e-h}	0.028 ^d	0.046 ^b
	50	0.035 ^{figh}	0.044 ^{c-h}	0.056 ^{c-f}	0.045 ^c	
	100	0.057 ^{b-e}	0.066 ^{b-e}	0.073 ^{bcd}	0.065 ^b	
Interaction of Cultivar X Zn %		0.043 ^{cd}	0.061 ^b	0.086 ^a	Effect of BA Conce. MgL ⁻¹	0.033 ^c
		0.037 ^d	0.045 ^{cd}	0.056 ^{bc}		0.054 ^b
Effect of Zn%		0.040 ^c	0.053 ^b	0.071 ^a		0.077 ^a

Carbohydrate content:

Table 5 shows that cultivars significantly influenced the carbohydrate content in leaves. Zinnia Lavanda cultivar recorded a significantly higher carbohydrate content compared to Zinnia Rosso Scarlatta cultivar, with the latter showing a lower (5.964 and 5.051) %, respectively. The concentration of BA also proved to have a significant effect on carbohydrate content, with increased BA promoting higher carbohydrate levels. Application of 100 mgL⁻¹ BA resulted in the highest carbohydrate content, 5.753%, followed by 5.791% for 50 mgL⁻¹ BA, and the lowest in the control, 4.978%. The level of Zn significantly influenced carbohydrate content, with the level of 0.75% Zn significantly increasing the carbohydrate content, which gave the maximum value, reaching 5.913%, while the control recorded lower values of 5.046% carbohydrate content.

About the interaction between cultivar and BA, significant results

were obtained with the spraying of the Zinnia Lavanda cultivar with 100 mgL⁻¹ BA, reaching a maximum carbohydrate content (6.351%), while the minimum in the Zinnia Rosso Scarlatta cultivar without BA application was observed (4.484%). The interaction between cultivar and Zn also refers to the fact that the Zinnia Lavanda cultivar at 0.75% Zn recorded the highest carbohydrate content, reaching 6.420%, while a minimum percentage (4.557%) was recorded in Zinnia Rosso Scarlatta cultivar without Zn application.

On the other hand, the combination of the three study factors significantly affected carbohydrate content. The highest significant carbohydrate content was observed in the Zinnia Lavanda cultivar that was sprayed with 100 mgL⁻¹ BA and 0.75% Zn, reaching a maximum value of 6.788%, while the Zinnia Lavanda cultivar that did not receive BA and Zn treatment had a significantly lower carbohydrate content, reaching 3.525%

Table 5: Effect of foliar application of BA concentrations and Zn% on carbohydrate content in leaf of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	5.138 ^{de}	5.322 ^{cde}	5.955 ^{a-d}	5.472 ^b	5.964 ^a
	50	5.548 ^{b-e}	6.138 ^{a-d}	6.518 ^{ab}	6.068 ^a	
	100	5.918 ^{a-d}	6.348 ^{abc}	6.788 ^a	6.351 ^a	
Z. rosso scarlatta	0	3.525 ^f	4.541 ^e	5.385 ^{cde}	4.484 ^c	5.051 ^b
	50	5.116 ^{de}	5.661 ^{b-e}	5.766 ^{a-d}	5.515 ^b	
	100	5.031 ^{de}	5.366 ^{cde}	5.064 ^{de}	5.154 ^b	
Interaction of Cultivar X Zn %		5.535 ^{bc}	5.936 ^{ab}	6.420 ^a	Effect of BA	4.978 ^b
		4.557 ^d	5.190 ^c	5.405 ^{bc}	Conce. MgL ⁻¹	5.791 ^a
Effect of Zn%		5.046 ^b	5.563 ^a	5.913 ^a		5.753 ^a

Anthocyanin pigment:

Data from Table 6 indicate that the cultivar significantly influenced the anthocyanin pigment in flower petals. The Zinnia Rosso Scarlatta cultivar recorded a significantly higher anthocyanin content (172.428%) compared to the Zinnia Lavanda cultivar, which had an anthocyanin level of 167.076%. BA concentration also recorded a significant effect on anthocyanin content, with increased BA at 100 mgL⁻¹ resulting in 205.372% anthocyanin, it was significant compared to 50 mgL⁻¹ BA and the control, which reached to 169.483% and 134.400%, respectively. Zinc application significantly increased the anthocyanin content in the treated samples. Specifically, the Zinc treatment at a rate of 0.75% was superior to both the 0.50% treatment and the control, yielding anthocyanin values of (192.925, 165.681 and 150.650) %, respectively.

Also, the interaction between cultivar and BA produced the

highest significant results, and the highest anthocyanin content of 210.500% was produced by the Zinnia Rosso Scarlatta cultivar treated with 100 mgL⁻¹ of BA, while the lowest content of 131.622% was recorded from the Zinnia Lavanda cultivar when treated with 50 mgL⁻¹ of BA. The interaction between the cultivar and Zn percent showed that the highest anthocyanin concentration of 194.250 and 191.600% was produced by the Zinnia Rosso Scarlatta and Zinnia Lavanda cultivar treated with 0.75% Zn respectively, while the lowest content of 145.528% was produced by the Zinnia Lavanda cultivar but untreated with Zn.

The highest anthocyanin content was recorded in the Zinnia cultivar 'Rosso Scarlatta' when plants were sprayed with 100 mg L⁻¹ BA and 0.75% Zn, reaching 236.233%, as revealed by the interaction among the three study factors. Conversely, the lowest anthocyanin content was in the Zinnia Lavanda cultivar that did not receive BA or Zn treatment, with a value of 116.250%.

Table 6: Effect of foliar application of BA concentrations and Zn% on anthocyanin pigment in petals of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	116.250 ⁱ	128.100 ^{hi}	150.517 ^{ef}	131.622 ^d	167.076 ^b
	50	140.450 ^{fgh}	172.017 ^d	195.617 ^b	169.361 ^c	
	100	179.883 ^{cd}	192.183 ^{bc}	228.667 ^a	200.244 ^b	
Z. rosso scarlatta	0	120.850 ⁱ	134.400 ^{gh}	156.283 ^c	137.178 ^d	172.428 ^a
	50	145.550 ^{efg}	173.033 ^d	190.233 ^{bc}	169.606 ^c	
	100	200.917 ^b	194.350 ^b	236.233 ^a	210.500 ^a	
Interaction of Cultivar X Zn %		145.528 ^d	164.100 ^b	191.600 ^a	Effect of BA	134.400 ^c
		155.772 ^c	167.261 ^b	194.250 ^a	Conce. MgL ⁻¹	169.483 ^b
Effect of Zn%		150.650 ^c	165.681 ^b	192.925 ^a		205.372 ^a

Total chlorophyll (Chl a+b) mg g⁻¹:

Data in Table 7 show that the cultivar significantly impacted the total chlorophyll content in leaves. The Zinnia Lavanda cultivar recorded the best significant result in chlorophyll content (22.287 mg g⁻¹) compared to the Zinnia Rosso Scarlatta cultivar, with a value of (17.778 mg g⁻¹). The concentration of BA also obtained a highly significant effect on total chlorophyll when spraying the plant with 100 mgL⁻¹ BA resulted in the highest chlorophyll content of 27.422 mg g⁻¹, followed by 19.885 mg g⁻¹ for 50 mgL⁻¹ BA and 12.791 mg g⁻¹ for the control. The level of Zn significantly influenced total chlorophyll, with 0.75% Zn increasing chlorophyll to 25.421, while 0.50% Zn and the control treatment recorded (21.266 and 13.412) mg g⁻¹, respectively.

In the interaction between cultivar and BA, significant results

were obtained with the spraying of the Zinnia Lavanda cultivar with 100 mgL⁻¹ BA, reaching (33.209 mg g⁻¹), while the minimum results found in the same cultivar without BA application were (11.468 mg g⁻¹). A significant interaction between cultivar and Zinc application was observed. The highest chlorophyll content (28.464 mg g⁻¹) was recorded in Zinnia Lavanda sprayed with 0.75% Zn. Conversely, the lowest value (12.110 mg g⁻¹) occurred in untreated Zinnia Rosso Scarlatta.

Among the combinations of three factors, the following results were observed. The highest chlorophyll content of Zinnia Lavanda cultivar found, when it was sprayed with 100 mgL⁻¹ BA and 0.75% Zn the highest value (39.381 mg g⁻¹), while the chlorophyll content of the Zinnia Rosso Scarlatta cultivar that did not receive BA and Zn treatment was significantly lower (7.262 mg g⁻¹).

Table 7: Effect of foliar application of BA concentrations and Zn% on total chlorophyll in leaf of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Z. Lavanda	0	9.721 ^f	11.506 ^{ef}	13.178 ^{def}	11.468 ^d	22.287 ^a
	50	12.736 ^{def}	20.986 ^{cde}	32.833 ^{ab}	22.185 ^b	
	100	21.682 ^{cd}	38.564 ^a	39.381 ^a	33.209 ^a	
Z. rosso scarlatta	0	7.262 ^f	10.105 ^f	24.976 ^{bc}	14.114 ^{cd}	17.778 ^b
	50	14.248 ^{def}	24.715 ^{bc}	13.792 ^{def}	17.585 ^{bc}	
	100	14.821 ^{def}	21.722 ^{cd}	28.365 ^{bc}	21.636 ^b	
Interaction of Cultivar X Zn %		14.713 ^{cd}	23.685 ^{ab}	28.464 ^a	Effect of BA	12.791 ^c
		12.110 ^d	18.847 ^{bc}	22.378 ^b	Conce. MgL ⁻¹	19.885 ^b
Effect of Zn%		13.412 ^c	21.266 ^b	25.421 ^a		27.422 ^a

Total carotene (mg g⁻¹)

⁻¹): Carotene content in leaves was significantly affected by the cultivars (Table 8). Zinnia Lavanda cultivar recorded a significantly higher carotene (12.435 mg g⁻¹) compared to Zinnia Rosso Scarlatta cultivar, obtaining (9.514 mg g⁻¹). The concentration of BA also has a significant effect on carotene, with the increase in BA promoting the increase in carotene, 100 and 50 mgL⁻¹ BA had (12.726 and 12.905 mg g⁻¹) carotene, compared to the control reaching (7.293 mg g⁻¹). Level of Zn significantly influenced carotene, with 0.75% Zn increasing the carotene to 13.453 mg g⁻¹, superior to the 0.50% Zn and the control treatments (7.973 and 11.498) mg g⁻¹, respectively.

Regarding the interaction between cultivar and BA, significant results were obtained with the spraying of Zinnia Lavanda cultivar with 100 mgL⁻¹ BA, reaching a maximum carotene of 15.164 mg g⁻¹, while the minimum value in the same cultivar without BA application was 6.819 mg g⁻¹. The interaction between cultivar and Zn also indicated that Zinnia Lavanda cultivar at 0.75% Zn had the maximum carotene at 15.074 mg g⁻¹, while a minimum of 7.512 mg g⁻¹ was recorded in Zinnia Rosso Scarlatta cultivar without Zn application.

Among the combinations of three factors, the following results were observed: Zinnia Lavanda cultivar that was sprayed with 100 mgL⁻¹ BA and 0.75% Zn had the highest carotene of 19.174 mg g⁻¹, while the carotene of the Zinnia Rosso Scarlatta cultivar that did not receive BA and Zn treatment was significantly lower at 5.326 mg g⁻¹.

Table 8: Effect of foliar application of BA concentrations and Zn% on total carotene in leaf of two cultivars of zinnia plants

Cultivar	BA Conce. MgL ⁻¹	Zn %			Interaction cultivar X BA	Effect of cultivar
		0.00	0.50	0.75		
Zinnia Lavanda	0	6.512 ^{gh}	7.363 ^{fgh}	9.426 ^{d-g}	7.767 ^c	12.435 ^a
	50	10.134 ^{def}	16.368 ^{ab}	16.622 ^{ab}	14.375 ^a	
	100	8.654 ^{efg}	17.664 ^{ab}	19.174 ^a	15.164 ^a	
Zinnia rosso scarlatta	0	5.326 ^h	6.216 ^{gh}	8.915 ^{efg}	6.819 ^c	9.514 ^b
	50	10.168 ^{def}	9.213 ^{d-g}	14.924 ^{bc}	11.435 ^b	
	100	7.043 ^{fgh}	12.166 ^{cd}	11.657 ^{de}	10.288 ^b	
Interaction of Cultivar X Zn %		8.433 ^c	13.798 ^a	15.074 ^a	Effect of BA	7.293 ^b
		7.512 ^c	9.198 ^c	11.832 ^b	Conce. MgL ⁻¹	12.905 ^a
Effect of Zn%		7.973 ^c	11.498 ^b	13.453 ^a		12.726 ^a

4. DISCUSSION

The results of this study, as demonstrated in Tables 1 and 4, reveal the increased rate of absorption of macro nutrient elements, such as N, P, and K, and micronutrient element Zn by the roots of Zinnia plants with increasing application rates of BA and Zn spraying. These findings were supported in the studies done by Xue *et al.* (2021) and Fan *et al.* (2021), where it was found that the optimum supply of nitrogen and Zn facilitates the optimum uptake of potassium as well as phosphorus, and Zinc from the soil, also called the synergism effect. Also, this study showed that the quantity of pigments (Tables 6, 7, and 8) in the two cultivars of zinnia plants differed, and this difference in coloration as seen among plants could be as a result of the varying concentration of the variations seen in flower colors in the plants could be due to differences in the amount of pigments present in the flowers such as carotenoids, chlorophylls, and anthocyanins. This result support the results obtained by Rezende, *et al.* (2025). Such pigments were formed in the primary metabolism via different biosynthesis processes, resulting in variations in the flower colors in time and space. In addition, the changes in the colors of flowers during anthesis to senescence occur due to the complex molecular mechanisms involved in the process, specifically, as regards the structures of the compounds and the pathways of their syntheses. It was noted that recent progress in this subject focuses on the employment of molecu-

lar biology and genetics in the modification of pigment-synthesizing pathways in cells. Interestingly, applying 100 mg·L⁻¹ BA alone or their interaction with Zn resulted in the highest carotenoid content, with no significant changes observed (Table 8). Concerning chlorophyll levels, the most effective treatments involved combining 100 mg·L⁻¹ BA alone or their interaction with Zn (Table 7).

Although, BA application enhanced carotenoid accumulation, it also contributed to an increase in leaf chlorophyll concentration (Tables 7 and 8). This indicates a synergistic interaction between BA and other factors in promoting elevated levels of both carotenoids and chlorophyll. Spraying zinnia cultivars with 0.75% Zinc sulfate yielded superior improvements in chlorophyll, nitrogen, phosphorus, potassium, Zinc, and carbohydrates compared to other treatments. The experiment showed that micronutrient application significantly enhanced chemical traits, especially chlorophyll and nitrogen. The most effective treatment combined BA at 100 mg/L and Zinc sulfate at 0.75%, excelling in four traits: chlorophyll, phosphorus, potassium in leaves, and leaf carbohydrate content, despite some conflicting interaction results (Tables 7, 2, 3, and 5).

Regulation of anthocyanin biosynthesis in response to hormonal signals hormonal regulation of anthocyanin biosynthesis involves a number of hormonal regulations, as well as interactions between transcriptional regulatory networks. Several recent studies have shown that phytohormones, like cytokinins, can regulate anthocyanin syn-

thesis through the regulation of structural and regulatory genes responsible for the process of biosynthesis of flavonoids. In ornamental crops, regulation of anthocyanin biosynthesis is connected to the transcriptional regulators of flower color, especially MYB transcription factors (Yin *et al.*, 2021; Cappellini *et al.*, 2021; Li and Ahammed, 2023). Of interest to the industry, BA was shown to have a significant effect on rose metabolites, and some aromatically important compounds increased following the application of 100 mg/L or 200 mg/L BA by Ibrahim *et al.* (2018). These results agree with those reported by Abou-El-Ghait (2020) on carnation plants, Ouyang *et al.* (2019) on garden roses, Hasan *et al.* (2019) on navel orange saplings, and Monder and Pacholczak (2020) on once-blooming rose shrubs, who showed the significance of plant growth regulators and carbohydrate metabolism in affecting the physiology and development of horticultural and ornamental plants. Increases in the percentages of N, P, and K in *Zinnia* leaves were observed following BA application at a concentration of 100 mg L⁻¹. These results were pointed in the same direction of Shi *et al.* (2023) and on *Chlorophytum comosum*, *Peperomia obtusifolia*, *Brassia actinophylla*, and tuberose, respectively.

Zinc (Zn), being a micronutrient element essential for various biological processes such as carbohydrates, auxins, and nucleic acids, protein synthesis (Solanki & Nandal, 2021), membrane stability, and detoxification of highly reactive superoxide free radicals, acts as a cofactor to influence the configuration of proteins significantly. The indispensable role of Zinc in enzymatic activation, protein synthesis, chlorophyll formation, and carbohydrate metabolism underscores its irreplaceable function in sustaining plant vitality, as noted by Alamer *et al.* (2020) and Oliveira *et al.* (2023). In this experiment, the accumulation of various nutrients, N, P, K, and Zn, increased in the leaves of *Zinnia* due to application of the *Zinnia* plants which augmented some role whereby early spike emergence and flowering was noticed. It also enhanced durability and duration of flowering. The reason for enhanced flowering attributes is due to an optimum supply of micronutrients as advocated by Jayakumar *et al.* (2024), who corroborated that proper nutritional status, i.e., nitrogen, potassium, Zinc, copper, etc., and hormonal level within the plants might be the reason for color expression. The promotion of early flowering with an extension of the flowering duration was observed due to the action of translocation of sucrose and phytohormones from the leaves to the shoot apical meristem after the application of these micronutrients. The study also observed that 0.4% solution of ZnSO₄ increased the chances of flowering in *Lilium* (Singh *et al.*, 2017). The role of carbohydrates in floral development and reproductive processes, as well as the interaction between sugars and phytohormone signaling, has also been emphasized by Borghi and Fernie (2017) and Sami *et al.* (2019).

Application of Zinc sulfate increased chlorophyll content. This increase in chlorophyll can be explained by the favorable impact of Zinc on the uptake of nitrogen, iron, and other nutrients that are either directly used as the component of chlorophyll or involved in its biosynthesis pathway (Umair Hassan *et al.*, 2020; Anwar *et al.*, 2021). These results are consistent with Shelp *et al.* (2020), who studied that the application of micronutrients through foliage improved yield and nutrient uptake in chrysanthemums plants.

CONCLUSIONS

In this study, the peak flowering of *Zinnia* plants occurred when Zinc (Zn), in concentrations of 0, 0.50, and 0.75%, in combination with benzyl adenine (BA), in concentrations of 0, 50, and 100 mgL⁻¹ Lavanda and Rosso Scarlatta. The research revealed that the *Zinnia* Lavanda variant surpassed the *Zinnia* Rosso Scarlatta variant in the chemical composition, including the content of the main components and colors: nitrogen, phosphorus, potassium, Zinc, etc. These were further improved by 100 mgL⁻¹ BA and 75% Zinc along with anthocyanin pigments, photosynthesis pigments, and carbohydrates. The highest improvement in all the traits studied was observed when *Zinnia* Lavanda plants were subjected to combined treatment of 100 mgL⁻¹ BA and 75% Zinc. These, therefore, indicate that critical growth regulators and levels of micronutrients improve the chemical and physiological characteristics in *Zinnia* varieties.

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Ethical Statement:

This research involved plant materials only and did not involve human participants or animals. The study was conducted in accordance with the research guidelines of the Department of Horticulture, College of Agricultural Engineering Sciences, University of Duhok, Duhok, Iraq.

Conflict of Interests:

The authors declare no competing interests.
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Author Contributions:

B.J.K., N.S.H., L.S.M.: data collection, data curation; L.S.M and A.M.J.: data analysis; B.J.K., N.S.H.: visualization; L.S.M.: writing-original draft; A. Ç.: writing-review and editing, supervision. All authors have read and agreed to the published version of the manuscript.

Data Availability:

Data is available from the corresponding author upon request.

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