Journal of Applied Horticulture, 27(2): 311-317, 2025
https://doi.org/10.37855/jah.2025.v27i02.58
Journal of Applied Horticulture
ISSN: 0972-1045

Effect of foliar application of nano-NPK and nano-micro elements on the growth, flowering, and biochemical composition of *Zinnia elegans*

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Abstract

Zinnia elegans, a widely utilized flowering plant for pots, cut flowers, bouquets, and gardens, necessitates macro- and micro-nutrients for optimal growth, development, and flowering. This study, conducted in 2023 and 2024, aimed to enhance the plant's growth and flowering response through foliar applications of Nano-NPK, Nano-micronutrients, and their combination.The results indicated that all treatments significantly affected the plant growth parameters (plant height, stem diameter, number of leaves, fresh and dry weights and root length) compared to control. In most cases, spraying with Nano-NPK 4 mL/L, and NPK + Nano fmicro-elements (4 mL/L) increased the plant height, formation of leaves and branches per plant, the weights of the leaves, stem thickness to the highestvalues and exhibited the longest roots. The impact of nano fertilizers on flowering revealed that the highest number of flowering heads was recorded in plants treated with Nano-NPK + Nano-micro 2 and 4 mL/L and the largest flowering head size with Nano-NPK+ Nano-micro 4 mL/L. The Nano treatments significantly increased the fresh weight of flowers, especially with the mixture of Nano-NPK + Nano-micro at 4 mL/ L. Compared to the control, using of Nano fertilizers significantly increased all the flowering parameters. All the Nano-treatments significantly increased the contents of chlorophyll-a, b and total chlorophyll, and carbohydrates.

Key words: *Zinnia elegans,* nano-NPK, nano-micro elements, foliar applications, plant growth parameters

Introduction

Zinnia (*Zinnia elegans*), with large, often brightly coloured flowers that tolerate the heat of summer, are commonly grown garden plants that are native to Mexico, New Mexico, Colorado and Chile. Offering crimson to dark purple shades with a long bloom period, this cut flower plant also works in a flower border. Zinnia is an upright plant, ranging from 0.5 m to 70 cm wide, with linear leaves (6-8 cm) arranged oppositely. Flowering heads are orange, yellow, red, or gold from 5-10 cm in size, having coloured, beautiful petals. Zinnia plants grow fast in full sun and well-drained soil, and they bloom best in warm weather, making them a great partner to use in mixed bouquets. Zinnia is a moderately feeding warm-season annual that ideally benefits from light trellising and moderate soil fertility (Maughan *et al.*, 2020). But they are susceptible to boron deficiency which can lead to tip abortion, crinkled leaves and leaf edge burn. To encourage branching, tall varieties may be pinched when young, and old flowers should be removed to promote continued flowering. This plant plays an essential role in the floral industry. While there are 20 species of zinnias, *Zinnia elegans* is the most popular (Larson, 2013).

Nanotechnology has become increasingly important in modern agriculture as an alternative to traditional fertilizers. It has received significant attention for its potential to enhance agricultural production with improved quality, environmental safety, and biological benefits. Foliar fertilization, a popular method of plant nutrition, has been shown to be more efficient, as conventional macronutrients (N, P, and K) applied to soil can be lost in significant amounts (40-70%, 80-90%, and 50-90%, respectively). While nano-fertilizers and foliar fertilization have gained attention, research on the foliar application of nano-fertilizers is still less extensive than that on soil application. Studies have shown that nanoparticles, when used at safe doses, can promote plant development and overall performance. Foliar fertilization is now widely adopted in crop management due to its cost-effectiveness and efficiency. In addition to that, usage and applications of nano-fertilizers improve nutrient use efficiency, further decrease toxicity, minimize chances of negative impacts due to overdosing, and reduces the frequency of application (Sadique *et al.*, 2017). Since nano-fertilizers have very small particle sizes they show better absorption through soil and leaves, leaving minimal residue, while their slow-release style contributes to optimum metabolism. Nano-fertilizers are a green biotechnological option that could minimize reliance on inorganic fertilizers and their adverse environmental effects and can be considered a suitable tool for enhancing growth, flowering, productivity, and product quality in agriculture and horticulture (Zahedi *et al.*, 2020; Mohammadi *et al.*, 2019).

Although nano-NPK and nano-micronutrient fertilizers have been proven effective, only limited studies are available on the effects of nano fertilizers on annual plant growth and flowering. So, this study was done with the aim of investigating the response of Zinnia to foliar spraying of NPK and micro-element nano-fertilizers in terms of nutrient use efficiency along with growth, flowering, and quality characteristics of the plant.

Materials and methods

The present study was conducted over two seasons, 2023 and 2024, to evaluate the effect of Nano-NPK, Nano-micro-elements, and their combination on the growth, flowering, and chemical composition of Zinnia plants under natural conditions at Al-Azhar Park, Cairo Governorate. Zinnia seeds were obtained from the Horticulture Department, Faculty of Agriculture, Cairo University. The study commenced on February 15th and continued until the end of the production period in both seasons. The seeds were sown in perforated black plastic bags (30 cm wide x 40 cm high), filled with a soil mixture of washed sand, light clay soil, and compost in a 3:2:1 v/v/v ratio. Agricultural sulfur (½ kg/m³) was added for soil disinfection. The bags were placed in the nursery at Al-Azhar Park, ensuring exposure to sunlight throughout the day.

Each bag contained 6 kg of the soil mixture (Table 1), and three seeds were sown at a depth of 2 cm. After 21 days, the seedlings were thinned to one per bag. Irrigation was provided as needed.

Nano-NPK (20:20:20) and Nano-micro-elements (Fe, Cu, B) fertilizers were sourced from Nano-Tech Company, 6th October City (Biota Mix). One week after thinning, the plants were subjected to the following Nano-treatments as foliar sprays until the point of run-off: 1) Control, 2) Nano-NPK 2 mL/L (N-NPK-1), 3) Nano-NPK 4 mL/L (N-NPK-2), 4) Nano-micro-elements 2 mL/L (N-Micro1), 5) Nano-micro-elements 4 mL/L (N-Micro2), 6) N-NPK-1 + N-Micro1, and 7) N-NPK-2 + N-Micro2. These treatments were applied biweekly until the appearance of the flowering bud initiation.

Table 1. Physical and chemical properties of the growing mixture

Growing mixture	pH	B.Dg/cm³	WHC %	E.C dS/m	N%	P %
Sand +loam+ compost (3:2:1 v/v/v)	7.2	1.10	35.3	1.32	0.29	0.16

WHC: Water Holding capacity E.C: Electrical conductivity B.D: Bulk density

Data recorded: The growth and flowering parameters viz., plant height (mm), stem diameter (mm), number of leaves per plant, fresh leaf weight (g), dry leaf weight (g), root length (mm), number of flowers per plant, flower diameter (mm), fresh flower weight (g), and dry flower weight (g) were recorded.

Chemical analysis: Chlorophyll-a, chlorophyll-b, and total chlorophyll content (mg/g) were determined according to Saric *et al.* (1976). Total carbohydrate content (% dry weight) was estimated as per Herbert *et al.* (1971). Nitrogen content (dry weight %) was determined using the micro-Kjeldahl apparatus (Blake, 1965), and phosphorus content was measured by the ascorbic acid method as described by John (1970). The contents of potassium, iron, copper, and boron in the leaves were determined using a flame photometer (Dewis and Freitas, 1970).

Statistical analysis: The experimental treatments were replicated three times, with each treatment consisting of six plants (six bags), including six treatments in addition to the control. The obtained data were statistically analyzed using analysis of variance (ANOVA), and the means of treatments were compared using the least significant difference (L.S.D.) test at the 5% level (Snedecor and Cochran, 1989).

Results

Effect of Nano fertilizer on vegetative growth: The data obtained (Table 1) indicated that in both seasons, all Nano treatments significantly increased plant height and leaf formation per plant compared to the control. Additionally, all Nano treatments resulted in significant increases in stem thickness.

The application of Nano-NPK at 4 mL/L and the combined treatment of Nano-NPK + Nano-micro elements at 4 mL/L resulted in the tallest plants in both seasons, measuring 70.3 cm, 69.5 cm, 100.6 cm, and 112.6 cm, compared to 48.5 cm and 45.5 cm for the control plants, respectively.

The treatments of Nano-NPK at 4 mL/L and Nano-NPK + Nano-micro elements at 4 mL/L were the most effective in promoting leaf formation in both seasons. A notable increase in leaf formation in Zinnia plants was recorded with both the Nano-NPK at 4 mL/L and the combined treatment of Nano-NPK + Nano-micro elements at 4 mL/L. Specifically, the combined treatment of Nano-NPK + Nano-micro elements resulted in 91.3 leaves in the first season, while the Nano-NPK treatment at 4 mL/L resulted in 89.6 leaves. In the second season, these treatments resulted in 118.5 and 108.6 leaves, respectively.

A significant increase in stem thickness was also observed in plants treated with Nano-NPK + Nano-micro elements at 4 mL/L and Nano-NPK at 4 mL/L in both seasons. The thickest stems in the first season (9.1 mm) were obtained with the Nano-NPK + Nano-micro elements treatment at 4 mL/L, compared to 5.8 mm in the control group. In the second season, the combined treatment of Nano-NPK + Nano-micro elements increased stem thickness to 11.3 mm, compared to 5.4 mm for the control plants.

Table 2. Effect of Nano-NPK, Nano-micro-elements (NPs) on plant height, No. of leaves, and stem thickness of the *Zinnia* plant during 2023 and 2024 seasons

Treatment	Plant height (cm)	Number of leaves /plant	Stem thickness (mm)
First season (2023)			
Control	48.5	63	5.8
Nano-NPK 2 mL/L (Nano-1)*	67.6	81.3	7.5
Nano NPK 4 mL/L (Nano-2)	70.3	89.6	8.1
Nano-micro 2 mL/L (Nano-3)	65.6	77.6	6.5
Nano-micro 4 mL/ l(Nano-4)	60.6	79.6	6.9
Nano-5 (Nano-1+Nano-3)	68.3	88.6	8.3
Nano-6 (Nano-2 +Nano-4)	69.5	91.3	9.1
LSD 5%	5.6	3.9	0.8
Second season (2024)			
Control	45.5	66	5.4
Nano-NPK 2 mL/L (Nano-1) *	94.0	103.3	7.0
Nano NPK 4 mL/L (Nano-2)	100.6	108.6	7.8
Nano-micro 2 mL/L (Nano-3)	83.3	76.6	7.1
Nano-micro 4 mL/ l(Nano-4)	87.6	81.3	6.9
Nano-5 (Nano-1+Nano-3)	99.3	102	8.2
Nano-6 (Nano-2 +Nano-4)	112.6	118.5	11.3
LSD 5%	5.9	6.7	1.8

*Nano-NPK 2 mL/L (Nano-1)- Nano NPK 4 mL/L (Nano-2)- Nano-microelements2 mL/L (Nano-3)- Nano-micro-elements4 mL/L (Nano-4)- Nano-NPK 2 mL/L +Nano-micro-elements2 mL/L (Nano-5)- and Nano-NPK 4 mL/L +Nano-micro-elements 4 mL/L (Nano-6).

Data indicated (Table 3) that the treatments of all Nano fertilizers showed a significant effect on the formation of branches/plant (except the Nano-micro-elements 2 mL/L compared to the control. The fresh and dry weights of leaves in season two were also, increased due to these treatments. Nano-NPK at 4 mL/L and Nano-NPK + micro-elements 4 mL/ L were the most effective in both seasons in increasing the formation of branches, giving 8.3 and 7.8 branches/plant in the first and second seasons, respectively, against 5.8 for the control and 7.5 and 7.2 branches/ plant, in the second one, respectively, against 5.8 and 3.7 for the control.

The most effective treatments in increasing the weights of the leaves were the treatments Nano NPK 4 mL/L for Fw (61.22g) followed by Nano NPK+ micro-elements at 4 mL/L (55.27g), against (27.33g) for the control plant with percentage increases of 124.0% and 102.23%, respectively. In the second season, there were augmented increases in the fresh weight of leaves due to the application of all treatments with Nano-NPK and Nano-micro-elements and the most effective treatments were the Nano-NPK 4mL/L (80.11 g), followed by Nano-NPK + micro-element 4 mL/L (79.3 g), and the fresh weight for control was 38.80 g. The dry weight of leaves was significantly affected by the different treatments with Nano-NPK or Nano-micro-elements in both seasons over the control. The highest value of dry weight in the first season was11.70 g and in the second one it was 7.5 g/plant, Followed by plants treated with NPK fertilizers + micro-elements 4mL/ L, which amounted to 10.03g, and in the second season, it was 7.2g.

The response of root length to the treatments of Nano-NPK and Nano- Nano-microelements and their combinations (Table 2) indicated that in both seasons, most of the Nano treatments significantly increased the root length as compared with the control, the longest roots in the first season (23 cm) and in the second one (31.9 cm) were obtained from the application of Nano-NPK 4 mL/L alone, as compared with the control which gave roots of 12 and 12.5 cm, in the first and second seasons, respectively.

Table 3. Effect of Nano-NPK, Nano-micro-elements (NPs) on the number of branches fresh and dry weights of leaf and length of the root of *Zinnia* plant, during 2023 and 2024

Treatments	Branches (No)	FW leaves	DW leaves (mg)	Root length (cm)
First season (2023)				
Control	5.80	27.33	4.73	12.00
Nano-NPK 2 mL/L (Nano-1)*	6.90	38.34	6.60	16.20
Nano NPK 4 mL/L (Nano-2)	8.30	61.22	11.70	23.00
Nano-micro 2 mL/L (Nano-3)	6.00	38.09	6.47	13.10
Nano-micro 4 mL/ l(Nano-4)	6.60	40.00	7.73	15.50
Nano-5 (Nano-1+Nano-3)	7.50	54.55	9.45	17.00
Nano-6 (Nano-2 +Nano-4)	7.80	55.27	10.03	18.70
LSD at 5 %	0.60	3.40	2.10	2.90
Second season (2024)				
Control	3.7	38.8	3.7	12.5
Nano-NPK 2 mL/L (Nano-1)*	6.30	65.50	6.30	18.00
Nano NPK 4 mL/L (Nano-2)	7.50	80.11	7.50	31.90
Nano-micro 2 mL/L (Nano-3)	6.30	36.62	6.30	13.70
Nano-micro 4 mL/ l(Nano-4)	6.60	60.44	6.60	19.00
Nano-5 (Nano-1+Nano-3)	6.90	61.00	6.90	21.10
Nano-6 (Nano-2 +Nano-4)	7.20	79.30	7.20	22.00
LSD at 5 %	0.90	3.70	0.90	3.14

Effect on flowering parameters: The response of number of flowering heads/plant to the application of Nano-fertilizer treatments either with Nano-NPK or Nano-microelements(Table 4) showed that the highest number of flowering heads (15.3 and 17.0/plant) in the first and second seasons, respectively was formed in plants treated with Nano-NPK +Nano-micro 4 mL/ L, followed by the application of Nano-NPK +Nano-micro 2 mL/ L, in the first season (15 flowers)and Nano-microelements 4 mL/L, in the second one (16.1 flowers). Whereas, the lowest value in the first season was 8 flowers and in the second one was 8.6 flowers for the control plants.

The obtained data (Table 4) concerning the average flower diameter mm indicated that in the first season, treating plants with Nano NPK+ Nano-micro 4 mL/L was the most effective treatment on increasing the flower size to the highest value (7.6cm), followed by the treatment of Nano NPK +Nano-micro 2 mL/L (7.0 cm) then Nano NPK at 4 mL/L (6.7cm), the smallest value for flower diameter (5.1 cm) was measured for the control plants. In the second season, treating plants with Nano NPK at 4 mL/L alone or combined with Nano-micro 4 mL/L, was the most effective in increasing the flower diameter to the highest value (6.8 and 7.0 cm, respectively), followed by the treatments of Nano NPK +Nano-micro 2 mL/ L(6.6 cm), the smallest flower size 3.7 cm was for the untreated plants.

Table 4. Effect of nano-NPK, nano-micro-elements (NPs) on the characteristics of the flower of *Zinnia* plant during the 2023 and 2024 seasons

Treatments	Number of flowering heads	Flower diameter (cm)	FW (g) flower	DW (g) flower
2023				
Control	8.0	5.1	3.95	0.8
Nano-NPK 2 mL/L (Nano-1)*	11.0	6.3	4.81	0.91
Nano NPK 4 mL/L (Nano-2)	13.3	6.7	5.23	1.06
Nano-micro 2 mL/L (Nano-3)	14.9	6.1	4.85	0.93
Nano-micro 4 mL/ l(Nano-4)	14.8	6.1	4.30	0.76
Nano-5 (Nano-1+Nano-3)	15.0	7.0	5.93	1.07
Nano-6 (Nano-2 +Nano-4)	15.3	7.6	6.62	1.33
LSD at 5 %	1.3	0.7	0.53	0.21
2024				
Control	8.6	3.7	3.29	0.61
Nano-NPK 2 mL/L (Nano-1)*	13.4	5.6	4.73	0.83
Nano NPK 4 mL/L (Nano-2)	15.4	6.8	5.39	1.13
Nano-micro 2 mL/L (Nano-3)	14.2	5.8	3.86	0.65
Nano-micro 4 mL/ l(Nano-4)	15.4	6.2	4.1	0.69
Nano-5 (Nano-1+Nano-3)	16.1	6.6	5.16	1.11
Nano-6 (Nano-2 +Nano-4)	17.0	7.0	6.25	1.27
LSD at 5 %	2.7	1.1	0.5	0.32

In Table 4, the obtained data indicated that in both seasons all the Nano treatments used in this study (except nano-microelements 2mL/L in the first season) significantly increased the fresh weight of flowers as compared with the control. The heaviest fresh weights in the first season (6.62 g) and in the second one (6.25 g) were obtained from the application of the combined treatment of Nano NPK + Nano-micro at 4 mL/ L. In contrast, the control plants resulted in the lowest fresh weight 3.95 and 3.29g for the first and second seasons, respectively.

Data in Table 4 indicated that the treatments of Nano NPK + Nano-micro 4 mL/L and Nano NPK alone 4 mL/L significantly increased the dry weight of flowers as compared with the control. The heaviest dry weights in the first season (1.33 g) and in the second one (1.27g) were obtained with the combined treatment of Nano-NPK + Nano-micro at 4 mL/ L, whereas the control plants gave the lowest dry weights, 0.80 and 0.61 g, respectively.

Effect on chemical composition: The response of the contents of chlorophyll- a, - b and total chlorophyll to the application of Nano-fertilizer: Nano-NPK- and Nano-microelements (Table 4) showed that, in both seasons, all the treatments significantly increased the contents in comparison with the control. The impact of the foliar applications of Nano- fertilizer, Nano-NPK and Nano-microelements on the contents of carbohydrates in the different plant parts revealed that there was a significant increase with the application of these treatments in both seasons.

The contents of chlorophyll-a, b and total chl. recorded the highest values (2.387, 1.015 and 1.373 mg/g fw) in the first season with the application of Nano-NPK combined with micro-elements 4 mL/ L, followed by Nano-NPK at 4 mL/L (2.203, 0.929 and 1.278, respectively). A similar trend was obtained in the second season also. Raising the concentration of the treatments markedly increased chlorophyll contents.

In the case of stem carbohydrate content, both seasons showed increases due to the application of Nano-fertilizers, which were significant, except the application of Nano-micro-fertilizer either at 2 or 4 mL/L alone, but it was significant, in the combined treatments with Nano-NPK. The contents reached to the highest value in the first season in stems (25.1%) with Nano-NPK alone and in the second one (23.9%) with the combined treatment of Nano-NPK + minor elements 4 mL/ L.

In both seasons, the contents of carbohydrates in the roots in response to the foliar application of Nano-fertilizers (Table 4) indicated that the significant highest increase in root content of carbohydrates was recorded with Nano-NPK 4 mL/ L. 22.4 in the first season and 23.2 in the second season.

The impact of the foliar applications of Nano-fertilizers on the content of carbohydrates in flowers revealed that it ranged between 20.2 and 25.9 % in the first season and from 19.5 to 27.8 %, in the second one, treating zinnia plant with Nano- NPK at 4 mL/L combined with micro- elements 4 mL/ L, resulted in the highest significant increase and the flowers of the control gave the lowest values, in both seasons.

Concerning the contents of N, P and K in the leaves (Fig. 1), in response to Nano-fertilization, it can be revealed that the nitrogen content the highest value of plant response to nano-fertilizers in the first season was for plants that were sprayed with NPK + micro-elements fertilizers at a concentration of 4 mL/L and 2 mL/ L, and recorded 1.757% and 1.610%, respectively. In contrast, the control plants had the lowest values. In the second season, the highest values were for plants treated with NPK fertilizer + micro-elements at a concentration of 4 mL/L, followed by plants sprayed with NPK fertilizers alone, recording 1.622%, and the control plants had the lowest.

In the first season, the treatments of Nano NPK 4 mL/ L and NPK + micro-elements 4 mL/L were the most effective in increasing the leaf content of phosphorus; it produced the highest P-content in the leaves in both seasons and the control plants contained the lowest K-values. The impact of the foliar applications of Nano-fertilizer: Nano-NPK and Nano-microelements on the leaf content of potassium revealed that in both seasons, the highest contents of K were obtained with the applications of Nano NPK mL/L and Nano-NPK + micro-element 4 mL/L, and the control plants contained the lowest K-values.

Regarding the leaf contents of Fe, Cu and B, it can be observed that the Fe and B contents were the highest when zinnia plants were treated with the foliar applications of micro-element 4 mL/L, followed by Nano micro-elements 2 mL/L, the control plants contained the lowest Fe and B values (Fig. 2). The Cu content in the leaves reached the highest values with Nano micro-elements 4 mL/ L, followed by the Nano-NPK + Nano-micro-element 4 mL/ L.

Discussion

Zinnia plants are sensitive to deficiency of boron and nutrition plays a key role in plant growth, development and flowering. The response of Zinnia to the foliar application of Nano-NPK and Nano-micro elements, either individual or in the combined mixture, in our study indicated that all treatments of nano-fertilizers significantly affected the plant growth parameters (plant height, stem diameter, No. of leaves, fresh and dry weights and root length) compared to control. Moreover, our results indicated that in most cases, Nano NPK at 4 mL/L and NPK + Nano micro-elements (4 mL/L) increased the plant height and the formation of leaves and branches per plant, the weights of the leaves, stem thickness to the highest values, plants exhibited the longest roots with Nano NPK 4 mL/L when applied alone.

These effects can be attributed to the known fact that nano-fertilizers (NFs) are materials with small size (1-100 nm) that support the nutrition the plants (Avila-Quezada *et al*, 2022), could improve the nutrient use efficiencies, reduce nutrient loss and consequently increase the plant growth (Kumar *et al.,* 2021).

Table 5. Effect of nano-NPK, nano-micro-elements on the leaf contents of chlorophylls (mg/ g FW), and total carbohydrates (% DW) of different parts of *Zinnia* plants during 2023 and 2024

Treatment	Chlorophyll			Total carbohydrates (DW%)				Chlorophyll			Total carbo-hydrates (DW%)			
	a	b	Total	Leaf	Stem	Root	Flower	a	b	Total	Leaf	Stem	Root	Flower
	2023							2024						
Control	0.869	0.768	1.637	20.8	21.7	17.4	20.2	0.725	0.768	1.492	21.7	19.3	17.8	19.5
Nano-1*	1.209	0.897	2.106	24.6	24.6	20.9	23.2	1.008	0.897	1.905	23.8	22.7	21.5	22.3
Nano-2	1.278	0.929	2.203	26.2	25.1	22.4	25.7	1.059	0.929	1.988	26.4	23.3	23.2	25.6
Nano-3	1.035	0.779	1.805	24.4	23.5	19.3	23.3	0.862	0.77	1.633	24	20.8	18.9	23.6
Nano-4	1.083	0.806	1.886	24.9	22.9	18.6	23.4	0.903	0.806	1.709	24.7	19.7	20	23
Nano-5 (Nano-1+Nano-3)	1.189	0.882	2.075	24.7	24.4	21	23.5	0.991	0.882	1.874	25.1	22.3	21.3	24.1
Nano-6 (Nano-2 +Nano-4)	1.373	1.015	2.387	26	24.7	21.9	25.9	1.144	1.015	2.159	26.3	23.9	22	27.8
LSD 5%	0.228	0.201	0.341	2.2	2.6	2.7	3	0.305	0.135	0.278	1.9	2.1	2.5	2.6

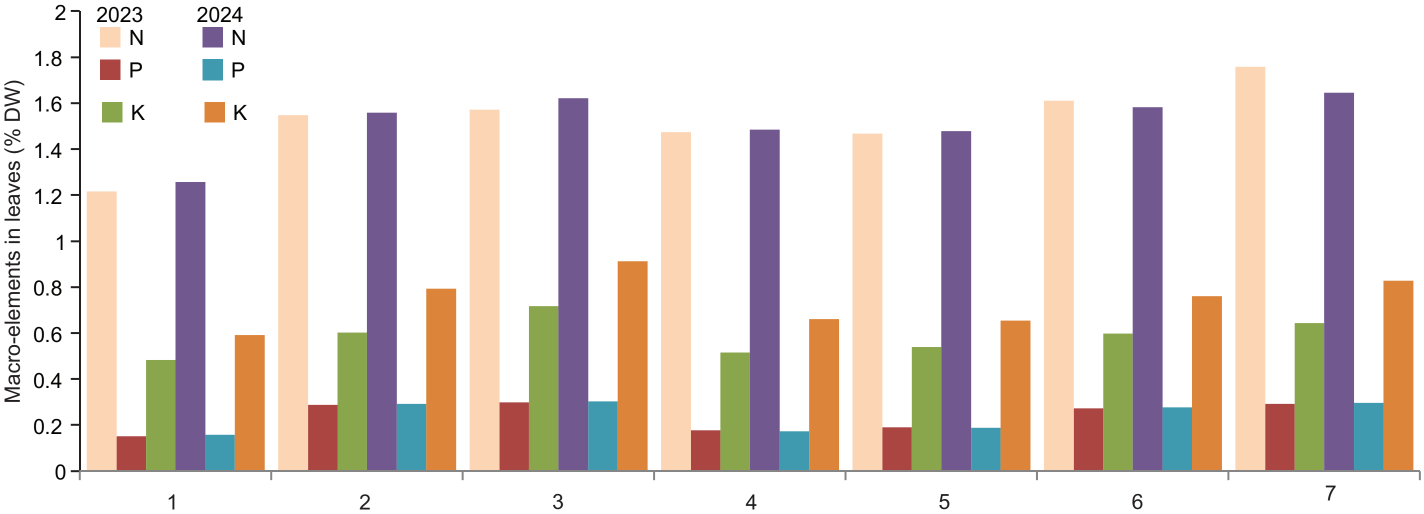

Fig. 1. Effect of nano-NPK, nano-microelements on the contents of N, P and K (%DW) in the leaves of *Zinnia* plant during 2023 and 2024 seasons

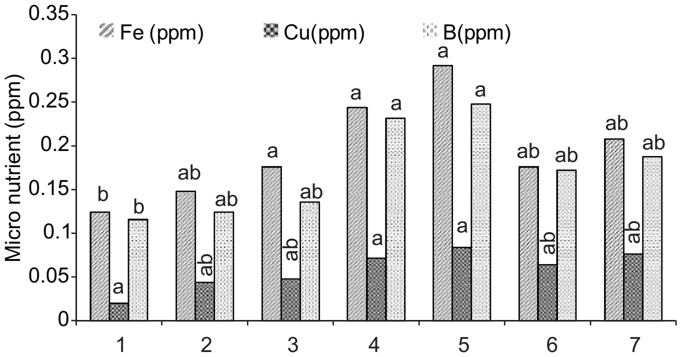

Fig. 2. Effect of Nano-NPK and Nano-microelements on the leaf content of microelements (Fe, Cu and B: in ppm): 1-Control- 2-Nano NPK at 2 mL/L, 3-Nano NPK at 4 mL/L, 4-Microelements 2 mL / 5-

Using micro-NP promoted plant growth by increasing chloroplast numbers and promoting antioxidant activity (Yuan *et al.,* 2018). Micronutrients perform an essential function in many plant processes, including metabolism, nutrition, reproductive growth regulation, chlorophyll synthesis, carbohydrate biosynthesis, and more. They increase the production and translocation of photosynthates to various plant parts by these nanoparticles because of their larger surface area than traditional fertilizers, nanoparticles are absorbed more efficiently, improving the vegetative as well as flowering parameters (Hayam *et al.,* 2024a).

Nano-fertilizers can optimize the nutrient supply and can be considered an economical alternative to chemical fertilizers (Josef and Katarína, 2015). It could increase the quality of various horticultural plants as reported by Mandal *et al.*(2021); Alhasan *et al.* (2021) and El-Saadony *et al.* (2021). They attributed this improvement to the chemical and physical properties of nano-molecules. Farsi *et al.* (2015) on chamomile plants indicated that foliar spraying of nano treatments significantly increased plant height, branch formation, fresh weight and length of roots. Also, Kamali *et al.* (2023) on *Echinacea purpurea* showed that using of nano-bio fertilizer resulted in the highest root growth. The marked efficiency of the nano-fertilizers in increasing the formation of leaves can probably due to its effect on enhancing enzymes (Raliya and Tarafdar 2013). Because of their tiny size and huge surface area, nano-fertilizers improve the absorption surface, which in turn increases the rate of photosynthesis and increased active compounds in plants, which is one of many advantages of utilizing nano-fertilizers (Hayam et al., 2024a; 2024b).

On the other hand, the results of the studies showed that the addition of the triple NPK fertilizer in the form of nano had a positive effect in improving the plant content of N, P, and K in the plant, which had a role in increasing plant growth parameters. Using nano-N-fertilizer and nano-P has a very high efficiency, rapid release and direct absorption by plants. This superiority may be due to the higher surface area than conventional fertilizers. Also, its small particle size gives it a wide surface area, expands the effective area of the reaction and boosts enzyme efficiency as well as increases great number of biochemical reactions and increases the number of cell divisions (Haydar *et al.,* 2024).

Compared to the control, using Nano fertilizers significantly increased all the flowering parameters. It can be mentioned that Nano fertilizers are quickly absorbed by the leaves, causing the presence of sufficient nutrients, increase in chlorophyll formation, enzyme activity and photosynthesis rate, photosynthetic materials and plant dry matter, which increase the formation of branches and ultimately lead to increased flowering and improved flowers production per plant, which is consistent with the results of Mousavi *et al.* (2015). Also, Naeij *et al.* (2023) indicated the smaller dimensions of nano-fertilizers have led to more and faster absorption of nutrients and consequently increase the efficiency of fertilization. Moreover, this effect can be attributed to the role of nano-particles in improving nutrient use efficiency, which reduces nutrient loss which increases plant growth and consequently flowering traits (Kumar *et al.,* 2021), or to increasing chloroplast numbers and chlorophyll content (Yuan *et al.,* 2018). In this regard, Asgari *et al.* (2014) on the narcissus plant stated that Nano-fertilizers could optimize the nutrient supply, and found that nano-potassium as spraying at 2.5 g/L produced the maximum number of flowers and nano-K at 1g/L increased its inflorescence diameter. On *Eustoma* cv. Mariachi Blue, Mohammadi (2019) stated that Nano-ZnO increased the production of flowers and induced early flowering. Moreover, Abdul Azeez *et al.* (2020) on freesia found that nano-K and Fe-fertilizers at 2 g/L, decreased days to first floret opening but increased the fresh weight of flowers. Meanwhile, using 1g/L nano-NPK significantly increased the spike's fresh and dry weights and flower size of gladiolus. (Sarhan *et al.,* 2022). On sunflower, Almayali *et al.* (2020) reported that using nano-Zn oxide induced early flowering.

Salih and Kamall-Eldeen (2021), on two types of rose found that spraying with nanoparticles was superior in all flower characters, producing the highest number of flowers/ plant and weight and flower diameter. Treating gladiolus with nano-iron at 0.25g/L gave the longest spikes and largest flower diameter (Velisala and Prasad, 2022). Recently, Nofal *et al.* (2024) found that nano-NPK and nano-micronutrients increased the number of *Tecoma stans* inflorescences and florets/inflorescence.

In both seasons (Table 4) all the Nano-fertilization treatments significantly increased the contents of chlorophyll-a, b and total chlorophyll, and the highest contents were recorded in plants treated with Nano-NPK +micro-elements 4 mL/ L, followed by Nano-NPK at 4 mL/ L. The contents of carbohydrates in the different plant parts were also significantly increased with these treatments, in comparison with the control.

The treatment of Nano NPK + micro-elements 4 mL/L and NPK alone 4 mL/L was the most effective in increasing the N-content, also. In contrast, Nano NPK + micro-elements 4 mL/L and NPK alone 4 mL/L were the most effective in increasing the leaf P-content. Meanwhile, the highest K-contents were obtained in plants treated with Nano NPK 4 mL/L and Nano-NPK + micro-element 4 mL/ L. Regarding the leaf contents of Fe, Cu and B (Fig.1), it can be observed that the Fe, Cu and B contents were the highest in *Zinnia* plants treated with Nano-micro-elements 4 mL/ L, followed by 2 m/L. This result can be attributed to the role of nano-particles on improving nutrient use efficiency and reduction in nutrient loss, which increases its contents in plants. In this regard, total chlorophyll, total carbohydrate, iron content were significantly enhanced with Nano-treatments, as reported by Rostami *et al.* (2018) on saffron (*Crocus sativus*) found that the effects of nano-fertilizers of (Fe, B, Mn, K and Zn) on relative water content, protein and total sugars were significant and non-significant on chlorophyll b, carotenoids, catalase and peroxidase activity, the highest amount of chlorophyll was measured in Fe, Mohammadi (2019) on *Eustoma grandiflorum* (using nano ZnO), Salih and Kamall-Eldeen (2021) on rose reported that nanoparticles gave the highest concentration of N and K nutrients in the leaves and carbohydrate content, while Sarhan *et al.* (2022) on gladiolus they found positive effects of nano-treatments on as leaf content of minerals. Al-Hamad *et al.* (2022) reported that spraying broccoli with nano-microelements (1% zinc, 9% iron, and 1% manganese) at 1.5 mL L^{-1} significantly and favorably affected the protein, carbohydrates NPK (%), flavonoids and phenols. Using 150 mg L^{-1} of Fe-NPs produced the highest result of carotenoid and total chlorophyll content, according to El-Shawa *et al.* (2022) on philodendron plants. On *Solidago virgaurea,* Ahmed *et al.* (2023) reported that foliar spraying of Fe-nanoparticles resulted in the highest contents of N, P, K and Cu. Moreover, Nofal *et al.* (2024) on *Tecoma stans* treated with nano (NPK and micronutrients) stated that all treatments increased the contents of chlorophyll a and b, total carotenoids, mineral N, P, and K, peroxidase and catalase activity in the leaves, 2 mL/L of nano-NPK + 1.5 mL of nano-micronutrients produced the most significant contents.

Several studies reported that utilizing nano-fertilizers could control the release of nutrients, making them more efficient and cost-effective than traditional fertilizers. They are designed to deliver plant nutrients in a controlled manner, ensuring that the nutrients are gradually released over an extended period, thus providing a steady supply of essential elements to the plants, it is composed of microscopic particles, enabling them to penetrate deeper into the leaf tissue causing a higher absorption rate than traditional fertilizers, delivering nutrients more quickly and efficiently in plants, they improve nutrient utilization, controlled nutrient release, targeted nutrient delivery, reduced nutrient loss and boosts hormone synthesis (Hong *et al.,* 2021; Yadav *et al.,* 2023 and Kamali *et al.,* 2023).

Based on the findings of the present study, spraying *Zinnia* with nano-NPK fertilizer alone or Nano-NPK+ Nano-microelements for the better growth and flowering traits, biochemical, and physiological parameters can be recommended.

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Received: February, 2025; Revised: April, 2025; Accepted: April, 2025