Response of single and triple female cucumber hybrids to different levels of nano-zinc under protected cultivation conditions

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Abstract

This study was conducted during the 2025–2026 growing season in an unheated plastic house belonging to the College of Agriculture / University of Anbar, to evaluate the response of some single and triple female cucumber hybrids to spraying with nano zinc oxide under protected cultivation conditions. The experiment included 5 female hybrids and 3 levels of nano-zinc (0, 50, and 100 mg L^{-1}), and it was implemented as a factorial experiment arranged in a split-plot within a randomized complete block design (RCBD) with three replicates. The results revealed significant superiority of the single hybrid V1 compared other hybrids, recording the maximum plant length of 296.89 cm, the highest leaf zinc concentration of 164.64 mg kg^{-1}, high fruit number (43.03 fruit $plant^{-1}$) and total yield (4.330 t $greenhouse^{-1}$), compared with the lowest values recorded by the triple hybrid V4. The nano-zinc spray level at a dose of 100 mg L^{-1} (Zn2) also showed significant superiority in plant length, reaching 305.72 cm, and leaf zinc concentration (194.01 mg kg^{-1}), in addition to its superiority in fruit number (41.67 fruit $plant^{-1}$) and total yield (4.229 t $greenhouse^{-1}$), compared to control treatment Zn0, that achieved the least values for these traits. The interaction Zn2V1 achieved the highest values in plant length (317.22 cm), zinc concentration (269.60 mg kg^{-1}), fruit number (47.78 fruit $plant^{-1}$), and total yield (4.920 t $greenhouse^{-1}$), compared with Zn0V4 treatment, which confirms the efficiency of this interaction in improving cucumber productivity. The results indicate the importance of adopting single hybrids with nano-zinc spraying to improve cucumber productivity under protected cultivation conditions.

Keywords: Nano zinc oxide, Cucumber hybrids, Protected cultivation, Fruit yield

Introduction

Cucumber (*Cucumis sativus* L.) belong to Cucurbitaceae family. Studies have indicated that the original habitat of this crop is South Asia, before it gradually spread to different regions of the world [1]. Cucumber fruits are characterized by high water concentration, as water constitutes the largest proportion of the fresh fruit weight, in addition to containing important mineral elements such as Ca, P, and K, and some vitamins [2]. Recent studies have shown that cucumber has nutritional and health importance because it contains nutrients and bioactive compounds that contribute to supporting human health, as well as its role in hydrating body cells and regulating some physiological processes [3]. Cucumber fruits are considered a rich dietary source of several important vitamins, especially vitamins K and C and some B-group vitamins, which enhances their nutritional value within healthy dietary systems [4].

Cucumber hybrids, especially single hybrids (produced from crossing two pure lines that are genetically distant), are among the important components of protected cultivation, as they are characterized by plant uniformity, strong vegetative and fruit growth, and high fruit quality when appropriate crop management is applied inside greenhouses, which is positively reflected in production efficiency and stability of performance [5, 6]. Sources indicate that triple cucumber hybrids (produced from crossing a pure line with a single hybrid without repeating any line in the crossing) are among the components for increasing growth and production in the protected environment and are adopted in improvement programs for this crop, due to their role in benefiting from genetic diversity and improving some traits related to growth and production, in addition to their contribution to achieving stability of field performance [7, 8].

The season of growth and production of vegetable crops (cucumber in particular) in the protected environment under the conditions of Iraq is characterized by its short duration, which requires adopting effective nutritional programs that ensure providing the nutritional requirements of the plant within a short time period, in a manner that achieves the best growth and yield for the cucumber crop and reduces the amount of fertilizer used, which reduces production costs. Among the most efficient nutritional programs that suit the short growing season is the use of nutrient elements in their nano-form.

Nanotechnology is considered one of the modern techniques in plant nutrition, as the small size of the fertilizer particles used contributes to increasing the efficiency of element absorption compared with the conventional form of the same element, and this technology also contributes greatly to reducing the amount of fertilizer used, which markedly reduces production costs [9]. One of the most important elements used in foliar nutrition in the protected environment is nano-zinc, which is characterized by high efficiency compared with conventional zinc. The small size of its particles increases the effective surface area, improves its absorption and translocation within the plant, and reduces losses. Nano-zinc also contributes to supporting some physiological processes such as enzyme activation and improving photosynthetic efficiency, which is positively reflected on growth and yield, especially under protected cultivation conditions [10]. Accordingly, the study aims to:

1. Evaluate the field performance of single and triple cucumber hybrids under different levels of nano-zinc spraying inside greenhouses.
2. Determine the best hybrids and the best nano-zinc concentration that achieves the highest growth and yield under protected cultivation conditions.

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Materials and Methods

The experiment was conducted at the College of Agriculture, University of Anbar, Ramadi, in unheated plastic houses located in the Department of Horticulture and Landscape Engineering. The site is geographically situated at latitude 33.4263° N and longitude 43.3332° E in Ramadi city. The experiment was initiated on 1/9/2025 with the preparation of the plastic house, and all necessary operations were carried out to remove residues from the previous crop and weeds. Organic fertilizers were applied according to the fertilization practices adopted under Iraqi greenhouse conditions [11]. The fertilizer recommendation for cucumber was applied as stated by Al-Sahhaf *et al.* [12], where the addition of 260 kg urea ha^{-1}, 340 kg superphosphate ha^{-1}, and 100 kg K fertilizer ha^{-1} was adopted, with the implementation of insect and fungal control as a preventive measure and as needed.

The plastic house was split into 5 beds measuring 80 cm wide and 42 m long along the plastic house (with spaces left between one bed and another). The plastic house was fitted with a GR drip irrigation system, with two lines per bed and a distance of 40 cm between one dripper and another. After that, the beds were covered with black polyethylene (mulch). The greenhouse was divided into 45 experimental units, each measuring 2.80 m in length. The seedlings were planted in two rows on each bed. with a spacing of 40 cm between plants, with 14 plants experimental $unit^{-1}$.

The study included planting five female hybrids (locally produced) of cucumber, consisting of three single hybrids and two triple hybrids. Hybrids seeds planted in cork trays in a peatmoss medium, and the trays and the medium were disinfected with a fungicide before sowing. After the emergence of the second true leaf, the saplings were transferred to the plastic house for planting on the designated beds for cultivation. The ridges were covered with black plastic mulch to suppress weed growth around the plants. Weeds that emerged in the uncovered spaces between ridges were removed manually whenever necessary to avoid competition. All recommended service operations in protected cultivation were carried out according to standard practices [13], including fertilization, hoeing between ridges, and training the plants on one stem only. All lateral branches were pruned, in addition to removing the lower leaves close to the soil surface to improve ventilation and reduce disease incidence.

The study included two factors:

1. Single and triple female hybrids, numbering (5); where 3 single hybrids and two triple hybrids produced by the Department of Horticulture and Landscape Engineering were planted.
2. Spraying with nano zinc oxide ZnO at three levels (0, 50, 100 mg L^{-1}) [14], with three sprays: The plants were sprayed 10 days apart before the appearance of flowers (one month after planting). The plants were sprayed in the early morning until complete wetting, and a plastic barrier was used to separate the treatments to avoid overlap in spraying the nutrient.

The field study was implemented as a factorial experiment with a split-plot arrangement within RCBD with three replicates, where the nano-zinc spray levels allocated to main plots while the hybrids were allocated to subplots. Means were tested by least significant difference test at 5% level of significance using the statistical package GenStat for Windows. After the plants reached the fruiting stage, the yield was harvested at the rate of one harvest every three days. Growth and yield data were taken as shown below.

Vegetative growth traits:

Five plants were chosen at random to assess vegetative growth characteristics per experimental unit, which consisted of the following.:

Plant length (cm): Measure the plant length (cm) from the base of the stem where it meets the soil to the tip of the apical meristem at the end of the plant's growth season.

Total nodes per plant (node plant^{-1}): it was measured at the end of the growth season by. Count the nodes found solely on the main stem.

Leaf area (LA) (dm^2 plant^{-1}): By collecting three leaves from different positions of each plant (lower, middle, upper). The leaf area was measured using the Digimizer program following method of as stated by Sadik *et al.* [15] "

LA (dm^2 plant^{-1}) = LA × mean number of leaves plant^{-1}."

Chemical analysis traits, which included:

Leaf zinc concentration (mg g^{-1}): according to the method of Davis [16] using an Atomic Absorption Spectrophotometer (AAS).

Results and discussion

Total leaf chlorophyll concentration (mg L^{-1}):

Total chlorophyll concentration was estimated followed the procedure of Arnon [17] by the extraction method in the presence of acetone at a concentration of 80%, then the optical absorbance of the extract was assessed using a spectrophotometer at wavelengths of 645 and 663 nm. After that, total chlorophyll concentration (mg L^{-1}) was calculated based on the equation indicated by Arnon [17], as follows:

Total Chlorophyll (mg L^{-1}) = 20.2 × D_{645} + 8.02 × D_{663}

D_{645} = optical absorbance at a wavelength of 645 nm

D_{663} = optical absorbance at a wavelength of 663 nm"

Yield traits, which included**:**

Number of fruits per plant (fruit plant^{-1}):

It was measured by counting the number of fruits per experimental unit during the production season and dividing it by the plant number per experimental unit.

Plant yield (kg plant^{-1}):

$$\text{Plany yield} = \frac{\text{yield of experiment unit}}{\text{number of plants}}$$

Plastic house yield (ton plastic house^{-1}):

Plastic house yield was assessed by (yield of one plant × the total number of plants in the plastic house) / 1000 so that the result is ton plastic house^{-1}.

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The results indicated significant and clear differences among the studied hybrids in all traits under investigation (Table 1). The single-cross hybrid V1 showed significant superiority and achieved the highest values for plant length, node number, leaf area, leaf zinc concentration, total chlorophyll plant^{-1}, fruit number, plant yield, and total yield, reaching (296.89 cm, 34.73 node plant^{-1}, 131.90 dm^2, 164.64 mg kg^{-1}, 194.48 mg 100 g^{-1} fresh weight, 43.03 fruit plant^{-1}, 3.497 kg plant^{-1}, and 4.330 t greenhouse^{-1}, respectively), compared with the least values achieved by the triple hybrid V4, which were (278.90 cm, 30.49 node plant^{-1}, 114.00 dm^2, 101.11 mg kg^{-1}, 156.32 mg 100 g^{-1} fresh weight, 35.65 fruit plant^{-1}, 2.890 kg plant^{-1}, and 3.469 t greenhouse^{-1}, respectively). This variation is due to the genetic differences among the hybrids and their different capacity for vegetative growth and yield formation, and this agrees with Altamari et al. [18], who indicated the presence of clear significant differences in growth and yield traits among several single and triple cucumber hybrids.

Table 1. Effect of single and triple hybrids on the growth and yield of cucumber under protected cultivation conditions

Hybrid	Plant length (cm)	Number of nodes	Leaf Area (dm^2 plant^{-1})	Zinc concentration (mg g^{-1})	Chlorophyll mg L^{-1}	Number of fruits plant^{-1}	Plant yield (kg plant^{-1})	Total yield (t house^{-1})
V1	296.89	34.73	131.90	164.64	194.48	43.03	3.497	4.330
V2	287.88	33.07	120.82	136.77	165.16	39.82	3.276	3.931
V3	290.88	33.89	127.25	143.20	182.81	40.59	3.246	4.060
V4	278.90	30.49	114.00	101.11	156.32	35.65	2.890	3.469
V5	284.42	31.58	117.26	106.50	162.16	36.91	3.010	3.611
LSD $_{(0.05)}$	1.74	0.30	1.542	1.791	3.98	0.88	0.238	0.097

The results revealed the presence of significant differences among the levels of nano-zinc spraying. The highest concentration (Zn2) showed superiority and reached the peak values in the growth and yield traits (plant length, number of nodes, leaf area, zinc concentration, chlorophyll concentration, number of fruits, plant yield, and total yield), reaching (305.72 cm, 34.77 node plant^{-1}, 129.75 dm^2, 194.01 mg kg^{-1}, 184.26 mg 100 g^{-1} fresh weight, 41.67 fruit plant^{-1}, 3.376 kg plant^{-1}, and 4.229 t greenhouse^{-1}, respectively), compared with the least values achieved by the control treatment 270.23 cm, 30.44 node plant^{-1}, 114.20 dm^2, 79.08 mg

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kg^{-1}, 159.47 mg 100 g^{-1} fresh weight, 37.69 fruit plant^{-1}, 3.014 kg plant^{-1}, and 3.617 t greenhouse^{-1}, respectively.

The superiority of the spraying treatment at 100 mg L^{-1} is attributed to the physiological role of nano-zinc, as it contributes to enhancing vegetative growth of the plant by activating many enzymes associated with cell division processes and cell elongation, in addition to its role in regulating auxin biosynthesis, which leads to enhance the efficiency of vegetative growth. This was positively reflected in leaf chlorophyll concentration due to the role of zinc in stabilizing plastid membranes and activating the enzymes responsible for chlorophyll formation, which contributed to raising the efficiency of photosynthesis, and consequently increasing yield and its components. The enhancement in chlorophyll concentration is associated with the photosynthetic efficiency of the plant [19]. These finding agree with those results of Gupta et al. [20], Nisar et al. [21], and Hussein and Khalaf [14], who indicated the positive role of zinc, especially when used in modern forms, in improving vegetative growth and yield traits of cucumber cultivated in protective conditions.

Table 2. Effect of nano-zinc levels on the growth and yield of cucumber under protected cultivation conditions

Zinc level	Plant length (cm)	Number of nodes	Leaf Area (dm² plant^{-1})	Zinc concentration (mg g^{-1})	Chlorophyll mg L^{-1}	Number of fruits plant^{-1}	Plant yield (kg plant^{-1})	Total yield (t house^{-1})
Zn0	270.23	30.44	114.20	79.08	159.47	37.69	3.014	3.617
Zn1	287.44	33.04	122.79	118.24	172.82	38.25	3.162	3.794
Zn2	305.72	34.77	129.75	194.01	184.26	41.67	3.376	4.229
LSD (0.05)	**1.85**	**0.22**	**3.26**	**5.413**	**7.29**	**1.25**	**0.108**	**0.101**

The results revealed that the two-way interaction between the hybrids and the nano-zinc concentrations was significant (Table 3). The Zn2V1 treatment was superior and achieved the highest values in the traits (plant length, number of nodes plant^{-1}, leaf area, zinc concentration, chlorophyll concentration, number of fruits plant^{-1}, plant yield, and total yield), reaching (317.22 cm, 36.60 node plant^{-1}, 138.78 dm², 269.60 mg kg^{-1}, 211.03 mg 100 g^{-1} fresh weight, 47.78 fruit plant^{-1}, 3.765 kg plant^{-1}, and 4.920 t greenhouse^{-1}, respectively), compared with the least values reported by the control treatment for the triple hybrid Zn0V4, which achieved the least values of 267.04 cm, 28.73 node plant^{-1},

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107.18 dm², 67.87 mg kg⁻ ¹, 149.30 mg 100 g⁻ ¹ fresh weight, 34.12 fruit plant⁻ ¹, 2.684 kg plant⁻ ¹, and 3.223 t greenhouse⁻ ¹, respectively.

Table 3. Effect of the interaction between hybrids and nano-zinc levels on the growth and yield of cucumber under protected cultivation conditions

Interaction treatments	Plant length (cm)	Number of nodes	Leaf Area (dm² plant⁻ ¹)	Zinc concentration (mg g⁻ ¹)	Chlorophyll mg L⁻ ¹	Number of fruits plant^{-1}	Plant yield (kg plant⁻ ¹)	Total yield (t house⁻ ¹)
Zn0V1	274.82	31.87	124.14	96.57	178.53	40.61	3.317	3.980
Zn0V2	269.53	30.60	111.58	76.23	152.77	38.33	3.046	3.657
Zn0V3	270.99	31.40	118.74	83.07	163.23	39.49	3.190	3.830
Zn0V4	267.04	28.73	107.18	67.87	149.30	34.12	2.684	3.223
Zn0V5	268.78	29.60	109.35	71.67	153.53	35.88	2.832	3.397
Zn1V1	298.64	35.73	132.78	127.77	193.87	40.69	3.409	4.090
Zn1V2	287.49	33.53	120.47	118.67	165.47	38.89	3.210	3.853
Zn1V3	290.23	33.93	127.58	125.07	185.67	38.72	3.231	3.877
Zn1V4	277.73	30.47	115.05	108.07	156.30	36.32	2.961	3.557
Zn1V5	283.10	31.53	118.09	111.63	162.80	36.61	2.996	3.593
Zn2V1	317.22	36.60	138.78	269.60	211.03	47.78	3.765	4.920
Zn2V2	306.61	35.07	130.41	215.40	177.23	42.24	3.571	4.283
Zn2V3	311.42	36.33	135.44	221.47	199.53	43.55	3.317	4.473
Zn2V4	291.94	32.27	119.78	127.40	163.37	36.52	3.025	3.627
Zn2V5	301.39	33.60	124.36	136.20	170.13	38.24	3.202	3.843
LSD $_{(0.05)}$	3.012	0.50	N. S	5.417	8.41	1.662	N. S	0.167

The significant interaction between the single hybrid and the highest nano-zinc concentration may be attributed to the superior genetic efficiency of the hybrid and its greater ability to utilize zinc in nano-form. Nano-zinc enhances chlorophyll synthesis, enzyme activity, and assimilate translocation, which collectively improve growth and yield traits. Therefore, combining the superior hybrid with the highest nano-zinc concentration resulted in a pronounced synergistic effect. These findings are consistent with Abdelkhalik et al. [22] and Muhemed and Mijwel [23], who reported significant improvements and interaction effects under protected cultivation conditions.

Conclusions:

The results of this study revealed significant variation among the evaluated single and triple cucumber hybrids in growth traits, chemical content, and yield performance under protected cultivation conditions. Single hybrids are generally characterized by high productivity under protected environments due to hybrid vigor (heterosis) resulting from crossing two genetically diverse pure lines, which enhances physiological efficiency and yield potential.

In contrast, triple hybrids may exhibit characteristics such as rapid growth or improved disease tolerance; however, the heterotic effect may be distributed across three genetic backgrounds, which can influence yield performance differently. Foliar application of nano-zinc significantly enhanced growth and yield traits, with improvements increasing proportionally to concentration. The interaction between genetic background and nano-zinc levels reached its maximum under the Zn2V1 treatment, indicating that field performance under nano-zinc application is closely associated with the genetic characteristics of the hybrid used.

Recommendations:

Based on the study findings, we suggest the following:

Multiplying the pure lines of the single hybrid V1 for the purpose of maintaining the production of this hybrid, and cultivating it in more than one environment for the purpose of confirming its genetic stability, in preparation for submitting it for adoption. Using higher concentrations of nano-zinc due to the presence of a linear response in growth and yield with increasing the concentration of added zinc.

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