



Research Article

Effect of Nano-Super Fertilizer and Foliar Nano-Iron on Agronomic and Yield Productivity of Cucumber under Greenhouse Conditions

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Abstract | The study evaluated the effect of nano superphosphate fertilization and foliar application of nano iron on the response, yield, and nutrient status of three cucumber (*Cucumis sativus* L.) hybrids under greenhouse conditions. The experiment was conducted a factorial design with a split-plot arrangement in a Randomized Complete Block Design (RCBD) with three replicates. The three tested hybrids were 182-108, Falcon Star RZ, and 62-145 (Beta Alpha type). Four fertilization treatments were applied: control, nano superphosphate (6 kg/ha), foliar nano-chelated iron (2 g/plant), and a combination of both. The results indicated that hybrid 62-145 achieved the highest performance among the tested cultivars, producing 29.39 fruits per plant, with an average fruit weight of 78.25 g, yielding 2,319 kg per plant and a total greenhouse yield of 3.246 tons. This hybrid also exhibited superior leaf nutrient content, with nitrogen at 4.72%, phosphorous at 0.408%, iron at 152.2 mg/kg, and chlorophyll content of 41.80 mg/100 g fresh weight, and fruit fiber content of 1.315%. Fertilization with nano superphosphate alone resulted in the highest leaf proline accumulation (10.72 mg/kg). Moreover, the combination of hybrid 182-108 with the combined fertilization treatment produced the maximum yield per plant (2.930 kg) and total greenhouse yield (4.102 tons). The results exhibited that the combined application of nano superphosphate and foliar nano iron can effectively enhance growth, nutrient uptake, and yield of cucumber hybrids in greenhouse cultivation, providing a promising strategy for improving productivity and fruit quality under controlled conditions.

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Introduction

Cucumber (*Cucumis sativus* L.) is a summer vegetable crop belonging to the *Cucurbitaceae* family. It is monoecious, producing both male and female flowers on the same plant, and relies on cross-

pollination. It is widely cultivated in tropical and subtropical regions, with its origin traced to India and Africa (Behera *et al.*, 2022). In Iraq, cucumbers are cultivated in the spring and autumn, as well as in controlled conditions such as greenhouse system and plastic tunnels (Matloub *et al.*, 1989). They

are commonly consumed fresh or pickled and are frequently included in salads and fast food dishes (Vänninen, 2019). The total cucumber production in Iraq reaches 185,484 tons, with an average yield of 8.8 tons/ha over 21,018.7 hectares (Central Statistical Organization, 2021).

Despite this, local cucumber productivity in Iraq remains lower than global averages, largely due to the deterioration of local genetic strains from inbreeding, genetic mixing, and suboptimal crop management. Yield can be improved through the cultivation of high-performing, pest-resistant, and environmentally resilient varieties, coupled with modern agronomic practices. Gynocious cucumber hybrids, which produce only female flowers, fruit earlier, and yield more in a shorter time, are particularly advantageous under protected cultivation compared to monoecious varieties grown in open fields. The choice of hybrid is influenced by farmer preferences and market demands (Lu *et al.*, 2020).

Modern fertilization techniques, including nanofertilizer technology, play an important role in enhancing vegetable production (Ditta, 2012; Alkarawi and Hasan, 2021). Nanofertilizers, operating at scales below 100 nanometers, possess a large surface area that improves nutrient absorption and photosynthesis, thereby boosting plant growth and yield (Singh, 2016). Iron (Fe) is an essential micronutrient involved in photosynthesis, respiration, enzymatic activity, hormone synthesis, DNA replication, and oxygen transport in plants (Sega *et al.*, 2020). Although abundant in the Earth's crust, iron availability is often limited in soils with neutral to high pH, causing deficiencies that negatively affect crop quality and productivity (Konate *et al.*, 2018).

Previous research has shown that both hybrid selection and fertilization strategies can significantly enhance cucumber performance. For example, Dahham *et al.* (2025) respond superior fruit diameter in the poinsett-75 cultivar, whereas the Darina cultivar excelled in fruit number, weight, and total yield. Kasali *et al.* (2024) observed that Greengo, when fertilized with 5 tons/ha of organic mineral fertilizer, produced the highest number of leaves, longest fruits, and earliest flowering. Merghany *et al.* (2019) demonstrated that foliar application of liquid nano NPK at 6 ml/L increased plant height, leaf area, and leaf number. Similarly, Alkarawi *et al.* (2024) found

that foliar nano iron at 1.5 g L⁻¹ improved total yield, fruit of cayenne pepper, and enhanced leaf chlorophyll content. On the basis of these findings, the present study was designed to evaluate the productivity and yield responses of cucumber hybrids under controlled cultivation and to assess the effects of nano mineral fertilizers and foliar nano iron application on their growth performance and productivity.

Materials and Methods

Before initiating the experiment, the soil samples were collected from multiple locations within the study area at a depth of 0-30 cm. The samples were dried in air, crushed, and sieved with a 2 mm mesh, then analyzed for their physico-chemical characteristics (Table 1). Field preparation involved clearing existing vegetation, plowing, leveling, and smoothing the soil to ensure uniformity. The experimental area was divided into three sectors, each containing 12 plots (sample units). Each sample plot measured 3.0 x 0.8m, with 0.75 m spacing between units to prevent cross contamination between treatments.

Table 1: *Physico-chemical composition of the experimental soil prior to crop establishment.*

Trait	Values	Standard unit
Soil pH	7.9	
Electrical conductivity EC	3.1	d S m ⁻¹
Organic matter	3.4	g. kg
Available nitrogen	12	mg. kg
Available phosphorus	4.9	mg. kg
Available potassium	15.0	mg. kg
Bulk density	1.13	g. cm ³
Sand fraction	155	g kg
Silt fraction	600	g kg
Clay	245	g kg
Soil Texture	Silty clay loam	

Additional buffer zones were left at both ends of each sector. Each plot contained 12 plants with 50 cm distance along the sides of the row, and water regime was provided using a drip system.

Seedlings were transplanted into a 508 m² plastic greenhouse on September 23, 2023, after the emergence at the two leaf growth stage. To protect seedlings from wilt disease, Pentanol fungicide was mixed with the water application at a level of 1 ml/L immediately after transplanting.

Experimental factors

Experiment included two factors:

Cucumber hybrids:

V1: Hybrid 182-108

V2: Hybrid 62-145 (classified under Beta Alpha type)

V3: Hybrid Falcon Star RZ

Nano-fertilization treatments

F0: Control

F1: Super nano-chemical fertilizer at a rate of 6 kg/ha

F2: Foliar feeding with nano-chelated iron (2 g/L)

F3: Foliar application of nano-chelated iron + super-nano fertilizer

The nano superphosphate fertilizer was dissolved in water and applied evenly under the plants in each plot. Applications were repeated three times during the growing period. Foliar sprays of nano-chelated iron and nano superphosphate was applied four times at 10-day intervals, beginning one month after germination. Spraying continued until plants were fully wetted, and a surfactant was added to improve leaf coverage.

Table 2: Components of the super nano fertilizer.

Property	Units	Super Nano Fertilizer
Humic acid	%	-
C Organic	%	-
N Total	%	6
Amino acids	%	-
P ₂ O ₅	%	3
K ₂ O	%	17
Mn	%	2
Mg	%	3
Ca	%	1
S	%	6
Zn	%	4
Cu	%	0.5
Fe	%	4
B	%	0.5
Mo	%	0.1
Produced in Iran	-	

Experimental design

The study followed a split-plot arrangement within an Randomized Complete Block Design (RCBD) fame work, consisting of three replicates (4 x 3) and 36 experimental units overall. Fertilizer treatments were assigned to the main plots, while cucumber hybrids were arranged in subplots. Treatments were distributed randomly according to the procedure described by [Al-Sahoky and Wahayib \(1990\)](#).

Measured parameters

The total number of fruits on each plant (fruit/plant), Average weight of each fruit (g), Yield of each plant (kg), Total greenhouse yield (ton/508 m²), Leaf nitrogen content (%) ([Jackson, 2005](#)), Leaf phosphorous content (%) ([Olsen and Sommers, 1982](#)), Leaf iron content (mg/kg) ([Katyal and Sharma, 1980](#)), Relative content of chlorophyll in leaves (mg/100g f.wt) ([Goodwin, 1976](#)), Leaf proline content (mg/kg) ([Bates, 1973](#)), Fruit fiber content (% dry weight basis) ([AOAC, 2000](#)).

Results and Discussion

The significant variations were observed among the cucumber hybrids for the studied traits ([Table 3](#)). Hybrid 62 (V2) recorded the highest averages for most growth and yield traits, like the no. and weight of fruits, yield per plant, total greenhouse yield, and leaf chlorophyll contents. The respective values were 29.389 fruits/plant, 78.25 g, 2.319 kg, 3.246 tons, and 40.70 mg/100g fresh weight. In comparison, hybrids 182 (V1) and Falcon (V3) exhibited lower averages for these characteristics.

Table 3: Impact of hybrids and nano based fertilization treatments, as well as their interaction on plant growth traits.

Hybrids	Number of fruits (Fruit/plant)	Fruit weight (g)	Yield of one plant (kg)	Total yield (Tons)	Chlorophyll (mg.100 gm fresh weight)
V1	25.612	72.47	1.901	2.662	39.59
V2	29.389	78.25	2.319	3.246	40.70
V3	24.805	77.64	1.963	2.748	40.15
LSD 0.05	0.3768	2.195	0.0649	0.0909	1.053
F0	19.631	66.74	1.313	1.838	39.10
F1	23.888	74.04	1.776	2.486	39.30
F2	28.000	81.07	2.286	3.200	40.40
F3	34.889	82.63	2.870	4.018	41.80
LSD 0.05	0.2149	2.709	0.0774	0.1084	1.260
V1F0	18.890	64.00	1.209	1.693	37.95
V1F1	22.997	68.45	1.574	2.204	39.03
V1F2	26.223	72.11	1.891	2.648	40.02
V1F3	34.337	85.33	2.930	4.102	41.36
V2F0	21.447	68.33	1.469	2.057	39.26
V2F1	26.447	80.00	2.116	2.962	39.99
V2F2	31.667	89.44	2.833	3.966	41.01
V2F3	37.997	75.22	2.857	4.000	42.55
V3F0	18.557	67.89	1.260	1.764	40.09
V3F1	22.220	73.66	1.637	2.292	38.87
V3F2	26.110	81.66	2.132	2.985	40.17
V3F3	32.333	87.33	2.824	3.953	41.49
LSD0.05	0.4361	4.336	0.1245	0.1743	2.123

A significant interaction between cucumber hybrids and nano-fertilization treatments was also noted. The combination of hybrid 62 with the integrated nano-fertilization treatment (V2F3) produced the highest averages for the number of fruits (37.997 fruits/plant) and chlorophyll content (42.55 mg/100 g fresh weight). Conversely, the Falcon hybrid under the control treatment (V3F0) produced the fewest fruits, while hybrid 182 under the control (V1F0) recorded the lowest chlorophyll content.

In terms of fruit weight, hybrid 62 with foliar nano-iron treatment (V2F2) achieved the highest average (89.44 g), whereas hybrid 182 with the control (V1F0) produced the lowest. The interaction between hybrid 182 and the combined nano supernanophosphate nano-iron treatment (V1F3) recorded the greatest yield per plant (2.930 kg) and total greenhouse yield (4.102 tons), while the control (V1F0) produced the lowest. The interaction between hybrid 182 and the combined nano superphosphate nano-iron treatment (V1F3) recorded the greatest yield per plant (2.930 kg) and total greenhouse yield (4.102 tons), while the control (V1F0) showed the lowest values in both categories.

The data in Table 4 reveal significant differences among the cucumber hybrids in terms of nutrient composition and biochemical traits. Hybrid 62 (V2) recorded the maximim concentration of nitrogen (4.718%), and iron (153.2 mg/kg) in the leaves, outperforming hybrid 182(V1) and Falcon (V3), exhibiting comparatively lower value. Conversely, hybrid 182 accumulated the highest level of proline (11.81 mg/kg), while the Falcon hybrid exhibited the greatest fruit fiber content (1.125%). Nano-fertilization treatments also exerted a significant influence on nutrient accumulation, amino acid levels, and fruit fiber content. The combined treatment of nano superphosphate fertilizer and foliar nano-iron application (F3) resulted in the highest values for nitrogen (5.51%),phosphorous (0.5078%),iron (186.2 mg/kg), and fiber (1.315%), whereas the control (F0) treatment yielded the lowest results for these parameters. In contrast, the nano superphosphate fertilizer alone (F1) produced the highest proline concentration in the leaves (10.73 mg/kg), while nano-iron application alone recorded the lowest.

A significant interaction between hybrids and nano-fertilization treatments was also observed. The

treatment of hybrid 62 and the integrated treatment (V2F3) exhibited the highest concentration of nitrogen (6.03%), phosphorous (0.5633%), iron (194.1 mg/kg), and proline (12.66 mg/kg) in the leaves. Meanwhile, the Falcon hybrid under the same treatment (V3F3) produced the higher fiber percentage in fruits (1.651%), whereas hybrid 182 under control conditions (V1F0) showed the lowest fiber content.

Table 4: *Effect of hybrids and nano chemical fertilization treatments and interaction on some growth traits.*

Hybrids	N% (Leaves)	P% (Leaves)	Fe% (Leaves)	Proline (Mg kg ⁻¹)	% fiber (fruits)
V1	4.264	0.3358	146.4	11.81	0.962
V2	4.718	0.4083	153.2	11.06	1.067
V3	4.107	0.3467	148.0	07.09	1.125
LSD 0.05	0.0600	0.0212	0.857	0.186	0.191
F0	3.05	0.2489	107.6	10.08	0.885
F1	3.98	0.3044	136.8	10.73	0.940
F2	4.90	0.3933	166.2	09.49	1.064
F3	5.51	0.5078	186.2	09.65	1.315
LSD 0.05	0.0559	0.0204	2.64	0.193	0.150
V1F0	3.00	0.2233	105.3	11.68	0.851
V1F1	3.83	0.2833	133.7	10.88	0.897
V1F2	4.72	0.3633	162.9	12.26	0.955
V1F3	5.49	0.4733	183.7	12.41	1.144
V2F0	3.17	0.2533	109.5	09.65	0.961
V2F1	4.25	0.3533	138.8	11.52	0.992
V2F2	5.41	0.4633	170.5	10.42	1.164
V2F3	6.03	0.5633	194.1	12.66	1.150
V3F0	2.99	0.2700	108.0	08.91	0.844
V3F1	3.86	0.2767	138.1	09.81	0.931
V3F2	4.56	0.3533	165.4	05.78	1.075
V3F3	5.00	0.4867	180.8	03.87	1.651
LSD 0.05	0.0942	0.0341	4.00	0.318	0.265

Overall, the findings presented in Tables 3 and 4 indicate that the differences among hybrids are primarily due to genetic variability and their adaptive response to environmental and soil conditions during the growing period. Similar observations were exhibited by Mohammed *et al.* (2021), Dahham *et al.* (2025), and Manea (2017).

The enhanced performance observed with nano-superphosphate and nano-iron applications can be attributed to the role of nano-fertilizers in supplying macro and micro nutrients in readily

available form. These nutrients are vital for enzymatic activation, protein synthesis, chlorophyll and carotenoid formation, and regulation of metabolic and cellular processes that promote growth and productivity. Adequate nutrient availability enhances photosynthetic efficiency, amino acid and nucleic acid synthesis, and energy metabolism, leading to improved flowering, fruit formation, and yield.

Moreover, micronutrients such as iron and zinc protect chlorophyll from degradation and maintain protein stability within cells (Stanton *et al.*, 2022). The higher accumulation of nitrogen, phosphorous, potassium, and iron in nano-fertilized plants is likely due to the unique characteristics of nano-fertilizers particularly their small particle size, large surface area, and high penetration capacity through cell walls facilitating rapid absorption and translocation within plant tissues (Ruttkay-Nedecky *et al.*, 2017).

Iron is especially important for chlorophyll biosynthesis and overall metabolic functioning, often interacting with elements such as zinc, boron, copper, and molybdenum to sustain photosynthetic and enzymatic activities (Hawkesford *et al.*, 2023). The application of iron in nano form improves its solubility, uptake efficiency, and physiological utilization within plants (Mankotia *et al.*, 2021). These outcomes align with findings reported by Alkarawi and Hasan (2021), Gupta *et al.* (2022), Guillén-Enríquez *et al.* (2023), and Mahdi *et al.* (2023).

Conclusions

In conclusion, hybrid 62, when combined with nano superphosphate and nano-iron foliar treatments, demonstrated superior performance in terms of chlorophyll value, fruit number, individual and total yield, and leaf nutrient concentration highlighting its potential as a high-performing cultivar under greenhouse conditions with nano-fertilizer management. Hybrid 62, along with super nano fertilization and nano-iron foliar application, achieved the highest percentages of chlorophyll, number of fruits, plant yield, total yield, and nutrient content in leaves.

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Novelty Statement

The study is novel in comprehensively evaluating the combined effect of nano superphosphate fertilizer and foliar nano-iron application on the growth, yield, and biochemical performance of different cucumber hybrids under greenhouse conditions in Iraq. The research provides new insights into how nanoscale fertilization strategies can enhance nutrient uptake efficiency, photosynthetic activity, and fruit productivity in cucumber (*Cucumis sativus* L.).

Author's Contribution

A. I. Manea and H. W. Al-Juthery conceived the original idea. A.A. Dahham and A. I. Manea put together the experimental design, ran the tests, and subsequently compiled and assessed the data. A. I. Manea and H. W. Al-Juthery supervised the research work. A.A. Dahham discussed the results and wrote the preliminary manuscript. H.W. Al-Juthery provided technical proofreading for the manuscript. Every author has reviewed and consented to the final manuscript.

Generative AI and AI assisted technology statement

The authors declare that no generative AI and AI assisted technology was used in the creation of this manuscript.

Conflict of interest

The authors have declared no conflict of interest.

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