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Response of Growth, Yield and Content of Coriander (Coriandrum Sativum L.) fruits of Active Ingredients by Influence of planting distance Between Rows and Spraying of Nano-Iron

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Abstract: A field experiment was implemented during a winter season of 2023 in the Botanical Garden of the College of Basic Education - Al-Mustansiriya University to find out the response of growth, yield and content of coriander seeds of active ingredients by influence of planting distance between rows and spraying of nano-iron. A randomized complete block design (RCBD) according to split-plots arranging was used with three replications. The main plots including three distances between rows (10, 20 and 30 cm), whilst the sub plots included spraying of two concentrations of nano-iron (10 and 20 mg L^{-1}) as well as spraying of distilled water (0 mg nano-Fe L^{-1}). The results revealed that the 30 cm distance between rows was significantly excelled in the main branches number, chlorophyll index, fruits number and fruits content of essential oil (7.74 branch $plant^{-1}$, 34.12 Spad, 86.42 fruit $plant^{-1}$ and 2.48%) sequentially, while the 10 cm distance between rows was significantly superiority in the plant height and 1000-fruits weight (66.13 cm and 12.97 g) sequentially. The plant that sprayed with nano-iron at a concentration of 10 mg L^{-1} was significantly superiority in the main branches number, chlorophyll index and fruits number (7.30 branch $plant^{-1}$, 34.61 Spad and 85.83 fruit $plant^{-1}$) sequentially, whereas the spraying of nano-iron at a 20 mg L^{-1} was significantly superiority in the plant height, 1000-fruits weight and fruits content of essential oil (66.65 cm, 11.60 g and 2.33%) sequentially. The di-interaction had significant effect on the most of studied traits. Further, the results of HPLC analysis indicated a difference in the percentages of the active ingredients (camphor, limonene and linalool) of coriander essential oil.

Keywords: *Coriandrum Sativum*, Inter-Rows, Fe-Nanoparticles, Volatile Oil, Active Compounds

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1. Introduction

Medicinal plants represent an important economic and health component of biodiversity such as coriander plants, which is a herbaceous plant belonging to the Apiaceae family. It is distinguished by its medicinal and nutritional importance because its fruits contain of essential oil, in addition to, their content of carbohydrates, proteins, fibers and nutrients [1,2]. The essential oil of coriander is characterized by containing varying percentages of medically active Ingredients, including limonene, linalool, pinene, terpinene, geranyl acetate, camphor, geranol, etc. [3].

The yield, percentage of essential oil and its content of active ingredients of any medicinal plant is affected by the genetic composition and environmental factors during the growing season [4], as well as the various crop service operations, including the planting distance between the rows (Inter-rows), which is one of the technologies through which the plant's productivity and final yield can be enhanced, as the changing planting distance means different of water, nutrients and solar radiation efficiency by the plant, which will affect the cultivar genetic energy within the environmental conditions in which it grows, which will be reflected in the photosynthesis process activity and its products, and then the growth and productivity of plant [5].

Changing the planting distance between rows alone isn't sufficient unless accompanied by foliar leafy with the nutrients necessary for growth, especially the low-availability elements in Iraqi soil, as the Iraqi soils tend to have a high pH, which leads to a decrease in the availability of most of the micronutrients already present in the soil, including the iron, which is affected by these conditions as a result of its exposure to stabilization and sedimentation processes, and then its absorption decreases [6]. Therefore, spraying of iron is one of the factors that can be invested in improving plant productivity. Iron plays an important role in increasing the activity of a number of enzymes such as NO2-reductase, NO3-reductase, catalase and peroxidase, as well as it is involved in the composition of the essential components of the plant cell, such as cytochromes, the main component in the electronic transportation system, and ferrodoxin in the chain of electronic transfer [7]. Spraying of iron as a nano-scale may it will increase the advantage of plant from this in the various growth stages, and the positive effect of this will be in stimulating vegetative growth, increasing the effectiveness of the photosynthesis process, and improving the seed yield and their components and secondary metabolic compounds as a result of the nanoparticles properties due to their small diameter, which will increase their chemical effectiveness and provide a larger area for metabolic reactions [8,9], in addition to, their rapid absorption and spread within the plant system, therefore, they are considered a suitable mechanism for transferring nutrients to the targeted parts of the plant, which may increase the efficiency of its use and compensate the deficiency in nutrients that the plant needs [10]. Therefore, the research was implemented to find out the response of growth, yield and content of coriander seeds of active ingredients by influence of planting distance between rows and spraying of nano-iron.

2. Materials and Methods

A field experiment was implemented during a winter season of 2023 in the Botanical Garden of the College of Basic Education - Al-Mustansiriya University in a silt loam soil, to find out the response of growth, yield and content of coriander seeds of active ingredients by influence of planting distance between rows and spraying of nano-iron. A randomized complete block design (RCBD) according to split-plots arranging was used with three replications. The main plots included three distances between rows (10, 20 and 30 cm), whilst the sub plots included spraying of two concentrations of nano-iron (10 and 20 mg L^{-1}) as well as spraying of distilled water (0 mg nano-Fe L^{-1}). The spraying was carried out in the early morning using a 16 liter dorsal sprinkler until the leaves were completely wet at twice, the first at a 4 true leaves appearance and the second after two weeks of the first.

Soil service operators were implemented, and then the area was splitted into 27 plots, the area of each plot was 4 m^2 (2 m × 2 m). The distance between plants was 25 cm while the distance between rows according to treatment. The seeds of coriander were planted on the 15/11/2022 by 3 seeds per hill, and then thinned to one seedling after emergence. Crop service operators were implemented. The plants were harvested a the maturity stage. The plant height (cm), main branches number per plant, chlorophyll index (Spad), fruits number per plant, 1000-fruits weight (g) and the percentage of essential oil in the fruits (%), as well as, the essential oil content of camphor, limonene and linalool were measured.

2.1 Extraction of essential oil

The essential oil was extracted using a Clevenger device [11], as 100 g of ground dry fruits were taken and placed in the device's beaker. 1 L of distilled water was added to it, then, the hydro-distillation process was carried out by heating the flask for 3 hours for each sample to obtain the largest amount of essential oil. After that, the essential oil samples were extracted using a separatory funnel. The extracted solution was taken and placed in the funnel and left to cool. The essential oil layer separated to the top, while the bottom layer was a mixture of oil and water. The process was repeated three times to extract and separate the largest amount of essential oil. The samples of essential oil were placed at a 4 °C until further tests. The percentage of essential oil was estimated using the following equation [12]:

$$\text{Essential oil (\%)} = \frac{\textbf{Weight of produced essential oil (g)}}{\textbf{Weight of samples}} \times 100$$

2.2 Separating of some active ingredients from the essential oil:

Some active ingredients were separated using a high-performance liquid chromatography (HPLC) device, type 210 LC Shizmadzu, based on standard samples obtained from Sigma Company and under separation conditions shown in the (Table 1). The HPLC was injected with known concentrations of each standard sample (10 μ ml^{-1}). The retention time and peaks areas of the standard samples were measured, and then the where 20 μl of crude essential oil was taken and injected into the HPLC device, and then the qualitative detection of active ingredients was performed by comparing the retention time of each compounds in the crude essential oil with the retention time in the standard compounds, whereas the quantitative measurement of the compounds present in the crude essential oil was done using the following equation [13]:

$$\text{Concentration of active ingredients in the crude essential oil} = \frac{\textbf{Ac}}{\textbf{As}} \times C \times D$$

As:

Ac = Area of the active ingredient in the crude

As = Area of the active ingredient in the standard compound

C = Concentration of standard compound

D = Number of dilution times

Table 1: HPLC separation conditions

Separation conditions	
Column length	50 x 2.0 mm I.D
Mobile phase	Methanol : deionized water : phosphric acid (88 : 12 : 0.1 V/V)
Particle size	3 um
Mobile phase flow speed	1.2 ml min^{-1}
Detector type	UV set at 285 nm
Separation temperature	20 °C

The data underwent statistical analysis using Genstat program, and the least significant difference (LSD) test was utilized to compare between averages at a significance level of 0.05 [14].

3. Results and Discussion

3.1 Plant height (cm)

The results in the (Table 2) indicate that the 10 cm distance between rows was significantly excelled and achieved a highest average of this trait (66.13 cm) compared to the 30 cm distance between rows which was a lowest (57.90 cm). The increasing of plant height when reducing the planting distance between the rows may be due to an increase the number of plants per unit area and then increasing the competition between plants on the growth factors, especially light, which prompts the plants to elongate their stems to obtain sufficient light. Likewise, the increasing of shading between plants when reduced the planting distance encourages an increase the concentration of plant hormones responsible for stem elongation, such as auxins and gibberellins [15].

The plants that sprayed with nano-iron at a concentration of 20 mg L^{-1} was significantly superiority and gave a highest average of this trait (66.65 cm) compared to the plants that sprayed with distilled water which was a lowest (57.44 cm). The superiority of plants which sprayed with nano-iron in the plant height could be attributed to its chemical effectiveness as a result of the small size of its particles, which will increase their chemical effectiveness and the number of particles present on the outer surface of the leaves and providing a larger area for biochemical reactions [8], which may have led to an increase the effectiveness of nano-iron in stimulating the physiological processes that get in the tissues, as it is involved in the composition of the essential components of the plant cell, such as cytochromes, the main component in the electronic transportation system, and ferrodoxin in the chain of electronic transfer [7].

The di0interaction had significant effect on this trait (Table 2). The 20 cm distance between rows with spraying of nano-iron at a 20 mg L^{-1} combination recoded a highest value (70.94 cm) with non-significant difference with the 30 cm distance between rows with spraying of nano-iron at a of 10 mg L^{-1} combination, while the 30 cm distance between rows with spraying of distilled water combination recorded a lowest (53.68 cm).

Table 2. Response of coriander plant height (cm) to planting distance between rows, spraying of nano-iron and their interaction

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)			Average
	10	20	30	
0	62.05	56.60	53.68	57.44
10	68.72	58.22	61.65	62.86
20	67.63	70.94	61.36	66.65
Lsd	4.00*			1.54*
Average	66.13	61.92	57.90	
Lsd	2.31*			

* There were significant differences at the level of $P \le 0.05$.

3.2 Main branches number per plant

The results in the (Table 3) reveal that the 30 cm distance between rows was significantly superiority and gave a highest average of this trait (7.74 branch $plant^{-1}$) compared to the 10 cm distance between rows which gave a lowest (4.86 branch $plant^{-1}$). The increasing could be due to an increment the light transmittance, which may lead to the oxidation of auxin and reduce its transferred concentration to the lateral buds as a result of the increased the activity of the peroxidase and IAA-oxidase enzymes, which is associated with a decrease the plant density and an increase the area that is occupied by a plant, which will facilitate the flow of nutrients and water into the lateral buds as a result of the expansion of the vessels transporting xilema and phloem, thus increasing their emergence and growth [16].

According to the research data in the (Table 3), the spraying of nano-iron at a concentration of 10 mg L^{-1} was significantly superiority and gave a highest average (7.30 branch $plant^{-1}$) compared to the plants that sprayed with distilled water which gave a lowest (5.34 branch $plant^{-1}$). The increasing could be attributed to the nano-iron properties, including rapid absorption and transfer and providing a larger area for biochemical reactions in the plant as a result of the small diameter of its particles [8], which may have led to an increase the efficiency of the photosynthesis process and its products and their balanced distributing among the different plant parts, which has been positively reflected in increment cell division and thus increasing plant growth towards the growth of branches [17].

The di-interaction had significant effect on this trait (Table 3), as the 30 cm distance between rows with spraying of nano-iron at a 10 mg L^{-1} combination recoded a highest value (8.36 branch $plant^{-1}$), whereas the 10 cm distance between rows with spraying of distilled water combination recorded a lowest (4.42 branch $plant^{-1}$).

Table 3. Response of main branches number per plant of coriander to planting distance between rows, spraying of nano-iron and their interaction

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)			Average
	10	20	30	
0	4.42	4.46	7.14	5.34
10	5.47	8.08	8.36	7.30
20	4.70	7.57	7.72	6.66
Lsd	1.37*			0.64*
Average	4.86	6.70	7.74	
Lsd	0.79*			

*

*There were significant differences at the level of $P \leq 0.05$.

3.3 Chlorophyll index (Spad)

According to the results of (Table 4), the 30 cm distance between rows was significantly superiority in this trait and gave a highest average (34.12 Spad) compared to the 10 cm distance between rows which gave a lowest (24.01 Spad). The reason of increasing may be due to the positive role of increasing the planting distance between the rows in reducing the competition between plants for absorbed nutrients from the soil solution, including the elements that enter into the synthesis of the chlorophyll moleculer and investing in stimulating its biosynthesis process, which was positively reflected on increasing its content in the leaves [5].

As for nano-iron, the spraying of nano-iron at a of 10 mg L^{-1} was significantly superiority and recorded a highest average of this trait (34.61 Spad) compared to distilled water spraying which recorded a lowest (21.58 Spad). The reason of increasing may be due to the chemical and physiological effectiveness of nano-iron fertilizer as a result of the small size of its particles and the speed of its spread and transfer within the plant, which led to the activation of green pigment biosynthesis reactions [18], as 80% of the iron present inside plant cells, it participates in the photosynthesis process and maintains the structure and functions of chloroplasts [19].

The di-interaction had significant effect on this trait (Table 4), as the 30 cm distance between rows with spraying of nano-iron at a 10 mg L^{-1} combination gave a highest value (37.22 Spad), while the 10 cm distance between rows with spraying of distilled water combination recorded a lowest (15.26 Spad).

Table 4. Response of chlorophyll index (Spad) of coriander to planting distance between rows, spraying of nano-iron and their interaction

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)			Average
	10	20	30	
0	15.26	21.30	28.17	21.58
10	30.64	35.97	37.22	34.61
20	26.12	24.66	36.99	29.25
Lsd	2.23*			1.47*
Average	24.01	27.31	34.12	
Lsd	1.29*			

* There were significant differences at the level of $P \leq 0.05$.

3.4 Fruits number per plant

The findings of the (Table 5) indicate that the 30 cm distance between rows was significantly superiority and recorded a highest average of this trait (86.42 fruit $plant^{-1}$) compared to the 10 cm distance between rows which gave a lowest (68.86 fruit $plant^{-1}$). The reason of increasing could be attributed to the role of increasing the planting distance between rows in providing suitable growth conditions, resulting in it giving the highest results for the number of branches per plant (Table 3) and chlorophyll index (Table 4), which may have contributed to increasing the rate of pollination and fertilization.

According to the (Table 5) findings, the spraying of10 mg L^{-1} of nano-iron was significantly superiority and recorded a highest average of fruits number (85.83 fruit $plant^{-1}$) compared to distilled water spraying which recorded a lowest (68.11 fruit $plant^{-1}$). The increasing of the fruits number may be attributed to the it excellence in the main branches number (Table 3) and chlorophyll index (Table 4).

The results in the (Table 5) reveal that there was significant effect of the interaction between two studied factors on the fruit number per plant, as the 30 cm distance between rows with spraying of nano-iron at a 20 mg L^{-1} combination had a highest value (96.02 fruit $plant^{-1}$) with non-significant difference with the 30 cm distance between rows with spraying of nano-iron at a 10 mg L^{-1} combination (88.86 fruit $plant^{-1}$), whereas the 10 cm distance between rows with spraying of distilled water combination had a lowest (60.02 fruit $plant^{-1}$).

Table 5. Response of fruit number per plant of coriander to planting distance between rows, spraying of nano-iron and their interaction

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)			Average
	10	20	30	
0	60.02	69.91	74.39	68.11
10	75.19	93.44	88.86	85.83
20	71.38	81.63	96.02	83.01

Lsd	8.52*			3.43*
Average	68.86	81.66	86.42	
Lsd	4.92*			

* There were significant differences at the level of $P \leq 0.05$.

1000-fruits weight (g)

The findings of the (Table 6) clarify that the 1000-fruits weight was significantly affected with distance between rows, as the 10 cm distance between rows gave a highest average (12.97 g) compared to the 30 cm distance between rows that gave a lowest (8.31 g). The increasing of 1000-fruits weight when planting at a distance of 10 cm between rows may be due to a decrease the number of fruits per plant (Table 5). as the decrease fruits number means less competition between them on the metabolic products of the photosynthesis process, which leads to the distribution and partitioning of these products into a smaller number of fruits, thus increasing their weight according to the compensation base.

Also, findings of the (Table 6) show that the spraying of nano-iron at a 20 mg L^{-1} was significantly superiority in the 1000-fruits weight (11.60 g) compared to spraying of nano-iron at a 10 mg L^{-1} distilled water which were the lowest (9.88 and 9.94 g) respectively. The decrease of 1000-fruits weight of plants sprayed at a 10 mg L^{-1} of nano-iron could be due to their superiority in the fruits number (Table 5). This indicates an increase the competition between fruits on the metabolic products at the stage of development and filling, which was negatively affected the size of the fruits and their weight, i.e. these plants have invested the available growth factors towards increasing the number of sinks at the expense of sink capacity.

The di-interaction between two studied factors hadn't significant effect on the 1000-fruits weight (Table 6).

Table 6. Response of 1000-fruits weight of coriander to planting distance between rows, spraying of nano-iron and their interaction

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)			Average
	10	20	30	
0	12.68	9.53	7.61	9.94
10	11.86	10.00	7.78	9.88
20	14.37	10.89	9.55	11.60
Lsd	$1.11^{N.S}$			1.07*
Average	12.97	10.14	8.31	
Lsd	0.47*			

* There were significant differences at the level of $P \leq 0.05$.
N.S: not significant.

3.5 Percentage of essential oil (%)

The findings of the (Table 7) explain that the 30 cm distance between rows was significantly superiority in the essential oil percentage (2.48%) compared to the 10 cm distance between rows which was a lowest (1.30%). The increasing of essential oil percentage could be attributed to an increasing the plant area, which led to reducing the competition for water and nutrients and increasing their investment in stimulating the biochemical processes that occur within plant tissues, and the effect of this in raising the physiological activities efficiency and increasing the synthesis of secondary metabolic products of the photosynthesis process [20, 4].

Regarding of nano-iron, the findings of (Table 7) reveal that the spraying of nano-iron at a 20 mg L^{-1} was significantly superiority in the essential oil percentage (2.33%) compared to distilled water spraying which was a lowest (1.61%). The increasing of essential oil percentage when spraying of 20 mg L^{-1} of nano-iron could be attributed to the superiority of the same concentration in the weight of 1000 fruits (Table 6).

The di-interaction had significant effect on the essential oil percentage (Table 7), as the 20 cm distance between rows with spraying of nano-iron at a 20 mg L^{-1} combination gave a highest value (2.85%) with non-significant difference with the 30 cm distance between rows with spraying of nano-iron at a 20 mg L^{-1} combination, whereas the 10 cm distance between rows with spraying of distilled water combination recorded a lowest (1.06%).

Table 7. Response of essential oil (%) of coriander to planting distance between rows, spraying of nano-iron and their interaction

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)			Average
	10	20	30	
0	1.06	1.33	2.44	1.61
10	1.21	2.39	2.47	2.03
20	1.62	2.85	2.53	2.33
Lsd	0.44*			0.15*
Average	1.30	2.19	2.48	
Lsd	0.25*			

* There were significant differences at the level of $P \leq 0.05$.

3.6 Essential oil content of active ingredients

The results of high-performance liquid chromatography (HPLC) analysis in the (Table 8) show that the 20 cm distance between rows and spraying of nano-iron at a 10 mg L^{-1} achieved a highest percentage of camphor compound in the essential oil of coriander, amounting to 8.59%, followed by the 10 cm distance between rows and spraying of nano-iron at a 20 mg L^{-1}, which achieved 8.26%, and the 20 cm distance between rows and spraying of nano-iron at a 20 mg L^{-1}, which achieved 8.07%, while the 10 cm distance between rows and spraying of distilled water achieved a lowest percentage of camphor compound in coriander essential oil (2.44%). As for the limonene compound, the results in the (Table 8) reveal that the 20 cm distance between rows and spraying of nano-iron at a 10 mg L^{-1} had a highest percentage of this compound in the essential oil of coriander, amounting to 12.77%, followed by the 10 cm distance between rows and spraying of nano-iron at a 10 mg L^{-1}, which had 11.96%, and the 10 cm distance between rows and spraying of nano-iron at a 20 mg L^{-1} which had 10.45%. In contrast, the 30 cm distance between rows and spraying of nano-iron at a 20 mg L^{-1} had a lowest percentage of the limonene compound in the essential oil of coriander (3.52%). Regarding of linalool compound, it appears from the results of (Table 8) that the 20 cm distance between rows and spraying of distilled water recorded a highest percentage of this compound in the essential oil of coriander, amounting to 6.93%, followed by the 10 cm distance between rows and spraying of nano-iron at a 10 mg L^{-1}, which recorded 6.40%, and the 10 cm distance between rows and spraying of nano-iron at a 20 mg L^{-1}, which recorded 6.24%, whereas the 30 cm distance between rows and spraying of nano-iron at a 10 mg L^{-1} recorded a lowest percentage of the linalool compound in the essential oil of coriander (2.56%). The reason of varied in the active ingredients content of coriander essential oil may be due to the influence of the two factors on the efficiency of the biochemical processes that occur within the plant tissues and the effect of this on the efficacy of the enzymes and co-enzymatic responsible for the biosynthesis of the essential oil, which will be reflected in the activation of the metabolic pathways related to biosynthesis of the active ingredients in the essential oil [21].

Table 8. Coriander essential oil content of active ingredients (%)

Nano-Fe Conc. (mg L^{-1})	Planting distance between rows (cm)	Camphor	Limonene	Linalool
0	10	2.44	9.11	5.77
	20	2.89	5.22	6.93
	30	4.68	9.82	4.46
10	10	6.76	11.96	6.40

	20	**8.59**	**12.77**	**3.44**
	30	**7.17**	**6.70**	**2.56**
20	**10**	**8.26**	**10.45**	**6.24**
	20	**8.07**	**6.04**	**3.57**
	30	**7.28**	**3.52**	**4.87**

4. Conclusion

We can be concluded that the coriander plants showed a response to increasing the planting distance between rows and spraying of nano-iron. Also, the increasing of planting distance between rows led to improved most of the growth traits of coriander, that led to an increment the fruits number and their essential oil content. Likewise, the spraying of nano-iron had a clear effect in stimulating growth, which was positively reflected in increasing the physiological efficiency of the plant and increasing the products of secondary metabolites. Further, the percentages of the active ingredients (camphor, limonene and linalool) of coriander essential oil were varied.

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