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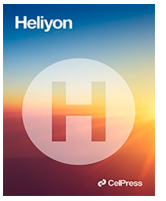

Research article

Effect of foliar application frequency and different levels of nano fertilizer on growth and development of coriander (*Coriandrum sativum* L.)

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ABSTRACT

The aim of this study was investigation of PHARMAX nano fertilizer and its frequency of foliar application effects on morphological characteristics, straw yield, fruit yield, percentage and yield of essential oil of (*Coriandrum sativum* L.). A factorial experiment was conducted based on a randomized complete block design with 8 treatments and 3 replications. Factors were included frequency of foliar application (tillering stage and two weeks after the first foliar application) and concentration of nano fertilizer (0, 1, 3 and 5 ml/L). Finally, the results were statistically analyzed using MSTAT-C software and the mean data were compared with Duncan test at the statistical level of 5 %. The results showed that a significant effect of number of foliar sprays on plant height, number of umbrellas/plant, number of umbrellas/square meter, number of grain/umbrella, grain yield, straw yield, single plant grain weight, single plant biomass yield, percentage and essential oil yield. In addition, different concentrations of nano fertilizer had a significant effect on most traits except the number of grain/umbrella, 1000-Grain weight and essential oil percentage. The interaction of two factors on all traits except number of umbrellas/plant, number of grain/umbrella and percentage and yield of essential oil was significant. With increasing the concentration of nano fertilizer from 0 to 5 ml/L, the number of umbrellas/square meter, grain yields, straw and essential oil yield, increased 62.5, 74.1, 74.3, 186.8 % respectively. In addition, increasing the frequency of foliar application increased the mentioned traits. According to the results, it seems that the treatment of twice-foliar application and concentration of 5 ml/L nano-fertilizer was the best treatment due to increased yield and other traits.

1. Introduction

The growing trend towards herbal medicine in the treatment of diseases both globally and domestically makes the necessity of cultivating various medicinal plants inevitable [1]. (*Coriandrum sativum* L.) is an annual plant of the genus Umbelliferae, which due to its active ingredient (essential oil) and the main composition of linalool, is of great importance in the pharmaceutical, food, cosmetic and health industries. In traditional medicine, it is used as a food digester, anti-flatulence, also, as an appetite suppressant, muscle pain reliever and sedative [2]. Coriander contains at least 0.3 % of volatile oil (vol/wt). The use of coriander in various infectious diseases (such as typhoid fever and in general various diseases with a general origin of bacilli and granular fevers is recommended. Its antimicrobial and fungal effects have been confirmed against *Bacillus, Escherichia coli, Staphylococcus, Pseudomonas* bacteria [3]. In

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medicinal plants, although the production of active ingredients is genetically controlled, but their production is also significantly affected by environmental factors, so environmental factors in addition to affecting the growth and development of plants in the quantity and quality of active ingredients. They also affect soil fertility is one of the factors that have a positive effect on the quality and quantity of the final product [4]. The use of nano fertilizers leads to increasing the efficiency of nutrient consumption, reducing soil toxicity, minimizing the negative effects of excessive fertilizer application and reducing the number of fertilizer applications. By using nano fertilizers, the time and speed of release of elements is in accordance with the nutritional needs of the plant, so the plant is able to absorb the maximum amount of nutrients and as a result, while reducing leaching of elements, product yield increases. The use of appropriate chemicals during the planting, holding and harvesting of plants not only plays a major role in achieving maximum yield, but also improves its quality [5–7].

Adequate amount of fertilizer application is one of the most important agricultural issues in medicinal plants. By examining the effect of 40, 50, 60 and 70 kg/ha of nitrogen on coriander, it was concluded that significantly increased the number of umbels per plant, number of seeds per umbel and fruit yield [8,9]. Angeli et al. (2016) reported that application of 100 kg/ha of Nitrogen had highest fruit yield on coriander [10].

In the greenhouse study, the effect of 0, 100, 150 and 200 kg/ha of nitrogen on coriander was reported that with increasing nitrogen application, fruit yield increased significantly and the number of umbrellas per plant, rather than of non-application of nitrogen. There was a significant difference, but all three levels of nitrogen application in this trait were in the top statistical group [11]. Effect of nitrogen fertilizer levels and plant density in coriander reported that the highest fruit yield was related to the treatments of 60 kg/ha N and plant densities of 30 and 40 cm per m^2 with averages of 2829 and 2703 kg/ha, respectively. There has not been any report of the application of nano-fertilize on coriander in Iran. The use of fertilizer containing nanoparticles at a concentration of 50 mg/l has the greatest effect on increasing the yield of small potato tubers compared to the control [9,11–13]. Concentration of 50 mg/L of nano-silver treatment of increases germination percentage stem and root length and eventually improved wheat establishment [2]. Nanoparticles increased the shoot-to-root ratio in lettuce [14]. The effect of nano iron chelate on growth parameters and activity of antioxidant enzymes of *Ocimum basilicum* were reported. This study showed that growth parameters increased in basil when exposed to iron fertilizer with a concentration of 1 kg/ha and nano-iron fertilizer with a concentration of 1 kg/ha, compared to the control. In general, their results showed that the replacement of iron fertilizer prepared with nanotechnology in comparison with conventional iron fertilizers could increase the quantitative and qualitative growth of basil. Therefore, this study were investigated according to the need of the pharmaceutical industry for this plant and the importance of nutrition on the quantitative yield and amount of active ingredients of medicinal plants in different concentrations of nano fertilizer and the frequency of foliar application on coriander [15]. According to what was said and also the acceptance of the use of nano products in the improvement of medicinal plants, the development of these nano products is increasing strongly. One of these products is PHARMAX nano fertilizer. The review of the literature shows that so far no comprehensive study has been done regarding the use of this product in improving the performance of plants as well as essential oil. Studying this nano product can be of great help to farmers as well as medicinal plants production industries. The main objective of this research was investigation of PHARMAX nano fertilizer and its frequency of foliar application effects on morphological characteristics, biological yield, fruit yield, percentage and yield of essential oil of (*Coriandrum sativum* L.).

2. Material and methods

These experiments was conducted in the research greenhouses of the Faculty of Agriculture, Khoy Azad University. Physical and chemical properties of soil used in the experiment are given in Table 1. Properties related to the environmental conditions of the greenhouse are given in Table 2. In order to investigate the effect of frequency of foliar application and different concentrations of nano fertilizer on morphological characteristics, yield and percentage of essential oil coriander, an experimental factorial experiment was performed based on a randomized complete block design with 8 treatments of 3 replications. Factors included the number of foliar applications (tillering stage and two weeks after the first foliar application) and the concentration of PHARMAX nano fertilizer (0, 1, 3 and 5 mL/l). The characteristics of PHARMAX nano fertilizer are shown in Table 3. Coriander seeds mixed with sand and planted in spring of 2020. Irrigation was done twice a week until the emergence of seedlings. The date of the first foliar spraying was done on May 10, 2020 in the fifting stage and the second date of foliar spraying was done on May 24, 2020. To determine the number of umbrellas/plant, number of grain/umbrella, grain yield and biomass of grain of plant, 10 plants were randomly selected and necessary measurements were made. To measure the number of umbrellas/square meter, grain yield, straw yield/plant and harvest index of isolated plants in the shade and in dry air and different parts were isolated. To determine the weight of 1000-grain, a sample of 1000-grain was separated from the seed mass and seeded carefully with a digital scale [2]. In addition, from dividing grain yield to straw yield and multiplying it by 100, the grain harvest index per plant was calculated. Then 5 g of dried plant was weighed accurately and prepared for essential oil extraction [9]. The essential oil was extracted by water distillation for 3 h under exactly the same conditions using a Clevenger apparatus. The results were statistically analyzed using MSTAT-C software and the mean data were compared with Duncan test at the statistical level of 5 %.

Table 1
Physical and chemical properties of soil used in the experiment.

Texture	pH	EC (mmhos/cm)	P (mg/kg)	K (mg/kg)	Total N (mg/kg)	Organic Carbon %	Saturation percentage %	Lime %
Loam Silt	7.1	1.2	10	350	500	0.80	40.46	15.2

Table 2
Properties of related to the environmental conditions of the greenhouse.

environmental conditions Greenhouse	Greenhouse cover	Greenhouse air humidity (%)	Mean light intensity (Foot candle)	Maximum temperature)cm)	Minimum temperature)cm)
	Plastic	45.65	4652	46	21

3. Results

3.1. Number of foliar application and concentrations

The results of analysis of variance showed that the effect of the number of foliar application and different concentrations of nano fertilizer on plant height was significant but their interaction was not significant (Table 4). In general, with increasing the concentration of nano fertilizer to a concentration of 5 ml/L, the plant height was increased, in concentration of 0 nano fertilizer height of plant was 55.88 cm (lowest of height plant) and the highest height was obtained in3 ml/L concentration with mean 62.73 cm. As shown in Table 5, the maximum plant height of 60.25 cm was related to the double foliar treatment during the vegetative growth period.

3.2. Number of umbrellas/plant

The results of analysis of variance showed that the effect of number of foliar sprays and different concentrations of nano fertilizer on the number of umbrellas/plant was significant but their interaction was not significant (Table 4). Comparison of the mean of the above traits in Table 5 shows that with increasing the concentration of nano fertilizer, the number of umbrellas/plant increased, so that at a concentration of 5 ml/L, the highest number of umbrellas/plant with mean of 11.84 and the lowest number of umbrellas/plant belong to control treatment. Nano fertilizer had a mean of 7.32. The highest number of umbrellas/plant was related to twice-foliar application with mean of 10.95.

3.3. Number of umbrellas/square meter

According to the results of analysis of variance in Table 4, the number of foliar sprays and different concentrations of nano fertilizer and the interaction effect were significant (Table 4). Comparison of mean in Table 5 showed that the highest number of umbrellas/square meter with 412.07 was related to the treatment of 3 ml/L of nanofertilizers and twice foliar spraying and the lowest number of umbrellas/square meter belongs to the 0 ml/L nanofertilizer treatment with 285/13 and foliar application at tillering stage (Fig. 1).

3.4. Number of grain/umbrella

The results of analysis of variance showed that the effect of the number of foliar sprays on the number of grain/umbrella was significant, but the different concentrations of nano fertilizers had no statistically significant interaction (Table 4). Foliar application at the tillering stage with mean of 16.06 had the highest number of grain/umbrella. It seems that the increase in the number of grain/umbrella is mainly related to the sharp decrease in the number of umbrellas/square meter and in line with the balance of source and reservoir.

3.5. Weight of 1000- grain

The results of analysis of variance in Table 4 showed that the effect of different concentration of nano fertilizer and the effect of number of foliar sprays on the 1000- grain weight were not significant but their interaction were affected at the level of 5 %. The highest 1000- grain weight were obtained at 5 ml/L of nano fertilizer and foliar application in the tillering stage with mean of 10 g and the lowest 1000- grain weight was related to the 0 ml/L of nano fertilizer treatment and foliar application in the tillering stage with mean of 8.35 g (Fig. 2).

3.6. Grain yield

The results of analysis of variance showed that the effect of number of foliar sprays and different concentrations of nano fertilizer and its interaction on grain yield was significant at the level of 1 % (Table 4). So that the highest grain yield was related to treatment 5 ml/L of nano fertilizer and two times foliar application with mean of 674.68 kg/ha and the lowest grain yield was related to control treatment and foliar application at tillering stage with mean of 353.24 kg/ha (Fig. 3).

3.7. Straw yield

The results of analysis of variance showed that the effect of number of foliar applications and different concentrations of nano

Table 3
Properties of PHARMAX nano-fertilizer used in this experiment.

Composition	CaO	F	SiO_2	MgO	SO_3	ZnO	Fe_2O_3	Al_2O_3	Na_2O	MoO_3	K_2O	CuO	NiO	CoO	SrO	Total
Concentration (%w/w)	33.74	15.58	9.63	0.83	0.802	0.330	0.288	0.190	0.160	0.075	0.069	0.0510	0.046/	0.0390	0.036	100

Table 4
Results of analysis of variance of the measured traits of coriander.

(S. O. V)	Df	Mean of squares Height of plant (cm)	Number of umbrellas/plant	Number of umbrellas/square meter	Number of grain/ umbrella	Weight of a thousand grain (g)	Grain yield (kg/ha)
Repeat	3	23.2425630	1.954 ns	2745.84ns	2.62ns	1.005ns	22920.10ns
Number of times of foliar application	1	98.5907715**	38.9 **	60055.60**	60.60*	0.13ns	106482.22**
Fertilizer concentration	3	187.1004780**	22.86 **	21570.32**	3.18ns	0.66ns	50803.83**
Fertilizer concentration × Number of times of foliar application	3	36.3977715	0.117ns	963.78**	1.85ns	0.84*	5241.5**
Error	16	13.732932	0.179	259.45	2.14	0.20	178.010
CV%	–	25.12	14.48	14.35	9.38	12.24	12.45

ns, * and **: Nonsignificant and significant at the 5 and 1 % levels of probability, respectively.

Table 5
Continues of analysis of variance of the measured traits of coriander.

(S. O. V)	df	Mean of squares Straw yield/ plant (kg/ha)	Harvest Index (%)	Yield of single grain/plant(g)	Biomass yield of single grain(g)	Percentage of essential oils (%)	Essential oil yield (kg/ha)
Repeat	3	151413.7 ns	3.850ns	0.154ns	1.01ns	0.003ns	0.122ns
Number of times of foliar application	1	559826.50 **	11.814ns	0.715**	3.76**	0.047**	1.822**
Fertilizer concentration	3	137227.27 **	37.60**	0.25**	2.36**	0.003ns	0.387*
Fertilizer concentration × Number of times of foliar application	3	20346.20*	4.01*	0.03*	0.18*	0.003ns	0.1ns
Error	16	6297.97	0.95	0.01	0.04	0.002	0.72
CV%	–	17.34	16.23	18.28	14.07	10.20	14.03

ns, * and **: Nonsignificant and significant at the 5 and 1 % levels of probability, respectively.

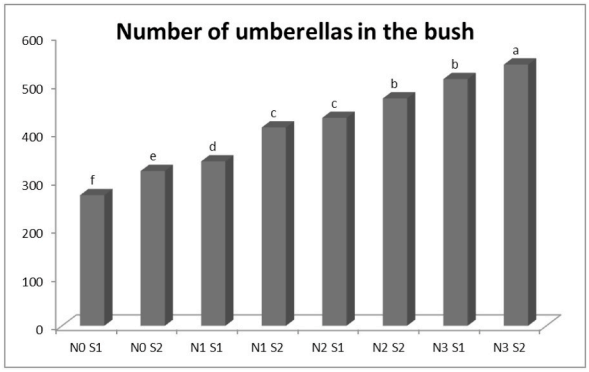

Fig. 1. Interaction of foliar application time and nano-fertilizer on the number of umbrellas/square meter of coriander.

fertilizer and its interaction on straw yield was significant at the level of 1 % (Table 4). The highest straw yield was related to the treatment of 5 ml/L foliar spraying with mean of 1389.70 kg/ha and the lowest grain yield was related to the control treatment and foliar spraying at the tillering stage with mean of 797.52 kg/ha (Fig. 4).

3.8. Harvest index

The results of analysis of variance showed that the number of foliar sprays had no significant effect on the harvest index, but different concentrations of nano fertilizers at the level of 1 % and their interaction at the level of 5 % had significant effect on harvest index (Table 4). The highest harvest index was related to foliar application of treatment 3 ml/L nano fertilizers in the tillering stage with mean of 44.27 % and the lowest harvest index was related to the control treatment of nano fertilizer and foliar application in the tillering stage (43.95 %) (Fig. 5).

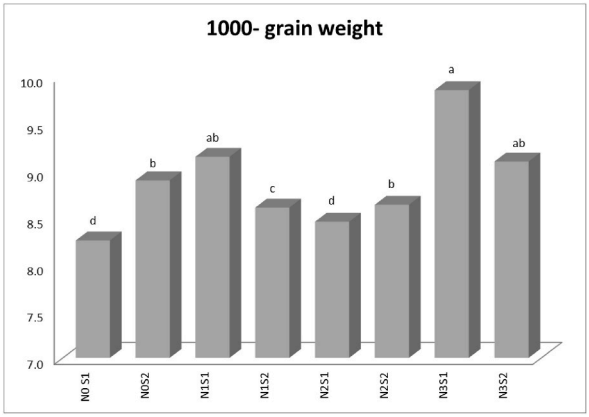

Fig. 2. Interaction of foliar application time and nano-fertilizer on the 1000- grain weight of coriander.

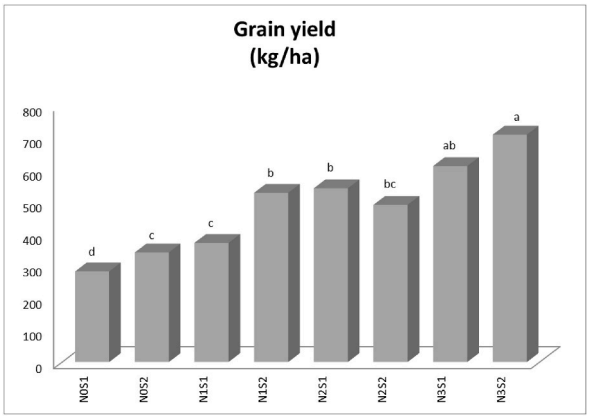

Fig. 3. Interaction of foliar application time and nano-fertilizer on grain yield of coriander.

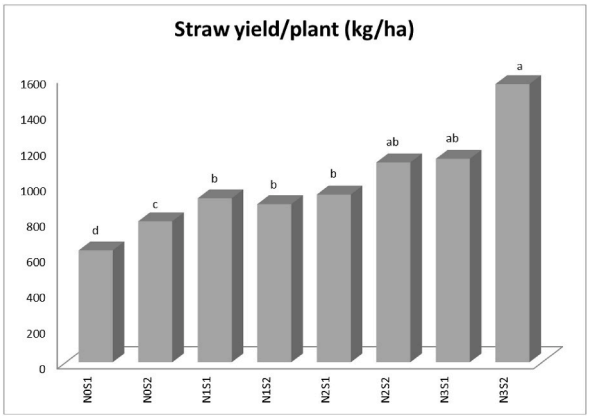

Fig. 4. Interaction of foliar application time and nano-fertilizer on straw yield/plant of coriander.

3.9. Biomass of single grain

The results of analysis of variance showed that the simple and interaction effects of foliar application frequency and different concentrations of nano fertilizer on biomass of single grain and grain of yield significantly affect (Table 4). The highest biomass of single grain and grain yield with mean of 1.55 and 3.53 g, respectively, was related to the treatment of 5 ml/L nano fertilizers and foliar application at the tillering stage, and the lowest yield of grain and biomass of single grain was related to the control treatment (Figs. 6

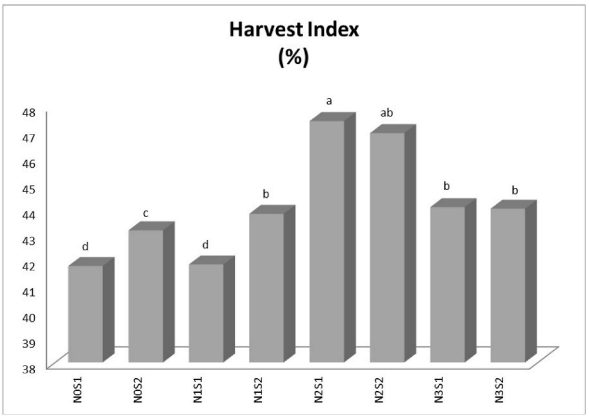

Fig. 5. Interaction of foliar application time and nano-fertilizer on harvest index of coriander.

and 7).

3.10. Percentage and yield of essential oil

The results of analysis of variance showed that the effect of foliar application frequency significantly affected the percentage and yield of essential oil, but different concentrations of nano fertilizer were significant only on essential oil yield. Also, the interaction of foliar application frequency and different concentrations of nano fertilizer on these traits was not significant (Table 4). Comparison of means showed that nano-fertilizer had a positive effect on the percentage of essential oil (Table 5). At Tables 6 and 7 results analysis mean of comparing of measured traits of coriander under the influence of PHARMAX nano fertilizer and mean of comparing of measured traits of coriander under the influence of foliar application are presented.

4. Discussion

PHARMAX nano fertilizer has improved its performance due to having all the elements needed by the plant. Also, as a result of the gradual release of the elements needed by the plant in all stages of growth, the increase in soil moisture retention and the availability of more elements absorption and the increase in photosynthesis of the plant have led to the improvement of its performance. It can also lead to a reduction in the use of chemical fertilizers, which will reduce environmental effects. According to our results, it was observed that the use of nano fertilizer with twice-foliar application increased the height of the coriander. The results are consistent with research of Dehghani et al. (2010). hat they also reported the positive effect of fertilizer on plant height. It is possible that the faster growth of the plant with increasing the use of nano-fertilizer, followed by better use of environmental factors, has led to more branching and reaching the plant to full umbrella capacity [16]. Umbrella has been involved in the plant. This result is consistent with the results (Rassam et al., 2006) in dill (*Anethum graveolens*) [1]. No information is available on the effect of nano fertilizer on plant growth. It seems that the silica nanoparticles in this fertilizer have increased the photosynthetic material of the plant and these materials have provided the conditions for improving the vegetative growth of the plant. Potassium, sulfur, low concentration of iron, zinc, copper, molybdenum, cobalt and useful elements such as nickel, sodium and flora, were necessary elements and the reason for the

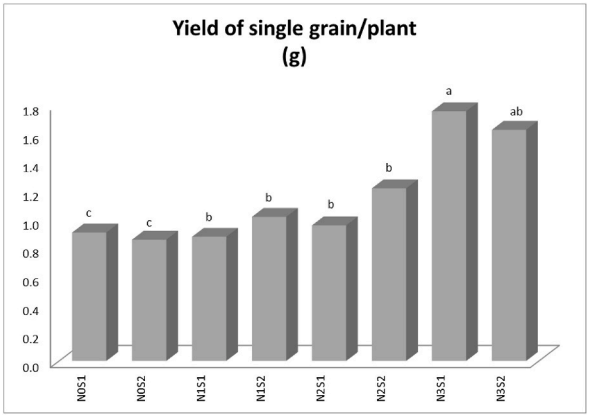

Fig. 6. Interaction of foliar application time and nano-fertilizer on yield of single grain/plant of coriander.

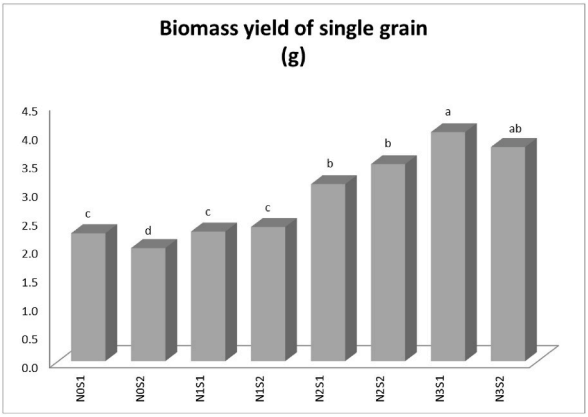

Fig. 7. Interaction of foliar application time and nano-fertilizer on biomass yield of single grain of coriander.

increase in plant growth due to the application of this fertilizer can be increased by providing nutrients improved availability and greater adsorption by plants have been attributed to the high adsorption efficiency and specific surface area of nanoparticles compared to conventional particles, which may justify the greater effectiveness of these particles [17].

The results of our study show that, the use of nano fertilizer has increased these traits, which is consistent with the results of Mousavi et al. (2015) [12,18]. They reported an increase in the number of umbrellas/plant due to the presence of sufficient nutrients and the lack of canopy growth to the stage that causes severe shading of the upper layers on the lower parts has been able to significantly increase the number of umbrellas/square meter. It seems that with the increase of foliar application, in addition to the production of photosynthetic materials and branching in the plant, the number of umbrellas/square meter increases. In general, the use of nano fertilizer has increased this trait, which is consistent with the results of Mousavi et al. (2015) [12]. Increase in the number of umbrellas per plant due to the presence of sufficient nutrients. The results of Gujar et al. (2005) in fennel showed that Nitrogen consumption had a significant effect on the weight of a thousand fruits [19]. In other words, reducing the number of grain (reservoir) at higher densities, the share of each grain in plant photosynthetic material increased, resulting in a significant increase in grain weight. These results indicate the positive effects of nano fertilizer on these traits, which is consistent with the research of Fatahi et al. [20]. They reported that the use of fertilizer, biological fertilizers and compost increased plant biomass. Increased plant dry weight in spinach due to nanoparticle treatment increased TiO. Treatment with nanoparticles of chlorophyll formation, Rubisco enzyme activity and photosynthesis rate in spinach resulted in increased plant dry weight [21]. Moosavi et al. (2015) reported in fennel that the effect of nitrogen consumption on harvest index is not significant, which is consistent with the results of our study [12].

Fertilizers increase plant yield by optimizing plant access to nutrients compared to control treatment. Nano fertilizers were quickly and completely absorbed by the plant and well address the plant's nutritional needs and deficiencies. Also, nano fertilizers increase the rate of photosynthesis and thus increase the number of flowers per plant [21].

Naeij et al. (2023) indicated the smaller dimensions of nano-fertilizers have led to more and faster absorption of nutrients and consequently increase efficiency in fertilizers with nano-structure. It seems that nano fertilizer, due to the controlled release of nutrients throughout the growing season, has increased water retention and provided more nutrient uptake, increased photosynthesis and plant dry matter, which ultimately led to increased flowering, increased reproductive growth and improvement [22]. Although yield and yield component are completed. Silica is more effective on plant reproductive growth, so it seems that the silica nanoparticles of this Formax nano fertilizer have increased plant reproductive growth by increasing the amount of photosynthesis and leaf chlorophyll content [7].

It seems that in the mentioned treatments, more application of nano fertilizer stimulated the vegetative growth of the plant and on the other hand, intensified the competition between plants and the yield of single grain was significantly reduced [17]. Also, the biomass of single grain was significantly reduced. It is possible that the application of nano fertilizer stimulated the vegetative growth of single plant and, increasing the frequency of foliar application has a twice and aggravating effect on increasing inter-plant competition, resulting in a significant reduction in material accumulation. Dried in a single plant coriander.

It seems that the application of nano fertilizer due to the increase of photosynthetic activity and plant material production and the effect on the production of active substance increases the percentage of essential oil in the plant. Since the yield of essential oil was obtained by multiplying the two components of percentage of essential oil and grain yield, according to the results of this study, the high yield of essential oil in 5 ml/L of nano treatment was mainly related to high grain yield and high essential oil content. Researchers reported the positive effect of nitrogen application on essential oil yield per unit area in coriander [13].

5. Conclusion

The science and technology of nanostructures is one of the important fields of research and application that has gained special importance in recent years. Nanostructured materials refer to any material that has at least one of its dimensions at the nanometer scale (below 100 nm). In this small and atomic scale, interesting and remarkable properties and behaviors of materials such as high

Table 6
Mean of comparing of measured traits of coriander under the influence of PHARMAX nano fertilizer.

Treatment	Height of plant (cm)	Number of umbrellas/ plant	Number of umbrellas/ square meter	Number of grain/ umbrella	Weight of a thousand grain (g)	Grain yield (kg/ha)	Straw yield/ plant (kg ha)	Harvest Index (%)	Yield of single grain/r plant (g)	Biomass yield of single grain (g)	Percentage of essential oils (%)	Essential oil yield (kg ha)
N_0	51.88 c	7.32c	285.13c	15.21 ab	8.00a	353.24c	797.52c	43.95a	0.90d	2.01c	0.151c	0.540c
N_1	57.70 b	10.40b	405.57b	13.22b	7.96a	442.06bc	990.85bc	44.34a	1.11c	2.51c	0.225b	0.998b
N_2	62.73 a	11.82a	464.02a	15.76 ab	7.71a	615.14b	1134.47b	44.27a	1.23b	2.95b	0.241b	1.493a
N_3	62.10 a	11.84a	317.80c	18.37a	8.99a	674.68a	1389.70a	41.92a	1.55a	3.53a	0.330a	1.565a

N0: 0 ml/L of nano fertilizer, N1: 1 ml/L of nano fertilizer N2: 3 ml/L of nano fertilizer and N3: 5 ml/L of nano fertilizer. In each column, the same letters have no significant difference.

Table 7
Mean of comparing of measured traits of coriander under the influence of foliar application.

Treatment	Height of plant (cm)	Number of umbrellas/ plant	Number of umbrellas/ square meter	Number of grain /umbrella	Weight of a thousand grain (g)	Grain yield (kg ha)	Straw yield/ plant (kg ha)	Harvest Index (%)	Yield of single grain/plant (g)	Biomass yield of single grain (g)	Percentage of essential oils (%)	Essential oil yield (kg ha)
S_1	55.1 b	8.25b	325.8b	16.06a	8.68a	410.15b	976.10c	41.02b	1.35a	3.22a	0.227a	0.938b
S_2	60.25 a	10.95a	412.7a	15.05a	9.15a	538.35a	1189.40a	45.52a	1.06b	2.36 b	0.252a	1.370a

S1: Foliar application at tillering stage, S2: Foliar application 2 weeks after tillering. In each column, the same letters have no significant difference.

reactivity and mobility, self-control and intelligence properties were observed, the main reason being the high specific surface area of materials in this scale. Other interesting features of nanomaterials are lightness and smallness, use in small quantities, versatility and economy in consumables and with the use of nanoparticles and nanocapsules can be produced fertilizers with controlled release or delay. Absorption of fertilizers produced with these dimensions has become more common and has a greater effect than conventional fertilizers. In addition, biocompatible chemical fertilizers can be created and environmental pollution and excessive soil salinity can be prevented. Some fertilizers contain only micronutrients or only macronutrients; others fall into both categories. PHARMAX nano-fertilizer contains both macro and microelements, the use of which not only increased the yield, but also increased the amount of essential oil and essential oil yield. The results indicate that twice foliar application during the growth period and a concentration of 5 ml/L of nano fertilizer had a maximum height of 6.02.02 cm grain yield of 674.68 kg/ha and the highest yield of essential oil of 1.565 kg/ha related to twice foliar application of 5 ml/L nanofertilizers. Due to the slow and controlled release of nutrients, increasing the supply of nutrients required by plants and the ability to release nutrients in accordance with plant needs, nanofertilizers lead to maximum absorption of nutrients by plants and increase growth. No information is available on the effect of PHARMAX nanofertilizer on plant growth. It seems that the nanoparticles of nutrients in this fertilizer have increased the photosynthetic material of the plant and these materials have provided conditions for improving the vegetative growth of the plant, as in the coriander increases the height, number of umbrellas/plant, grain yield, biomass and other traits. Nano fertilizer also have a wide range of high-consumption nutrients (oxygen, calcium, magnesium, potassium, sulfur) and low-consumption (iron, zinc, copper, molybdenum, cobalt) and useful elements (nickel, sodium and flora), so the reason for the increase. The vegetative growth of the plant due to the application of this fertilizer can be attributed to the increase in the supply of nutrients, improved availability and greater absorption by the plant. The high adsorption efficiency and specific surface area of nanoparticles compared to conventional particles can justify the greater effectiveness of these particles [7]. Cu and Zn, Si, in addition to being essential elements for the plant and their presence in the plant in sufficient quantities to increase yield, cause plant resistance to diseases, especially fungi and pests. It seems that the availability of more nutrients for the plant in fertilizer treatments has increased the production of photosynthetic materials, which in turn has increased the production of secondary metabolites. Proper nutrition of plants in the form of different fertilizers strengthens the pathways involved in the production of secondary metabolites. Fertilizer treatments are involved in the construction of enzymes that are involved in the biochemical pathways involved in the synthesis of active plant substances. Just as nutrient deficiencies reduce yield and consequently reduce the amount of effective substances, imbalances in the application of fertilizers have a similar effect and reduce the amount of essential oil produced [12].

The use of PHARMAX nano fertilizer increased the traits studied in this experiment on coriander compared to the control. Therefore, according to the obtained results, the use of this nano fertilizer was recommended to increase the yield of coriander. Based on the findings of this study, it seems that the use of Formax nano fertilizer with a concentration of 5 ml/L and twice-foliar application during the vegetative growth period compared to other treatments has increased the traits and yield of coriander. It is suggested to study the use of PHARMAX nano fertilizer on other plants in field conditions. It can also lead to a reduction in the use of chemical fertilizers, which will reduce environmental effects.

Data availability statement

No data was used for the research described in the article.

CRediT authorship contribution statement

Fatemeh Nejatzadeh: Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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