Journal of Plant Production

Journal homepage & Available online at: www.jpp.journals.ekb.eg

Improvement in Productivity of Black Cumin Plants under Irrigation with Magnetized Water and some Foliar Spray Stimulants

Heba Y. El-Banna*

Veget. and Flori. Dept., Fac. Agric., Mansoura Univ.

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ABSTRACT

This study was performed during the winter seasons of 2022 and 2023 to examine the effect of irrigation water treatments (magnetized and non-magnetized), foliar applications (humic acid, seaweed, yeast, and garlic extract) and their interactions on vegetative measurements, seed yield, oil productivity, and essential oil constituents of black cumin (*Nigella sativa* L.). All plants under the different foliar applications treatments received half of the required quantity from mineral fertilizer (NPK) compared to the control treatment (full recommended dosage of NPK). According to the results, the plants watered with magnetized water in both seasons showed the highest significant levels of essential oil constituents, oil output, seed yield, and vegetative growth when compared to plants irrigated with untreated water. When comparing the effects of foliar treatments, garlic extract at 5 g/L had a superior effect on all of the aforementioned factors. Thus, both previous treatments, magnetized water and foliar spraying with garlic extract at 5 g/L in interaction, succeed to record highest values for some traits under study, such as seed yield, volatile oil production, and essential oil constituents without significant difference between magnetized water with full recommended dosage of NPK (control). This might be suggested to enhance black cumin plants, particularly in terms of seed yield and volatile oil output with premium essential oil ingredients, in order to lower production costs, lessen environmental pollution, and safeguard public health.

Keywords*:* irrigation, magnetized water, foliar application.

INTRODUCTION

One of the most serious repercussions of global climate change is water scarcity, which has impacted numerous countries. Therefore, developing better ways to irrigate with fresh water, as well as implementing up-to-date agricultural technologies and practices, could considerably contribute to enhancing water efficiency and lessening pressure on scarce resources. One of the most promising ideas in this area is to use magnetized water to conserve water while enhancing agricultural output and quality (Pizetta *et al*., 2022). Also it is safe and environmentally beneficial (Alattar *et al*., 2022).

Techniques for treating water with magnetism have gained acceptance as one of the best ways to improve the sector of agriculture. Irrigation with magnetically induced water has shown benefits in several agricultural domains, including improving soil qualities (Mostafazadeh-Fard *et al*., 2011), increment in soil moisture, water economy (Khoshravesh *et al*., 2011; Zlotopolski, 2017), increasing fertilizers efficiency and reducing cost of farm operations (Hozayn and Abdul-Qados, 2010; Suchitra and Babu, 2011). Several investigators reported the positive effect of irrigation with magnetic water such as Hashem and Hegab (2018) on lavender, Khater (2019) on marjoram, and Elhindi *et al.* (2020) on Calendula. These findings were linked by the researchers to the possibility that variations in the osmotic pressure due to the magnetic field could enhance the cellular absorption of water (Massah, 2019). Also, the intended impact of magnetically treated water on nutrient uptake could be explained by the reorientation of membrane phospholipids, which increases membrane permeability and affects sodium and calcium channels in the membrane, allowing ions to enter the cell (Selim *et al*., 2019). Since membrane phospholipids are reoriented, the membrane's sodium and calcium channels are altered, which allows ions to enter the cell and produces the desired impact of magnetically treated water on nutrient uptake (Al-Ogaidi *et al*., 2017; Mghaiouini *et al*., 2022). Following application to the soil, the magnetically treated water was said to cause modifications, including a decrease in water retention in the ground and a corresponding drop in water tension, which was connected to changes in the water structure (Surendran *et al*., 2016). Additionally, magnetism improves the quality of water by enhancing its capacity to enter root cells, decreasing its viscosity, attracting molecules together, and breaking hydrogen bonds, all of which encourage roots to absorb water (Abdul-Qados and Hozayn, 2010).

In addition to water availability, nutritional balance is another critical factor for plant growth and development (Hassan *et. al*., 2015). Mineral fertilization (NPK) is one of the primary factors influencing plant production; however, the application of chemical fertilizers has resulted in several drawbacks, including deteriorating soil fertility, rising production costs, and negative effects on the environment and public health (Boraste *et al*., 2009). Therefore, to feed plants in a safe, environmentally friendly manner and increase plant productivity, we need to find substitute sources of artificial nutrients or synthetic growth regulators. One of the highly recommended ways to lessen pollution is using bio-stimulant compounds (Fawzy *et al*., 2012) as it lately gained focus

*** Corresponding author.**
E-mail address: hebayossef@hotmail.com

DOI: 10.21608/jpp.2024.269632.1311

attention among the research fields of green agriculture. The effect of different bio-stimulants on enhancing nutritional status, growth development, flower and seed production of ornamental and medicinal plants were reported by many investigators (Mazrou, 2019; Massoud *et al.*, 2020; Attia *et al.*, 2020; Khudair and Hajam, 2021).

Garlic extract, the sap of *Allium sativum* bulb has a high nutritional content. It stands out for having a significant concentration of biological substances like volatile oil, iodine, allicin, ajoene, alliin, sugar, diallyl diallyl, sallylcysteine, allylpropyl, sallylmercaptocystein, trisulfide, vinyldithiines and others (Al Mayahi and Fayadh 2015; El-Saadony *et al.*,2017). Furthermore noted by Dahab *et al.* (2018), garlic extract has a variety of effects because of its hormonal character, which is crucial for cell elongation and lateral expansion. Garlic is also thought to be an excellent source of minerals, vitamins, and antioxidants (Pekowska and Skupień, 2009), even being regarded as an abundant source of additional non-volatile phytonutrients such as flavonoids, phenolic compounds, proteins, saponins, amides, sapogenins, and nitrogen oxides (Lanzotti *et al.*, 2014).

Recently, several reports focused on humic acid (HA) in various fields such as environmental sciences, soil chemistry, fertility, and plant physiology as a result of the several ways in which HA might improve plant development and nutrient uptake (Paksoy *et al.*, 2010). HA is a complex material that is produced during the breakdown of organic matter and is the primary organic component of soil and plays a significant role in the cycling of numerous elements within it (Senesi *et al.*, 1996; Sani, 2014). Also, numerous components in HA keep nutrients on mineral surfaces, increasing their availability and enhancing soil fertility, which in turn promotes plant development and productivity (Abdel-Razzak, and El-Sharkawy, 2013). Applying HA topically to the leaves of many plants stimulates their growth, yield, and quality by boosting nutrient uptake, acting as a source of mineral nutrients, and controlling nutrient release (Karakurt *et al.*, 2009; Bakry *et al.*, 2015). Furthermore, HA exerts an influence on the quantity of amino acids, nitrate accumulation, sugars, and respiration mechanisms (Boehme *et al.*, 2005).

One type of bio-stimulant that is produced from seaweed, particularly brown algae, is called seaweed extract (Chapman and Chapman, 1980). Seaweed extract (SE) is rich in macro and micronutrients and mainly contains natural hormones, such as gibberellin, cytokinin, auxin, abscisic acid, and other active substances such as seaweed betaine, polysaccharide, sugar alcohol, and phenolic compounds (Jardin, 2012; Battacharyya *et al.*, 2015). Numerous studies on the application of SE in agriculture have revealed a variety of benefits, including improved soil and increased crop development (Mukherjee and Patel, 2020). Also, it increased plant root and shoot growth by raising soil colony counts and soil microbial metabolic activity (Alam *et al.*, 2013), enhanced plant absorption of nutrients from the soil (Boukhari *et al.*, 2020), and strengthened plant defenses against biotic (Ben Salah *et al.*, 2018).

Yeast is a highly abundant source of critical amino acids including tryptophan and lysine. Several enzymes, as well as mineral elements including iron, cobalt, and calcium and vitamin B groups like B_{12}, B_6, B_2, and B_1, are also present (Barnett *et.al.*, 1990; Mahmoud, 2001). Additionally, particularly important components like auxins and cytokinins can be found in abundance in yeast extract (Barnett *et.al.*, 1990; Amer, 2004), which can provide plants with an easily accessible growth supplement, hence increasing plant productivity (Ghoname *et al.*, 2010) because it stimulated the production of chlorophyll, proteins, and nucleic acids, as well as cell division and expansion (Castel-franco and Beale,1983).

So, the goal of this study was to find a safe and environmentally beneficial way to achieve a water and nutrient balance for the high-quality production of vegetative growth, yield, and chemical composition of black cumin plants by using irrigation with magnetized water and some foliar applications as a trial for minimizing the use of synthetics chemical fertilizers, resulting in a notable decrease in the cost of production and pollutant levels.

MATERIALS AND METHODS

To assess the performance of black cumin plants (*Nigella sativa* L.) in response to irrigation water treatments (magnetized and non-magnetized), foliar applications (humic acid, seaweed, yeast, and garlic extract), and their interactions, the current study was carried out at a private farm near Aga, Dakahlia Governorate, Egypt, throughout two consecutive winter seasons (2022 and 2023). For some of the physical and chemical qualities as shown in Table (1), random soil samples were gathered from the experimental field area at a depth of 0 to 30 cm before sowing to estimate the physical and chemical properties of the soil in accordance with Chapman and Pratt (1971).

Black cumin seeds were acquired from the Agricultural Research Center's Medicinal and Aromatic Plants Section at El-Dokky, Cairo, and were sowed on 15th October of each winter season. The design of the experiment was a split plot in a randomized complete block design with four replicates. While the sub-plots were used for foliar spray stimulants, and the major plots were used for irrigation water treatments. The experimental unit area measured 7.5 m^2 (2.5×3 m^2), with hills at 25 cm plant spacing on one side of each of the four rows that were 30 cm wide. After fifteen days of sowing, the number of plants was reduced to two per hill.

Two water irrigation treatments (using magnetized and non-magnetized water) and six foliar application treatments counting humic acid, seaweed, yeast extract (5 and 10 g/L), garlic extract (5 and 10 g/L), and the control treatment (using the full recommended dosage of mineral fertilizers) comprised the 14 treatments in the experiment. The magnetized water was obtained by running the irrigation water through magnetized device in a permanent magnet unit. Seaweed and humic acid (Canada Humex) are obtained as commercial compounds. While, yeast extract was made in accordance with Ghamriny *et al.* (1999) and garlic extract according to Hanafy *et al.* (2012). Using a hand sprayer, apply foliar spray in the early morning till it drops. All foliar spraying treatments received half the required quantity of mineral fertilizer (NPK), and solutions were administered three times in 15-day intervals beginning 25 days after thinning. Mineral NPK (recommended dose) was applied to black cumin plants at a rate of 300 + 200 + 50 kg/fed of ammonium sulfate (20.5% N), calcium superphosphate (15.5% P_2O_5), and potassium sulfate (48% K_2O), respectively. The fourteen treatments are as follows:

1. Non-magnetized irrigation water.
1- 100 % NPK (Control, recommended dose).
2- 50 % NPK + humic acid (1.5 ml/L).
3- 50 % NPK + Seaweed (3.0 cm^3/L).
4- 50 % NPK + yeast extract (5 g/L).
5- 50 % NPK + yeast extract (10 g/L).
6- 50 % NPK + garlic extract (5 g/L).
7- 50 % NPK + garlic extract (10 g/L).

2. Magnetized irrigation water.
1- 100 % NPK (Control, recommended dose).
2- 50 % NPK + humic acid (1.5 ml/L).
3- 50 % NPK + Seaweed (3.0 cm^3/ L).
4- 50 % NPK + yeast extract (5 g/L).
5- 50 % NPK + yeast extract (10 g/L).
6- 50 % NPK + garlic extract (5 g/L).
7- 50 % NPK + garlic extract (10 g/L).

Table 1. Some physical and chemical properties of experimental soil during the 2022 and 2023 seasons.

Season	Mechanical analysis (%)				Texture	OM	SP	T. $CaCO_3$	EC $dS.m^{-1}$	pH	Available (ppm)		
	Coarse Sand	Fine Sand	Silt	Clay	Class	(%)	(%)	g/kg	1:5	(1:2.5)	N	P	K
1st	4.95	30.17	34.72	31.21	Clay Loamy	1.37	63.2	3.87	1.45	8.23	49.51	5.51	182.1
2nd	4.13	31.83	36.02	29.13	Clay Loamy	1.49	65.4	4.03	1.17	8.01	53.23	6.42	188.2

SP: Saturation percentage OM: Organic matter EC: Electrical conductivity

Data recorded:

Vegetative growth and yield measurements:

A random sample of twelve plants from each treatment was taken at the harvesting stage to determine the following parameters: plant height (cm), number of branches /$plant^{-1}$, herb fresh and dry weight (g/plant), seed yield/plant (g) and seed yield/fed (Kg).

Volatile and fixed oils determinations:

A sample of black cumin seeds was randomly taken from each treatment to calculate volatile oil percentage (%), volatile oil yield (ml/plant and L/feddan), fixed oil percentage (%), and fixed oil yield (ml/plant and L/feddan). After the dehydration of volatile oil with anhydrous sodium sulfate, the oil was kept cold and dark until GC-MS analysis.

Seed volatile oil was extracted using the hydro distillation method as described by British Pharmacopoeia (1963). Samples weighing 100 g were placed straight into extraction units then the percentage of volatile oil was evaluated by the following equation:

Volatile oil (%) =

oil volume in the graduated tube/weight of sample x 100

Fixed oil was estimated by Soxhlet apparatus using petroleum ether (BP 40-60°C) as solvent according to the Association of Official Agricultural Chemists (A.O.A.C. 1980).

Statistical Analysis.

Utilizing the COSTAT statistical package (CoHort software, 2006; Cary, NC, USA), data were subjected to analysis of variance (ANOVA) applying a split plot analysis in a Complete Randomized Block design with four replications. In addition, to compare means, Duncan's Multiple Range Test was used at P=0.05. Standard errors were displayed alongside the means.

RESULTS AND DISCUSSION

Results

Vegetative and yield parameters.

Effects of magnetic treatment of irrigation water:

Table (2) shows the growth performance of black cumin plants in response to watering with non-magnetized and magnetized water. According to the results, irrigation water treatments caused a substantial difference in growth parameters such as plant height, number of branches, as well as fresh and dry weights. In both growth seasons plants that were irrigated with magnetized water notably had the greatest values of all the previously described attributes when compared to plants that were irrigated with un-magnetized water.

Examining the response of the irrigation water treatments on seed yield/plant (g) and seed yield/fed (Kg), the results in Table (3) showed a similar trend to the previous parameters. The irrigation with magnetized water recorded the highest significant seed yield per plant (g) and seed yield per fed in both seasons (12.50 ± and 13.19 ± 0.37 g) and (720 ± 20.39 and 759.91 ±21.38 Kg), respectively.

Effects of foliar spray stimulants:

The data presented in Table (2) unambiguously show that the control (full recommended dosage of NPK) was associated with higher significant values of all investigated parameters. However, it is reported that foliar application stimulants, in addition to the half-recommended dose of NPK, produced good parameters. In both seasons, the greatest significant values for total vegetative growth were obtained by spraying 5 g/L of garlic extract, followed by the treatment of 10 g/L yeast extract. Throughout both seasons, the seaweed plants had the lowest values for every vegetative parameter that was examined.

For seed yield/plant (g) and seed yield/fed (Kg) as shown in Table (3), the control (full recommended dosage of NPK) in the first season gave the highest significant values of the two parameters, followed by the foliar application of 5 g/L of garlic extract. While, in the second season the data showed obviously that both previous treatments recorded the highest significant values for the two parameters without significant difference between them (15.16 ± 0.31 and 14.68 ± 0.42 g) and (873.36 ± 18.37 and 718.56 ± 12.01 Kg), respectively.

Effect of interaction between irrigation water treatments and foliar spray stimulants:

The information presented in Table (2) indicates that over the two growth seasons, the interplay between irrigation water and foliar application treatments had a substantial impact on plant height, branch number, fresh and dry weight per plant. Using magnetized water with all application treatments had the superiority in this regard as it recorded the highest values of all the aforementioned characters in both seasons when compared to non-magnetized water at the same treatment. Although magnetized water with the recommended dose of NPK came in the first order, the foliar application of 5 g/L of garlic extract came in the second order in outperforming the recommended dose of NPK with non-magnetized water for all vegetative growth parameters. On the other hand, lower values were recorded when plants were irrigated with non-magnetized water and sprayed seaweed in the two growing seasons.

The results in Table (3) showed a similar trend to the parameters of seed yield/plant (g) and seed yield/fed (Kg).

Magnetized water with all foliar application treatments had the upper hand in this regard when compared to non-magnetized water at the same foliar application. In the two seasons, magnetized water with the recommended quantity of NPK or foliar spray of 5 g/L garlic extract produced the highest significant seed yield per plant (g) and seed yield per fed compared to all other treatments.

Table 2. Effect of irrigation water treatments, some foliar spray stimulants and their interactions on plant height, No. of branches, herb fresh and dry weight /plant⁻ of black cumin plant at 2021/2022 and 2022/2023 seasons.

Treatments		Plant height (cm)		Branch number/plant		Herb fresh weight (g/plant)		Herb dry weight (g/plant)	
		2021/22	2022/23	2021/22	2022/23	2021/22	2022/23	2021/22	2022/23
Irrigation water treatments									
Non- magnetized water		47.22±0.79 b	47.74±0.81 b	10.79±0.25 b	11.32±0.26 b	67.48±0.63 b	68.16±0.62 b	21.32± 0.28 b	21.91±0.30 b
Magnetized water		51.16±0.71 a	52.04±0.72 a	12.11±0.31 a	12.87±0.30 a	70.88±0.51 a	71.64±0.52 a	22.64±0.29 a	23.24±0.30 a
NPK and Foliar applications treatments									
Control (NPK)		56.40±0.55 a	57.08±0.63 a	14.25± 0.40 a	14.74±0.41 a	73.98±0.64 a	74.73±0.63 a	24.40±0.43 a	25.03±0.43 a
Humic		47.08±0.62 e	47.82±0.74 d	10.88±0.31 d	11.75±0.36 c	68.30±0.57 d	69.05±0.61 d	21.09±0.25 e	21.59±0.27 d
Seaweed		44.38±0.82 g	45.25±0.98 f	9.78± 0.26 f	10.57±0.40 d	65.11±0.97 f	65.99±0.94 f	19.94±0.32 g	20.52±0.37 e
Yeast extract 5 g/L		45.98±1.06 f	46.53±1.10 e	10.34±0.24 e	10.84±0.37 d	66.11±0.92 e	66.76±1.00 e	20.60±0.35 f	21.10±0.35 de
Yeast extract 10 g/L		49.58±0.86 c	50.07±0.87 c	11.41± 0.20 c	11.66±0.23 c	69.96±0.59 c	70.59±0.64 c	22.61±0.16 c	23.32±0.14 b
Garlic extract 5 g/L		52.88±0.77 b	53.95±0.90 b	12.56±0.33 b	13.27±0.45 b	72.03±0.58 b	72.81±0.68 b	23.16± ٠,٢٧ b	23.88±0.33 b
Garlic extract 10 g/L		48.08±0.66 d	48.50±0.68 d	10.96±0.23 d	11.84±0.27 c	68.77±0.41 d	69.39±0.38 d	22.05± ٠,١٦ d	22.59±0.29 c
Interactions									
Non- magnetized	Control (NPK)	54.83±0.40 b	55.50±0.11 b	13.25± 0.18 b	13.75±0.27 b	72.39±0.42 c	73.14±0.26 c	23.30±0.18 c	24.05±0.27 bc
	Humic	45.48±0.28 i	45.98±0.32 f	10.19± 0.33 f	10.94±0.28 f	66.84±0.14 i	67.59±0.47 g	20.48±0.10 f	20.98±0.25 gh
	Seaweed	42.25±0.23 k	42.75±0.35 g	9.25±0.18 g	9.75±0.34 g	62.59±0.21 k	63.59±0.39 h	19.14±0.03 h	19.64±0.29 i
	Yeast extract 5 g/L	43.2±0.33 j	43.70±0.33 g	9.81±0.26 fg	10.06±0.28 g	63.70±0.18 j	64.20±0.21 h	19.68± 0.06 g	20.28±0.27 hi
	Yeast extract 10 g/L	47.33±0.29 g	47.83±0.24 e	10.94±0.12 d	11.19±0.21 ef	68.48±0.27 g	68.98±0.26 f	22.42±0.23 d	22.97±0.07 de
	Garlic extract 5 g/L	50.93±0.27 d	51.68±0.35 c	11.75±0.10 c	12.15±0.23 cde	70.59±0.33 e	71.09±0.14 d	22.51± 0.20 d	23.33±0.31 cd
	Garlic extract 10 g/L	46.38±0.21 h	46.73±0.11 f	10.38±0.07 def	11.38±0.36 def	67.81±0.23 gh	68.56±0.38 fg	21.68± 0.09 e	22.15±0.15 ef
Magnetized	Control (NPK)	57.80±0.14 a	58.65±0.45 a	15.24±0.26 a	15.74±0.27 a	75.57±0.27 a	76.32±0.37 a	25.50±0.15 a	26.00±0.43 a
	Humic	48.68±0.06 f	49.67±0.39 d	11.56±0.11 c	12.56±0.31 c	69.76±0.24 f	70.50±0.32 d	21.69±0.17 e	22.19±0.22 ef
	Seaweed	46.50± 0.24 h	47.75±0.39 e	10.31±0.33 ef	11.39±0.44 def	67.64±0.30 h	68.39±0.29 fg	20.74±0.22 f	21.41±0.24 fg
	Yeast extract 5 g/L	48.75±0.21 f	49.38±0.45 d	10.88±0.13 de	11.63±0.43 cdef	68.53±0.28 g	69.33±0.54 ef	21.53±0.14 e	21.93±0.26 f
	Yeast extract 10 g/L	51.83±0.11 c	52.33±0.26 c	11.88±0.16 c	12.13±0.26 cde	71.45±0.31 d	72.19 ±0.36 c	22.79±0.21 d	23.67±0.11 bcd
	Garlic extract 5 g/L	55.00±0.25 b	56.23±0.48 b	13.38±0.21 b	14.38±0.22 b	73.48±0.23 b	74.53±0.45 b	23.83±0.15 b	24.42±0.47 b
	Garlic extract 10 g/L	49.78±0.19 e	50.28±0.25 d	11.55±0.11 c	12.30±0.29 cd	69.73±0.36 f	70.23±0.29 de	22.42±0.17 d	23.03±0.51 de

Table 3. Effect of irrigation water treatments, some foliar spray stimulants and their interactions on seeds yield (g plant^{-1} and Kg fad^{-1}) of black cumin plant at 2021/2022 and 2022/2023 seasons

Treatments		seeds yield (g/plant)		seeds yield (Kg/fed)	
		2021/22	2022/23	2021/22	2022/23
Irrigation water treatments					
Non- magnetized water		11.24 ± 0.31 b	11.99 ± 0.32 b	647.59 ± 17.82 b	690.99 ± 18.50 b
Magnetized water		12.50 ± 0.35 a	13.19 ± 0.37 a	720.00 ± 20.39 a	759.91± 21.38 a
NPK and Foliar applications treatments					
Control (NPK)		14.58 ± 0.32 a	15.16 ± 0.31 a	839.52 ± 18.37 a	873.36 ± 18.37 a
Humic		10.99 ± 0.29 e	11.66 ± 0.30 d	632.88 ± 16.95 e	671.76 ± 17.44 d
Seaweeds		9.49 ± 0.15 g	10.15 ± 0.20 f	546.48 ± 8.39 g	584.64 ± 11.77 f
Yeast extract 5 g/L		10.15 ± 0.25 f	10.95 ± 0.36 e	584.64 ± 14.93 f	630.72 ± 20.53 e
Yeast extract 10 g/L		12.48 ± 0.16 c	13.09 ± 0.25 b	718.56 ± 9.47 c	753.84 ± 14.45 b
Garlic extract 5 g/L		13.69 ± 0.45 b	14.68 ± 0.42 a	788.40 ± 26.27 b	845.28 ± 24.52 a
Garlic extract 10 g/L		11.74 ± 0.17 d	12.48 ± 0.20 c	676.08 ± 9.91 d	718.56 ± 12.01 c
Interactions					
Non-magnetized	Control (NPK)	13.88 ± 0.36 b	14.38 ± 0.20 b	799.20 ± 20.95 b	828.00 ± 11.60 b
	Humic	10.25 ± 0.06 h	11.00 ± 0.24 gh	590.40 ± 3.71 h	633.60 ± 13.91 gh
	Seaweeds	9.15 ± 0.10 j	9.80 ± 0.15 i	527.04 ± 5.99 j	564.48 ± 8.48 i
	Yeast extract 5 g/L	9.53 ± 0.13 ij	10.28 ± 0.39 hi	548.64 ± 7.20 ij	591.84 ± 22.23 hi
	Yeast extract 10 g/L	12.08 ± 0.09 de	12.80 ± 0.44 de	695.52 ± 4.91 de	737.28 ± 24.77 de
	Garlic extract 5 g/L	12.50 ± 0.11 cd	13.60 ± 0.27 c	720.00 ± 6.22 cd	783.36 ± 15.42 c
	Garlic extract 10 g/L	11.33 ± 0.09 f	12.13 ± 0.29 ef	652.32 ± 4.92 f	698.40 ± 17.01 ef
Magnetized	Control (NPK)	15.28 ± 0.13 a	15.95 ± 0.14 a	879.84 ± 7.20 a	918.72 ± 8.31 a
	Humic	11.73 ± 0.19 ef	12.33 ± 0.28 ef	675.36 ± 11.12 ef	709.92 ± 16.01 ef
	Seaweeds	9.83 ± 0.11 hi	10.50 ± 0.30 hi	565.92 ± 6.38 hi	604.80 ± 17.44 hi
	Yeast extract 5 g/L	10.78 ± 0.19 g	11.63 ± 0.37 fg	620.64 ± 11.12 g	669.60 ± 21.6 fg
	Yeast extract 10 g/L	12.88 ± 0.11 c	13.38 ± 0.23 cd	741.60 ± 6.39 c	770.40 ± 13.38 cd
	Garlic extract 5 g/L	14.87 ± 0.14 a	15.75 ± 0.06 a	856.80 ± 7.93 a	907.20 ± 3.72 a
	Garlic extract 10 g/L	12.15 ± 0.13 de	12.83 ± 0.18 cde	699.84 ± 7.62 de	738.72 ± 10.61 cde

Volatile and fixed oils determinations.

Effects of magnetic treatment of irrigation water:

Data presented in Tables (4 and 5) indicate that the volatile and fixed oil percentage and yield (per plant and fed) were significantly enhanced by using magnetized water in irrigation compared to non-magnetized water in both experimental seasons.

Table 4. Effect of irrigation water treatments, some foliar spray stimulants and their interactions on volatile oil percentage and volatile oil yield (ml plant^{-1} and L fad^{-1}) of black cumin plant at 2021/2022 and 2022/2023 seasons.

Treatments		Volatile Oil (%)		Volatile Oil yield (ml/plant)		Volatile Oil yield (L/fed)	
		2021/22	2022/23	2021/22	2022/23	2021/22	2022/23
Irrigation water treatments							
Non- magnetized water		0.28 ± 0.005 b	0.29 ± 0.01 b	0.034 b	0.035 b	1.94 ± 0.06 b	2.02 ± 0.06 b
Magnetized water		0.31 ± 0.006 a	0.33 ± 0.01 a	0.041 a	0.042 a	2.36 ± 0.08a	2.44 ± 0.08 a
NPK and Foliar applications treatments							
Control (NPK)		0.34 ± 0.009 a	0.36 ± 0.007 a	0.048 a	0.049 a	2.76 ± 0.08 a	2.86 ± 0.07 a
Humic		0.28 ± 0.007 d	0.31 ± 0.013 b	0.034 e	0.035 e	1.94 ± 0.06 e	1.99 ± 0.05 e
Seaweeds		0.26 ± 0.006 e	0.28 ± 0.008 c	0.029 g	0.029 g	1.66 ± 0.06 g	1.71 ± 0.05 g
Yeast extract 5 g/L		0.27 ± 0.006 e	0.27 ± 0.004 c	0.031 f	0.032 f	1.77 ± 0.06 f	1.84 ± 0.06 f
Yeast extract 10 g/L		0.29 ± 0.009 cd	0.30 ± 0.009 b	0.037 d	0.038 d	2.11 ± 0.10 d	2.19 ± 0.09 d
Garlic extract 5 g/L		0.33 ± 0.009 b	0.35 ± 0.006 a	0.045 b	0.046 b	2.58 ± 0.13 b	2.64 ± 0.13 b
Garlic extract 10 g/L		0.30 ± 0.008 c	0.32 ± 0.011 b	0.039 c	0.041 c	2.30 ± 0.12 c	2.36 ± 0.12 c
Interactions							
Non-magnetized	Control (NPK)	0.32 ± 0.004 b	0.34 ± 0.005 bc	0.045 b	0.046 b	2.56 ± 0.04 b	2.67 ± 0.02 b
	Humic	0.27 ± 0.005 de	0.28 ± 0.004 ef	0.031 g	0.033 hi	1.80 ± 0.04 g	1.87 ± 0.05 hi
	Seaweeds	0.25 ± 0.005 e	0.26 ± 0.003 f	0.027 h	0.027 k	1.53 ± 0.04 h	1.57 ± 0.03 k
	Yeast extract 5 g/L	0.26 ± 0.005 e	0.26 ± 0.004 f	0.028 h	0.029 j	1.63 ± 0.04 h	1.69 ± 0.05 j
	Yeast extract 10 g/L	0.27 ± 0.008 de	0.28 ± 0.006 ef	0.032 g	0.033 gh	1.85 ± 0.02 g	1.95 ± 0.03 gh
	Garlic extract 5 g/L	0.31 ± 0.010 bc	0.34 ± 0.009 bc	0.039 d	0.040 d	2.22 ± 0.06 d	2.30 ± 0.04 d
	Garlic extract 10 g/L	0.28 ± 0.008 d	0.31 ± 0.022 de	0.034 ef	0.036 ef	1.98 ± 0.02 ef	2.05 ± 0.01 ef
Magnetized	Control (NPK)	0.36 ± 0.009 a	0.38 ± 0.003 a	0.052 a	0.053 a	2.97 ± 0.04 a	3.05 ± 0.02 a
	Humic	0.30 ± 0.004 c	0.33 ± 0.022 cd	0.036 e	0.037 e	2.07 ± 0.02 e	2.10 ± 0.02 e
	Seaweeds	0.27 ± 0.009 de	0.29 ± 0.010 e	0.031 g	0.032 i	1.80 ± 0.06 g	1.84 ± 0.02 i
	Yeast extract 5 g/L	0.28 ± 0.007 d	0.28 ± 0.005 ef	0.033 fg	0.034 fg	1.92 ± 0.02 fg	1.98 ± 0.03 fg
	Yeast extract 10 g/L	0.31 ± 0.006 bc	0.32 ± 0.008 cd	0.041 c	0.042 c	2.38 ± 0.04 c	2.43 ± 0.03 c
	Garlic extract 5 g/L	0.35 ± 0.004 a	0.37 ± 0.003 ab	0.051 a	0.052 a	2.94 ± 0.04 a	2.98 ± 0.03 a
	Garlic extract 10 g/L	0.32 ± 0.003 b	0.33 ± 0.003 cd	0.046 b	0.047 b	2.62 ± 0.04 b	2.68 ± 0.04 b

Table 5. Effect of irrigation water treatments, some foliar spray stimulants and their interactions on fixed oil percentage and fixed oil yield (ml plant^{-1} and L fad^{-1}) of black cumin plant at 2021/2022 and 2022/2023 seasons.

Treatments		Fixed Oil (%)		Fixed Oil yield (ml/plant)		Fixed Oil yield (L/fed)	
		2021/22	2022/23	2021/22	2022/23	2021/22	2022/23
Irrigation water treatments							
Non- magnetized water		٢٦,٧٨ ± ٠,٣١b	27.39 ± 0.31 b	3.74 ± 0.19 b	4.11 ± 0.20 b	215.58± 11.35 b	236.81± 11.64 b
Magnetized water		30.86 ± 0.39 a	31.56 ± 0.41 a	5.21 ± 0.27 a	5.57 ± 0.28 a	300.38± 15.45 a	320.83± 16.21 a
NPK and Foliar applications treatments							
Control (NPK)		32.03± 0.76 a	32.62 ± 0.83 a	6.32 ± 0.40 a	6.73 ± 0.41 a	363.89 ±٢٣,١٧ a	387.79 ± 23.43 a
Humic		28.15± 0.86 d	28.85 ± 0.85 d	3.67 ± 0.23 e	4.15 ± 0.26 e	211.46± 13.43 e	238.82 ± 14.79 e
Seaweeds		26.34± 0.46 f	26.97 ± 0.44 f	2.89 ± 0.22 g	3.23 ± 0.19 g	166.68± 12.65 g	185.76 ± 11.01 g
Yeast extract 5 g/L		27.26± 0.73 e	27.98 ± 0.78 e	3.30 ± 0.19 f	3.62 ± 0.21 f	189.94± 11.22 f	208.66 ± 12.14 f
Yeast extract 10 g/L		28.95± 0.95 c	29.49 ± 0.96 c	4.42 ± 0.29 d	4.67 ± 0.33 d	254.66± 17.07 d	269.06 ± 19.15 d
Garlic extract 5 g/L		30.34± 0.96 b	31.16 ± 1.02 b	5.88 ± 0.37 b	6.31 ± 0.37 b	338.40± 21.71 b	363.60 ± 21.75 b
Garlic extract 10 g/L		28.65± 0.75 c	29.23 ± 0.73 cd	4.86 ± 0.26 c	5.18 ± 0.30 c	280.87± 15.24 c	298.08 ± 17.49 c
Interactions							
Non-magnetized	Control (NPK)	30.01± 0.16 e	30.46 ± 0.32 de	5.26 ± 0.10 d	5.69 ± 0.13 cd	303.12± 6.02 d	327.88 ± 7.53 cd
	Humic	25.91± 0.09 ij	26.61 ± 0.19 hi	3.07 ± 0.05 i	3.54 ± 0.19 hi	176.54± 2.90 i	203.90 ± 11.39 hi
	Seaweeds	25.14± 0.11 k	25.83 ± 0.12 i	2.32 ± 0.06 j	2.75 ± 0.07 j	133.78± 3.96 j	158.26 ± 4.19 j
	Yeast extract 5 g/L	25.36± 0.25 jk	25.96 ± 0.37 i	2.81 ± 0.09 i	3.19 ± 0.17 ij	162.00± 4.94 i	183.60 ± 9.81 ij
	Yeast extract 10 g/L	26.46± 0.25 hi	26.96 ± 0.03 h	3.65 ± 0.08 gh	3.83 ± 0.07 gh	210.24± 4.39 gh	220.32 ± 4.12 gh
	Garlic extract 5 g/L	27.88± 0.44 g	28.55 ± 0.46 f	4.91 ± 0.11 e	5.38 ± 0.16 d	282.68± 6.48 e	310.03 ± 9.24 d
	Garlic extract 10 g/L	26.69± 0.14 h	27.37 ± 0.31 gh	4.18 ± 0.02 f	4.41 ± 0.11 ef	240.77± 1.35 f	253.73 ± 6.327 ef
Magnetized	Control (NPK)	34.05± 0.05 a	34.78 ± 0.24 a	7.37 ± 0.05 a	7.77 ± 0.18 a	424.66± 2.85 a	447.69 ± 10.61 a
	Humic	30.39± 0.28 de	31.09 ± 0.10 d	4.28 ± 0.08 f	4.75 ± 0.15 e	246.39± 4.47 f	273.75 ± 8.91 e
	Seaweeds	27.53± 0.14 g	28.11 ± 0.17 fg	3.47 ± 0.05 h	3.70 ± 0.12 gh	199.58± 2.98 h	213.26 ± 6.64 gh
	Yeast extract 5 g/L	29.16± 0.11 f	30.01 ± 0.14 e	3.78 ± 0.11 g	4.06 ± 0.23 fg	217.87± 6.57 g	233.71 ± 13.15 fg
	Yeast extract 10 g/L	31.44± 0.08 c	32.04 ± 0.23 c	5.19 ± 0.08 d	5.52 ± 0.18 cd	299.09± 4.96 d	317.81 ± 10.46 cd
	Garlic extract 5 g/L	32.81± 0.08 b	33.76 ± 0.40 b	6.84 ± 0.16 b	7.24 ± 0.25 b	394.12± 9.29 b	417.17 ± 14.46 b
	Garlic extract 10 g/L	30.62± 0.25 d	31.11 ± 0.27 d	5.54 ± 0.07 c	5.95 ± 0.15 c	320.98± 3.02 c	342.43 ± 8.72 c

Effects of foliar spray stimulants:

The obtained results in Table (4) showed that the highest significant volatile oil percentage and yield (per plant and fed) in both seasons resulted from the treatment of control (full recommended dosage of NPK). The next positive effects for all parameters were recorded with the foliar application of 5 g/L garlic extract with significant differences among all other foliar applications. Otherwise, the weakest effect in this regard was recorded with seaweed treatment in the two seasons.

The same tendency was noticed regarding the fixed oil content of black cumin seeds and the results go in the same direction of volatile oil (Table 5)

Effect of interaction between irrigation water treatments and foliar spray stimulants:

Volatile oil percentage and yield (per plant and fed) in response to the interaction between irrigation water treatments and foliar spray stimulants are presented in Tables (4). Data indicated that the best values of all the previously mentioned metrics significantly enhanced in response to irrigation with magnetized water when compared to non-magnetized water at the same foliar applications during both seasons. The highest values of volatile oil percentage and yield (per plant and fed) in both seasons were obtained with magnetized water with NPK at the recommended dose (control) followed by the foliar application of garlic extract at 5 g/L without significant difference between them. The fixed oil percentage and yield (per plant and fed) followed the same trend since irrigation with magnetized water inoculation with NPK fertilization at the recommended dose gave the highest significant values of the aforementioned parameters in both seasons followed by irrigation with magnetized water and garlic extract at 5 g/L as shown in Table (5).

The lowest values of all these metrics were realized for the plants that were irrigated with non-magnetized water and seaweed. In both the 2022 and 2023 seasons, the same effect was observed.

Volatile oil constituents' percentage.

Different components identified in essential oils extracted from black cumin seeds as a result of different irrigation water and foliar application treatments were illustrated in Table (6). About seventeen components were detected and defined by GC-MS analysis. The major constituents of essential oils seeds were thymoquinone (23.35–26.86%), trans-Anethol (10.31 – 12.51%), P-cymene (10.79– 12.56%), α-Thujene (2.34 -5.62%), thymol (2.94 – 3.82%), γ-Terpinene (4.71 - 6.91%), limonene (3.67- 5.82%), carvacrol (1.53–4.34%), and longifolene (3.03 - 4.23%).

Interestingly, magnetized water with all treatments enhanced volatile oil components as compared to non-magnetized water at the same treatment. Moreover, the treatment of magnetized water with garlic extract at 5 g/L succeeded in recording the highest values for all components when compared to non-magnetized water with NPK at the recommended dose (control). The highest values of some main components of volatile oil were obtained from the treatment of magnetized water and foliar of garlic extract at 5 g/L such as thymoquinone (26.86%), γ-Terpinene (6.91%), limonene (5.82%), longifolene (4.23%), and thymol (3.82%). While the other main components recorded the highest values with the treatment of magnetized water with NPK at the recommended dose (control).

Table 6. The interaction effect of irrigation water treatments and some foliar spray stimulants on volatile oil constituents of black cumin plants.

Components	Volatile oil constituents (%)					
	Non-magnetized water			Magnetized water		
	Control (NPK)	Yeast extract 10 g/L	Garlic extract 5 g/L	Control (NPK)	Yeast extract 10 g/L	Garlic extract 5 g/L
α-pinne	2.11	1.21	1.97	2.45	1.52	2.31
Sabinene	1.47	0.96	1.38	1.63	1.12	1.53
Myrcene	0.53	0.20	0.45	0.61	0.31	0.58
β-pinene	2.33	1.41	2.16	2.71	1.95	2.54
Trans-Anethol	11.67	10.31	11.51	12.51	10.73	12.36
P-Cymene	12.15	10.79	11.61	12.56	11.10	11.95
γ-Terpinene	5.94	4.71	6.62	6.54	5.38	6.91
Carvone	3.17	2.13	2.62	3.83	2.95	3.58
Thymol	3.32	2.94	3.51	3.63	3.01	3.82
Terpinen-4-ol	1.32	0.66	1.25	1.50	0.81	1.43
Thymoquinone	25.21	23.35	25.61	26.17	24.89	26.86
Carvacrol	3.42	2.53	3.23	4.34	3.01	3.86
α-Thujene	4.86	3.34	4.52	5.62	4.15	5.06
Limonene	4.20	3.67	4.65	5.13	4.51	5.82
α-Phellandrene	0.51	0.34	0.48	0.62	0.41	0.57
α-Longipinene	1.03	0.55	0.98	1.37	0.67	1.20
Longifolene	3.01	3.03	3.21	3.96	3.21	4.23
Total compounds	86.25	72.13	85.76	95.18	79.73	94.61
Other compounds	13.75	30.87	14.24	4.82	23.27	5.39

Discussion

In the present study, significant enhancements were observed in the growth of black cumin plant parameters from irrigation with magnetized water as compared to un-magnetized water. Similar enhancing effects were obtained by several investigators who reported the positive effect of irrigation with magnetic water such as Hashem and Hegab (2018) on lavender, Elhindi *et al.* (2020) on Calendula, and Khater (2019) on marjoram as they mentioned that plants irrigated with magnetized water had numerous advantages for vegetative development, essential oil production, and chemical components. These findings were linked by the researchers to the possibility that variations in the osmotic pressure due to the magnetic field could enhance cellular absorption of water (Massah, 2019). The intended impact of magnetically treated water on nutrient uptake could be explained by the reorientation of membrane phospholipids, which increases membrane permeability and affects sodium and calcium channels in the membrane, allowing ions to enter the cell (Selim *et al.*, 2019). Since membrane phospholipids are reoriented, the membrane's sodium and calcium channels are altered, which allows ions to enter the cell and produces the desired impact of magnetically treated water on nutrient uptake (Al-Ogaidi *et al.*, 2017; Mghaiouini *et al.*, 2022). Additionally, magnetism improves the quality of water by enhancing its capacity to enter root cells, decreasing its viscosity, attracting molecules together, and breaking hydrogen bonds, all of which encourage roots to absorb water (Abdul-Qados and Hozayn, 2010). On the other hand, magnetized water has been demonstrated by Dawa *et al.* (2017) to improve and increase the population and activity of free-living microorganisms in soil, hence augmenting root development. Besides, the activation of phytohormones influences different metabolic pathway activities, such as cytokinins, GA3, and IAA (Swelam, 2018). Ultimately, this will result in healthy mineral and phytohormone contents in plant tissues, which will improve the parameters of root and vegetative growth, which will then be reflected in yield, fixed, and essential oil parameters.

Regarding the effects of foliar application and soil mineral NPK fertilizers, our findings demonstrated that fertilizing the black cumin with 100% NPK produced the greatest values of vegetative growth, yield, Volatile and fixed oils parameters. These findings could be due to the increased availability of soil nutrients in the growing areas since NPK is a crucial plant nutrient with complementary physiological and metabolic roles that influence plant growth. Nitrogen is a significant element of nucleic acids, proteins, and co-enzymes, phosphorus also has an integral part in N2 fixation and boosts the process of photosynthesis; potassium stimulates certain enzymes and plays a significant role in controlling the opening and closing of stomata (Doklega, 2017).

Additionally, foliar spray and reducing NPK to half the recommended amount (50%) demonstrated positive outcomes and the potential to partially substitute chemical fertilizers, with high growth parameter values. Where the second positive effect was using a foliar application of 5 g/L of garlic extract with 50% NPK, which succeeded in recording high values for some parameters without a significant difference between 100% NPK. Garlic extract's stimulating effects on plant growth performance could be related to it stands out for having a significant concentration of biological substances like volatile oil, iodine, allicin, ajoene, alliin, sugar, diallyl, sallylcysteine, allylpropyl, sallylmercaptocystein, trisulfide, and vinyldithiines (Al Mayahi and Fayadh 2015; El-Saadony *et al.*,2017). Furthermore, noted by Abou Hussein *et al.* (1975), garlic extract has a variety of effects because of its hormonal (auxin-like) character, which is crucial for cell elongation and lateral expansion. Garlic is also thought to be an excellent source of minerals such as (Fe, Mg, Na, Mn, Zn, Ca, K, and P), vitamins (B and C), enzymes, carbohydrates, and antioxidants (Pekowska and Skupień, 2009; Abd El-Hamied and El-Amary, 2015), even being regarded as an abundant source of additional non-volatile phytonutrients such as flavonoids, phenolic compounds, proteins, saponins, amides, sapogenins, and nitrogen oxides (Lanzotti *et al.*, 2014). Consequently, it presents a constant nutritional supply and a variety of biological substance sources that are vital to plants which leads to promoting plant growth. These results are in harmony with the findings of Attia *et al.* (2020) on the Hedychium plant and Massoud *et al.* (2020) on Zanthoxylum plant.

CONCLUSION

Under the condition of this study, it was concluded that irrigation of black cumin plants with magnetized water and foliar spraying with garlic extract at 5 g/L under fertilization of 50 % NPK from recommended dose enhanced vegetative growth parameters, yield, and volatile oil output with premium essential oil ingredients, in order to lower production costs, lessen environmental pollution, and safeguard public health.

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تحسين إنتاجية نباتات حبة البركة تحت الري بالماء الممغنط وبعض منشطات الرش الورقي

هبة يوسف البنا

قسم الخضر و الزينة - كلية الزراعة - جامعة المنصورة.

الملخص

أجريت هذه الدراسة خلال موسمى الشتاء ٢٠٢٢/٢٠٢١ و 2023/2022 لدراسة تأثير معاملات مياه الري (الممغنطة وغير الممغنطة) والرش الورقي ببعض المحسنات الطبيعية (حامض الهيوميك، الطحالب البحرية، مستخلص الخميرة ومستخلص الثوم) والتفاعل بينهم على القياسات الخضرية, إنتاج البذور، إنتاج الزيت ومكونات الزيت العطري لنبات حبة البركة (*Nigella sativa* L.). ولقد حصلت جميع النباتات تحت معاملات الرش الورقية المختلفة على نصف الكمية المطلوبة من الأسمدة المعدنية (NPK) مقارنة بمعاملة الكنترول (باستخدام الجرعة الكاملة الموصى بها من NPK). ووفقاً للنتائج، أظهرت النباتات المروية بالمياه الممغنطة في كلا موسمي الدراسة أعلى مستويات معنوية لمكونات الزيت العطري، وإنتاج الزيت، وإنتاجية البذور، والنمو الخضري مقارنة بالنباتات المروية بالمياه غير المعالجة. و بمقارنة تأثيرات المعاملات الورقية، كان لمستخلص الثوم بمعدل ٥ جم/لتر تأثير متفوق لجميع الصفات المدروسة. وبذلك نجحت المعاملات السابقة وهي الماء الممغنط والرش الورقي بمستخلص الثوم ٥ جم/لتر بالتفاعل في تسجيل أعلى القيم لبعض الصفات قيد الدراسة مثل محصول البذور وإنتاج الزيت الطيار ومكونات الزيت العطري دون فرق معنوي بين الماء الممغنط مع الجرعة الكاملة الموصى بها من NPK (الكنترول). قد يُقترح ذلك لتعزيز انتاجية نباتات حبة البركة، لا سيما من حيث إنتاج البذور وإنتاج الزيت العطري بمكونات الزيت الأساسية الممتازة، من أجل خفض تكاليف الإنتاج، وتقليل التلوث البيئي، وحماية الصحة العامة.