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(Original Article)

Investigating the Impact of Vermicompost, Humic Acid and Biostimulants Application on Growth, Productivity and Essential Oil Profile of Coriander (*Coriandrum sativum* L.) Plants

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Abstract

This study was conducted over two consecutive seasons (2022/2023) and 2023/2024) at the Farm of the Faculty of Agriculture, Al-Azhar University (Assiut Branch), Egypt, to evaluate the effects of two organic manure types (vermicompost and humic acid) and foliar applications of biostimulants (chitosan, amino acids, and dry yeast extract) on vegetative growth, yield, volatile oil production, and chemical composition of coriander (*Coriandrum sativum* L.) plant. Among five organic manure treatments, vermicompost at 5 m^3/fed produced the best results, with plants showing the greatest number of branches, dry herb weight, fruit yield, and volatile oil quality. Foliar application of dry yeast extract at 10 g/l significantly enhanced vegetative growth, yield, volatile oil content, and chemical composition. The combination of vermicompost at 5 m^3/fed and dry yeast extract at 10 g/l achieved the highest values of all recorded parameters, demonstrating a synergistic effect between both treatments that significantly improved plant performance. It is recommended that coriander plants could be treated with the combination of vermicompost at 5 m^3/fed and dry yeast extract at 10 g/l to optimize growth, yield, and essential oil quality.

Keywords: *Coriandrum sativum, Biostimulants, Humic acid, Vermicompost, Volatile oil.*

Introduction

Coriander (*Coriandrum sativum* L.), an annual herb belongs to family *Apiaceae*, is widely cultivated for its culinary uses and distinctive aroma, as noted by Scandar *et al*. (2023) and Ganesan *et al*. (2013). Its leaves (known as cilantro or Chinese parsley) and seeds are used in cooking and various industries. Coriander has health benefits, including antimicrobial properties against bacteria like *Escherichia coli* and *Staphylococcus aureus*, as researched by Kacˇániová *et al*. (2020), Shoaib *et al*. (2023), Dima *et al.* (2016), Silva *et al.* (2011), and Mandal and Mandal (2015). The compound linalool, the main component of the essential oil, contributes to anticancer, anti-inflammatory, and antioxidant effects (Kamatou and Viljoen, 2008), with additional properties such as anticarcinogenic (Huang *et al*., 2020), antioxidant (Ghazanfari *et al*., 2020), and anti-diabetic (Hajlaoui *et al*., 2021).

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Organic farming, using organic fertilizers and biostimulants, supports sustainable agriculture by improving soil fertility, conserving resources, and promoting environmentally friendly food production (Moradir, 2009; Jahan *et al.,* 2010; Darzi *et al.,* 2011; Zarandi *et al.,* 2011). Vermicompost (VC) is an organic fertilizer produced by earthworms digesting organic wastes such as manure and crop residues (Arancon *et al*., 2004). It enhances soil's physical, chemical, and biological properties by improving water and nutrient absorption, increasing soil porosity, and promoting aeration and drainage (Darzi *et al.,* 2010; Saeednezhad *et al.,* 2010; Asgharipour, 2012). Rich in essential nutrients, vitamins, growth hormones, humic substances, enzymes, and antioxidants, VC is effective for cultivating various plants, including medicinal and ornamental species (Hidalgo *et al.,* 2006; Balaji *et al.,* 2006; Warade *et al*., 2007; Singh, 2007; Shadanpour *et al.,* 2011). Humic acid (HA), making up 60-70% of soil organic matter, has a complex structure that enhances nutrient retention, soil carbon sequestration, and micronutrient availability (Stevenson, 1982; Newcomb, 2003; Lal, 2016). As a biostimulant and organic mineral fertilizer, HA supplies essential elements and promotes biomass production by modulating enzyme activities and metabolic pathways (Danesh-Talab *et al.,* 2014; Ghania *et al.,* 2015; Ampong *et al*., 2022). It also mitigates oxidative damage under stress conditions and enhances growth by influencing hormone fluxes, photosynthesis, and cellular respiration (Ahmad and Ashraf, 2010; Haghighi *et al*., 2012; Das and Mukherjee, 2015; García *et al*., 2016; De Azevedo *et al*., 2019; Altaf *et al*., 2023).

Chitosan, a biopolymer derived from chitin, is eco-friendly and bioactive, with antimicrobial properties and high adsorption capacity (Peniston and Johnson, 1980; Dias *et al*., 2013). It acts as a carrier for agrochemicals, enhances nutrient stability, and activates plant defense mechanisms (Kashyap *et al.,* 2015; Sharif *et al.,* 2018; Eun *et al*., 2020; Riseh *et al*., 2022a, b). Additionally, it provides essential nutrients and promotes plant growth, offering a sustainable alternative to chemical fertilizers (Prajapati *et al*., 2022). Amino acids are vital for protein synthesis and plant growth, improving water and nutrient uptake, stimulating protein synthesis, and boosting carbon assimilation (Abu-Dahi and Al-Younis, 1988; Dreccer *et al*., 2000; Sharma-Natu and Ghildiyal, 2005). They contribute to cell division, pigment synthesis, and the biosynthesis of natural hormones like indole-3-acetic acid (IAA), gibberellic acid (GA_3), and ethylene (Ahmed and Abd El-Hameed, 2003; Ahmed *et al*., 2007, 2014; Madian and Refaai, 2011). Active dry yeast, applied foliarly, enhances plant growth and yield by providing proteins, vitamins, amino acids, and cytokinins (Hegab *et al.,* 1997). It stimulates cell division, promotes growth substances, improves photosynthesis, and increases nutrient availability (Fathy *et al*., 2000; Tortoura, 2001; Mekhemar and Al-Kahal, 2002; Mohamed, 2005; Medani, 2006). High yeast concentrations elevate cytokinin levels and enhance leaf nutrient content (Somida *et al*., 2005; El-Yazal and Somida, 2007).

The objective of this study was to improve the performance of field-grown coriander by integrating organic manure with biostimulant substances. Specifically, it aimed to evaluate the effects of these treatments on plant morphology, fruit production, and volatile oil yield, with the goal of providing recommendations for growers in the Assiut Governorate.

Materials and Methods

Soil preparation and agricultural operations

A field trial was conducted over two consecutive growing seasons (2022/2023 and 2023/2024) at the Faculty of Agriculture Farm, Al-Azhar University, Assiut, Egypt, to evaluate the response of coriander plants to two types of organic manures (vermicompost and humic acid) and foliar applications of biostimulants (chitosan, amino acids, and dry yeast extract). This study focused on assessing the effects of these treatments on vegetative growth, yield and volatile oil production. Fertilization included superphosphate at 200 kg per fed during soil preparation, nitrogen (ammonium sulphate) at 200 kg per fed, applied in two equal doses (100 kg per fed after thinning and 100 kg per fed at flowering) as described by Nasr-Allah (2012), and potassium (potassium sulphate) at 50 kg per fed with the second nitrogen dose. Coriander seeds were obtained from the Department of Medicinal and Aromatic Plants at the Agricultural Research Center. The experimental design featured three replications per treatment, with each plot consisting of three rows (60 cm wide, 2.1 m long). Sowing occurred on November 10th during each season, and thinning was performed 45 days later, retaining two plants per hill (30 cm apart) to achieve 42 plants per plot (44444 plants per fed). Random soil samples from the top 0-30 cm layer were collected and analyzed for physical and chemical properties following standard methods described by Jackson (1973) and detailed in Table 1.

Table 1. Initial physical and chemical properties of the experimental soil

Particle size distribution (%)				pH (1:2.5)	EC (ds/m)	$CaCO_3$ (%)	O.M. (%)	Soluble ions (meq/l)								Total N (%)	Total P (%)	Total K (%)
								Anions				Cations						
Sand	Silt	Clay	Texture					Cl^-	CO_3^{--}	HCO_3^-	SO_4^{--}	Ca^{++}	Mg^{++}	Na^+	K^+			
17.3	29.7	53.0	Clay	7.01	1.12	1.87	1.05	3.29	-	4.89	3.09	5.38	0.57	1.22	4.10	0.78	0.29	0.74

Experimental design and treatments

A completely randomized block design arranged in a split-plot scheme with three replicates was employed to evaluate the effects of organic manures and biostimulants on coriander plants. The main plots (A) consisted of five organic manure treatments applied to the soil: a control (no organic manure), vermicompost at 2.5 (VC1) and 5 m^3 per feddan (VC2), humic acid at 3 (HA1) and 6 kg per feddan (HA2). The subplots were assigned seven foliar spraying treatments: tap water (control, T1), chitosan at 150 (T2) and 300 ppm (T3), amino acids as a mixture (tryptophan, glycine and phenylalanine) at 100 (T4) and 200 ppm (T5), dry yeast extract at 5 (T6) and 10 g/l (T7). This factorial arrangement resulted in 35 treatment combinations derived from the interaction of the main and subplot factors (A×B).

In both seasons, during the soil preparation phase before planting, vermicompost was systematically incorporated into the soil. Humic acid was applied to the soil three times at two-week intervals, beginning 30 days after sowing. Foliar applications of the designated biostimulants were administered until run-off on three occasions: 60, 75 and 90 days after sowing, with a one-day interval between each spray. All spray solutions included Triton B as a wetting agent, and control plants were sprayed with tap water. All other field practices, were carried out according to the recommended protocols.

Vermicompost was produced by preparing boxes lined with a metal net at the bottom for proper drainage and aeration. These boxes were filled with raw materials, including animal manure and approximately 500 g of *Eisenia fetida* earthworms, and maintained under optimal heat and humidity conditions for four months. The resulting vermicompost was then incorporated into the top 5 cm layer of soil in the experimental plots before coriander seed planting, with its analysis detailed in Table 2. Humic acid (potassium humate) with a 96% humic acid content was sourced from Abu Zaabal Fertilizers Company.

Chitosan was procured from the National Research Center, Giza, Egypt. The amino acids were acquired from Techno Gene Company (TGC), Dokky, Giza, Egypt. Active dry yeast (*Saccharomyces cerevisiae*) was activated by dissolving it in water with sugar in a 1:1 ratio, followed by overnight incubation to promote yeast reproduction and activation (El-Tohamy *et al*., 2008). The compositional analysis of active dry yeast, detailed in Table 3.

Table 2. Nutrient contents of vermicompost

	Nutrient contents											
	Organic carbon (%)	Organic manure (%)	EC (ds/m)	pH	N (%)	P (%)	K (%)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)	Boron (ppm)
Values	12.8	23.9	3.7	6.9	2.8	1.6	2.2	1972	91.2	27.8	17.9	12.7

Table 3. Composition of dry yeast extract

Protein	47%		**Minerals**	8%		**Nucleic acids**		8%			
Carbohydrates	33%		**Lipids**	4%							
Minerals composition (mg/g)											
Na	0.12	**Mg**	1.65	**Fe**	0.02	**Va**	0.04	**K**	21.0	**Cr**	2.20
Ca	0.75	**Ni**	3.00	**Mo**	0.40	**Zn**	0.17	**P**	13.5	**Sn**	3.00
Si	0.03	**Se**	0.10	**Cu**	8.00	**Mn**	0.02	**S**	13.5	**Li**	0.17
Vitamins/Amino acids (mg/g)											
Thiamine	60 - 100		**Pyridoxine HCL**	28		**Biotin**		1.3			
Riboflavin	35 - 50		**Pantorhenate**	70		**Cholin**		40			
Niacin	300 - 500		**Folic acid**	5 - 13		**Vit. B12**		0.001			

Data collected and measurements

1. Growth parameters

At the stage when approximately 50% of the flowers had reached bloom, ten plants were randomly selected from each experimental unit for detailed analysis of key morphological traits. The parameters measured included number of branches and dry weight of herb (g/plant).

2. Yield attributes

At the end of the growing season, approximately 170 days after sowing at the fruit maturity stage, yield data were collected from all ten plants per experimental plot. Parameters included fruit yield (recorded as g per plant) and the average fruit weight (g/plant) was extrapolated to calculate fruit yield in kg/fed.

3. Volatile oil yield

Air-dried fruit samples were used for volatile oil extraction via hydrodistillation with a Clevenger-type apparatus (Koşar *et al*., 2007). For each treatment, 100 g fruit samples from three replicates were ground, immersed in distilled water, and distilled for 3 hours. The extracted oil was dried over anhydrous sodium sulfate (Na_2SO_4), stored at 4◦C, and analyzed via gas chromatography-mass spectrometry (GC/MS). The percentage yield of volatile oil was recorded, and oil yield was calculated per plant and per feddan.

4. GC-MS analysis of volatile oil

Gas chromatography-mass spectrometry (GC-MS) was performed on volatile oil from five treatment groups: the control and the four most effective treatments (VC1 + T7, VC2 + T7, HA1 + T7, and HA2 + T7). Volatile oil constituents (% composition was analyzed using a DS Chrom 6200 gas chromatograph with a flame ionization detector (FID). Component separation was achieved via gas-liquid chromatography (GLC), and relative percentages were determined by comparing retention times (RT) with authentic reference samples (Guenther and Joseph, 1978).

5. The percentages of nitrogen, phosphorus, and potassium

N, P and k% in dried herb samples were quantified following AOAC (1990) methods.

6. Statistical analysis

Experimental data were analyzed using analysis of variance (ANOVA) for a split-plot design. The least significant difference (LSD) test at p = 0.05 was used to assess differences among treatment means (Gomez and Gomez, 1984). Statistical computations were performed using Statistix version 9.0 software (Analytical Software, 2008).

Results

1. Vegetative growth traits

Table 4 demonstrates the effects of organic fertilizers, VC, and HA on coriander vegetative growth traits, including number of branches, and herb dry weight. Both fertilizers significantly improved these traits compared to the untreated control. The VC2 treatment yielded the highest results, with branch counts of 10.25 and 11.09, and herb dry weights of 50.9 and 58.3 g in the respective seasons. The HA2 treatment followed, with branch counts of 9.59 and 10.62, and herb dry weights of 41.8 and 48.5 g over the two seasons, respectively. These enhancements were statistically significant relative to the control. No significant differences were observed between VC1 and HA1 for branch numbers in both seasons.

Table 4 indicates that biostimulants significantly enhanced coriander growth compared to the control, except for T4, which had no significant effect on branch numbers in either season. Foliar applications improved vegetative traits, with T7 achieving the greatest branch numbers of 9.76 and 10.86, and the highest herb dry weights of 44.9 g and 51.4 g in the two seasons, respectively.

Table 4. Impact of organic fertilizers types, foliar-applied biostimulants, and their interactions on plant height (cm), branches number/plant and herb dry weight/plant (g) of coriander during both growing seasons

Biostimulant substances (B)	Organic manures (A)											
	First season						Second season					
	Control	VC1	VC2	HA1	HA2	Means (B)	Control	VC1	VC2	HA1	HA2	Mean (B)
Branch number/plant												
T1	6.55	7.91	9.33	7.67	8.81	**8.06**	7.16	8.66	10.21	8.62	9.89	**8.91**
T2	7.23	8.29	9.95	8.10	9.47	**8.61**	7.90	9.08	10.88	9.11	10.11	**9.41**
T3	7.67	9.35	10.52	8.65	9.92	**9.22**	8.38	10.22	10.99	9.72	10.57	**9.98**
T4	7.07	8.00	9.74	7.87	9.00	**8.33**	7.73	8.75	10.29	8.84	10.00	**9.12**
T5	7.57	8.20	10.32	8.23	9.21	**8.71**	8.27	8.97	10.69	8.99	10.53	**9.49**
T6	7.67	8.43	10.33	8.45	9.90	**8.96**	8.39	9.21	11.61	9.49	11.12	**9.96**
T7	8.13	9.24	11.55	9.05	10.80	**9.76**	8.90	10.11	12.97	10.17	12.13	**10.86**
Mean (A)	7.41	8.49	10.25	8.29	9.59		8.10	9.29	11.09	9.28	10.62	
LSD 0.05	**A= 0.40 B= 0.44 AB= 0.98**						**A= 0.62 B= 0.50 AB= 1.11**					
Herb dry weight/plant (g)												
T1	21.9	29.8	42.5	27.6	35.5	**31.5**	25.8	35.2	49.6	32.2	41.4	**36.8**
T2	25.2	33.9	49.9	29.1	39.2	**35.4**	29.7	40.0	58.0	33.9	45.6	**41.5**
T3	27.2	37.4	53.2	37.0	43.9	**39.7**	32.1	44.0	61.9	43.1	51.1	**46.5**
T4	24.4	32.4	46.8	28.5	38.3	**34.1**	28.9	38.3	54.4	33.3	44.6	**39.9**
T5	25.2	35.2	47.6	29.5	39.4	**35.4**	29.8	41.6	55.4	34.4	46.0	**41.4**
T6	26.4	38.0	54.0	32.3	44.3	**39.0**	31.3	44.8	60.9	37.7	51.6	**45.3**
T7	30.8	44.0	62.4	35.6	51.7	**44.9**	36.4	51.9	68.1	41.5	58.9	**51.4**
Mean (A)	25.9	35.8	50.9	31.4	41.8		30.6	42.3	58.3	36.6	48.5	
LSD 0.05	**A= 1.3 B= 2.6 AB= 5.8**						**A= 1.8 B= 3.0 AB= 6.7**					

VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA = Humic acid (3 kg/fed), HA2 = Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Dry yeast extract (5 g/ l), T7= Dry yeast extract (10 g/ l).

Table 4 shows the interaction effects of organic fertilizers and foliar biostimulants on coriander growth parameters during the 2022/2023 and 2023/2024 seasons. Most combinations significantly improved branch number, and herb dry weight compared to the control, except for control fertilization with T2 and T4 (no effect on branch numbers in the first and second seasons); and T2, T3, T4, T5, and T6 (no effect on herb dry weight during both seasons). The VC2 + T7 combination yielded the highest results: branch numbers of 11.55 and 12.97, and herb dry weights of 62.4 and 68.1 g. The HA2 + T7 combination was followed by branch numbers of 10.80 and 12.13, and herb dry weights of 51.7 and 58.9 g during both seasons, respectively. Vermicompost with dry yeast extract outperformed other treatments and the control in both seasons.

2. Yield attributes

Table 5 shows that applying VC and HA at all rates significantly increased fruit yield per plant and per feddan compared to the control in both seasons. The highest values were recorded with VC2, followed by HA2, with significant differences in fruit yield per plant in both seasons and in fruit yield per feddan in the first season, but no significant difference in fruit yield per feddan in the second season. VC2 increased and fruit yields by 67.8% and 77.9% over the control, yielding 1341.6 and 1565.0 kg/fed in the two seasons, respectively, compared to control yields of 798.9 and 879.2 kg/fed.

Table 5. Impact of organic fertilizers types, foliar-applied biostimulants, and their interactions on fruit yield plant^{-1} (g) and feddan^{-1} (kg) of coriander during both growing seasons

Biostimulant substances (B)	Organic manures (A)											
	First season						Second season					
	Control	VC1	VC2	HA1	HA2	Means (B)	Control	VC1	VC2	HA1	HA2	Mean (B)
	Fruit weight plant^{-1} (g)											
T1	14.6	18.9	24.5	17.7	23.5	**19.8**	16.1	20.8	29.0	21.4	28.4	**23.1**
T2	16.3	21.0	27.1	19.8	26.0	**22.1**	18.0	23.1	32.2	23.9	31.4	**25.7**
T3	19.7	25.0	32.5	23.6	31.1	**26.4**	21.8	29.4	38.5	28.5	37.5	**31.1**
T4	15.2	19.6	25.2	19.2	24.3	**20.7**	16.7	21.5	29.9	23.2	29.3	**24.1**
T5	17.6	22.7	29.3	21.0	28.2	**23.8**	19.3	26.9	34.7	25.4	34.0	**28.1**
T6	19.6	25.3	32.6	23.3	30.7	**26.3**	21.5	30.0	37.9	28.2	37.0	**30.9**
T7	22.8	29.5	40.1	28.2	37.9	**31.7**	25.0	34.9	44.3	34.0	42.8	**36.2**
Mean (A)	**18.0**	**23.1**	**30.2**	**21.8**	**28.8**		**19.8**	**26.6**	**35.2**	**26.4**	**34.3**	
LSD 0.05	**A= 1.9 B= 1.1 AB= 2.5**						**A= 2.1 B= 1.3 AB= 2.9**					
	Fruit yield fed^{-1} (kg)											
T1	650.5	840.6	1087.5	786.2	1043.7	**881.7**	716.4	923.1	1290.4	951.6	1260.4	**1028.4**
T2	726.1	935.1	1205.7	880.0	1157.7	**980.9**	798.1	1025.4	1429.7	1064.2	1396.8	**1142.8**
T3	874.1	1112.9	1442.9	1051.0	1383.7	**1172.9**	970.7	1306.4	1709.1	1268.7	1666.9	**1384.4**
T4	674.5	869.2	1121.3	852.8	1077.9	**919.1**	742.3	954.0	1330.2	1031.8	1300.8	**1071.8**
T5	782.7	1009.3	1302.8	933.3	1252.8	**1056.2**	859.7	1193.6	1544.1	1127.9	1510.5	**1247.2**
T6	869.9	1122.5	1449.8	1037.0	1362.9	**1168.4**	954.7	1331.7	1683.2	1252.8	1642.9	**1373.1**
T7	1014.8	1310.6	1781.0	1253.2	1682.3	**1408.4**	1112.3	1553.2	1968.6	1511.3	1904.3	**1609.9**
Mean (A)	**798.9**	**1028.6**	**1341.6**	**970.5**	**1280.2**		**879.2**	**1183.9**	**1565.0**	**1172.6**	**1526.1**	
LSD 0.05	**A= 83.2 B= 50.5 AB= 112.9**						**A= 92.6 B= 59.0 AB= 131.9**					

VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA2= Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Dry yeast extract (5 g/ l), T7= Dry yeast extract (10 g/ l).

Table 5 indicates that foliar application of biostimulants significantly enhanced yield attributes, increasing fruit yield compared to the control, except for T4, which showed no significant effect in both seasons. T7 provided the greatest improvement, increasing fruit yields by 60.1% and 56.7%, producing 1408.4 kg/fed and 1609.9 kg/fed compared to control yields of 881.7 and 1028.4 kg/fed in the two seasons, respectively.

Table 5 demonstrates that combining organic fertilizers with foliar biostimulants significantly increased fruit yield (g/plant and kg/fed) compared to untreated plants. The highest yields were achieved with VC2 + T7, followed by HA2 + T7, producing fruit yields of 1781.0 and 1968.6 kg/fed and 1682.3 and 1904.3 kg/fed compared to control yields of 650.5 and 716.4 kg/fed, in the first and second seasons, respectively.

3. Volatile oil production

Table 6 and Figures 1 and 2 demonstrate that VC and HA significantly enhanced essential oil production. VC2 significantly increased essential oil percentages to 0.331% and 0.342% in the first and second seasons, respectively, compared to control values of 0.248% and 0.252%, reflecting increases of 33.5% and 35.7%. HA2 also showed significant effects, yielding 0.321% and 0.335% (increases of 29.4% and 32.9% over control). The VC2 followed by HA2 produced the highest oil content per plant (0.101 and 0.121 ml in the first season; 0.093 and 0.116 ml in the second season) (Figure 1) and essential oil yield per feddan (4.47 and 5.37 l/fed in the first season; 4.14 and 5.14 l/fed in the second season), compared to control yields of 2.00 and 2.24 l/fed (Figure 2).

Table 6. Impact of organic fertilizers types, foliar-applied biostimulants, and their interactions on volatile oil production of coriander during both growing seasons

Biostimulant substances (B)	Organic manures (A)											
	First season						Second season					
	Control	VC1	VC2	HA1	HA2	Means (B)	Control	VC1	VC2	HA1	HA2	Mean (B)
	Volatile oil %											
T1	0.233	0.269	0.311	0.261	0.302	**0.275**	0.238	0.280	0.323	0.279	0.310	**0.286**
T2	0.239	0.276	0.319	0.268	0.310	**0.283**	0.250	0.297	0.342	0.288	0.332	**0.302**
T3	0.255	0.297	0.340	0.284	0.328	**0.301**	0.258	0.305	0.345	0.301	0.339	**0.310**
T4	0.236	0.272	0.314	0.264	0.305	**0.278**	0.239	0.289	0.334	0.281	0.324	**0.293**
T5	0.249	0.287	0.332	0.279	0.322	**0.294**	0.250	0.297	0.338	0.291	0.335	**0.302**
T6	0.254	0.294	0.339	0.284	0.330	**0.300**	0.255	0.304	0.347	0.295	0.344	**0.309**
T7	0.270	0.313	0.359	0.304	0.349	**0.319**	0.278	0.327	0.362	0.313	0.357	**0.327**
Mean (A)	**0.248**	**0.287**	**0.331**	**0.278**	**0.321**		**0.252**	**0.300**	**0.342**	**0.292**	**0.335**	
LSD 0.05	**A= 0.003 B= 0.006 AB= 0.013**						**A= 0.008 B= 0.007 AB= 0.014**					

VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA2= Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Active dry yeast (5 g/ l), T7= Active dry yeast (10 g/ l).

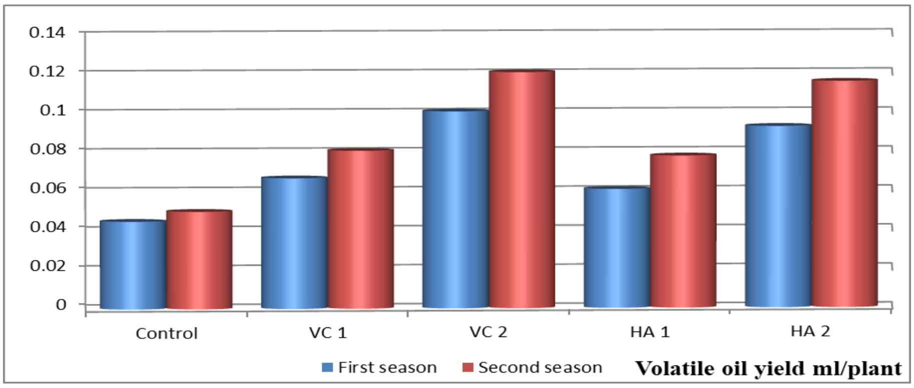

Fig. 1. Impact of vermicompost and or/humic acid on volatile oil yield plant^{-1} (ml) of coriander plant during both growing seasons. VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA2= Humic acid (6 kg/fed).

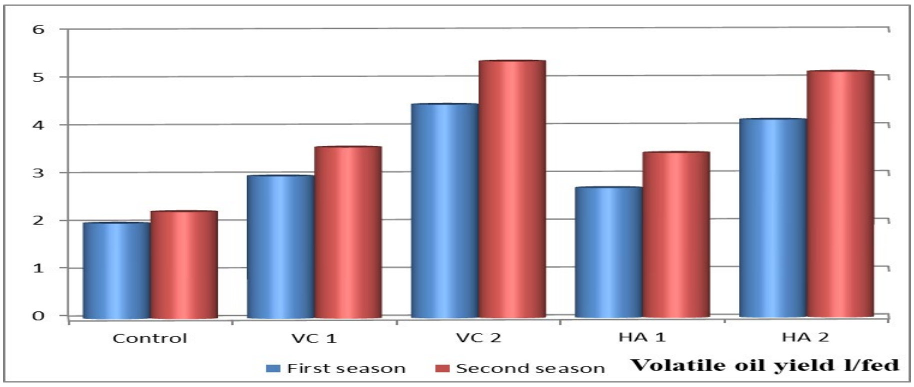

Fig. 2. Impact of vermicompost and or/humic acid on volatile oil yield fed^{-1} (l) of coriander plant during both growing seasons. VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA2= Humic acid (6 kg/fed).

Figures 3 and 4 indicate that foliar application of T7 was the most effective, achieving the highest volatile oil percentages (0.319% and 0.327%) and yields compared to the control, followed by T3 (0.301 and 0.310%) in both seasons. T7 produced volatile oil yields of 4.59 and 5.37 l/fed, and T3 yielded 3.59 and 4.37 l/fed, compared to control yields of 2.47 and 3.01 l/fed in the two seasons, respectively (Figure 4).

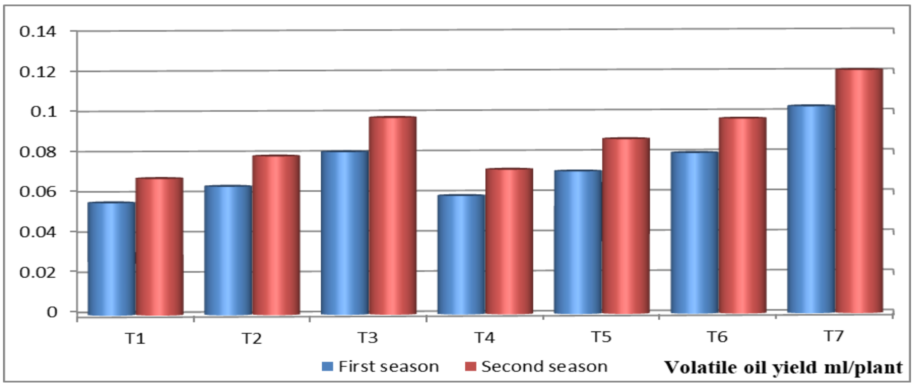

Fig. 3. Impact of biostimulants on volatile oil yield plant^{-1} (ml) of coriander plant during both growing seasons. T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Dry yeast extract (5 g/ l), T7= Dry yeast extract (10 g/ l).

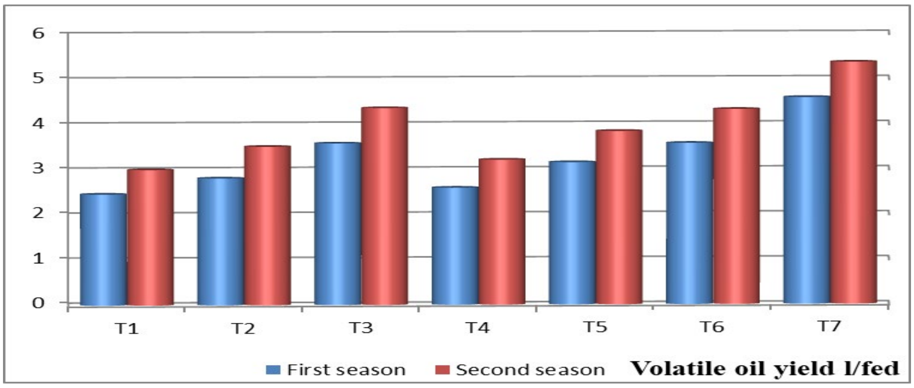

Fig. 4. Impact of biostimulants on volatile oil yield plant^{-1} (l) of coriander plant during both growing seasons. T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Dry yeast extract (5 g/ l), T7= Dry yeast extract (10 g/ l).

Table 6 and Figures 5 and 6 show that the interaction of treatments significantly affected volatile oil production. The combination of VC2 with T7 yielded the highest percentage, content, and yield of volatile oil, followed by HA2 with T7, compared to untreated plants. VC2 interactions consistently outperformed HA2 interactions. These treatments produced volatile oil yields of 6.40 and 7.13 l/fed in the first season and 5.88 and 6.79 l/fed in the second season, compared to control yields of 1.52 and 1.70 l/fed (Figure 6).

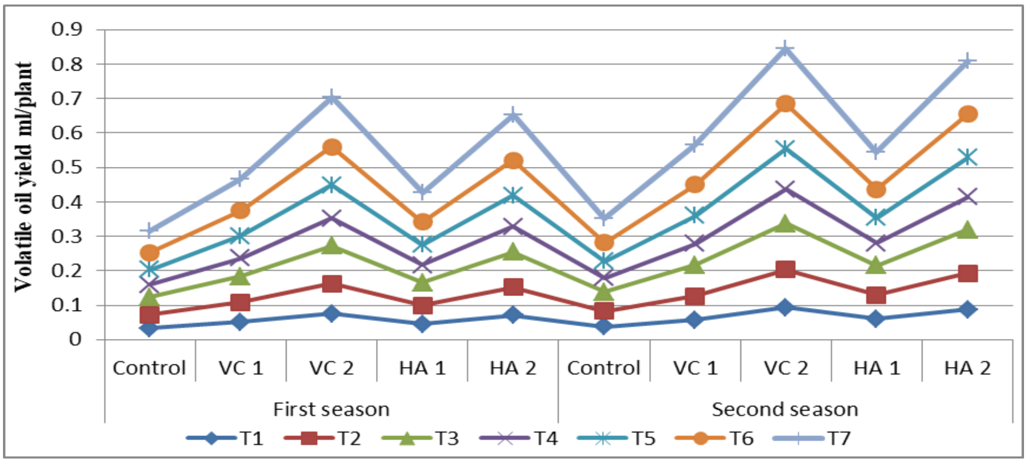

Fig. 5. Impact of interaction between organic fertilizer types and biostimulants on the on volatile oil yield plant^{-1} (ml) of coriander plant during both growing seasons. VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA2= Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Active dry yeast (5 g/ l), T7= Active dry yeast (10 g/ l).

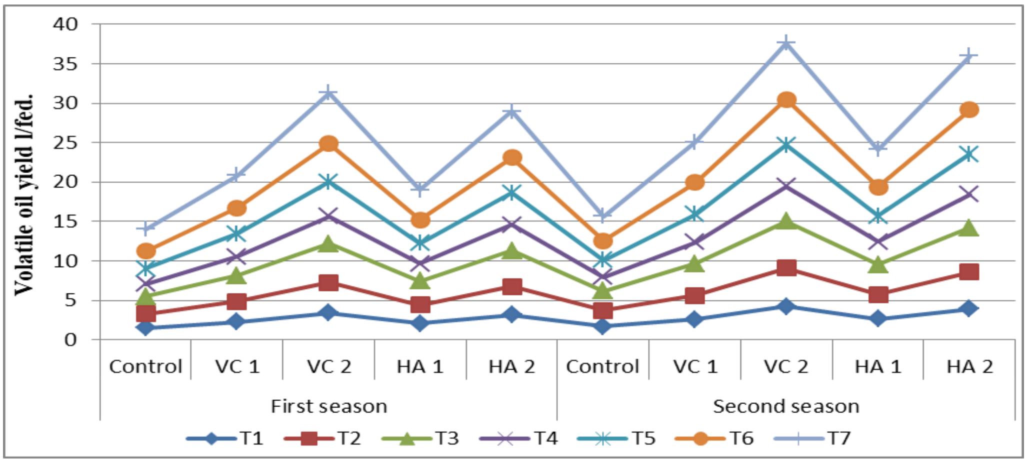

Fig. 6. Impact of interaction between organic fertilizer types and biostimulants on the on volatile oil yield plant^{-1}(l) of coriander plant during both growing seasons. VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA2= Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Active dry yeast (5 g/ l), T7= Active dry yeast (10 g/ l).

4. Chemical constituents of the volatile oil

Gas chromatography analysis (Figure 7) identified 14 compounds in coriander oil, with notable variations across treatments combining organic amendments (VC1, VC2 , HA1 and HA2) and dry yeast extract (T7). Key findings include: α-Pinene increased from 3.09% (control) to 5.28% (VC1 + T7), with 4.19% (VC2 + T7), 3.64% (HA1 + T7), and 4.57% (HA2 + T7). β-Pinene decreased from 2.97% (control) to 1.11-2.51% across treatments. Sabinene dropped significantly from 13.25% (control) to 8.19% (VC2 + T7) and 7.86% (HA2 + T7). Limonene rose slightly from 5.06% (control) to 6.22% (VC1 + T7) and remained higher (5.35–6.08%) in all treatments. β-Terpinene increased from 3.42% (control) to 3.88–5.04%, peaking under VC1 + T7. Myrcene surged from 1.92% to 6.18% (VC1 + T7). β-Cymene decreased from 10.84% (control) but remained notable (5.87–9.01%). Linalool, the primary constituent, increased from 30.08% (control) to 34.94–41.53%, peaking under VC2 + T7. Geraniol rose from 16.17% (control) to 18.99% (VC1 + T7) and 20.87% (HA1 + T7). Borneol, absent in the control, reached 3.28–4.01% in three treatments, highest in VC2 + T7. linalyl acetate doubled from 3.45% to 8.81% (HA1 + T7). Geranyl acetate rose from 3.09% to 5.89% (VC1 + T7). Nerol slightly decreased from 4.27% (control) to 2.53–4.11%. Camphor rose from 2.13% (control) to 2.19–2.22% under HA2 + T7 and VC1 + T7. Overall, the treatments enhanced oxygenated monoterpenes (e.g., linalool, geraniol) and introduced compounds like borneol, with VC1 + T7 and HA1 + T7 most effective in boosting key aroma and bioactivity compounds.

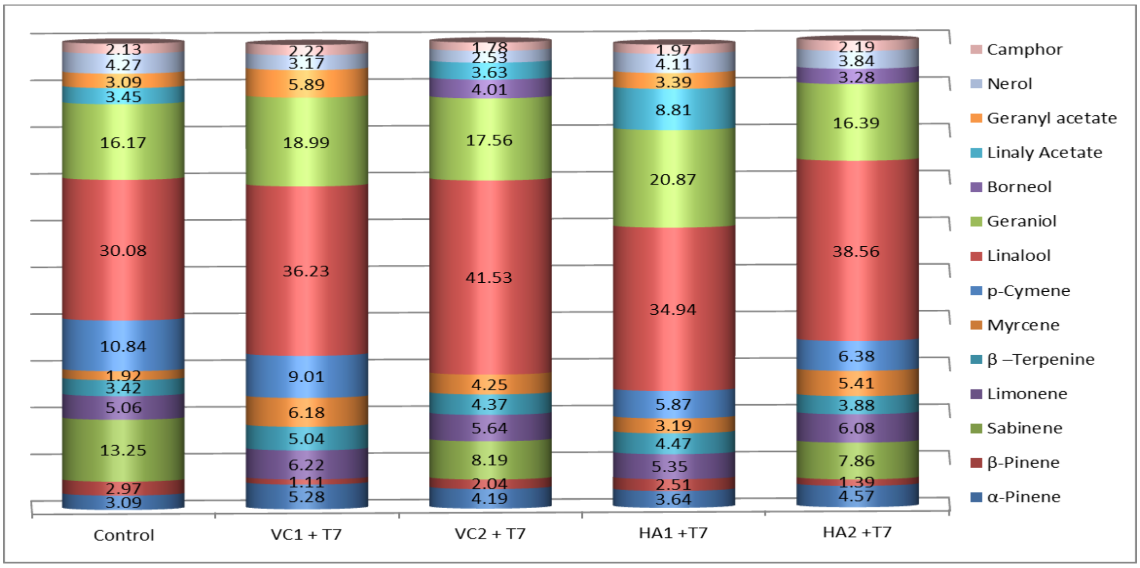

Fig. 7. GLC of coriander volatile oil constituents % as affected by the interaction between organic fertilizer types with some biostimulants at second season (2023/2024). VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA1= Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Active dry yeast (5 g/ l), T7= Active dry yeast (10 g/ l).

5. Nitrogen, Phosphorus, and Potassium percentages

Table 7 highlights the effects of organic fertilizers on nutrient percentages during both seasons. VC2 was most effective for nitrogen, yielding 2.36% and 2.48% (increases of 32.6% and 31.9% over control), followed by HA2 with 2.29% and 2.42% (28.6% and 27.7% increases). For phosphorus, VC2 achieved the highest percentages (0.279% and 0.302%, up 21.8% and 21.3%), while HA2 recorded 0.256% and 0.278% (11.8% and 11.6% increases). For potassium, HA2 outperformed with 1.30% and 1.37%, followed by VC2 at 1.26% and 1.33%, showing increases of 32.7%, 31.7%, 28.6%, and 27.9% over control values of 0.98% and 1.04% in the 1st and 2nd seasons, respectively.

Table 7 shows that foliar application of biostimulants increased nitrogen, phosphorus, and potassium percentages compared to untreated plants in both seasons.

T7 was the most effective, increasing nitrogen by 15.7% (first season) and 16.4% (second season), phosphorus by 19.0% and 19.1%, and potassium by 16.7% and 16.6% compared to the control during both seasons, respectively.

Table 7 reveals that the interaction of organic fertilizers and biostimulants significantly affected nutrient percentages in coriander's dried herb. The combination of VC2 with T7 achieved the highest nitrogen (2.45% and 2.58%) and phosphorus (0.303% and 0.330%) in both seasons, respectively. HA2 with T7 followed with nitrogen at 2.40% and 2.50% and phosphorus at 0.281% and 0.306% in the two seasons, respectively. For potassium, HA2 with T7 recorded the highest values (1.35% and 1.43%), followed by VC2 with T7 (1.32% and 1.39%), compared to the control in both seasons, respectively.

Table 7. Impact of organic fertilizers types, foliar-applied biostimulants, and their interactions on nitrogen, phosphorus, and potassium percentages of coriander during both growing seasons.

Biostimulant substances (B)	Organic manures (A)											
	First season						Second season					
	Control	VC1	VC2	HA1	HA2	Means (B)	Control	VC1	VC2	HA1	HA2	Mean (B)
N %												
T1	1.60	1.94	2.29	1.82	2.17	**1.97**	1.69	2.01	2.42	1.92	2.30	**2.07**
T2	1.76	2.08	2.32	2.05	2.30	**2.10**	1.88	2.20	2.45	2.17	2.43	**2.22**
T3	1.82	2.20	2.38	2.16	2.35	**2.18**	1.93	2.31	2.49	2.28	2.48	**2.30**
T4	1.70	2.04	2.31	2.03	2.22	**2.06**	1.79	2.15	2.44	2.14	2.35	**2.17**
T5	1.81	2.09	2.36	2.06	2.27	**2.12**	1.91	2.20	2.49	2.17	2.39	**2.23**
T6	1.76	2.19	2.41	2.11	2.35	**2.16**	1.86	2.31	2.48	2.23	2.48	**2.27**
T7	2.01	2.38	2.45	2.19	2.40	**2.28**	2.12	2.52	2.58	2.31	2.50	**2.41**
Mean (A)	1.78	2.13	2.36	2.06	2.29		1.88	2.24	2.48	2.18	2.42	
L.S.D 5 %	A= 0.09 B= 0.05 AB= 0.11						A= 0.08 B= 0.06 AB= 0.13					
P %												
T1	0.211	0.231	0.258	0.218	0.236	**0.231**	0.231	0.251	0.280	0.236	0.257	**0.251**
T2	0.223	0.244	0.272	0.241	0.249	**0.246**	0.242	0.265	0.296	0.262	0.271	**0.267**
T3	0.234	0.255	0.284	0.253	0.261	**0.257**	0.254	0.277	0.309	0.275	0.283	**0.279**
T4	0.221	0.242	0.270	0.235	0.248	**0.243**	0.241	0.263	0.294	0.256	0.269	**0.264**
T5	0.231	0.252	0.281	0.251	0.258	**0.255**	0.251	0.274	0.305	0.272	0.280	**0.276**
T6	0.233	0.254	0.284	0.249	0.260	**0.256**	0.253	0.276	0.303	0.270	0.281	**0.277**
T7	0.252	0.275	0.303	0.266	0.281	**0.275**	0.274	0.299	0.330	0.288	0.306	**0.299**
Mean (A)	0.229	0.250	0.279	0.245	0.256		0.249	0.272	0.302	0.266	0.278	
L.S.D 5 %	A= 0.008 B= 0.010 AB= 0.022						A= 0.009 B= 0.011 AB= 0.025					
K %												
T1	0.88	1.00	1.19	1.07	1.26	**1.08**	0.93	1.06	1.27	1.11	1.34	**1.14**
T2	0.97	1.13	1.27	1.15	1.28	**1.16**	1.03	1.19	1.34	1.21	1.35	**1.23**
T3	1.01	1.19	1.30	1.21	1.31	**1.20**	1.07	1.26	1.37	1.27	1.38	**1.27**
T4	0.94	1.12	1.22	1.12	1.27	**1.13**	0.99	1.18	1.29	1.19	1.35	**1.20**
T5	1.00	1.13	1.25	1.15	1.30	**1.17**	1.06	1.20	1.32	1.22	1.38	**1.23**
T6	0.97	1.16	1.29	1.20	1.32	**1.19**	1.03	1.23	1.37	1.28	1.37	**1.25**
T7	1.11	1.20	1.32	1.31	1.35	**1.26**	1.17	1.27	1.39	1.38	1.43	**1.33**
Mean (A)	0.98	1.13	1.26	1.17	1.30		1.04	1.20	1.33	1.24	1.37	
L.S.D 5 %	A= 0.04 B= 0.03 AB= 0.07						A= 0.03 B= 0.03 AB= 0.07					

VC1= Vermicompost (2.5 m^3/fed), VC2= Vermicompost (5 m^3/fed), HA1= Humic acid (3 kg/fed), HA1= Humic acid (6 kg/fed), T1= Control, T2= Chitosan (150 ppm), T3= Chitosan (300 ppm), T4= Amino acids (100 ppm), T5= Amino acids (200 ppm), T6= Active dry yeast (5 g/ l), T7= Active dry yeast (10 g/ l).

Discussion

Vermicompost and humic acid are key organic amendments in modern agriculture, enhancing soil fertility and crop productivity while supporting sustainable practices. Vermicompost, formed through earthworm and microbial breakdown of organic matter, is a nutrient-rich, peat-like material with high porosity, aeration, drainage, and water-holding capacity (Atiyeh *et al*., 2002; Arancon *et al*., 2005). It provides readily available nutrients (nitrates, phosphates, calcium, and potassium), improving soil structure, root development, and nutrient uptake, which increases biomass, plant height, and vegetative growth (Edwards *et al*., 2004; Lazcano *et al*., 2010). Research indicates vermicompost boosts umbel numbers, seed yield, and essential oil content in crops like cumin (Nejad and Moghaddam, 2011) and French basil (Anwar *et al*., 2005), while enhancing produce quality in strawberries (Arancon *et al*., 2004) and rice (Mishara, 2005). Humic acid promotes plant growth through hormone-like effects, enhancing respiration, photosynthesis, and protein synthesis (Zandonadi *et al*., 2006). It complexes with potassium, stimulates soil microbial activity, and improves nutrient availability (calcium, nitrogen, phosphorus, trace minerals) (Fan *et al*., 2014; Yazdani *et al*., 2014). Additionally, it enhances shoot development via increased Rubisco activity, thus boosting photosynthetic efficiency (Abaszadeh *et al*., 2018); lowers soil pH for better nutrient uptake (Akladious and Mohamed, 2018); and increases phosphorus solubility and secondary metabolite production (Schiavon *et al*., 2010), supporting growth and stress tolerance in crops like *Ocimum* sp. (El-Sayed *et al*., 2015), coriander (Sharifirad, 2018), and parsley (Tuncay *et al*., 2019).

This study demonstrates that biostimulant treatments, including chitosan, amino acids, and dry yeast extract, significantly enhance coriander productivity through multiple physiological mechanisms. Chitosan acts as a growth regulator, stimulating nitrogen metabolism, photosynthesis, and protein synthesis, while improving water-use efficiency and stress tolerance by regulating stomatal function and inducing defense responses such as phytoalexin accumulation and enzyme activation (Ortmann and Moerschbacher, 2006; Górnik *et al*., 2008; Iriti *et al*., 2009; Sultana *et al.,* 2017; Khan *et al*., 2018; Lim *et al*., 2015). It also promotes nutrient and water uptake, cell enlargement, and hormone production (e.g., indole-3-acetic acid and gibberellic acid), supporting growth in various plants (Guan *et al*., 2009; Algam *et al*., 2010; Chookhongkha *et al*., 2012; Mondal *et al*., 2013; Malekpoor *et al*., 2016; Salachna *et al*., 2017). Foliar application of amino acids enhances plant growth by stimulating phytohormone synthesis (IAA and gibberellic acid), increasing biomass, and serving as a readily available nitrogen source for synthesizing essential compounds like vitamins and pigments (Phillips, 1971; Thon *et al*., 1981; Arbid and Marquardt, 1985; Walter and Nawacki, 1987; Kamar and Omar, 1987). Amino acids also improve nutrient uptake, mitigate biotic stress, and promote secondary metabolite production (e.g., glucosinolates and flavonoids), enhancing photosynthesis and vegetative growth (Bidwell, 1979; Kowalczyk and Zielony, 2008; Wink, 2010; Shaheen *et al*., 2010; Papenfus *et al*., 2013). The study highlights the significant role of dry yeast extract in enhancing coriander productivity through its diverse physiological and biological effects. Rich in vitamin B, yeast extract supports plant growth and helps control fungal diseases (Tarrow and Nakase, 1975). It contains a complex mix of constituents, including dry matter, proteins, phytohormones (IAA, cytokinins), essential amino acids (e.g., tryptophan, methionine, lysine), and nutrients like nitrogen, phosphorus, potassium, and magnesium (Abou-Zaid, 1984; Nagodawithana, 1991). These components promote dry matter accumulation, increase endogenous phytohormone levels (IAA, cytokinins), reduce abscisic acid, and enhance nutrient availability, thereby improving plant growth and development (Heikal, 2005; Mady, 2009; Khalil and Ismael, 2010).

Conclusion

This field study demonstrated that vermicompost, humic acid, and foliar biostimulants (chitosan, amino acids, and dry yeast extract) significantly increased coriander seed yield and essential oil content. Combined applications of these organic amendments and biostimulants outperformed individual treatments, enhancing vegetative growth, seed production, and volatile oil content and composition. These results underscore the effectiveness of integrated organic-biological fertilization as a sustainable alternative to synthetic inputs in medicinal herb production, improving soil structure, nutrient dynamics, and plant metabolic processes while supporting ecological agriculture and maintaining crop performance and quality.

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دراســـة تأثير إضـــافة كمبوست الديدان وحمض الهيوميك والمنشـــطات الحيوية على نمو وإنتاجية وخصائص الزيوت العطرية لنباتات الكزبرة

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الملخص

أُجريت هذه التجربة على مدار موســـمين متتاليين (2023/2022 ، 2024/2023) بمزرعة كلية الزراعة، جامعة الأزهر، أسيوط، مصر، لدراسة تأثير نوعين من السماد العضوي (كمبوست الديدان وحمض الهيوميك) والرش الورقي بالمنشـــطات الحيوية (الشـــيتوزان، الأحماض الأمينية، مســـتخلص الخميرة الجافة) على النمو الخضري، والمحصول، وإنتاج الزيوت الطيارة، والتركيب الكيميائي لنباتات الكزبرة. من بين خمس معاملات للسماد العضوي، حقق التسميد بكمبوست الديدان بمعدل 5 متر مكعب للفدان أفضل النتائج، حيث أظهرت النباتات أعلى عدد للفروع، وأثقل وزن للعشب الجاف، وأعلي إنتاج من الثمار، وجودة أفضل للزيوت الطيارة. كما أدى الرش الورقي لمستخلص الخميرة الجافة بمعدل 10 جرام لكل لتر إلى تحسين ملحوظ في النمو الخضري، والمحصول، ومحتوى الزيوت الطيارة، والتركيب الكيميائي للكزبرة. حقق التداخل بين إضـــافة كمبوست الديدان بمعدل 5 متر مكعب للفدان مع الرش بمســـتخلص الخميرة الجافة بمعدل 10 جرام لكل لتر أعلى القيم في جميع الصـــفات، مما أظهر تأثيرًا تآزريًا حسّن أداء النبات بشكل ملحوظ. يُنصح بمعاملة نباتات الكزبرة بكمبوست الديدان بمعدل 5 متر مكعب للفدان مع الرش بمســـتخلص الخميرة الجافة بمعدل 10 جرام لكل لتر لتحســـين النمو والإنتاجية وجودة الزيوت العطرية.

الكلمات المفتاحية: *الزيوت الطيارة ، المنشطات الحيوية ، الكزبرة ، حمض الهيوميك، كمبوست الديدان*