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Effects of fertilizer type on phenolic compounds, essential oil content, and biological activities of *Coriandrum sativum* L.

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Gübre tipinin *Coriandrum sativum* L.'un fenolik bileşikleri, uçucu yağ içeriği ve biyolojik aktiviteleri üzerine etkileri

Abstract: Organic and inorganic fertilizers play an important role in improving the nutritional quality of coriander plant (*Coriandrum sativum* L.). This study consists of 3 different fertilizer applications to coriander: Control-T_0 (no fertilizer); organic fertilizer- T_1 (300-600 mL/da); chemical fertilizer-T_2 (2-3 L/da); vermicompost-T_3 (1.5 L/da). It was conducted in three replicates in a randomized block design to evaluate the effect of different fertilizer applications on the morphological, biochemical and antioxidant potential of coriander plants. It has been observed that fertilizer applications have a significant effect on the morphological, biochemical and antioxidant properties of the plant, and especially in the coriander of seeds organic fertilizer and vermicompost applications have higher phenolic and flavonoid contents (1.82, 2.14 mg GAE/g DW and 2.57, 2.46 mg QE/g DW, respectively). In the GC-MS analysis, linalool was determined as the main compound and the highest concentration of 76.44% was obtained as a result of organic fertilizer application. Antioxidant potential was evaluated by DPPH radical-scavenging assay and the most effective antioxidant activity was determined from organic origin fertilizer (organic-IC_{50}: 27.35±2.52 µg/mL, vermicompost-IC_{50}: 29.42±2.41 µg/mL) applications.

Key words: *Coriandrum sativum*, fertilizer, essential oil, antioxidant activity

Özet: Organik ve inorganik gübreler kişniş bitkisinin (*Coriandrum sativum* L.) besin kalitesinin iyileştirilmesinde önemli bir rol oynamaktadır. Bu çalışma kişnişe 3 farklı gübre uygulamasından oluşmaktadır: Kontrol-T_0 (gübresiz); organik gübre- T_1 (300-600 mL/da); kimyasal gübre-T_2 (2-3 L/da); vermikompost-T_3 (1.5 L/da). Farklı gübre uygulamalarının kişniş bitkisinin morfolojik, biyokimyasal ve antioksidan potansiyeli üzerindeki etkisini değerlendirmek için tesadüfi blok tasarımında üç tekrarlı olarak yürütülmüştür. Gübre uygulamalarının bitkinin morfolojik, biyokimyasal ve antioksidan özellikleri üzerinde önemli bir etkiye sahip olduğu ve özellikle kişniş tohumlarında organik gübre ve vermikompost uygulamalarının daha yüksek fenolik ve flavonoid içeriğine sahip olduğu görülmüştür (sırasıyla 1.82, 2.14 mg GAE/g DW ve 2.57, 2.46 mg QE/g DW). GC-MS analizinde linalool ana bileşik olarak belirlenmiş ve organik gübre uygulaması sonucunda %76.44 ile en yüksek konsantrasyon elde edilmiştir. Antioksidan potansiyel DPPH radikal giderme testi ile değerlendirilmiş ve en etkili antioksidan aktivite organik kökenli gübre (organik-IC_{50}: 27.35±2.52 µg/mL, vermikompost-IC_{50}: 29.42±2.41 µg/mL) uygulamalarından elde edilmiştir.

Anahtar Kelimeler: *Coriandrum sativum*, gübre, uçucu yağ, antioksidan aktivite

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1. Introduction

Environmental and agricultural sustainability relies on the delicate interplay between climatic factors, soil characteristics, and the accessibility of necessary mineral nutrients for crop production. In recent years, extensive use of chemical fertilizers in conventional agricultural systems has caused various ecological issues, such as soil and water pollution, reduced nutritional quality of harvested crops, and disturbance of soil microbial ecosystems (Melero et al., 2008). The approach taken towards promoting a sustainable agricultural framework has undergone significant evolution due to the adoption of innovative management techniques. This change in paradigm emphasises the need to concentrate on biological and integrated systems, with a particular focus on applying organic fertilizers. The intentional incorporation of organic fertilizers into agriculture partly fulfils plants nutrient needs and diminishes reliance on chemical fertilizers (Siddique et al., 2014). The most basic principle of sustainable agriculture is the use of organic fertilizers (animal manure, humic acid, plant residues, etc.). Forming a reservoir rich in macronutrients, micronutrients, enzymes, vitamins and hormones, these organic fertilizers are not only economically viable but also ecologically sustainable. This comprehensive nutrient profile is crucial in maintaining soil fertility and having a positive impact on crop or medicinal plant production by increasing both yield and quality (Saha et al., 2019).

Coriandrum sativum L., known as coriander, of the Apiaceae family, is an aromatic, annual medicinal plant. This plant species originates from the Mediterranean region, North Africa and Southwest Asia, and its fresh leaves and seeds are generally used in the food industry for food preservation (Rasouli et al., 2022). The essential oil obtained from its seeds has been proven to have antioxidant and antimicrobial properties as a result of many studies (Kačániová et al., 2020; Neffati et al., 2011). In addition, the principal components found in coriander essential oil, namely linalool, 2-decenal, caryophyllene oxide, 2-dodecanal, and caprolactone, possess notable pharmacological properties. These constituents have been identified to exhibit anti-inflammatory and analgesic effects, making them potentially valuable in pain management and inflammation control. Additionally, their anticonvulsant properties suggest a role in neurological health, while their capacity to lower blood pressure and cholesterol levels aligns with their potential utility in cardiovascular health (Yildiz, 2016; Yuan et al., 2020). Similar to the essential oil effect, valuable pharmacological effects were determined by evaluating different extracts (methanol, ethanol, water, etc.) obtained from coriander in different biological activities (antioxidant, acute and sub-chronic toxicity, antimicrobial) (Farah et al., 2015; Patel et al., 2012). The phenolic composition of coriander has been identified as 11 phenolic acids and 10 flavonoids, and these phytochemicals are identified with extremely important pharmacological properties (Msaada et al., 2017).

A substantial amount of scientific research indicates that adopting organic fertilizers has a favourable influence on diverse agronomic features of medicinal plants. These include, but are not restricted to, plant height, fresh and dry matter production, absorption of micronutrients, branch complexity, and essential oil content. These effects were particularly pronounced in medicinal plant species such as *Mentha piperita* L., *Mentha arvensis* L., *Nigella damascena* L. and the data obtained underline the potential benefits of organic fertilisation in improving the growth and biochemical composition of these valuable plant species (Asadi et al., 2018; Chaturvedi and Pandey, 2021; Ulusu and Şahin, 2021, 2022).

The main idea adopted in medicinal plant cultivation is the goal of achieving high quality crop production by organic means. Therefore, the importance of organic fertilizers in meeting the nutritional requirements of farmland is of great importance. In this context, this study is an evaluation and comparative analysis of organic and chemical fertilizer regimes in coriander cultivation. In addition to the determination of growth responses and phenolic compounds in the context of organic and chemical fertilizer application, it was also evaluated in terms of biological activities. In this context, in this study, the effects of organic and chemical fertilizer regimes applied on coriander cultivation to growth responses and phenolic compounds were evaluated and comparative analyzes were carried out. In addition, the contributions of these fertilizer applications to coriander in terms of biological activities were also evaluated. The results may provide additional information on applying the right type and amount of fertilizer to synthesize adequate levels of phytochemicals in *C. sativum* cultivation.

2. Materials and Method

The research was carried out in a controlled greenhouse environment that included a temperature range of 25-30°C, suitable lighting conditions and appropriate humidity level to ensure optimum growth conditions. The research was carried out following a randomised plot design with three replications to obtain reliable results and comprehensive information on the physicochemical properties of the soil samples (0-30 cm) used in the study is shown in Table 1. Contents of fertilizers used in the application; chemical fertilizer [N: P: K (7: 7: 7%)]; organic fertilizer (45% total organic matter, 19.5% C, 3% N, 7% K_2O); vermicompost (5% total organic matter, 1% N, 10% Humic+fulvic acid). Experimental factors included liquid organic fertilizer, chemical fertilizer and vermicompost types: (T_0) no fertilizer (control), (T_1) organic fertilizer before flowering (300-600 mL/da), (T_2) chemical fertilizer before flowering (2-3 L/da), (T_3) vermicompost before flowering (1.5 L/da).

Table 1. The physicochemical properties of the experimental soils

Physiochemical properties	Fertilized soil			
	T_0	T_1	T_2	T_3
Sand (%)	50.76	50.83	51.32	49.65
Silt (%)	25.52	26.22	25.22	25.63
Clay (%)	19.24	19.17	19.63	19.45
Field capacity (%)	25.12	26.26	26.41	26.52
pH	7.34	7.53	7.18	7.47
E.C (mhos/cm)	0.39	0.38	0.37	0.34
CaCO3 (%)	18.08	22.46	20.38	17.64
Organic matter (%)	4.33	5.53	4.66	5.28
N (%)	1.11	1.25	1.68	1.42
P (%)	8.47	9.33	12.68	9.21
K (%)	70.07	75.03	95.67	80.36
Mg (%)	6.13	6.22	6.52	5.84
Ca (%)	14.36	19.85	17.29	13.55
Cu (ppm)	2.59	3.41	1.30	1.76
Fe (ppm)	3.60	3.06	3.76	3.21
Mn (ppm)	16.25	19.17	18.38	15.74
Zn (ppm)	1.43	2.15	2.74	2.18

T_0: Control-no fertilizer; **T_1**: Organic fertilizer-300-600 mL/da; **T_2**: Chemical fertilizer-2-3 L/da; **T_3**: Vermicompost-1.5 L/da

2.2. Morphological analysis

After the plants matured (105-127 days after sowing), all plants samples were harvested separately and the impacts of the fertilizer treatments on the morphological traits of the plants were documented. Morphological characters: plant height (cm), plant dry weight (g), lateral branch number, biological yield (g/m^2), 1000 seeds weight (g), grain yield (g/m^2) and root length (cm).

2.3. Mineral content analysis

The levels of macro and micronutrients in coriander seeds and soil are influenced by fertilizer applications. Therefore, in the study, a comprehensive quantitative elemental analysis covering eight different elements was carried out according to the method specified by Ulusu and Şahin (2021). Kjeldahl method was utilized for N analysis, while spectrophotometric analysis was employed for P_2O_5 analysis. Atomic absorption spectroscopy was utilized to determine the levels of K_2O, Mg, Fe, Zn, Cu, Mn, and Ca in the samples.

2.4. Polyphenol extraction

The extraction was carried out with minor modifications to the method described by Mau et al. (2001). After harvesting, air-dried coriander seeds were ground in a grinder. Seed samples (5g) were extracted separately with 10 mL of pure methanol for 24 h in a magnetic stirrer. Then, the mixture underwent filtration utilizing a sterile filter featuring a pore size of 0.22 µm. Afterward, the filtrate was evaporated to dryness using a rotary evaporator maintained at 40°C. The resulting residue was then stored at +4°C until additional analysis could be conducted.

2.5. Total phenolics content (TPC) analysis

For the quantification of TPC, 0.1 mL of each extract was introduced into a 96 well microplate. Subsequently, 0.1 mL of Folin–Ciocalteu reagent and 1.6 mL of distilled water were added to each well. Following 3-min incubation, 0.2 mL of a saturated solution of Na_2CO_3 was introduced and the microplate was incubated at dark room temperature for 1 h. The absorbance measurements were conducted using a multi-plate reader at 725 nm. The findings were quantified as milligrams of gallic acid equivalents (GAE) per gram, determined through a standard curve ranging from 0 to 100 mg/mL (de Lima et al., 2024).

2.6. Total flavonoids content (TFC) analysis

75 µL $NaNO_2$ (5%) was added to 250 µL methanol extract solution and mixed. Following a 6-min incubation period, 10% $AlCl_3$ (150 µL) and NaOH (1 M) (500 µL) were introduced into the mixture. Subsequently, the volume was brought to 2.5 mL using distilled water. Subsequently, the absorbance was measured at 510 nm against a prepared blank. TFC of samples (triplicate per treatment) were quantified as mg quercetin equivalents (QE)/g, determined using a standard curve (50-500 mg/mL) (Dewanto et al., 2002).

2.7. Essential oil distillation

100 g of dried coriander seeds were subjected to hydrodistillation for 4 h in a Clevenger apparatus. The extract obtained was dried over Na_2SO_4 anhydrous and stored at 4°C until GC-MS analysis (Ulusu and Şahin, 2021).

2.8. GC-MS analysis

The Gas Chromatography/Mass Spectrometry analyses were conducted using an Agilent Technologies 7890A Network GC System, which was outfitted with an HP-5MS capillary column measuring 30 m × 0.25 mm × 0.25 µm, and an Agilent G4513A series auto-sampler. The temperature was programmed from 60 to 250 °C at 3°C/min and the split ratio was 1:10. the injector and interface temperature were 260 and 270 °C, respectively; scan range 40-340 amu; ionisation energy 70 eV; carrier gas was helium at 1.5 mL/min.

The determination of retention indices for all volatile constituents was conducted utilizing a homologous series of n-alkanes (C7–C25). The identification of oil components followed Adams' method, wherein the matching of retention indices (RI) and mass spectra was employed. The constituents of the essential oil were further characterized by GC-MS spectroscopy.

2.9. DPPH radical-scavenging assay

0.5 mL of DPPH methanolic solution (0.2 mM) was added to 1 mL of methanol seed extract of different concentrations (10-200 µg/mL). Following agitation of the mixture, it was stored in darkness at room temperature for 30 minutes, after which the absorbance value was recorded at 517 nm. DPPH and sample mixed solutions were used as sample, while only DPPH solution was used as negative control and ascorbic acid was used as a positive control. A mixture of DPPH and methanol extract was used as a sample, while only a DPPH solution served as the negative control and ascorbic acid functioned as the positive control (Msaada et al., 2017). Experiments were carried out in triplicate.

Radical scavenging activity was calculated using the following formula:

$$DPPH\ scavenging\ effect(\%) = \left[\frac{ODcontrol - OD\ sample}{OD\ control}\right] x100$$

2.10. Statistical analysis

The experimental methodology encompassed triplicate replicates for each treatment group to ensure robustness and reliability of the results. The collected data, encompassing variables related to fertilizer application, underwent statistical analysis through a two-way analysis of variance (ANOVA). Subsequent to ANOVA, post-hoc analysis was executed employing Duncan's test to discern specific variations between treatment groups. The entire statistical analysis was performed utilizing SPSS software, specifically version 24.0 developed by IBM Corp., headquartered in Armonk, NY, USA. A predetermined level of statistical significance was established at $p < 0.05$ to ascertain the validity and significance of observed differences.

3. Results and Discussion

3.1. Morphological characteristics

The results showed that plant height was positively affected by fertilizer treatments (Table 2). The highest plant height was obtained in vermicompost and chemical fertilizer treatment (63.11 and 59.45 cm, respectively). Thus, an increase of 47.06% and 43.80% was recorded in the vermicompost and chemical fertilizer groups, respectively, compared to the control group (33.41 cm) with the lowest height. Scientific research has shown that the use of fertilizers of organic origin improves soil fertility and modulates the structure of the microbial flora (Suman et al., 2017). Vermicompost, as a fertilizer of organic origin, represents an extremely rich source of nutrients containing essential elements (N, P, K, Mg). Vermicompost

Table 2. Morphological characteristics of *C. sativum* plants under the applications of different fertilizer

Treatments	Plant height (cm)	Plant dry weight (g/pot)	Lateral branch number	Biological yield (g/m^2)	1000 seeds weight (g)	Grain yield (g/m^2)
T_0	33.41±0.20^d	7.25±0.15^d	4.42±0.02^d	328.21±11.10^c	5.88±0.03^d	164.33±4.20^c
T_1	51.53±0.70^c	12.47±0.53^b	6.58±0.04^b	796.44±13.42^b	7.65±0.05^b	310.40±6.52^a
T_2	59.45±0.43^b	11.34±0.50^c	5.36±0.03^c	785.18±12.20^b	7.42±0.04^c	265.12±6.88^b
T_3	63.11±0.44^a	14.56±0.22^a	8.76±0.04^a	834.52±14.21^a	7.86±0.03^a	280.50±8.53^b

Values are represented as mean ± standard deviation of triplicates. The same letters in the same column were not differed statistically (Duncan) ($p < 0.05$)

application promotes the increase of nutrient absorption, photosynthetic activity and metabolic processes of numerous enzymes by influencing plant cell metabolism (Zuo et al., 2018). Consequently, these effects have a significant impact on plant growth and height. The findings of our study are in agreement with those of a previous parallel study on *N. damascena*, as documented in the reference (Ulusu and Şahin, 2021).

Various fertilizer inputs had a notable impact on plant dry weight (DW), as detailed in Table 2. The application of vermicompost fertilization resulted in the maximum plant DW, reaching 14.56 g. This represented a substantial increase of 50.20% compared to the control, where plant DW measured 7.25 g. The elevated numerical values observed for lateral branch number in the current study may be attributed to the beneficial impact of vermicompost such as the plant root system's metabolism and photosynthetic rate increase (Zuo et al., 2018). These cumulative effects contribute to an improvement in DW.

Lateral branch number was significantly affected by different fertilization treatments. Vermicompost application to coriander resulted in the highest number of lateral stems (8.76), which was 49.54% higher than the control (4.42). In addition, it was observed that organic fertilizer application was the most effective treatment on lateral branch number after vermicompost. Numerous scientific investigations have proposed that the application of organic fertilizers (vermicompost, manure etc.) enhances the availability of nutrients and facilitates improved mineral access for roots. Consequently, these fertilizers indirectly elevate the photosynthetic rate by fostering the development of an extensive root system. This augmentation in root functionality contributes to an increased assimilation of photo-assimilates, which are subsequently stored in the stem and thus culminates in the heightened production of lateral branches. Consistent with our findings, a study focusing on coriander corroborated that the utilization of vermicompost led to the highest count of lateral stems (Rasouli et al., 2022).

The biological yield (BY) of *C. sativum* exhibited significant variations based on the different fertilizer sources, as indicated in Table 2. The highest BY was recorded at 834.52 g/m^2, resulting from the vermicompost application. This represented a notable increase of 60.67% compared to the control, where the BY measured 328.21 g/m^2. The application of organic and chemical fertilizers resulted in a 58.79% and 58.19% increase in biological yield, respectively, compared to the control group. Vermicompost contributes to improved nutrient availability, plant quality and yield, especially by enhancing the adsorption of essential elements such as iron (Fe) and zinc (Zn). This is in agreement with the findings of Zaller (2007) who reported a significant increase in biomass yield (BM) of tomato associated with vermicompost application and supports our results.

The effects of various fertilizer sources exhibited statistical significance in terms of coriander 1000 seed weight as shown in Table 2. In particular, vermicompost application resulted in a maximum 1000 seed weight recorded at 7.86 g. This value represents a significant increase of 29% compared to the control group with a 1000 seed weight of 5.58 g. Moreover, the diverse fertilizer sources exerted a pronounced influence on grain yield, as evidenced by the statistical findings presented in Table 2. Organic fertilizer application yielded the highest grain yield, reaching 310.40 g/m^2 and demonstrated a significant distinction from the outcomes associated with alternative treatments. In contrast, the control group exhibited the lowest grain yield at 164.33 g/m^2, marking a substantial decrement of 88.88% when compared to the superior treatment. The application of fertilizers, whether chemical or organic, characterized by high nitrogen content, contributes to the development of photosynthetic organs, thereby augmenting the synthesis and storage of photo-assimilates. Nitrogen (N) availability proves indispensable for pivotal stages such as flowering, pollination, assimilate transfer, and seed filling, underscoring the critical role played by nitrogen-containing fertilizers in determining seed number and yield. Our results indicate a positive correlation between 1000 seed weight and N availability during the growth stage. Consistent with our current study, previous research indicates that the application of organic fertilizers can increase the N, P and K content in the soil, thereby promoting plant growth and increasing total yield (Adekiya et al., 2020; Gao et al., 2020).

3.2. Macro and micro-nutrients content

The results show that there were significant changes in macro and micronutrient contents of coriander as influenced by various fertilizer sources (Table 3). The application of vermicompost had the highest N (3.4%), K (0.55%), Zn (47.2 ppm), Fe (67.4 ppm) concentrations. In contrast, the highest levels of P (3.1%), Mg (1.9%) and Mn (41.2 ppm) were obtained with the use of chemical fertilizer. The control group had the lowest levels of both macro and micronutrient concentrations compared to all other treatment groups. Various fertilizer sources enhance the soil's cation exchange capacity, support the gradual release of nutrients, and influence the biological activities and physicochemical characteristics of the soil (Ostadi et al., 2020). As a result, fertilizer application contributes to an increase in the content of macro and micro-elements of the crop grown in the soil. Consistent with the findings, sweet basil plants treated with vermicompost showed a significant increase in both macro and micro-nutrients (Rezaei-Chiyaneh et al., 2021).

Table 3. Nutrient concentrations in C. sativum seeds under the applications of different fertilizer

Treatments	N(%)	P(%)	K(%)	Ca(%)	Mg(%)	Zn(ppm)	Fe(ppm)	Mn(ppm)
T_0	1.3±0.3^c	2.5±0.2^b	0.28±0.1^d	2.4±0.6^c	0.8±0.2^c	35.9±2.5^c	46.8±3.1^c	32.4±1.8^b
T_1	2.7±0.2^b	2.7±0.3^b	0.42±0.0^c	4.6±0.5^a	1.5±0.1^b	41.7±3.6^b	52.4±2.4^b	36.7±2.4^{ab}
T_2	3.1±0.3^a	3.1±0.4^a	0.45±0.1^b	4.2±0.7^a	1.9±0.1^a	43.8±1.5^b	58.6±5.4^{ab}	41.2±2.3^a
T_3	3.4±0.1^a	2.9±0.2^a	0.55±0.1^a	3.6±1.1^b	1.3±0.2^b	47.2±2.8^a	67.4±4.7^a	35.6±2.2^{ab}

Values are represented as mean ± standard deviation of triplicates. The same letters in the same column were not differed statistically (Duncan) ($p < 0.05$).

3.3. TPC and TFC

The concentration of TPC and TFC in methanol extracts of coriander grown with various fertilizer application is presented in Table 4. TPC differed significantly among the treatments studied (p<0.05). The TPC in coriander seed treated with vermicompost (2.14 mg GAE/g DW) was higher than the other treatments. However, TPC determined in organic (1.82 mg GAE/g DW) and chemical (1.79 mg GAE/g DW) fertilizer treatment groups were not statistically different. The control group had the lowest TPC content compared to the other treatment groups. Similar to our findings, the TPC determined as a result of organic and chemical fertilizer treatments applied to *Guadua angustifolia* Kunth plants was significantly higher compared to the control groups (Villamarin-Raad et al., 2023). In another study, it was stated that vermicompost had an improving effect on the amount of TPC in *Berberis integerrima* Bunge plants exposed to cadmium stress (Khosropour et al., 2021).

The highest TFC in coriander was determined in organic fertilizer (2.57 mg QE/g DW) application. This was followed by vermicompost (2.46 mg QE/g DW) application. In addition, the TFC determined in the control group lagged behind all fertilizer treatments (Table 4). There were statistical differences between all groups (p<0.05). Flavonoids and phenolic acids are recognized for their pivotal role in plant defence mechanisms. Flavonoids, phenolic compounds, exhibit a remarkable propensity for oxidation to quinones and thus contribute to the protection of ascorbic acid and unsaturated fatty acids in cellular membranes against oxidative damage (Zhang et al., 2021). This oxidation process may involve a ring-opening reaction that is facilitated under ultraviolet light conditions, especially in the presence of heavy metal ions (Havsteen, 2002). Recent research has extensively documented the therapeutic potential of flavonoids in the treatment of various diseases including autoimmune diseases, cardiovascular diseases and cancer (Abotaleb et al., 2018; Mozaffarian and Wu, 2018; Rengasamy et al., 2019). In this respect, the development of applications to induce flavonoid synthesis in plants is of utmost importance.

Table 4. TPC and TFC of the *C. sativum* seeds under the applications of different fertilizer

Treatment	TPC (mgGAE/g DW)	TFC (mgQE/g DW)	DPPH (IC_{50}, µg/mL)
T_0	$1.36±0.01^c$	$2.05±0.02^d$	$48.69±3.46^c$
T_1	$1.82±0.05^b$	$2.57±0.04^a$	$27.35±2.52^a$
T_2	$1.79±0.02^b$	$2.22±0.02^c$	$34.74±1.23^b$
T_3	$2.14±0.04^a$	$2.46±0.03^b$	$29.42±2.41^a$

DW: Dry weight; **GAE**: Gallic acid equivalents; **QE:** Quercetin equivalents; **IC_{50}:** Half maximal inhibitory concentration. Values are represented as mean ± standard deviation of triplicates. The same letters in the same column were not differed statistically (Duncan) (p < 0.05).

3.4. Essential oil constituents

13 distinct components were identified, comprising 88-99% of the total composition of coriander seed essential oil (EO). The main component was defined as linalool (monoterpenoid), which represents the majority with a range of 68.56-76.44%. In addition, γ-terpinene (4.88-5.76%), menthol (2.87-3.64%), p-cymene (1.95-2.17%) and geraniol (1.47-2.33%) were considered as other dominant components as indicated in Table 5. The highest monoterpene concentrations were observed especially in the organic fertilizer application. However, chemical and vermicompost applications caused similar effects on EO synthesis. Monoterpenoid concentrations were lower in the control group compared to all treatment groups. Essential oils, constituting a prominent class of plant secondary metabolites, fall within the category of terpenoids. The synthesis of terpene precursors, specifically isopentenyl pyrophosphate (IPP) and dimethylallyl pyrophosphate (DMAPP), necessitates adenosine triphosphate (ATP) and nicotinamide adenine dinucleotide phosphate (NADPH) derived from photosynthesis products. As such, the potential for photosynthesis directly influences the biosynthesis of EO (Rasouli et al., 2022). Various fertilizer applications have been documented to increase both essential oil content (EOC) and specific EO components in several plants such as *N. damascena* L. (Ulusu and Şahin, 2021), *Salvia officinalis* L. (Greco et al., 2021), *M. piperita*

Table 5. Composition of the *C. sativum* seeds essential oil influenced by different fertilizer applications

*RT (min)	Component Names	T0	T1	T2	T3
13.25	α-pinene	0.52±0.06	0.83±0.03	0.68±0.02	0.61±0.05
14.49	dl-limonene	1.08±0.03	1.32±0.13	1.58±0.17	1.12±0.16
15.34	p-Cymene	2.17±0.02	1.95±0.22	1.87±0.33	2.02±0.04
16.42	γ-Terpinene	4.89±0.03	5.54±0.26	5.76±0.20	4.88±0.42
17.53	o-Cymene	1.65±0.05	1.78±0.06	1.62±0.10	1.14±0.02
26.21	1-decyl aldehyde	1.22±0.01	2.41±0.05	1.08±0.15	1.45±0.08
26.78	n-Octanol	0.30±0.00	0.24±0.01	0.27±0.03	0.22±0.00
27.63	Linalool	68.56±0.55	76.44±1.20	70.25±0.55	72.37±1.54
29.32	Camphor	1.55±0.15	2.47±0.12	2.09±0.22	1.84±0.18
31.24	Menthol	2.87±0.21	3.64±0.24	3.51±0.67	2.96±0.32
32.67	a-Terpineol	1.23±0.14	1.01±0.10	1.00±0.04	0.84±0.17
34.44	Trans-2-dodecenil-ol	0.45±0.02	0.21±0.01	0.22±0.01	0.37±0.02
35.62	Geraniol	2.33±0.26	1.47±0.15	1.86±0.42	1.74±0.03
	Total indentified compounds (%)	**88.82**	**88.82**	**88.82**	**88.82**

*Retention time.

L. (Ostadi et al., 2020) and *Satureja hortensis* L. (Alizadeh et al., 2010) are in agreement with the findings of this study.

3.5. DPPH radical-scavenging activity

The assessment of antioxidant efficacy was conducted through the application of the 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay, and the corresponding results are presented in Table 4. The DPPH method utilizes the stable organic radical 1,1-diphenyl-2-picrylhydrazyl to measure the antioxidant's capacity for scavenging free radicals. The evaluation of coriander extracts inhibitory efficacy was determined through the comparative analysis with the benchmark pharmaceutical agent, ascorbic acid, to ascertain the extent of inhibition percentages. Within the treatment groups, the application of organic fertilizer proved to be the most potent inhibitor at the highest concentration (200 µg/mL), demonstrating an inhibition percentage of approximately 96.32% (p<0.05). In addition, the other fertilizer treatment groups also exhibited concentration-dependent DPPH activity and successfully scavenged DPPH radical ions at the highest concentration with respective inhibition percentages of 93.23% (vermicompost) and 88.62% (chemical) (Figure 1). Although the control group showed concentration-dependent DPPH activity, it caused the lowest inhibition (3.58%) among the treatment groups. The resultant IC_{50} value signifies the quantity of antioxidant required to reduce the initial concentration of DPPH by 50%, with lower values a indicative of heightened antioxidant activity, as elucidated by Molyneux (2004). Furthermore, the obtained IC_{50} values were 27.35 ± 3.46 µg/mL, 29.42 ± 2.41 µg/mL and 34.74 ± 1.23 µg/mL in organic, vermicompost and chemical fertilizer applications, respectively. Furthermore, the application of fertilizers significantly influenced the DPPH radical scavenging activity compared to the control (p<0.05). Similar to the data of this study, organic fertilization applied to coriander resulted in higher DPPH activity compared to chemical fertilizer application (Machado et al., 2021). The antiradical activity observed in coriander methanol extracts is attributed to the presence of phenolic compounds in the plants (Msaada et al., 2017). In particular, studies has been found that secondary metabolites such as phenols, flavonoids, tannins have the capacity to reduce DPPH and change its color thanks to their hydrogen-donation capacity (Mokrani and Madani, 2016). The accumulation of secondary metabolites in plants is strongly dependent on various environmental factors. Therefore, more yielding and pharmacologically more valuable plant cultivation is possible with improved environmental conditions.

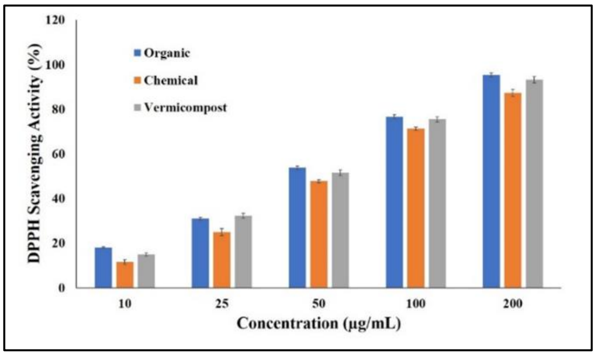

Figure 1. Effect of different fertilizer applications on DPPH scavenging activity

4. Conclusion

The results of this study revealed that *C. sativum* seeds grown with various fertilizer applications caused different effects on the morphological characters and contributed to the macro and micro nutrient element contents. It has been shown that it provides high polyphenol yield. However, fertilizer applications resulted in high polyphenol and flavonoid content in coriander, and these data were supported by GC-MS analysis. Fertilizer applications resulted in high polyphenol and flavonoid content in coriander, and these data were supported by GC-MS analysis. Moreover, in particular, organic fertilizer contributed to coriander seed exhibiting higher antioxidant activity than other applications. In this respect, considering the increasing use of synthetic antioxidants in the food industry, it is possible that phenolic compounds obtained from *C. sativum* extracts grown with the right environmental interventions can be used as natural antioxidant compounds.

Conflict of Interest

Author have declared no conflict of interest.

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