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Chemical components of essential oils and biological activities of the aqueous extract of *Anethum graveolens* L. grown under inorganic and organic conditions

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Abstract

Background: In sustainable agriculture, the use of farmyard manure (FYM) is of great interest to environmental security and is effective as a good nitrogen source for sustainable crop production. Therefore, determining the effective doses of FYM that will be an alternative to chemical fertilizers, is also important to improve soil fertility and produce healthy products. This study aimed to determine the effects of FYM and ammonium nitrate (AN) fertilizers on the biological value and essential oil content of dill (*Anethum graveolens* L.).

Methods: Different doses FYM (7.5, 10, 12.5 and 15 t ha^{-1}) and AN (30, 60, 90 and 120 kg ha^{-1}) were applied by sowing and compared to a control group (no manure). We evaluated the chemical constituents as well as the biological activities of dill herbs and seeds growing at various doses of FYM and AN fertilizers.

Results: The most abundant components of essential oils were found to be dill apiole (11.96 ± 0.83 and 18.65 ± 1.89%) and carvotanacetone (15.90 ± 2.34 and 21.76 ± 1.62%) in the leaves and seeds, respectively. Limonene (9.01 ± 1.11%), 4-isopropyltoluen (8.24 ± 0.89%), dill ether (9.13 ± 1.12%) and mycrene (7.44 ± 0.68%) were major essential oils components in herbs. The highest concentration of the essential oil components was determined as 12.5–15 t ha^{-1} in FYM and 90 AN applications. From the effective concentration (EC_{50}) of the samples, it was seen that 60 kg ha^{-1} AN infusion, 120 kg ha^{-1} AN decoction as well as 7.5 t ha^{-1} FYM and 10 t ha^{-1} FYM essential oils had the highest DPPH, $ABTS^{+}$ and superoxide anion radical scavenging activity as shown by the lowest value of EC_{50} compared to the control. Although the antioxidant activities of the samples were significantly lower than those of the reference antioxidant gallic acid, it was evident that they did show the antioxidative potential for hydrogen and a single electron donor activities, thus could serve as free radical scavengers, and act as reductant. In particular, the highest total phenolic content (18.36 ± 0.35 mg g^{-1}) was found in the infusion extract after applying the 60 kg ha^{-1} AN fertilizer. Essential oils extracted from the seeds also exhibited strong antibacterial activity against *Staphylococcus epidermidis, Enterococcus faecalis*, and *Pseudomonas aeruginosa*. The highest antibacterial activity against all tested microbial species was observed with the 10 t ha^{-1} FYM application.

Conclusion: The findings of the study suggest that the application of FYM has promising effects on dill leaf, seed, and herb and can be considered as a suitable substitute for chemical fertilizers when growing dill, a plant with increasing importance and demand.

Keywords: *Anethum graveolens*, Aqueous extract, Biological activity, Essential oil, Farmyard manure

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Background

Dill (*Anethum graveolens* L.) is an aromatic annual plant belonging to the Apiaceae family. It originates from Eastern Mediterranean. For many years, it has been used by boiling in water for the preparation of decoction or infusion to cure diseases [1].

Dill is frequently grown for flavoring and therapeutic features in various health problems, such as digestive disorders accompanied by meteorism, flatulence and gastro-intestinal spasms, urinary infections, insomnia, and galactogenicalhypo secretion. Seeds of dill are commonly utilized in food and pharmaceutical industries, as well as in traditional medicine to treat gastrointestinal problems and rheumatism [2].

The entire vegetative organ contains essence. Phellandrene, dill ether, carvone, limonene, apiol, dihydrocarvone, and myristicin are the major components of dill [3]. The plant contains phenolic acids and aromatic components; therefore, it has antioxidant, antimicrobial and antitumor activities [4]. The antioxidant activity mostly results from phenolic components and has significant roles in absorbing and deactivating free radicals, quenching singlet and triplet oxygen, or decomposing peroxides [5].

In sustainable agriculture, organic fertilizers not only supply plant nutrients but also improve soil organic matter content as a natural, renewable source [6]. Farmyard manure (FYM) is the most popular organic fertilizer maintaining soil fertility in alternative agriculture systems. FYM has a high proportion of organic material which nurtures soil organisms and is essential in maintaining an active soil life. The high organic matter content and active soil life improve or maintain friable soil structures, increase the cation exchange capacity, water holding capacity, and infiltration rate, and reduce the risk of soil pests building up [7]. In studies on FYM, to obtain high quality and yield, FYM is recommended to be used at a dose of 10 t ha^{-1} in palmarosa [8], 15 t ha^{-1} in lettuce [9], 15 t ha^{-1} in sweet potato [10], 11.5 t ha^{-1} in spider plant [11], and 10 t ha^{-1} in tomato [12]. Similarly, effective nitrogen doses were reported as 100 kg ha^{-1} for sater [13], 90 kg ha^{-1} for safflower [14], 120 kg ha^{-1} for lemon balm [15], and 50 kg ha^{-1} for sage [16].

Although it is known that alternative organic manures should be used instead of chemical fertilizers, there are insufficient studies on the effect of bio-fertilizers on the growth and yield of medicinal plants. While the chemical characters of dill have been evaluated in dill genotypes [17], such studies have not been conducted together with FYM in dill genotypes. Therefore, the current study can be accepted as the first extensive report to assess the effects of various rates of FYM and ammonium nitrate (AN) on total phenolic mater, antioxidant and antibacterial efficacy of essential oil, decoction and infusion extract of dill, and to identify the essential oil compounds contained in this plant. The purpose of this study was to determine the chemical constituents of dill herbs and seeds, as well as evaluate biological activity in samples grown using various doses of FYM and AN fertilizers.

Materials and methods

Growing conditions and treatments

The study was conducted in two successive years (2016 and 2017) at an experimental farm (40°28′43″N, 31°12′39″E) of Mudurnu Süreyya Astarcı Vocational High School (Bolu, Turkey). The elevation of the farm was approximately 830 m. The experiment was planned in a randomized complete-block design with a split-plot arrangement with three replications in April 2016 and 2017 in open-field conditions. Farmyard manure (FYM) and Ammonium nitrate (AN) were placed in the main plot, and sub-plot was four levels of FYM applications (7.5, 10, 12.5 and 15 t ha^{-1}) and AN (30, 60, 90 and 120 kg ha^{-1}) with a control (no fertilizer or manure).

Each experimental plot consisted of five rows, with a distance of 0.3 m between each row and 0.2 m between each plant, and the plot size was 5.6 m^2. For the distance between the plots, a meter block was considered. The soil was rich in phosphorus (14.86 g kg^{-1}), potassium (53.73 g kg^{-1}) and organic matter (13.6 g kg^{-1}), and classified as clay-loam and having neutral quality (pH = 7.25). According to the climatic data, the average temperature, humidity, and total rainfall from April to August in the two experimental years were 8.18 °C, 61%, and 208.8 mm, respectively [18].

FYM was composed of dung, urine, bedding and straw, and obtained from the rearing farm of a cattle or cow meat production facility in Bolu, Turkey. Dung mostly comes as undigested material and urine from digested material. Organic matter contents of dung are over 50%, being as a complex of lignin and protein, which are difficult to decompose. For that reason, nutrients in dung are slowly released but nutrients in urine are easily available and obtainable. To alleviate the urine loss and therefore to increase manure volume, straw, sawdust or other bedding materials are used in cattle shelters [19]. Wet manure from the barn was spread on a flat soil area at a height of 40–60 cm and width of 1.5–2 m, in the form of a trapezoid with a length permitted by the area. The manure from the barn, which was cleaned once a week, was laid in a series and transferred to the side every three days. It was well ventilated during this transfer, and this application was continued for 21 d. The compost pit was protected from rain, and small drainage channels were formed to divert run-on water. At the end, the pile

became odorless and black and white in color, with yellow worms being formed. This formation indicates that the manure was matured. Before application, FYM was stored for fermentation for about one year. Full dose of the FYM was applied to seedbeds and mixed with soil per treatment requirement. No inorganic fertilizer was applied to the FYM plots throughout the life of the plant. FYM properties used in experiment were provided in Table 1. FYM had the highest organic matter (406.8 g kg^{-1}), containing 18 g kg^{-1} nitrogen, 5.2 g kg^{-1} phosphorus, and 13.6 g kg^{-1} potassium, and it was slightly alkaline [20].

As experimental factors, different doses of FYM (7.5, 10, 12.5 and 15 t ha^{-1}) were applied a week before sowing. For the subsurface application, the manure was mixed in at soil a depth of approximately 10 cm with a rotary tiller. Also, 300 kg ha^{-1} diammonium phosphate (DAP) and half of 30, 60, 90 and 120 kg ha^{-1} AN (33%) as base fertilizer were applied by sowing. The remaining half of the AN fertilizer was applied as top dressing after the first harvest. Dill was regularly watered with a drip irrigation system. No pesticide was used in this study. Dill harvest was performed at the beginning of flowering at noontime; then, the plant was dried in shade to prepare it for laboratory analyses.

Table 1 Chemical analysis of farmyard manure

Analysis parameters	Unit	Results of the analysis
Organic matter	g kg^{-1}	406.8
Total nitrogen (N)	g kg^{-1}	18.00
Moisture	g kg^{-1}	595.00
pH (potentiometric)	–	7.61
EC (1/10)	mS cm^{-1}	3.26
Total phosphorus (P)	g kg^{-1}	5.20
Water soluble phosphorus (P_2O5)	g kg^{-1}	3.20
Total potassium (K)	g kg^{-1}	13.60
Water soluble potassium (K_2O5)	g kg^{-1}	10.40
Total calcium (Ca, ICP EPA 3052)	g kg^{-1}	7.758
Total Magnesium (Mg, ICP EPA 3052)	g kg^{-1}	5.099
Total iron (Fe, ICP EPA 3052)	g kg^{-1}	10.606
Total copper (Cu, ICP EPA 3052)	g kg^{-1}	0.025
Total zinc (Zn, ICP EPA 3052)	g kg^{-1}	0.09
Total manganese (Mn, ICP EPA 3052)	g kg^{-1}	0.37
Total lead (Pb, ICP EPA 3052)	g kg^{-1}	0.002
Total cadmium (Cd, ICP EPA 3052)	g kg^{-1}	DLA
Total cobalt (Co, ICP EPA 3052)	g kg^{-1}	DLA

DLA detection limits: Cd < 0.00003 g kg^{-1}, Co < 0.00008 g kg^{-1} Pb < 0.00009 g kg^{-1}

Preparation of sample solution

To prepare infusions, each sample (5 g) was added to 25 mL of boiling distilled water and left to stand at room temperature for 5 min, and then filtered through Whatman No. 4 paper. To prepare decoctions, each sample (5 g) was added to 25 mL of distilled water, heated on a heating plate (VELP Scientific, Usmate, Italy) and boiled for 30 min. The mixture was left to stand at room temperature for 5 min more, and then filtered through Whatman No. 4 paper, and the extracts were kept at − 80 °C for 1 night and lyophilized (Free Zone 4.5, Labconco, Kansas City, MO, USA) for a minimum of 4 h. The extracts taken into bottles were kept in the refrigerator until the activity study was performed. The biological activities were evaluated directly on the decoctions/infusions [21].

To prepare essential oils, approximately 30 g dried herbs, leaves and seeds were used for the essential oil isolation in dill. Dried herbs, leaves and seeds were put into balloon using a clevenger apparatus with the TS8882 method throughout 3 h. Anhydroussodium sulphate was used to obtained dry essential oil isolation and was kept at 4 °C until use. The yields of essential oil were calculated after dried weight of each sample.

Gas chromatography-mass spectrometry/flame ionization detection (GC–MS/FID)

Essential oil components were analyzed using an Agilent Technologies 7890A (Santa Clara, CA, USA) coupled with a flame ionization detection detector and mass spectrometry (model 5975C) and HP-Innowax capillary column (60.0 m × 0.25 mm × 0.25 µm). Hexane was used for the essential oil components with dilution ratio 1:50. GC–MS/FID analysis was carried out using a split mode of 50:1. Injection volume and temperature were adjusted to 1 µL and 250 °C, respectively. Oven temperature gradually raised from 60 °C to 250 °C at 10 °C min^{-1}, held for 20 min and then holding at 250 °C for 8 min. Helium (purity 99.9%) was used the carrier gas at a flow rate of 1 mL min^{-1}. Mass scanning was from 35 to 450 amu, and the ionization mode used was electronic impact mode (70 eV). The relative percentage of the components was calculated from GC-FID peak areas and components were identified using the WILEY, NIST and FLAVOR libraries [22].

Determination of total phenolic compounds

Total soluble phenolics in the infusion and decoction preparations from the dried herbs of dill were determined with Folin–Ciocalteu reagent according to the method of Slinkard and Singleton [23] with some modifications. Aliquots (0.1 mL) of extracts were put into the

test tubes and their volumes made up to 4.6 mL using distilled water. Then, 0.1 mL Folin–Ciocalteu reagent (previously diluted threefold with distilled water) and 0.3 mL 2% Na_2CO_3 solution were added and tubes were vortexed and absorbance of mixture was recorded after 2 h at 760 nm against a blank containing 0.1 mL of extraction solvent. Gallic acid (0.05 mg mL^{-1}–0.4 mg mL^{-1}) was used for calibration of a standard curve. The results were expressed as gallic acid equivalents (GAE) g^{-1} of extract.

Determination of the antioxidant potential through free radical DPPH

The DPPH radical scavenging ability of the samples was assessed by the method described by Brand-Williams et al. [24]. A 0.1 mL extract aliquot (from 0.16 to 15 mg mL^{-1}) or quercetin (from 0.01 to 0.16 mg mL^{-1}) in methanol was added 3.9 mL of 6×10^{-5} M methanolic solution of DPPH. The mixture was shaken in a powerful way and allowed to stay in the dark at room temperature for 30 min. The decrease in absorbance of the resulting solution was measured in spectrophotometrically at 517 nm against methanol. A negative control (containing all reagents except the test sample) and positive controls (using the reference antioxidants) were used as controls for this test. The ability to scavenge DPPH radical was calculated by the following equation:

$$\text{DPPH radical scavenging activity (\%)} = [1 - (\text{Absorbance of sample at 517 nm/Absorbance of control at 517 nm})] \times 100.$$

Total radical antioxidant potential (TRAP) assay

The total radical antioxidant potential of the samples was measured using the Trolox equivalent antioxidant coefficient (TEAC) assay as described by Re et al. [25] with minor modifications. ABTS was dissolved in water to a 7 mM concentration. ABTS radical cation was produced by reacting $ABTS^{\cdot+}$ stock solution with 2.45 mM potassium persulfate (final concentration) and allowing the mixture to stand in the dark at room temperature for 12–16 h before use. At the beginning of the analysis day, $ABTS^{\cdot+}$ working solution was obtained by the dilution in 96% ethanol of the stock solution to an absorbance of 0.70 ± 0.02 at 734 nm. After addition of 990 µL of $ABTS^{\cdot+}$ solution to 10 µL of the extracts (from 0.625 to 15 mg mL^{-1}) or quercetin (from 0.01 to 0.16 mg mL^{-1}) or trolox standards (final concentration 0–20 µM l^{-1}) in absolute ethanol, the decrease in absorbance at 734 nm was monitored exactly 6 min after the initial mixing. Appropriate methanol blanks were run in each assay. All determinations were carried out in triplicate. The ability to scavenge $ABTS^{\cdot+}$ radical was calculated by the following equation: $ABTS^{\cdot+}$ radical scavenging activity (%) = [1—(Absorbance of sample at 734 nm/Absorbance of control at 734 nm)] × 100. The total antioxidant capacity value in a sample was assessed as TEAC. The TEAC value was calculated using a regression equation between the Trolox concentration and the percentage of inhibition of absorbance at 734 nm at 6 min of incubation and was expressed as mmol TEAC.

Ferric reducing antioxidant power (FRAP) assay

The reducing activity was determined according to the method described by Benzie and Strain [26]. The FRAP reagent included 2.5 mL of 10 mM TPTZ solution in 40 mM HCl plus 2.5 mL of 20 mM $FeCl_3.6H_2$ O and 25 mL of 0.3 M acetate buffer, pH 3.6. FRAP reagent (900 µL). This reagent was prepared freshly and incubated at 37 °C, then it was mixed with 90 µL of distilled water and 30 µL of the extracts (from 1.25 to 10 mg mL^{-1}) or quercetin (from 0.02 to 0.31 mg mL^{-1}) or water for the reagent blank. The increase was calculated at 4 min at 593 nm in absorbance. The FRAP values were calculated from a standard curve of $FeSO_4.7H_2O$ and expressed as mM Fe^{2+} equivalents.

Superoxide radical scavenging activity

Superoxide anion was formed with a PMS-NADH as non-enzymatically. Totally 3 ml reaction mixtures were used including 2.82 mL 40 mM sodium carbonate buffer consisting 1 mM EDTA (pH 10.0), 0.03 mL of 0.5% bovine serum albumin, 0.03 mL of 2.5 mM nitroblue tetrazolium, 0.06 mL of sample solution and 0.03 mL of 7.8 mM NADH. The mixture was kept at 25 or 37 °C and reaction was carried out. The reaction started by the addition of 0.03 mL of 155 µM PMS, and the absorbance at 560 nm was recorded for 60 s. [27]. As the control, 0.06 mL of Dimethyl Sulfoxide (DMSO) was used. The reaction ratio was estimated from increased the absorbance proportional, then obtained results as sample scavenging activity were noted as the percentage of inhibition.

Antimicrobial activity

American Type Culture Collection (ATCC) from different bacterial stains was used for assessment of antibacterial activity. *Staphylococcus aureus* (ATCC 29213), *Staphylococcus epidermidis* (ATCC 12228), methicillin-resistant MRSA (ATCC 43300) and *Enterococcus faecalis* (ATCC 29212) were used as Gram-positive species, and *Escherichia coli* (ATCC 25922), *Klebsiella pneumoniae* (ATCC 4352), *Pseudomonas aeruginosa* (ATCC 27853) were used as Gram-negative species, and as a yeast-shaped fungus *Candida albicans* (ATCC 10231) were determined by the microbroth dilutions technique

the Clinical Laboratory Standards Institute (CLSI) recommendations [28]. Mueller–Hinton broth for bacteria, RPMI-1640 medium buffered to pH 7.0 with MOPS for yeast strain was used as the test medium. Serial twofold dilutions ranging from 5000 µg mL^{-1} to 4.9 µg mL^{-1} were prepared in medium. The inoculum was prepared using a 4–6 h broth culture of each bacteria and 24 h culture of yeast strains adjusted to a turbidity equivalent to a 0.5 Mc Farland standard, diluted in broth media to give a final concentration of 5×10^5 cfu mL^{-1} for bacteria and 0.5×10^3–2.5×10^3 cfu mL^{-1} for yeast in the test tray. The trays were covered and placed in plastic bags to prevent evaporation. The trays containing Mueller–Hinton broth were incubated at 35 °C for 18–20 h and the trays containing RPMI-1640 medium were incubated at 35 °C for 46–50 h. The Minimum Inhibitory Concentration (MIC) was defined as the lowest concentration of compound giving complete inhibition of visible growth. As control, antimicrobial effects of the samples were investigated against test microorganisms. According to values of the controls, the results were evaluated.

Statistical analysis

All experiments were repeated three times and they were subjected to two-way analysis of variance (ANOVA) considering as factors the FYM and AN, and four levels of FYM applications (7.5, 10, 12.5 and 15 t ha^{-1}) and AN (30, 60, 90 and 120 kg ha^{-1}) with a control, while means were compared according to LSD test ($p < 0.05$). All the analyses were performed with the JMP 13 software.

Results and discussion

Essential oil and components

There were statistically significant differences between the leaves, seeds and herbs (various parts) of dill grown with FYM and AN with respect to the essential oil and components ($p < 0.05$). Essential oil yield showed differences depending on the dose of FYM and AN fertilizer applications and varied between the different parts of the dill (Table 2). The essential oil content range was found to be 0.26 ± 0.12 to 0.72 ± 0.52% in dill herbs, 0.27 ± 0.12 to 1.70 ± 0.08% in dill leaves, and 4.58 ± 0.16 to 6.18 ± 0.55% in dill seeds. The highest leaf, seed and herb essential oil contents were obtained from the treatment of 15 t ha^{-1} FYM. In addition, the control application exhibited significantly higher essential oil content compared to all AN applications involving the use of dill leaves and herbs. Compared to the all essential oils, dill seeds had the highest essential oil yield, followed by leaves and herbs (Table 2). FYM applications of up to 15 t ha^{-1} increased the essential oil yield of dill, which may be related to the presence of more nutrients or effects of organic manure on soil structure [29].

The essential oil yield (0.26 ± 0.12–6.18 ± 0.55%) obtained from the current study was comparable to that reported in a study by Krüger and Hammer [30] who found that the essential oil percentage of different dill seeds varied from 1.91 to 7.25%. Similarly, Badoc and Lamarti [31] observed that the oil content of European dill seeds varied from 1.75 to 5.8%. In the current study, the essential oil content of dill seeds was within the ranges reported in these previous studies. In contrast, Stanojeviš et al. [32] reported the yield of the dill essential oils from seeds and herbs to be 4 and 2.80%, respectively. Furthermore, Said-Al Ahl and Omer [33] determined

Table 2 Leaf, seed and herb essential oil content and total phenolic content of the dried herbs of *A. graveolens* in the aqueous extract

Treatments	Essential oil content (%)			Phenolic content (mg g^{-1})	
	Leaf	Seed	Herb	Infusion	Decoction
Control	1.47 ± 0.52^{c}	5.59 ± 0.34^{d}	0.65 ± 0.26^{b}	15.51 ± 0.47^{c}	15.71 ± 0.45^{c}
30 kg ha^{-1} AN	1.33 ± 0.45^{d}	5.98 ± 0.63^{b}	0.34 ± 0.33^{d}	10.19 ± 0.37^{g}	10.12 ± 0.47^{e}
60 kg ha^{-1} AN	0.23 ± 0.02^{h}	4.63 ± 0.47^{h}	0.26 ± 0.12^{f}	18.36 ± 0.35^{a}	17.85 ± 0.24^{a}
90 kg ha^{-1} AN	0.30 ± 0.17^{f}	5.26 ± 0.61^{f}	0.26 ± 0.28^{f}	10.06 ± 0.34^{g}	10.20 ± 0.60^{e}
120 kg ha^{-1} AN	0.30 ± 0.03^{f}	5.23 ± 0.52^{g}	0.35 ± 0.45^{d}	17.28 ± 0.14^{b}	16.93 ± 0.95^{b}
7.5 t ha^{-1} FYM	0.27 ± 0.12^{g}	4.58 ± 0.16^{i}	0.30 ± 0.23^{e}	12.42 ± 0.38^{d}	12.38 ± 0.50^{d}
10 t ha^{-1} FYM	0.55 ± 0.03^{e}	5.56 ± 0.53^{e}	0.64 ± 0.15^{b}	11.06 ± 0.35^{e}	11.66 ± 0.53^{d}
12.5 t ha^{-1} FYM	1.50 ± 0.01^{b}	5.91 ± 0.93^{c}	0.55 ± 0.07^{c}	10.57 ± 0.34^{ef}	10.27 ± 0.23^{e}
15 t ha^{-1} FYM	1.70 ± 0.08^{a}	6.18 ± 0.55^{a}	0.72 ± 0.52^{a}	10.69 ± 0.23^{ef}	10.48 ± 0.29^{e}

AN Ammonium nitrate, *FYM* Farmyard manure

*There was no significant difference at $p < 0.05$

Average value of three replicates

Values with different letters in the same column indicate significant differences at $p < 0.05$

that the essential oil content of Egyptian dill herbs ranged from 1.933 to 3.267%. Such variations in the essential oil content of dill across countries can be attributed to the varied agroclimatic conditions of different geographical regions, as well as different fertilizer applications.

We found some differences in the quantity of the main components of essential oils extracted from different parts of dill. The total oil compositions of leaves were found to be in the range of 64.08–84.33% with dill apiole, carvotanacetone, α-phellandrene and limonene being the most abundant compounds constituting around 22.02 to 43.55% of the investigated total concentration of essential oils (Table 3). In seeds, 21 constituents were identified (76.37–90.84% of total oil samples) with limonene, dill apiole, α-phellandrene, dihydrocarvone and carvotanacetone being the most abundant compounds that totally constituted around 48.73–67.91% of the investigated essential oils (Table 3).

Table 3 shows that 7 compounds (limonene, 4-isopropyltoluen, α-phellandrene, dill ether, carvone, α-pinene and myrcene) clearly dominated the dill herbs essential oil, representing 42.26–56.43% of the total concentration of essential compounds. The percentages of dill apiole and carvantonacetone varied in leaves (2.62 ± 0.05–11.96 ± 0.83% and 2.98 ± 0.22–15.90 ± 2.34%, respectively), herbs (0.87 ± 0.03–2.05 ± 0.23% and 1.41 ± 0.23–1.89 ± 0.23%, respectively) and seeds (13.55 ± 1.13–18.65 ± 1.89% and 5.04 ± 0.62–21.76 ± 1.62%, respectively). Dill ether was present in leaves (5.42 ± 0.52–6.89 ± 0.52%) and herbs (3.79 ± 0.78–9.01 ± 1.12%), but was found only in a small amount in seeds (1.11 ± 0.18–2.53 ± 0.22%). The highest limonene content was obtained from seeds (10.23 ± 0.52–20.05 ± 0.45%), followed by leaves (7.44 ± 0.23–9.38 ± 0.56%), and herbs (3.79 ± 0.78–9.01 ± 1.11%). In addition, the principal essential oil components of dill seeds and leaves were α-phellandrene (7.99 ± 1.11–10.79 ± 1.26% and 5.62 ± 0.65–10.89 ± 1.01%, respectively), dihydrocarvone (8.08 ± 1.02–12.11 ± 1.32% and 1.78 ± 0.12–8.31 ± 1.18%, respectively), and β-phellandrene (0.04 ± 0.01–5.21 ± 0.32% and 3.61 ± 0.26–8.12 ± 0.22%, respectively), but herb oil contained α-phellandrene (3.72 ± 0.23–7.21 ± 0.86%), β-phellandrene (5.11 ± 0.56–7.08 ± 0.76%), and dihydrocarvone (1.22 ± 0.12–1.70 ± 0.23%). Therefore, the highest concentrations of limonene, dill apiole and carvotanacetone, which were the main components, were obtained from the essential oil extracted from seeds.

In dill leaves, the maximum concentration of carvotanacetone was obtained after applying 10 t ha^{-1} FYM, followed by 90 kg ha^{-1} AN, whereas the maximum concentration of dill apiole was obtained after applying 10 and 7.5 t ha^{-1} FYM, followed by 30 kg ha^{-1} AN and 12.5 t ha^{-1} FYM. The contents of carvotanacetone and dill apiole were higher in FYM applications than in AN applications. The highest concentration of dihydrocarvone was also found with the FYM application dose of 15 t ha^{-1}, followed by 120 kg ha^{-1} AN, whereas the lowest concentration was observed in the FYM application of 7.5 t ha^{-1}. Furthermore, α-phellandrene was also prevalent in almost all treatments. The FYM dose of 15 t ha^{-1} had the highest α-phellandrene content, followed by 12.5 t ha^{-1} FYM and 30 kg ha^{-1} AN (Table 3).

In dill herbs, all treatments resulted in similar percentages β-phellandrene (5.11 ± 0.56–7.08 ± 0.76%), whereas the 10 t ha^{-1} FYM application provided the highest α-phellandrene content at 7.08% (Table 3). The highest rates of limonene and myrcene were obtained from the FYM doses of 15 t ha^{-1} and 90 kg ha^{-1} AN, respectively, which significantly differed compared to the remaining doses and the control treatment. Therefore, dill herb and leave oil were found suitable for the production of α-phellandrene, limonene as a fragrance component in food, detergents, cosmetics, perfumes, and especially soaps, and they would also have economical value for the grower [34].

Dill ether was identified at the highest level after applying 60 kg ha^{-1} AN and the control application, followed by 12.5 t ha^{-1} and 15 t ha^{-1} FYM. Also, 4-isopropyltoluen and α-phellandrene had higher concentrations in the treatment with 90 kg ha^{-1} AN, followed by 120 kg ha^{-1} AN and 12.5 t ha^{-1} FYM. In dill seeds, the highest concentrations (5.04 ± 0.62–21.76 ± 1.62%) for carvantonacetone was obtained from the FYM application at a dose of 15 t ha^{-1}, whereas the lowest concentration was obtained from 120 kg ha^{-1} AN. The highest concentration of limonene was also found after the FYM treatment at a dose of 12.5 t ha^{-1}, whereas the lowest concentration was observed after the application of 10 t ha^{-1} FYM. Similarly, apiole was present in almost all treatments. The FYM dose of 7.5 t ha^{-1} resulted in the highest apiol content, followed by 90 kg ha^{-1} AN, 12.5 t ha^{-1} FYM and the control application. Apiole and dillapiole are effective, naturally occurring insecticides or insecticide synergists. Based on the results obtained, it is considered that dill seeds would be suitable for the production of apiole to be used in insecticides to act in synergy with pyrethrin and inhibit aflatoxin [35].

Dihydrocarvone was found in the application of FYM at a dose of 12.5 t ha^{-1}, followed by 30 kg ha^{-1} AN and 90 kg ha^{-1} AN. The highest α-phellandrene was obtained from 120 kg ha^{-1} AN, followed by 90 kg ha^{-1} AN and 15 t ha^{-1} FYM. Today, dihydrocarvone or carvone have both pharmaceutical and cosmetic uses, and some important applications in agriculture both for crop protection and as an antisprouting agent during tuber storage. Dill seed

Table 3 Leaf, seed and herb essential oil components of *A. graveolens*

	Essential oil components/ Treatments	RT (min)	Control	30 kg ha^{-1} AN	60 kg ha^{-1} AN	90 kg ha^{-1} AN	120 kg ha^{-1} AN	7.5 t ha^{-1} FYM	10 t ha^{-1} FYM	12.5 t ha^{-1} FYM	15 t ha^{-1} FYM
Leaf Essential oil components	α-pinene	13.21	4.35 ± 0.08^{f}	4.77 ± 0.22^{c}	5.66 ± 0.22^{a}	3.41 ± 0.22^{h}	4.63 ± 0.18^{e}	3.63 ± 0.12^{g}	3.22 ± 0.18ı	5.29 ± 0.78^{b}	4.67 ± 0.48^{d}
	β-pinene	14.28	0.64 ± 0.07^{b}	0.65 ± 0.07^{b}	0.78 ± 0.06^{a}	0.36 ± 0.04^{e}	0.47 ± 0.08^{d}	0.37 ± 0.08^{e}	0.37 ± 0.08^{e}	0.62 ± 0.03^{c}	0.48 ± 0.05^{d}
	Mycrene	14.46	2.07 ± 0.01^{f}	2.31 ± 0.02^{c}	2.59 ± 0.88^{a}	1.52 ± 0.12ı	2.15 ± 0.33^{e}	2.03 ± 0.12^{g}	1.66 ± 0.11^{h}	2.33 ± 0.16^{b}	2.25 ± 0.16^{d}
	α-phellandrene	14.97	8.47 ± 0.07^{e}	10.36 ± 1.12^{b}	5.62 ± 0.65ı	7.62 ± 0.36^{g}	8.75 ± 0.75^{d}	8.22 ± 0.56^{f}	6.08 ± 0.62^{h}	9.61 ± 0.88^{c}	10.89 ± 1.01^{a}
	Limonene	15.45	7.44 ± 0.23ı	8.51 ± 0.88^{f}	8.06 ± 0.68^{g}	9.23 ± 0.18^{c}	9.32 ± 0.56^{b}	9.38 ± 0.56^{a}	9.00 ± 0.65^{d}	7.59 ± 0.76^{h}	8.95 ± 0.72^{e}
	4-isopropyltoluen	15.57	2.13 ± 0.02^{c}	3.02 ± 0.18^{a}	1.74 ± 0.08^{d}	2.28 ± 0.08^{b}	1.20 ± 0.06^{f}	1.43 ± 0.05^{e}	1.03 ± 0.06^{g}	1.00 ± 0.03^{h}	0.95 ± 0.05ı
	β -phellandrene	15.61	6.24 ± 0.08^{f}	8.12 ± 0.22^{a}	7.16 ± 0.16^{c}	7.58 ± 0.52^{b}	4.37 ± 0.36^{g}	3.65 ± 0.23^{h}	6.48 ± 0.33^{e}	6.65 ± 0.28^{d}	3.61 ± 0.26ı
	Terpinen	16.73	0.21 ± 0.00^{c}	0.28 ± 0.05^{b}	0.32 ± 0.06^{a}	0.10 ± 0.01^{g}	0.19 ± 0.01^{d}	0.12 ± 0.02^{f}	0.14 ± 0.05^{e}	0.27 ± 0.03^{b}	0.19 ± 0.02^{d}
	Linalool	17.14	1.06 ± 0.05^{a}	0.64 ± 0.02^{g}	0.94 ± 0.03^{e}	0.87 ± 0.06^{f}	1.00 ± 0.02^{c}	0.97 ± 0.10^{d}	0.87 ± 0.02^{f}	0.64 ± 0.04^{g}	1.03 ± 0.08^{b}
	Limonen oxide	18.35	1.17 ± 0.08^{e}	0.63 ± 0.03^{g}	0.83 ± 0.^{03f}	1.83 ± 0.08^{a}	1.51 ± 0.11^{c}	1.20 ± 0.08^{d}	1.50 ± 0.08^{d}	0.52 ± 0.05^{h}	1.58 ± 0.12^{b}
	Dill ether	19.45	5.87 ± 0.10^{g}	6.55 ± 0.46^{d}	6.15 ± 0.73^{f}	6.72 ± 0.89^{c}	6.85 ± 0.26^{b}	5.42 ± 0.52^{h}	6.89 ± 0.52^{a}	6.42 ± 0.65^{e}	6.85 ± 0.76^{b}
	Carvone	20.17	6.50 ± 0.09^{g}	6.61 ± 0.18^{f}	7.22 ± 0.21^{d}	6.50 ± 1.14^{g}	7.81 ± 0.12^{a}	7.69 ± 0.22^{c}	6.95 ± 0.26^{e}	6.31 ± 0.19^{h}	7.71 ± 0.20^{b}
	Dihydro carvone	20.35	5.14 ± 0.10^{e}	1.78 ± 0.12^{h}	4.76 ± 0.16^{f}	6.67 ± 0.62^{d}	8.31 ± 1.18^{a}	7.71 ± 0.95^{c}	6.68 ± 0.66^{d}	4.47 ± 0.23^{g}	8.17 ± 0.62^{b}
	Anethole	20.55	0.51 ± 0.02^{h}	1.78 ± 0.16^{d}	0.94 ± 0.08^{g}	1.51 ± 0.52^{e}	2.92 ± 0.36^{b}	3.03 ± 0.38^{a}	2.32 ± 0.22^{c}	1.38 ± 0.22^{f}	2.93 ± 0.32^{b}
	Carvantonacetone	21.02	5.78 ± 0.23^{e}	7.68 ± 1.12^{c}	2.98 ± 0.22ı	15.90 ± 2.34^{a}	4.19 ± 0.52^{g}	3.65 ± 0.46^{h}	11.66 ± 1.89^{b}	6.40 ± 0.46^{b}	4.22 ± 0.56^{f}
	Methyl cinnamate	21.98	1.42 ± 0.08^{a}	1.06 ± 0.11^{g}	1.36 ± 0.11^{c}	1.12 ± 0.13^{e}	1.39 ± 0.23^{b}	1.06 ± 0.08^{g}	1.09 ± 0.09^{f}	1.22 ± 0.22^{d}	0.99 ± 0.12^{h}
	Isocaryophyllene	23.15	1.81 ± 0.05^{a}	1.01 ± 0.03^{c}	1.10 ± 0.04^{b}	0.02 ± 0.00^{f}	0.03 ± 0.00^{ef}	0.03 ± 0.00^{ef}	0.04 ± 0.00^{de}	0.05 ± 0.00^{d}	0.03 ± 0.00^{ef}
	α-humulene	24.14	0.38 ± 0.09^{a}	0.22 ± 0.04^{e}	0.32 ± 0.03^{c}	0.14 ± 0.01^{g}	0.33 ± 0.06^{bc}	0.15 ± 0.00^{g}	0.18 ± 0.00^{f}	0.34 ± 0.01^{b}	0.25 ± 0.03^{d}
	Caryophyllene oxide	27.42	0.35 ± 0.05^{b}	0.18 ± 0.01^{c}	0.12 ± 0.01^{d}	0.01 ± 0.00^{g}	0.05 ± 0.00^{e}	0.03 ± 0.00^{f}	1.13 ± 0.08^{a}	0.06 ± 0.00^{e}	0.05 ± 0.00^{e}
	Apiole	27.77	9.79 ± 0.36^{f}	10.45 ± 1.08^{d}	5.36 ± 0.22^{g}	10.80 ± 0.97^{c}	2.62 ± 0.05ı	11.10 ± 0.69^{b}	11.96 ± 0.83^{a}	10.39 ± 0.56^{e}	2.75 ± 0.09^{h}
	α-bisabolol	28.78	0.09 ± 0.00^{c}	0.06 ± 0.03^{e}	0.07 ± 0.02d^{e}	0.14 ± 0.05^{a}	0.12 ± 0.06^{b}	0.08 ± 0.03^{cd}	0.06 ± 0.03^{e}	0.15 ± 0.03^{a}	0.14 ± 0.00^{a}
	Total (%)		71.42 ± 0.19^{e}	76.67 ± 0.26^{c}	64.08 ± 0.18ı	84.33 ± 0.11^{a}	68.21 ± 0.16^{h}	70.95 ± 0.20^{f}	79.31 ± 0.20^{b}	71.71 ± 0.32^{d}	68.69 ± 0.26^{g}

Table 3 (continued)

	Essential oil components/ Treatments	RT (min)	Control	30 kg ha^{-1} AN	60 kg ha^{-1} AN	90 kg ha^{-1} AN	120 kg ha^{-1} AN	7.5 t ha^{-1} FYM	10 t ha^{-1} FYM	12.5 t ha^{-1} FYM	15 t ha^{-1} FYM
Herb essential oil components	α-pinene	13.21	5.53 ± 0.59^{d}	6.53 ± 0.63^{a}	3.91 ± 0.61^{h}	5.40 ± 0.89^{e}	3.80 ± 0.63ı	5.36 ± 0.61^{f}	6.39 ± 0.84^{b}	5.74 ± 0.63^{c}	4.73 ± 0.56^{g}
	β-pinene	14.28	1.05 ± 0.06^{a}	0.43 ± 0.02^{f}	0.98 ± 0.08^{b}	0.91 ± 0.11^{d}	0.92 ± 0.09d	0.91 ± 0.09^{d}	0.55 ± 0.09^{e}	0.95 ± 0.12^{c}	1.05 ± 0.13^{a}
	Mycrene	14.46	7.13 ± 0.89^{c}	5.22 ± 0.26ı	6.94 ± 0.36^{e}	7.44 ± 0.68^{a}	6.81 ± 0.66^{f}	6.65 ± 0.88^{g}	6.06 ± 1.01^{h}	7.04 ± 0.74^{d}	7.17 ± 0.78^{b}
	α-phellandrene	14.97	3.72 ± 0.23^{h}	6.17 ± 0.36^{g}	6.95 ± 0.42^{d}	7.21 ± 0.86^{a}	7.18 ± 0.86^{b}	6.49 ± 0.65^{f}	6.64 ± 0.62^{e}	7.11 ± 0.78^{c}	6.94 ± 0.68^{d}
	Limonene	15.45	7.71 ± 1.08^{d}	3.79 ± 0.78ı	7.47 ± 0.82^{f}	9.01 ± 1.11^{a}	8.56 ± 1.15^{c}	6.14 ± 0.88^{g}	5.90 ± 0.98^{h}	7.69 ± 0.56^{e}	8.75 ± 0.86^{b}
	4-isopropyltoluen	15.57	6.04 ± 0.53^{h}	7.29 ± 0.78^{e}	6.25 ± 0.89^{g}	8.24 ± 0.89^{a}	8.14 ± 0.88^{b}	7.67 ± 1.02^{c}	4.99 ± 0.88ı	7.39 ± 1.02^{d}	7.08 ± 0.68^{f}
	β -phellandrene	15.61	6.82 ± 0.68^{b}	5.94 ± 0.65^{d}	6.81 ± 0.75^{b}	6.37 ± 0.63^{c}	5.64 ± 0.46^{e}	5.11 ± 0.56^{g}	7.08 ± 0.76^{a}	5.58 ± 0.66^{f}	7.07 ± 0.78^{a}
	Terpinen	16.73	0.94 ± 0.02^{b}	0.34 ± 0.04^{g}	0.89 ± 0.05^{d}	0.99 ± 0.11^{a}	0.91 ± 0.05^{c}	0.91 ± 0.05^{c}	0.82 ± 0.03^{f}	0.93 ± 0.03^{b}	0.87 ± 0.03^{e}
	Linalool	17.14	0.87 ± 0.02^{b}	0.49 ± 0.03^{h}	0.79 ± 0.03^{cd}	0.66 ± 0.02^{g}	0.74 ± 0.02^{e}	0.78 ± 0.02^{d}	0.80 ± 0.02^{c}	0.96 ± 0.05^{a}	0.72 ± 0.05^{f}
	Limonen oxide	18.35	1.41 ± 0.12^{a}	0.69 ± 0.06^{g}	1.23 ± 0.16^{c}	1.17 ± 0.16^{f}	1.23 ± 0.05^{a}	0.06 ± 0.00^{h}	1.21 ± 0.12^{d}	1.26 ± 0.18^{b}	1.19 ± 0.16^{e}
	Dill ether	19.45	8.58 ± 0.89^{b}	7.16 ± 0.88ı	9.13 ± 1.12^{a}	7.90 ± 1.01^{e}	7.61 ± 0.72^{f}	7.52 ± 0.98^{g}	7.40 ± 0.62^{h}	8.41 ± 0.56^{c}	7.96 ± 0.62^{d}
	Carvone	20.17	6.84 ± 0.32^{b}	6.10 ± 0.56^{h}	6.65 ± 0.56^{e}	7.34 ± 0.65^{a}	3.98 ± 0.08ı	6.59 ± 0.12^{f}	6.67 ± 0.56^{d}	6.55 ± 0.72^{g}	6.75 ± 0.86^{c}
	Dihydro carvone	20.35	1.69 ± 0.08^{a}	1.22 ± 0.12^{e}	1.69 ± 0.13^{a}	1.23 ± 0.16^{e}	1.58 ± 0.22^{c}	1.70 ± 0.23^{a}	1.48 ± 0.12^{d}	1.69 ± 0.16^{a}	1.61 ± 0.26^{b}
	Anethole	20.55	0.08 ± 0.02^{b}	0.04 ± 0.01^{d}	0.08 ± 0.00^{b}	0.05 ± 0.00^{cd}	0.08 ± 0.00^{b}	0.10 ± 0.01^{a}	0.04 ± 0.00^{d}	0.06 ± 0.00^{c}	0.06 ± 0.00^{c}
	Carvantonacetone	21.02	1.44 ± 0.22^{f}	1.58 ± 0.36^{e}	1.71 ± 0.26^{c}	1.66 ± 0.09^{d}	1.89 ± 0.23^{a}	1.65 ± 0.26^{d}	1.82 ± 0.12^{b}	1.89 ± 0.23^{a}	1.41 ± 0.23^{g}
	Methyl cinnamate	21.98	0.86 ± 0.01^{c}	0.79 ± 0.08^{e}	0.80 ± 0.09^{de}	0.71 ± 0.08^{f}	0.90 ± 0.03^{b}	0.79 ± 0.01^{e}	1.18 ± 0.32^{a}	0.87 ± 0.14^{c}	0.81 ± 0.16^{d}
	Isocaryophyllene	23.15	0.08 ± 0.02^{c}	0.16 ± 0.01^{a}	0.06 ± 0.01^{d}	0.17 ± 0.02^{a}	0.02 ± 0.00^{e}	0.06 ± 0.00^{d}	0.10 ± 0.01^{b}	0.10 ± 0.00^{b}	0.07 ± 0.00^{cd}
	α-humulene	24.14	0.23 ± 0.06^{g}	2.72 ± 0.16^{a}	0.38 ± 0.09^{c}	0.46 ± 0.06^{b}	0.27 ± 0.13^{f}	0.34 ± 0.08^{d}	0.31 ± 0.08^{e}	0.18 ± 0.00^{h}	0.38 ± 0.09^{c}
	Caryophyllene oxide	27.42	0.10 ± 0.00^{e}	0.12 ± 0.00^{d}	0.05 ± 0.00^{f}	0.22 ± 0.01^{b}	0.01 ± 0.00^{g}	0.15 ± 0.01^{c}	0.29 ± 0.08^{a}	0.13 ± 0.01^{d}	0.12 ± 0.01^{d}
	Apiole	27.77	1.41 ± 0.08^{c}	0.87 ± 0.03^{h}	1.18 ± 0.06^{f}	0.83 ± 0.08ı	1.54 ± 0.22^{b}	2.05 ± 0.23^{a}	1.11 ± 0.13^{g}	1.32 ± 0.12^{d}	1.26 ± 0.16^{e}
	α-bisabolol	28.78	0.93 ± 0.02^{c}	1.09 ± 0.23^{a}	0.08 ± 0.00^{de}	0.04 ± 0.00^{g}	0.06 ± 0.00^{f}	1.04 ± 0.08^{b}	0.09 ± 0.01^{d}	0.06 ± 0.02^{f}	0.07 ± 0.02^{ef}
	Total (%)		63.46 ± 0.36^{e}	58.74 ± 0.28ı	64.03 ± 1.04^{d}	68.01 ± 0.56^{a}	61.87 ± 0.48^{g}	62.07 ± 0.38^{f}	60.93 ± 0.37^{h}	65.91 ± 0.29^{c}	66.07 ± 0.36^{b}

Table 3 (continued)

	Essential oil components/ Treatments	RT (min)	Control	30 kg ha^{-1} AN	60 kg ha^{-1} AN	90 kg ha^{-1} AN	120 kg ha^{-1} AN	7.5 t ha^{-1} FYM	10 t ha^{-1} FYM	12.5 t ha^{-1} FYM	15 t ha^{-1} FYM
Seed essential oil components	α-pinene	13.21	0.43 ± 0.22^{i}	0.51 ± 0.36^{h}	0.70 ± 0.35^{e}	0.93 ± 0.45^{d}	1.05 ± 0.12^{a}	0.59 ± 0.18^{g}	0.99 ± 0.11^{b}	0.61 ± 0.21^{f}	0.96 ± 0.12^{c}
	β-Pinene	14.28	0.22 ± 0.23^{de}	0.24 ± 0.45^{c}	0.21 ± 0.06^{e}	0.23 ± 0.06^{cd}	0.26 ± 0.08^{b}	0.23 ± 0.02^{cd}	0.28 ± 0.02^{a}	0.19 ± 0.02^{f}	0.26 ± 0.06^{b}
	Mycrene	14.46	1.25 ± 0.23^{f}	1.27 ± 0.62^{e}	1.37 ± 0.32^{d}	1.58 ± 0.22^{b}	1.56 ± 0.23^{c}	1.56 ± 0.32^{c}	1.97 ± 0.23^{a}	0.87 ± 0.23^{g}	1.56 ± 0.23^{c}
	α -phellandrene	14.97	9.03 ± 0.26^{h}	9.20 ± 1.16^{g}	9.59 ± 1.18^{e}	10.43 ± 1.59^{b}	10.79 ± 1.26^{a}	9.71 ± 1.33^{d}	9.50 ± 0.82^{f}	7.99 ± 1.11^{i}	10.34 ± 2.14^{c}
	Limonene	15.45	11.26 ± 0.56^{h}	11.61 ± 0.63^{g}	12.95 ± 0.56^{c}	15.11 ± 0.43^{b}	12.47 ± 0.45^{f}	12.88 ± 0.56^{d}	10.23 ± 0.52^{i}	20.05 ± 0.45^{a}	12.53 ± 0.62^{e}
	4-isopropyltoluen	15.57	4.26 ± 0.26^{d}	4.52 ± 0.23^{c}	2.63 ± 0.23^{e}	1.29 ± 0.18^{i}	1.82 ± 0.12^{g}	1.96 ± 0.18^{f}	6.78 ± 0.26^{a}	4.83 ± 0.12^{b}	1.55 ± 0.23^{h}
	β -phellandrene	15.61	2.66 ± 0.22^{f}	3.24 ± 0.08^{e}	3.45 ± 0.08^{c}	3.38 ± 0.08^{d}	2.49 ± 0.13^{g}	2.65 ± 0.22^{f}	5.21 ± 0.32^{a}	0.04 ± 0.01^{h}	3.61 ± 0.12^{b}
	Terpinen	16.73	0.05 ± 0.01^{cd}	0.04 ± 0.00^{d}	0.04 ± 0.01^{d}	0.06 ± 0.00^{c}	2.29 ± 0.09^{a}	0.05 ± 0.00^{cd}	0.10 ± 0.02^{b}	0.02 ± 0.00^{e}	0.05 ± 0.01^{cd}
	Linalool	17.14	1.47 ± 0.06^{f}	1.77 ± 0.08^{d}	1.67 ± 0.06^{e}	1.88 ± 0.12^{c}	4.01 ± 0.16^{a}	1.76 ± 0.08^{d}	2.71 ± 0.12^{b}	0.94 ± 0.06^{g}	1.76 ± 0.08^{d}
	Limonen oxide	18.35	2.09 ± 0.12^{d}	2.30 ± 0.22^{c}	2.07 ± 0.22^{e}	2.51 ± 0.22^{b}	0.04 ± 0.01^{g}	2.30 ± 0.11^{c}	3.48 ± 0.09^{a}	1.25 ± 0.10^{f}	2.09 ± 0.18^{d}
	Dill ether	19.45	1.52 ± 0.11^{f}	1.11 ± 0.18^{i}	1.31 ± 0.08^{g}	1.93 ± 0.11^{c}	1.79 ± 0.07^{d}	1.55 ± 0.11^{e}	2.53 ± 0.22^{a}	1.25 ± 0.11^{h}	2.27 ± 0.13^{b}
	Carvone	20.17	5.89 ± 0.26^{g}	6.71 ± 0.65^{b}	7.02 ± 0.33^{a}	5.82 ± 0.37^{h}	6.45 ± 0.48^{c}	6.24 ± 0.46^{f}	3.60 ± 0.26^{d}	6.32 ± 0.46^{d}	6.30 ± 0.36^{e}
	Dihydro carvone	20.35	9.82 ± 1.23^{e}	11.57 ± 2.32^{b}	10.09 ± 1.26^{d}	10.27 ± 0.98^{c}	9.66 ± 0.96^{f}	9.05 ± 0.88^{h}	8.08 ± 1.02^{i}	12.11 ± 1.32^{a}	9.07 ± 0.68^{g}
	Anethole	20.55	1.29 ± 0.11^{e}	2.88 ± 0.56^{a}	0.87 ± 0.08^{d}	1.32 ± 0.12^{d}	0.73 ± 0.06^{h}	0.83 ± 0.06^{g}	1.62 ± 0.05^{c}	1.72 ± 0.12^{b}	0.73 ± 0.06^{h}
	Carvantonacetone	21.02	12.28 ± 0.65^{d}	16.51 ± 1.12^{b}	15.10 ± 1.16^{c}	10.51 ± 0.99^{f}	5.04 ± 0.62^{i}	11.83 ± 0.92^{e}	6.06 ± 0.01^{g}	5.38 ± 0.18^{h}	21.76 ± 1.62^{a}
	Methyl cinnamate	21.98	1.34 ± 0.18^{g}	1.54 ± 0.22^{d}	1.58 ± 0.08^{c}	1.74 ± 0.16^{b}	1.36 ± 0.16^{f}	1.59 ± 0.16^{c}	2.30 ± 0.19^{a}	0.61 ± 0.08^{h}	1.50 ± 0.13^{e}
	Isocaryophyllene	23.15	0.15 ± 0.02^{de}	0.14 ± 0.01^{e}	0.21 ± 0.01^{b}	0.20 ± 0.01^{b}	0.17 ± 0.02^{c}	0.16 ± 0.02^{cd}	0.33 ± 0.03^{a}	0.09 ± 0.00^{f}	0.15 ± 0.03^{de}
	α-humulene	24.14	0.03 ± 0.00^{c}	0.04 ± 0.00^{bc}	0.05 ± 0.02^{ab}	0.06 ± 0.01^{a}	0.05 ± 0.01^{ab}	0.05 ± 0.01^{ab}	0.06 ± 0.01^{a}	0.04 ± 0.00^{bc}	0.04 ± 0.00^{bc}
	Caryophyllene oxide	27.42	0.01 ± 0.00^{c}	0.04 ± 0.00^{a}	0.01 ± 0.00^{c}	0.03 ± 0.01^{ab}	0.01 ± 0.00^{c}	0.03 ± 0.00^{ab}	0.01 ± 0.00^{c}	0.02 ± 0.00^{bc}	0.02 ± 0.00^{bc}
	Apiole	27.77	15.04 ± 0.89^{d}	14.29 ± 1.13^{f}	13.55 ± 1.13^{h}	16.40 ± 1.52^{b}	14.24 ± 1.23^{g}	18.65 ± 1.89^{a}	14.32 ± 0.98^{e}	15.95 ± 1.16^{c}	14.24 ± 0.78^{g}
	α-bisabolol	28.78	0.05 ± 0.01^{b}	0.05 ± 0.01^{b}	0.05 ± 0.01^{b}	$0.04 \pm 0.01b^{c}$	0.09 ± 0.00^{a}	$0.04 \pm 0.00b^{c}$	0.09 ± 0.01^{a}	0.03 ± 0.00^{c}	0.05 ± 0.00^{b}
	Total (%)		80.14 ± 0.32^{h}	89.58 ± 0.56^{b}	84.52 ± 0.36^{d}	85.72 ± 0.48^{c}	76.37 ± 0.72^{i}	83.71 ± 0.22^{e}	80.25 ± 0.48^{g}	80.31 ± 1.18^{f}	90.84 ± 0.73^{a}

**RT* Retention time, *AN* Ammonium nitrate, *FYM* Farmyard manure

Average values of three replicates

Values with different letters in the same column indicate significant differences at $p < 0.05$

Leaf, seed and herb essential oil components were evaluated separately

oil is also suitable for the production of dihydrocarvone or carvone used in traditional and new food products, including chewing gum, as well as in cosmetics and perfumes [36].

According to our result, FYM application contributed not only to an increase in essential oil content, but also increased the concentration of carvantonacetone, α-phellandrene, limonene and myrcene in the oil. Furthermore, we also noted that FYM application of up to 15 t ha^{-1} of increased the EO component yield effectively, which could be caused by the overall promotion effect of organic manure on the secondary metabolic pathways of the plants [37, 38].

The results of the current study were closely related to those reported by Hussein et al. [39], who determined the major components of dill vegetative herb essential oils as α-phellandrene (46.33%), limonene (13.72%), β-phellandrene (11.01%), p-cymene (17.88%), and carvone (13.10%), whereas carvone (62.48%), dillapiole (19.51%) and limonene (14.61%) were identified as the major compounds in seed essential oil. Furthermore, Ruangamnart et al. [40] indicated the major components of dill seeds oils in Thailand were dillapiole (19.98–48.9%), carvone (18.05–28.02%), and limonene (26.96–44.61%). Similarly, Kazemi [41] reported the major components of dill herb oils as α-phellandrene (19.12%), limonene (26.34%), dill ether (15.23%), sabinene (11.34%).

In another study, Madandoust and Fooladchang [42] determined the effect of different nitrogen doses (50, 100 and 150 kg ha^{-1}) on dill essential oil to be within the ranges of 2.00–2.25% (v w^{-1}). The authors also indicated that the highest essential oil was obtained from 100 kg ha^{-1} N and identified 17 compounds. Among the major components, the highest concentrations of α-phellandrene (49.54%) and limonene (13.79%) were obtained from the 150 kg ha^{-1} application, while the highest p-cymene concentration (18.19%) was seen in the 50 kg ha^{-1} application, and β-phellandrene (9.0%) in the control group. This is in agreement with our results, revealing that the essential oil and major components of dill were increased at a nitrogen dose of up to 120 kg ha^{-1}.

Moreover, Darzi et al. [43] emphasized the importance of bioorganic manure with respect to enhancement of the essential oils and components of dill seed. The highest values of essential oil content and components were obtained in dill plants grown in 4 and 8 t ha^{-1} vermicompost treatments. This result is partly in agreement with our finding indicating that the FYM application of up to 15 t ha^{-1} effectively increased the essential oil and component yield.

In contrast, Jianu et al. [44] identified the major components of dill mature seeds oils as carvone (52.37%) and limonene 39.20%. They also reported that the carvone concentration (34.62%) was lower than that of limonene (40.69%) in immature seeds. Singh et al. [45] noted that the major components of dill mature seed oils were carvone (55.2%), limonene (16.6%), dill apiole (43.2%) and linoleic acid (23.1%). In addition, Sharopov et al. [46] reported that the major components of dill aerial oils were carvone (51.7%), *trans*- dihydrocarvone (14.7%), dill ether (13.2%), α-phellandrene (8.1%), and limonene (6.9%).

The chemical profile of our dill essential oil sample contradicts the data reported by Singh et al. [44] and Sharopov et al. [46]. These differences in the chemical composition of oils may arise from several environmental and genetic differences and the nutritional status of the plants.

Phenolic contents

The results given in Table 2 showed that the mean of the total phenolic content per gram crude extract of both the 60 kg ha^{-1} AN infusion and decoction preparations (18.36 ± 0.35 and 17.85 ± 0.24 mg GAE g^{-1}, respectively) as well as 120 kg da^{-1} AN infusion and decoction (17.28 ± 0.14 and 16.93 ± 0.95 mg GAE g^{-1}, respectively) are significantly higher ($p < 0.05$) than that of infusion control (15.51 ± 0.47 mg GAE g^{-1}) and decoction control (15.71 ± 0.45 mg GAE g^{-1}).

So they can be considered as the good source of antioxidants due to their high level of phenolic compounds. 60 kg da^{-1} AN infusion and 120 kg da^{-1} AN decoction showed the similar antioxidant profile and content of phenols, indicating that the type of phenolic compounds in infusion and decoction did not varied markedly.

Infusion extracts were the most effective amongst all the tested extracts having a high content of total phenols. However, the essential oil extracts of dill herb were found to have no phenolic content all FYM and AN applications. A comparison of FYM and AN applications indicated that AN fertilizer extracts exhibited the highest phenolic content. Among the FYM extracts, the highest phenolic contents were found in treatments with decoction and infusion extract of 750 and 10 t ha^{-1} FYM, which were slightly different compared to the other treatments and the control treatment (Table 2).

Our results were comparable with the results described by Albayrak et al. [47] who found that the total phenolic content of dill infusion and decoction extracts were equivalent to 12.13 and 15.45 mg GAE g^{-1}, respectively. However, our values were greater than that reported by Zheng and Wang [48] report which determined that total phenolic contents of dill were 3.12 mg of GAE g^{-1}

of fresh weight. This discrepancy may be due to the additional contribution of FYM to the total phenolic amount. Our results were consistent with the previous observation on the total phenolic content of dill extracts using bio-fertilizer compared to chemical fertilizer [49, 50].

Antioxidant activity

The use of infusion and decoction of dill as a complement to daily food intake can provide considerable benefits for health, not only in the treatment of diseases related to reactive species production and oxidative stress but also against bacterial infections. These benefits of dill can be achieved through both internal and external use, and at recommended doses, it is safe with no adverse reactions having been described to date.

In the present study, the water extracts prepared as infusion and decoction and essential oils were screened for their antioxidant activities using 2,2,-diphenyl-1-picrylhydrazyl free radical and superoxide anion scavenging, trolox equivalent antioxidant capacity (TEAC) assay with $ABTS^{\bullet+}$ radical cation and ferric reducing antioxidant power (FRAP) assays. For comparison, Table 4 presents the results of the antioxidant activities, expressed as EC_{50} values.

From the EC_{50} values estimated from the dose–response curves, it was seen that infusions, decoctions and essential oils showed similar degrees of efficacy in scavenging DPPH, $ABTS^{\bullet+}$ and superoxide anion radicals as shown by the small differences of the EC_{50} values.

Both the infusions and decoctions as well as essential oils showed the DPPH, ABTS and superoxide radical scavenging activities in a dose-dependent manner. From the EC_{50} values (the effective concentration at which the DPPH, ABTS and superoxide anion radicals were scavenged by 50%), it was seen that among the infusions 60 kg ha^{-1} AN showed the highest DPPH, ABTS and superoxide radical scavenging activity as shown by the lowest value of 2.27 ± 0.10, 2.63 ± 0.11 and 2.42 ± 0.11 mg mL^{-1}, respectively.

Among the decoctions 120 kg ha^{-1}, AN showed the highest DPPH, ABTS and superoxide radical scavenging activities as shown by the lowest values of 2.39 ± 0.12, 2.72 ± 0.11 and 2.49 ± 0.10 mg mL^{-1}, respectively. These findings are in agreement with our observation on phenolic contents of the 60 kg ha^{-1} AN infusion and 12 kg ha^{-1} AN decoction and seem to suggest phenolics to be important contributors to their antioxidant activity.

Among the essential oils the best DPPH, ABTS and superoxide anion radical scavenging activity were shown by 7.5 t ha^{-1} FYM, and 10 t ha^{-1} FYM. The EC_{50} values of 60 kg ha^{-1} AN infusion, 120 kg ha^{-1} AN decoction as well as 7.5 t ha^{-1} FYM and 10 t ha^{-1} FYM essential oils were significantly lower compared to that of control ($p < 0.05$). These results suggested that the above-mentioned samples possess the strongest free radical scavenging activity. However, when compared to reference antioxidant, gallic acid, all the tested samples showed significantly ($p < 0.05$) lower radical scavenging activities.

The ABTS radical scavenging activity, measured at 6 min of incubation with ABTS radical cation was also expressed as the TEAC value. The TEAC reflects the ability of electron-donating antioxidants to scavenge the $ABTS^{\bullet+}$ radical cation compared to that of Trolox. The TEAC value is a quantification of the effective antioxidant activity of the extracts. Table 3 presents the results of antioxidant activities of the samples, expressed as TEAC and FRAP values. At 10 mg mL^{-1}, 60 kg ha^{-1} AN and 7.5 t ha^{-1} FYM infusions, and 120 kg ha^{-1} AN decoction as well as at 10 mg mL^{-1} 7.5 t ha^{-1} FYM and 10 t ha^{-1} FYM essential oils showed high antioxidant potential with high TEAC value of 2.0 mM Trolox, which corresponded to a high phenolic content of these samples. The TEAC value of the mentioned samples at 10 mg mL^{-1} was comparable to that of gallic acid (2.051 ± 0.004) at 0.8 mg mL^{-1} (Table 3).

In addition to their scavenging properties, infusion and decoction samples also showed high ferric reducing ability. In this assay, the antioxidant activity was determined on the basis of the ability of the samples to reduce ferric (III) iron to ferrous (II) iron. The results were expressed as mM ferrous ion equivalents. The higher FRAP value would imply greater antioxidant activity of the sample. At a concentration of 10 mg mL^{-1}, 60 kg ha^{-1} AN infusion, 7.5 t ha^{-1} FYM infusion, 60 kg ha^{-1} AN decoction and 120 kg ha^{-1} AN decoction had the reducing powers similar to that of gallic acid at 0.8 mg mL^{-1} (Table 5). This data re-inforced the greater antioxidant activity of the 60 kg ha^{-1} AN infusion and 120 kg ha^{-1} AN decoction in the DPPH, ABTS and superoxide anion radical scavenging assays compared to other samples. With regard to the FRAP values, the essential oils were considerably less effective ($p < 0.05$) reductions compared to the infusions and decoctions. At a concentration of mg 10 μl^{-1}, the most effective reductions were 7.5 t ha^{-1} FYM and 10 t ha^{-1} FYM essential oils. This indicated that the highest antioxidant activity might be attributed to the combined effects of reducing power, scavenging of radicals and donation of electrons. These results were in very good agreement with that of different extracts of dill, indicating comparable or higher antioxidant activity [41, 47, 48, 51–54].

On the other hand, Albayrak et al. [47] evaluated the antioxidant activities of 19 dill extracts and reported the highest antioxidant potential for methanol extract, followed by infusion, while decoction was found to be the least effective antioxidant. Similarly, Shyu et al.

Table 4 Antioxidant activities as DPPH, ABTS, SOD, TEAC and FRAP of *A. graveolens* infusion, decoction and essential oil (%)

Treatments	DPPH			ABTS			SOD			TEAC (mM) 10 mg mL^{-1}		TEAC (mM)	FRAP (mM) 10 mg mL^{-1}		FRAP (mM)
	Infusion EC_{50} (10 mg mL^{-1})	Decoction EC_{50} (10 mg mL^{-1})	Essential oil EC_{50} (mg 10 μl^{-1})	Infusion EC_{50} (10 mg mL^{-1})	Decoction EC_{50} (10 mg mL^{-1})	Essential oil EC_{50} (mg 10 μl^{-1})	Infusion EC_{50} (10 mg mL^{-1})	Decoction EC_{50} (10 mg mL^{-1})	Essential oil EC_{50} (mg 10 μl^{-1})	Infusion	Decoction	Essential oil	Infusion	Decoction	Essential oil
Control	3.70 ± 0.14^{e}	3.31 ± 0.20^{f}	4.13 ± 0.08^{d}	3.91 ± 0.05^{e}	3.76 ± 0.21^{e}	2.14 ± 0.04^{f}	3.59 ± 0.17^{de}	3.41 ± 0.22^{d}	3.89 ± 0.02^{c}	1.88 ± 0.03^{b}	1.93 ± 0.02^{c}	2.04 ± 0.01^{a}	2.08 ± 0.01^{a}	1.84 ± 0.03^{c}	0.28 ± 0.01^{ef}
30 kg ha^{-1} AN	4.82 ± 0.18^{b}c	3.79 ± 0.16^{e}	4.61 ± 0.13^{c}	4.75 ± 0.15^{d}	4.28 ± 0.21^{d}	2.34 ± 0.23^{e}	4.34 ± 0.15^{b}	3.84 ± 0.04^{b}	4.50 ± 0.03^{c}	1.83 ± 0.05^{c}	1.85 ± 0.02^{e}	1.86 ± 0.06^{c}	1.73 ± 0.02^{d}	1.51 ± 0.01^{ef}	0.89 ± 0.01^{d}
60 kg ha^{-1} AN	2.27 ± 0.10^{f}	3.30 ± 0.19^{f}	5.10 ± 0.09^{b}	2.63 ± 0.11^{g}	3.36 ± 0.03^{f}	3.68 ± 0.07^{c}	2.42 ± 0.11^{f}	3.76 ± 0.09^{bc}	3.82 ± 0.06^{d}	2.01 ± 0.03^{a}	1.97 ± 0.04^{b}	1.78 ± 0.01^{d}	1.98 ± 0.01^{b}	2.16 ± 0.02^{a}	0.26 ± 0.00^{ef}
90 kg ha^{-1} AN	6.30 ± 0.29^{a}	4.58 ± 0.14^{c}	5.86 ± 0.05^{a}	6.36 ± 0.07^{a}	4.61 ± 0.27^{bc}	5.41 ± 0.31^{a}	5.20 ± 0.15^{a}	4.35 ± 0.20^{a}	5.25 ± 0.09^{a}	1.39 ± 0.03^{f}	1.82 ± 0.03^{e}	1.51 ± 0.01^{f}	$1.30 \pm 0.02ı$	1.54 ± 0.03^{e}	0.26 ± 0.01^{ef}
120 kg ha^{-1} AN	3.75 ± 0.12^{e}	2.39 ± 0.12^{g}	3.79 ± 0.02^{e}	3.61 ± 0.08^{f}	2.72 ± 0.11^{g}	4.24 ± 0.09^{b}	3.62 ± 0.17^{de}	2.49 ± 0.10^{e}	3.90 ± 0.13^{d}	1.73 ± 0.06^{d}	2.06 ± 0.01^{a}	1.70 ± 0.02^{e}	1.69 ± 0.01^{e}	2.16 ± 0.02^{a}	0.25 ± 0.01^{f}
7.5 t ha^{-1} FYM	3.86 ± 0.15^{d}e	4.36 ± 0.04^{d}	2.69 ± 0.05^{f}	3.87 ± 0.13^{e}	4.39 ± 0.20^{cd}	2.93 ± 0.14^{d}	3.48 ± 0.37^{e}	3.80 ± 0.05^{bc}	2.31 ± 0.09^{e}	2.04 ± 0.02^{a}	1.81 ± 0.01^{e}	1.92 ± 0.01^{b}	1.95 ± 0.03^{c}	1.54 ± 0.01^{e}	1.37 ± 0.01^{c}
10 t ha^{-1} FYM	4.03 ± 0.16^{d}	4.23 ± 0.04^{d}	1.73 ± 0.18^{g}	5.72 ± 0.10^{b}	4.22 ± 0.17^{d}	1.47 ± 0.05^{g}	4.34 ± 0.30^{b}	3.66 ± 0.13^{c}	1.78 ± 0.05^{f}	1.56 ± 0.02^{e}	1.84 ± 0.02^{e}	2.07 ± 0.02^{a}	1.52 ± 0.01^{g}	1.76 ± 0.02^{d}	1.59 ± 0.08^{b}
12.5 t ha^{-1} FYM	4.63 ± 0.07^{c}	5.36 ± 0.07^{a}	3.94 ± 0.16^{e}	4.97 ± 0.02^{c}	5.20 ± 0.04^{a}	2.29 ± 0.01^{ef}	3.90 ± 0.05^{c}	3.34 ± 0.07^{d}	4.45 ± 0.07^{c}	1.76 ± 0.03^{d}	1.63 ± 0.05^{f}	1.75 ± 0.01^{d}	1.56 ± 0.03^{f}	1.36 ± 0.02^{g}	0.28 ± 0.01^{e}
15 t ha^{-1} FYM	4.93 ± 0.19^{b}	4.86 ± 0.20^{b}	4.74 ± 0.04^{c}	4.97 ± 0.25^{c}	4.78 ± 0.02^{b}	$2.20e \pm 0.05^{f}$	3.77 ± 0.07^{cd}	4.35 ± 0.04^{a}	4.80 ± 0.07^{b}	1.77 ± 0.05^{d}	1.89 ± 0.04^{d}	1.67 ± 0.01^{e}	1.51 ± 0.00^{h}	1.50 ± 0.01^{f}	0.24 ± 0.01^{f}
Gallic acid	0.02 ± 0.00^{g}	0.02 ± 0.00^{h}	0.02 ± 0.00^{h}	0.029 ± 0.00^{h}	0.029 ± 0.00^{h}	0.029 ± 0.00^{h}	0.028 ± 0.01^{g}	0.028 ± 0.01^{f}	0.028 ± 0.01^{g}	2.051 ± 0.00^{a}	2.051 ± 0.00^{a}	2.051 ± 0.00^{a}	2.078 ± 0.02^{a}	2.078 ± 0.02^{b}	2.078 ± 0.02^{a}

AN Ammonium nitrate, *FYM* Farmyard Manure, *DPPH* 1,1-Diphenyl-2-picrylhydrazyl radical, *ABTS* 2,2′-azino-bis-3-ethylbenzthiazoline-6-sulphonic acid, *SOD* Superoxide radical scavenging activity, *TEAC* Trolox equivalent antioxidant capacity, *FRAP* Ferric reducing antioxidant power

Values were the means of three replicates. Values with different letters in the same column were significantly ($p < 0.05$) different

EC_{50} value: The effective concentration at which the antioxidant activity was 50%; DPPH, ABTS and SOD were scavenged by 50%; Expressed as mM ferrous ions eqivalents. Determined at 10 mg ml^{-1}

Table 5 DPPH·, ABTS·+ and SOD percentages, TEAC and FRAP values depending on the gallic acid concentrations

Gallic acid (mg mL^{-1})	DPPH· (%)	ABTS·+ (%)	SOD (%)	TEAC (mM l^{-1})	FRAP (mM l^{-1})
0.16	98.90 ± 0.74^{a}	97.50 ± 0.95^{a}	94.19 ± 0.69^{a}	2.05 ± 0.00^{a}	3.48 ± 0.02^{a}
0.08	98.90 ± 0.074^{a}	97.50 ± 0.95^{a}	61.50 ± 0.60^{b}	2.05 ± 0.00^{a}	2.20 ± 0.02^{b}
0.04	90.44 ± 0.88^{b}	71.82 ± 4.12^{b}	43.38 ± 0.76^{c}	1.50 ± 0.05^{b}	1.18 ± 0.01^{c}
0.02	51.96 ± 0.99^{c}	47.69 ± 3.08^{c}	34.87 ± 1.74^{d}	1.02 ± 0.06^{c}	0.78 ± 0.02^{d}
0.01	22.41 ± 0.36^{d}	28.72 ± 3.39^{d}	27.30 ± 0.60^{e}	0.61 ± 0.07^{d}	0.51 ± 0.01^{e}

Values were the means of three replicates

Values with different letters in the same column were significantly ($p < 0.05$) different

[53] prepared n-hexane, ethyl acetate and ethanol soluble fractions from ethanolic extract of dill flower, and determined that the highest antioxidant activity was found in ethyl acetate fraction, and followed by ethanol fraction, original flower extract and n-hexane fraction, respectively. Variability of antioxidant activity between these finding and previous studies can be explained by extraction conditions and methods, different genotypes, soil ecology and secondary metabolite pathways of the plants, organic and chemical fertilizer [37, 38, 55].

Antimicrobial activity

Table 6 presents the results obtained from the evaluation of the antimicrobial activity of herb and seed essential oils in the infusion and decoction extracts prepared from dill. The results showed that all herb and seed essential oils were active against all the tested microbial species, including *Staphylococcus aureus* ATCC 29213; *Staphylococcus epidermidis* ATCC 12228, *Enterococcus faecalis* ATCC 29212, methicillin-resistant MRSA ATCC 43300, *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae* ATCC 4352, *Pseudomonas aeruginosa* ATCC 27853,

Table 6 Antimicrobial activities of *A. graveolens* herb and seed essential oils (%)

	Treatments	Gram-negative				Gram-positive			Fungi
		S.a	*S.e*	*MRSA*	*E.f*	*E.c*	*K.p*	*P.a**	*C.a*
Herb of dill	Control	12.50 ± 0.20^{a}	12.50 ± 0.20^{b}	6.25 ± 0.30^{b}	12.50 ± 0.36^{c}	6.25 ± 0.12^{c}	6.25 ± 0.33^{b}	12.50 ± 0.36	0.80 ± 0.03^{c}
	30 kg ha^{-1} AN	6.25 ± 0.20^{b}	25.00 ± 0.16^{a}	6.25 ± 0.26^{b}	50.00 ± 0.42^{a}	12.50 ± 0.23^{b}	12.50 ± 0.26^{a}	12.50 ± 0.22	0.40 ± 0.01^{d}
	60 kg ha^{-1} AN	6.25 ± 0.20^{b}	3.13 ± 0.09^{d}	6.25 ± 0.22^{b}	12.50 ± 0.36^{c}	3.13 ± 0.08^{d}	3.13 ± 0.23^{c}	12.50 ± 0.45	0.80 ± 0.03^{c}
	90 kg ha^{-1} AN	6.25 ± 0.30^{b}	25.00 ± 0.23^{a}	6.25 ± 0.22^{b}	50.00 ± 0.50^{a}	12.50 ± 0.23^{b}	12.50 ± 0.26^{a}	12.50 ± 0.36	0.80 ± 0.05^{c}
	120 kg ha^{-1} AN	6.25 ± 0.30^{b}	6.25 ± 0.21^{c}	1.60 ± 0.08^{c}	12.50 ± 0.22^{c}	6.25 ± 0.26^{c}	3.13 ± 0.23^{c}	12.50 ± 0.36	0.80 ± 0.05^{c}
	7.5 t ha^{-1} FYM	3.13 ± 0.18^{c}	6.25 ± 0.24^{c}	1.60 ± 0.08^{c}	6.25 ± 0.16^{d}	6.25 ± 0.26^{c}	6.25 ± 0.26^{b}	12.50 ± 0.48	1.60 ± 0.02^{b}
	10 t ha^{-1} FYM	12.50 ± 0.20^{a}	25.00 ± 0.26^{a}	25.00 ± 0.13^{a}	25.00 ± 0.32^{b}	25.00 ± 0.63^{a}	12.50 ± 0.23^{a}	25.00 ± 0.50	6.25 ± 0.10^{a}
	12.5 t ha^{-1} FYM	1.60 ± 0.16^{d}	6.25 ± 0.22^{c}	6.25 ± 0.11^{b}	12.50 ± 0.23^{c}	12.50 ± 0.22^{b}	6.25 ± 0.33^{b}	6.25 ± 0.26	0.80 ± 0.02^{c}
	15 t ha^{-1} FYM	3.13 ± 0.18^{c}	3.13 ± 0.22^{d}	6.25 ± 0.15^{b}	12.50 ± 0.25^{c}	6.25 ± 120^{c}	6.25 ± 0.32^{b}	6.25 ± 0.26	0.80 ± 0.02^{c}
Seed of dill	Control	25.00 ± 0.50^{a}	25.00 ± 0.12*	3.13 ± 0.08^{d}	25.00 ± 0.12*	12.50 ± 0.52^{b}	0.80 ± 0.08^{b}	25.00 ± 0.22^{a}	0.10 ± 0.01^{b}
	30 kg ha^{-1} AN	12.50 ± 0.23^{b}	25.00 ± 0.13	6.25 ± 0.12^{c}	25.00 ± 0.11	25.00 ± 0.86^{a}	0.80 ± 0.02^{b}	25.00 ± 0.33^{a}	0.10 ± 0.01^{b}
	60 kg ha^{-1} AN	25.00 ± 0.42^{a}	25.00 ± 0.13	12.5 ± 0.22^{b}	25.00 ± 0.12	12.50 ± 0.23^{b}	0.80 ± 0.01^{b}	25.00 ± 0.24^{a}	0.10 ± 0.01^{b}
	90 kg ha^{-1} AN	12.50 ± 0.46^{b}	25.00 ± 0.15	0.80 ± 0.00^{e}	25.00 ± 0.06	25.00 ± 0.62^{a}	0.80 ± 0.01^{b}	25.00 ± 0.24^{a}	0.10 ± 0.01^{b}
	120 kg ha^{-1} AN	12.50 ± 0.12^{b}	25.00 ± 0.16	6.25 ± 0.18^{c}	25.00 ± 0.06	25.00 ± 0.32^{a}	0.40 ± 0.01^{c}	12.50 ± 0.08^{b}	0.05 ± 0.00^{c}
	7.5 t ha^{-1} FYM	12.50 ± 0.22^{b}	25.00 ± 0.18	25.00 ± 0.36^{a}	25.00 ± 0.06	6.25 ± 0.08^{c}	0.80 ± 0.02^{b}	25.00 ± 0.12^{a}	0.10 ± 0.01^{b}
	10 t ha^{-1} FYM	25.00 ± 0.48^{a}	25.00 ± 0.14	3.13 ± 0.12^{d}	25.00 ± 0.12	25.00 ± 0.23^{a}	12.50 ± 0.13^{a}	25.00 ± 0.18^{a}	0.20 ± 0.02^{a}
	12.5 t ha^{-1} FYM	25.00 ± 0.52^{a}	25.00 ± 0.16	3.13 ± 0.08^{d}	25.00 ± 0.16	12.50 ± 0.08^{b}	0.80 ± 0.03^{b}	25.00 ± 0.22^{a}	0.10 ± 0.01^{b}
	15 t ha^{-1} FYM	12.50 ± 0.50^{b}	25.00 ± 0.16	3.13 ± 0.16^{d}	25.00 ± 0.15	12.50 ± 0.11^{b}	0.80 ± 0.03^{b}	25.00 ± 0.31^{a}	0.05 ± 0.00^{c}

S.a: S. aureus ATCC 29213; *S.e: S. epidermidis* ATCC 12228; *MRSA* Methicillin-Resistant *Staphylococcus aureus* ATCC 43300; *E.f: E. faecalis* 29212; E.c: *E. coli* ATCC 25922; *K.p: K. pneumoniae* ATCC 4352; *P.a: P. aeruginosa* ATCC 27853; *C.a: C. albicans* ATCC 10231

*There was not any statistical differences at $p < 0.05$ level

Values were the means of three replicates

Values with different letters in the same column were significantly ($p < 0.05$) different

Antimicrobial activities of dill herb and seed essential oils were evaluated separately

Candida albicans ATCC 10231. Moreover, the FYM application at different doses increased the antimicrobial activity compared to the control treatment.

The highest antibacterial activity against all tested microbial species was observed with the 10 t ha^{-1} FYM application (Table 6). The antimicrobial activity of dill grown with FYM was higher compared to the use of AN fertilizer. This high antimicrobial activity of FYM in our study can be attributed to soils fertilized with animal manure containing more potassium and other macro and trace elements [56]. When all the infusion and decoction extracts were evaluated together, the dill decoction extracts showed no activity against any of the tested microbial species, and the dill infusion extracts exhibited activity only against *E. coli* (625 µg ml^{-1} mic) with the 12.5 t ha^{-1} FYM application.

When all the herb essential oil extracts were evaluated together, they showed varying levels of antimicrobial activity against the tested microbial species, but the highest antimicrobial activity was observed against *E. faecalis* (50%) in the applications of 30 and 60 kg ha^{-1} AN (Table 6). The herb essential oils also exhibited stronger antifungal activity against *P. aeruginosa* when compared with the other microbial species tested. According to the results of the herb essential oils, among all the doses of FYM, the highest antibacterial activity against almost all the tested microbial species was observed with 10 t ha^{-1} (Table 6).

According to the results of the herb and seed essential oils, the latter showed higher antibacterial activity against all the tested microbial species than the former. Furthermore, the seed essential oils exhibited strong antifungal activity against *S. epidermidis*, *E. faecalis,* and *P. aeruginosa.* The rate of inhibition was greater on gram-negative bacteria (*P. aeruginosa*) than that observed on gram-positive bacterium (*S. epidermidis*, *E. faecalis*). The variation between the antibacterial activity of essential oils against Gram-negative and Gram-positive bacteria depends on several factors, such as tested bacterial strains and different concentrations, as well as the main constituents of essential oils [57–59]. These results suggest that the relation between EO component and antibacterial activity may be due to their major constituents, such as dill apiole and anethole, which have aromatic nucleus containing polar functional group [60]. Moreover, our findings strengthen the consistency of the high MIC value found for dill seed oil, which is likely due to the presence of dill apiole and carvantonacetone components.

Based on the results of some previous studies, Sharopov et al. [46] screened dill herb oil against *Bacillus cereus*, *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli* bacteria and *Aspergillus niger* fungi, but reported that the essential oil showed marginal antimicrobial activity only against *Escherichia coli* (MIC = 625 µg mL^{-1}). Similarly, Arora and Kaur [61] reported that the aqueous extracts of dill showed broad-spectrum antibacterial activity against *Staphylococcus aureus, Escherichia coli, Pseudomonas aeruginosa, Salmonella typhimurium*, *Shigella flexneri* and *Salmonella typhi*. However, dill seed oil showed activity at MIC (0.47, 0.37 and 0.17%) for *E. coli* (ATCC 43895), *S. aureus* (ATCC 25923) and *Saccharomyces cerevisiae*, respectively, whereas no activity was observed against *S. typhimurium, P. fragi* DC7 and *L. monocytogenes* (LCDC 81-861) [62]. The extracts of dill leaf and seed were studied for antimicrobial activity with the agar well diffusion technique against *S. aureus, E. coli* and *C. albicans*. The leaf extracts showed no antibacterial activity, whereas the extract of dill seed exhibited the inhibition of *C. albicans* growth (19 mm. inhibition zone) [63].

The results of the current study related to antibacterial activities of dill are in agreement with those of Sharopov et al. [46], Arora and Kaur [61] and Rasheed et al. [63], but different antibacterial activities were reported by Delaquis et al. [62]. With regard to different environmental and genetic factors, the changes in antibacterial activity of dill essential oils may be related to the different chemical compositions of these oils and the use of FYM.

Conclusion

The findings of this study suggest that the FYM application has promising effects on dill, and this is in agreement with scarce research available in the literature concerning the effect of organic fertilizers on medicinal plants. According to our results, it can be concluded that the application of different doses of FYM is not only suitable for the essential content and components but it is also a way for increasing the antioxidant activity and antimicrobial activities of dill. The results also showed that the application of 15 t ha^{-1} FYM had a better effect on the dill essential oil content. Furthermore, 60 kg ha^{-1} AN infusion and 120 kg ha^{-1} AN decoction, as well as 7.5 t ha^{-1} FYM and 10 t ha^{-1} FYM essential oils were the most effective hydrogen and electron donors, containing the highest amounts of phenolic compounds; thus, dill herb can be considered as the best antioxidant.

In all FYM and AN fertilizer applications, DPPH methods showed the highest antioxidant activity among the all the studied methods. In general, there was a relatively consistent and positive correlation between the essential oils extracted from dill herb and seed in terms of antimicrobial features; however, the later showed particularly higher antimicrobial activity. Thus, this study confirms the bioactive potential of dill, and in addition to its use as food condiment and in pharmaceutical industries, the

aqueous extracts of this plant can be utilized for antimicrobial and antioxidant purposes.

Abbreviations
FYM: Farmyard manure; AN: Ammonium nitrate; DAP: Diammonium phosphate; t ha^{-1}: Ton $hectar^{-1}$; kg ha^{-1}: Kilogram $hectar^{-1}$; d: Day; GC–MS/FID: Gas Chromatography-Mass spectrometry/Flame ionization detection; DPPH: 1,1-Diphenyl-2-picrylhydrazyl; TRAP: Total radical antioxidant potential assay; TEAC: Trolox equivalent antioxidant coefficient; FRAP: Ferric reducing antioxidant power assay.

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Declarations

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Competing interests
The author declares that they have no competing interests**.**

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