J. Sus. Agric. Sci. **Vol. 50,** No. 2, pp: 13 - 23 (2024)

Journal of Sustainable Agricultural Science

http://jsas.journals.ekb.eg/

Effect of Essential Oils on Strawberry Growth and Fruit Quality

Awad Y. Shala[1*], Rania Shawkey Abd El Hameed[2] and **Tahany Shaban Abd-ELbary [3]**

[1] *Medicinal and Aromatic Plants Research Department, Horticulture Research Institute, Agricultural Research Center, Giza 12619, Egypt*
[2] *Vegetables production Under Modified Environment Research Department, Horticulture Research Institute, Agricultural Research Center, Giza 12619, Egypt*
[3] *Potato and Vegetatively Propagated Vegetables Department, Horticulture Research Institute, Agricultural Research Center, Giza 12619, Egypt.*

ESSENTIAL oils have been considered as an efficient approach and environmentally safe as natural plant stimulants therefore, the current research evaluated the effect of foliar spray of essential oils of French lavender and citronella grass and their mixture (0, 2.5, 5 and 7.5 mL^{-1}) on strawberry plants under greenhouse conditions during the two consecutive seasons of 2022 and 2023. Chromatographic analysis of essential oil constituents identified 1,8-cineole (43.95%) and linalool (26.27%) were dominant in lavender essential oil while citronellal (27.64%) and geraniol (24.51%) were the most abundant compounds in citronella grass essential oil. Foliar application of essential oils significantly increased plant height, number of leaves, leaf area, fruit length, fruit diameter, fruit firmness, early yield, total yield and fruit quality, the highest content of phenolics, anthocyanins, ascorbic acid and total soluble solids especially after application of French lavender essential oil at high concentration as compared to the control. This study suggests the application of French lavender essential oil at 7.5 ml/l as a promising eco-friendly approach to improve strawberry plant growth and productivity towards a better fruit quality.

Keywords: Essential oils; strawberry; French lavender; citronella grass; anthocyanins; ascorbic acid

1. Introduction

Strawberry (*Fragaria x ananassa* Duch), a member of the Rosaceae family, is considered as one of the most significant vegetable crops grown in Egypt for fresh local consumption and export, particularly during the period from December to April due to its high anthocyanin content and other nutritional properties. Plants are grown in the open field or under controlled conditions. Strawberries are unique with highly desirable taste, flavor and excellent nutritional sources of potassium, ascorbic acid, simple sugar sources of energy and fiber (Pérez *et al*., 1997). Strawberries are in high demand due to their richness in anthocyanins, minerals, vitamins, organic acids, sugars flavonoids, and phenolic compounds which play an important role in human nutrition and health (Wang *et al*., 2007 and Parra-Palma *et al*., 2020).

There is an increasing interest for the use of natural alternatives of plant products to improve the plant quality one of these natural products are essential oils which has a great economic values especially in perfumery, food and pharmaceutical sectors that earlier used by various researchers in addition to the application of essential oils mostly required due to the essential oils less costly, safe and ecofriendly compounds as well as will not leave a toxic residue in plant products (El-Mougy, 2009).

Plant essential oils are secondary metabolites of plants, that can be extracted from various plant parts (*e.g*., leaves, flowers, stems, buds, roots, fruits or seeds). They possess versatile biologically active

*Corresponding author e-mail: awad.shala@yahoo.com (A.Y.S.)
Received: 10/05/2024; Accepted: 08/07/2024
DOI: 10.21608/JSAS.2024.282598.1459

constituents that are extensively used in various sectors such as cosmetics, pharmacology, food production and agriculture (pesticides and plant biostimulants (Souri and Bakhtiarizade, 2019; Górska-Drabik *et al*., 2024), antimicrobial agents (Ben-jabeur et al., 2015; Kumar *et al*., 2021; Hashem *et al*., 2023), root system enhancement in vitro (Chaouch *et al*., 2023), shelf life extension (Wang *et al*., 2007) and have been effectively applied in the stimulating of plant growth and biomass production (Pane *et al*., 2013; Souri and Bakhtiarizade, 2019; Mostafa *et al*., 2021 and Hashem *et al*., 2023).The promising results of essential oils as an environmentally friendly method for plant growth stimulation will encourage the farmers to use it as a promising plant growth enhancer.

In recent years, there has been an increasing consumer demand for safe agricultural products as well as an increasing awareness of chemical inputs, therefore the search for new strategies for sustainable crop production with elevated quality is very important (Seliem *et al*., 2020 and Gad El-Kareem *et al*., 2022). For this scope, foliar application of essential oils is proposed as a potential plant enhancer in the strawberry production to improve yield and quality as well as to reduce farmers' financial burden. One of these essential oil-containing plants is French lavender (*Lavandula dentata* L.), is a flowering plant, widely cultivated around the world, native to the Mediterranean region and belonging to the Lamiaceae family (Lis-Balchin, 2012). The highly aromatic odor of the plant is attributed to the essential oil present in glands that cover a large part of the plant surface. *L. dentata* has displayed a wide range of biological activities on plants (Barkaoui *et al*., 2022 and El Abdali *et al*., 2022). In addition, *Cymbopogon nardus* (L.) Rendle (citronella grass), an aromatic grass of the Poaceae family, originally native to southern India and Sri Lanka, it is now cultivated in many parts of the world and widely utilized in the production of citronella essential oil (Chan *et al*., 2005; Wei and Wee, 2013). Its oil has broad spectrum of biological activities such as antibacterial, antifungal and repellent activities (Wei and Wee, 2013; Dela Cueva and Balendres, 2018 and Loko *et al*., 2021).

Although essential oils have been used to control the causal agent of strawberry fruit rot under greenhouse conditions (Hosseini *et al*., 2020) and to promote strawberry root system in vitro (Chaouch *et al*., 2023) but its application for enhancing vegetative growth and yield as well as fruit quality of strawberry plants under greenhouse or open field has not been studied. Therefore, the authors hypothesized that the foliar application of essential oils to strawberry during the vegetative growth period would additionally enhance plant characteristics and anthocyanins, phenolic content and vitamins in plant tissues, which are responsible, for a wide range of biological potentials among others. Therefore, the aim of the present study is to evaluate the effectiveness of different concentrations of essential oils of French lavender and citronella grass, individually or in a mixture on the morphological and physiological characteristics of strawberry plants as well as fruit chemical constituents under greenhouse conditions to increase productivity, produce healthier strawberry fruits and enhance farmers income.

Materials and methods

A greenhouse experiment was performed at the experimental private farm in Beila District, Kafr El-Sheikh governorate, Egypt, during the growing seasons of 2022 and 2023 to evaluate the effect of foliar application of essential oils of French lavender and citronella grass as well as their mixture under greenhouse conditions. The experimental design was a randomized complete block design with 10 plots each consisting of 4 rows 120cm wide with plant spacing 25 cm, with 3 replicates for each treatment. Soil was covered with black plastic mulch before transplanting. Seedlings of Festival cultivar were obtained from Tabarak station, Ismailia governorate, Egypt. Seedlings were transplanted in the greenhouse on September 25 for the first season and on October 16 for the second season. The greenhouse soil was clay texture (64.31 % clay, 31.61% silt and 4.08% sand) with electrical conductivity (EC 0.98 dSm^{-1}) and pH (7.88) determined in the saturated soil paste as an average of 0- 30 cm depth according to Page *et al*. (1982). The missing plants were replaced by another seedling one week after transplanting. All agricultural practices; cultivation, irrigation, pest and disease control... etc., were carried out when it was necessary according to the recommendations of the Egyptian Ministry of Agriculture and Land Reclamation.

Essential oil extraction and its application

Fresh herbs of French lavender and citronella grass were air dried and subjected to hydrodistillation by Clevenger apparatus for 3.00 hours according to

(Pharmacopoeia, 1963). After extraction the essential oils were dried in anhydrous sodium sulfate and then stored in dark glass bottles in a refrigerator at 4℃ until Chromatographic analysis. The chemical analysis of the essential oil components was performed using the same procedure as formerly described by El-Shoraky and Shala (2018) and ELsayed *et al*. (2023). Essential oils as well as their mixture were used as foliar spray (at 4-5 true leaf stage) at the rate of (2.5, 5 and 7.5 ml/l) by dissolving the selected oils in sterilized distilled water with Tween 80 (0.1% of water volume) as emulsifier, and water as a control. All foliar spray treatments of essential oils treatments were started after one month from transplanting for each concentration then the following sprays were performed with 15 days interval by a portable sprayer in the early morning. Concentrations of essential oils greater than 7.5 ml/l have been tested in plants as an overdose assay.

Vegetative growth parameters including plant height (cm), number of leaves/plant and leaf area /plant (cm^2) were recorded at 60 days after transplanting from five randomly selected plants per plot.

Leaf area determination

Leaf area was evaluated via the fresh weight method according to Cho *et al*. (2007); the leaves were weighed after being cleaned from dust. Certain known discs were taken from the leaves with a cork punch, then the leaf area was determined according to the following formula:

leaf area (cm^2/plant) =

$$\frac{Leaves\ fresh\ weight \times\ disks\ leaf\ area}{Fresh\ weight\ of\ disks}$$

Fruit yield determination

Early and total yields as weight per square meter (kg) were calculated for a total of seven and nineteen harvests. The fruits were harvested at the harvesting stage（70% red stage of ripening）. Ten fruits from each plot were randomly taken of the fourth picking to study fruit yield characteristics measurements.

Fruit length and fruit diameter (mm) were measured by vernier caliper, whereas fruit firmness of strawberry fruit firmness was determined for each treatment by a texture analyzer using the FT011 Fruit Firmness Tester (Wagner Instruments, Greenwich, CT, USA). This instrument consists of penetrating cylinders (1 mm in diameter) that penetrate the pulp of fruit up to a constant distance of 5 mm at a speed of 2 mm/s. Finally, firmness was expressed as the maximum penetration force (N)

Fruit quality measurements

Two mid-term harvests of uniform and well-colored strawberries were used to measure the following quality parameters. Total soluble solids percentage (TSS%) was determined using a manual refractometer at 20 ◦C, and TSS results were expressed as Brix. Total acidity was determined by titration of pure strawberry fruit juice against NaOH 0.1 N and phenolphthalein until turning pink as an indicator according to the protocol presented in AOAC (2000). The acidity was expressed as the percentage of citric acid (%).

Total anthocyanin content in strawberry fruit extracts was determined by the pH difference method. Five grams of fresh berries were extracted with 25 ml of 80% acetone containing 0.2% formic acid. then the homogenate was centrifuged at 6,000 rpm at 4◦C for 15 min. The resulting supernatants were measured by using a spectrophotometer at 520 and 700 nm at two pH values and the final anthocyanin content was expressed as mg/100 g FW (Cheng and Breen, 1991). Ascorbic acid content was estimated by to the standard method presented in AOAC (2000) and its values were expressed as mg/100 g. Total phenolic content was determined using the modified Folin-Ciolcalteu reagent as formerly reported by Abeysinghe *et al*. (2007). Briefly, 0.5 ml of strawberry fruit extracts were mixed with 5 ml of Folin Ciolcalteu reagent (1:10). The mixture was neutralized by adding 4 ml of sodium bicarbonate. After incubation at room temperature for 5 min, the samples absorbance was read at 765 nm. Different concentrations of gallic acid were used for the standard curve and total phenolic content was expressed as mg gallic acid equivalents (GAE)/g F.W.

Antioxidant activity was evaluated by using 2,2-diphenyl-1-picryhydrazyl radical (DPPH) assay as described by Patras *et al*. (2009). For antioxidant efficacy measurement, 200 µL of crude strawberry fruit extracts were mixed with 500 µL of DPPH. After 30 min at 30◦C, samples absorbance was measured by spectrophotometer at 515 nm. The radical scavenging activity was reported as the percentage of DPPH inhibition.

Total amino acid concentrations in strawberry fruits were determined by the ninhydrin colorimetric method as illustrated by Liu *et al*. (2005). Glutamine was used as a standard.

Sugar composition (sucrose, fructose and glucose) in strawberry fruits was performed by HPLC procedure as previously described by Lo Scalzo *et al*. (2007) and the values of sucrose, fructose and glucose were expressed as mg/100g fresh weight.

Statistical analyses

The collected data were subjected to the analysis of variance (ANOVA). When the ANOVA was significant ($p \leq 0.05$), the means were separated by Duncan's multiple range test (Snedecor and Cochran, 1980).

Results and discussion

Chemical composition of essential oils

Gas chromatographic analysis of French lavender essential oil identified the presence of 19 different compounds of which 10 components of them account for (97.62%) of the essential oil composition, which were identified by the retention times measured from pure reference compounds and the major components were 1,8-cineole (43.95%), linalool (26.27%), terpine-4-ol (5.60%), camphene (3.57%) and α-pinene (3.44%). Our results were in conformity with the previous results of El Abdali *et al*. (2022) and Barkaoui *et al*. (2022).

Also, the chromatographic analysis of citronella grass essential oil as presented in our previous work (ELsayed *et al*., 2023) showed the existence of 14 different components of which 9 components of them accounted for (93.28%) of the essential oil composition. The citronella essential revealed the dominance of citronellal (27.64%), geraniol (24.51%), myrcene (20.77%), linalool (4.96%) and citronellol (4.70%), these results were consistent with the earlier studies reported by Wei and Wee, (2013) and Loko *et al*. (2021).

Vegetative growth characteristics

The results displayed that the foliar spray of essential oils significantly enhanced vegetative growth characteristics compared to the control when essential oils were applied either individually or in a mixture. The highest values of plant height, (14.17, 14.67, 14.17 and 14.17 cm) were resulted from plants sprayed with lavender essential oil at 5 and 7.5 ml/l without significant differences between them during both growing seasons while the greatest number of leaves (20.00,20.33, 21.00 and 19.33) were resulted from plants treated with lavender essential oil at 2.5 and 5 ml/l without significant differences between them during both growing seasons also the highest leaf area (59.01 and 50.75 cm^2/plant) was obtained from plants sprayed with lavender essential oil at 7.5 ml/l followed by plants sprayed with the mixture of both oils at 7.5 ml/l (56.15 and 50.25) without significant differences between them during both growing seasons as compared to the control which recorded the lowest values of the above-mentioned characters during the both cultivation seasons (Table 1).

Table 1. Effect of foliar application of essential oil on the morphology of strawberry plants under greenhouse conditions during two consecutive seasons of 2022 and 2023.

Treatments	Plant height (cm)		Number of leaves		Leaf area (cm^2/plant)	
	1st	2nd	1st	2nd	1st	2nd
T0	11.5b	10.17c	13.50c	12.83e	29.54e	32.86b
T1	14.17a	13.33ab	20.00a	20.33a	45.81bcd	41.14ab
T2	14.17a	14.17a	21.00a	19.33ab	50.75abc	46.19ab
T3	14.67a	14.17a	18.67ab	18.50abc	59.01a	50.75a
T4	13.50ab	11.83b	15.17bc	16.50bcd	34.68de	36.72ab
T5	13.00ab	11.83b	17.33abc	14.83de	46.76a-d	41.41ab
T6	12.50ab	13.50ab	20.17ab	16.33bcd	46.06a-d	42.46ab
T7	13.00ab	12.00b	16.83abc	15.67cde	39.97cde	42.83ab
T8	12.67ab	13.17ab	16.33abc	17.83abcd	49.14abc	43.19ab
T9	12.83ab	12.83ab	17.00abc	18.50abc	56.15ab	50.25a

Means followed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.

T0 = Control T1= Lavender essential oil at 2.5 ml/l T2=Lavender essential oil at 5 ml/l T3= Lavender essential oil at 7.5 ml/l
T4= Citronella essential oil at 2.5 ml/l T5= Citronella essential oil at 5 ml/l T6=Citronella essential oil at 7.5 ml/l
T7=Mixture of both oils at 2.5 ml/l T8=Mixture of both oils at 5 ml/l T9=Mixture of both oils at 7.5 ml/l

The exogenously applied essential oils individually or in a mixture effectively improved vegetative growth characteristics than the control. In this respect, the increase in leaf area in the essential oil treated plants compared to the control was due to the essential oil stimulating the production of runners, which in turn increased the number of leaves. In a similar report, Souri and Bakhtiarizade, (2019) found that the highest shoot fresh weight and root fresh weight of tomato seedlings resulted from foliar spraying of rosemary essential oil at1000 ppm than the control plants, on the other hand, plant height was lower at this concentration as compared to the control and the authors demonstrated that the essential oil of rosemary acts as a biostimulant. Also, Farouk *et al*. (2021) found that foliar spraying with jasmine essential oils at (2.5 ml/l) noticeably improved eggplant growth parameters (plant height, numbers of branches and leaves per plant, as well as area and relative leaf dry mass) as compared to control plants. In addition, Mostafa *et al*. (2021) on cucumber found that the highest increase in plant height, shoot fresh and dry weight was observed in plants treated with oil mixture (lemon + lemongrass + thyme + peppermint in equal proportions). Clove oil at 1ml increased seedling fresh weight and leaf length of globe artichoke seedlings during both cultivation seasons (Kamel *et al*., 2024).

The profound stimulating effects of essential oil application on plant growth characteristics may be due to high nutrient uptake, improvement of root growth and possible signaling influences that induced mild stress conditions or systemic resistance following rosemary essential oil application (Souri and Bakhtiarizade, 2019). Additionally, Mostafa *et al*.(2021) stated that the applied essential oils contain some plant growth promoters such as phenols as well as the induction of plant resistance against pathogens. Also, Hashem *et al*. (2023) stated that clove essential oil has stimulating compounds for plant growth as well as phenolic compounds that play protective role against unfavorable growth conditions also the oil induced plant resistance against biotic stress.

Fruit yield

Exogenous application of essential oils noticeably improved strawberry fruit yield and yield components compared to the control (Table 2). The greatest fruit length (47.27and 30.96 mm), fruit diameter (33.72 and 25.85 mm) and fruit firmness (245.00 and 225.00 N) were obtained from plants treated with lavender essential oil at 7.5 ml/l during both growing seasons relative to control plants (Table 2).

Strawberry yield was significantly enhanced in all used treatments and was significantly higher than the control (Table 2). The highest early strawberry fruit yield (2.07 and 1.91 kg/m^2) and total yield (7.97 and 7.63 kg/m^2) were detected in plants received lavender essential oil at 7.5 ml/l for both growing seasons respectively, followed by plants treated with the mixture of both essential oils at 7.5 ml/l, indicating the synergistic effect of the oil combination used. On the other hand, the lowest early yield (1.17 and 1.09 kg/m^2) and total yield (5.94 and 5.38 kg/m^2) were obtained from the control plants (Table 2).

Table 2. Effect of foliar application of essential oils on fruit yield and its components of strawberry plants during both growing seasons of 2022 and 2023.

Treatments	Fruit length (mm)		Fruit diameter (mm)		Fruit firmness (N)		Early yield(kg/m^2)		Total yield (kg/m^2)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T0	28.37c	17.33	20.91d	16.29d	141.67d	135.00d	1.17f	1.09f	5.94e	5.38e
T1	32.72bc	26.15bc	25.37bcd	19.27cd	159.17bcd	170.00bcd	1.55cd	1.52cde	6.57cd	6.48bcd
T2	38.39b	26.37bc	26.22a-d	27.82a	180.00bc	225.00a	1.78bc	1.83ab	7.58ab	7.22ab
T3	47.27a	30.96a	33.72a	25.85ab	245.00a	220.00a	2.07a	1.91a	7.97a	7.63a
T4	31.56bc	22.29d	23.38cd	19.75c	158.34cd	160.00bcd	1.23ef	1.30ef	6.31de	5.84de
T5	36.40bc	24.61cd	27.75a-d	20.60c	163.37bcd	150.00bcd	1.33def	1.39de	6.21de	6.17cde
T6	33.95bc	27.93b	30.39abc	19.15cd	183.33b	190.00ab	1.77bc	1.62bcd	6.97c	6.92abc
T7	30.00bc	24.46cd	28.77a-d	17.94cd	160.16bcd	158.26bcd	1.42de	1.47de	6.69cd	6.55bcd
T8	33.83bc	24.54cd	31.96ab	23.76b	162.71bcd	185.00abc	1.76bc	1.75abc	7.12bc	6.95abc
T9	37.52bc	30.18a	33.17ab	24.01b	163.34bcd	142.50cd	1.95ab	1.78ab	7.66a	7.44ab

Means followed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.

T0 = Control T1= Lavender essential oil at 2.5 ml/l T2=Lavender essential oil at 5 ml/l T3= Lavender essential oil at 7.5 ml/l

T4= Citronella essential oil at 2.5 ml/l T5= Citronella essential oil at 5 ml/l T6=Citronella essential oil at 7.5 ml/l

T7=Mixture of both oils at 2.5 ml/l T8=Mixture of both oils at 5 ml/l T9=Mixture of both oils at 7.5 ml/l

Strawberry yield and its components were increased by foliar application of essential oils which is compatible with the findings of El-Mougy (2009) who found that potato yield was increased by foliar spraying of thyme, caraway and carnation essential oils at 1% via enhancing plant health and Pane *et al.* (2013) found that tomato yield was significantly increased over the control in rosemary oil treated plots through biennial trials, on the other hand, thyme and oregano oil sprayed plots resulted in lower values of tomato yield. Moreover, Kumar *et al*. (2021) in a two-year experiment application of clove oil (2 ml/l) enhanced the number of fruits per plant as well as the total yield of pomegranate fruits and the increase in fruit yield was concomitant with enhancement of nitric oxide production as well as nitrate reductase activity and defense genes. Also, Farouk *et al*. (2021) observed that the application of jasmine essential oil improved fruit yield components and fruit yield/plant in treated eggplant as parallel with other treatments and the authors found that the increase in yield by natural essential oils may be ascribed to the motivational effect of these substances on the physio-biochemical pathways that reflect the enhancement of plant development and the subsequent energetic translocation of the photoassimilate to sink in plants as well as application of essential increased the macro-nutrients in plant tissues compared to untreated plants. Recently, Górska-Drabik *et al*. (2024) reported that foliar spraying of *Tanacetum vulgare* L. essential oil at 3% and 4.5% and *Satureja montana* L. essential oil at 1.5% increased fruit weight of *Aronia melanocarpa* (Michx.).

Fruit quality

The obtained results displayed that foliar application of essential oils markedly improved the quality of strawberry fruits (Fig. 1&2 Table 3). The highest total soluble solids concentration (8.00 and 8.03) was occurred in plants treated with lavender essential oil at 5 ml/l followed by plants treated with lavender essential oil at 7.5 ml/l without significant differences among them relative to the control. Also, lavender essential oil at 7.5 ml/l significantly decreased total acidity in strawberry fruits as scored (0.34 and 0.34 %) for both seasons respectively as compared with control which scored the highest acidity content (Fig. 2). These findings are compatible with the outcomes obtained by Farouk *et al*. (2021) who reported that the highest percentage of TSS in eggplant was increased after application of jasmine essential oil as compared to other treatments. While the application of jasmine essential oil decreased the total acidity of eggplant. Similarly, Abd El-Khalek *et al*. (2023) found positive effects of thyme essential oil on fruit quality. Spraying grape clusters with thyme essential oil at 0.2% before harvest increased the total soluble solids content in grape berries as compared to the control.

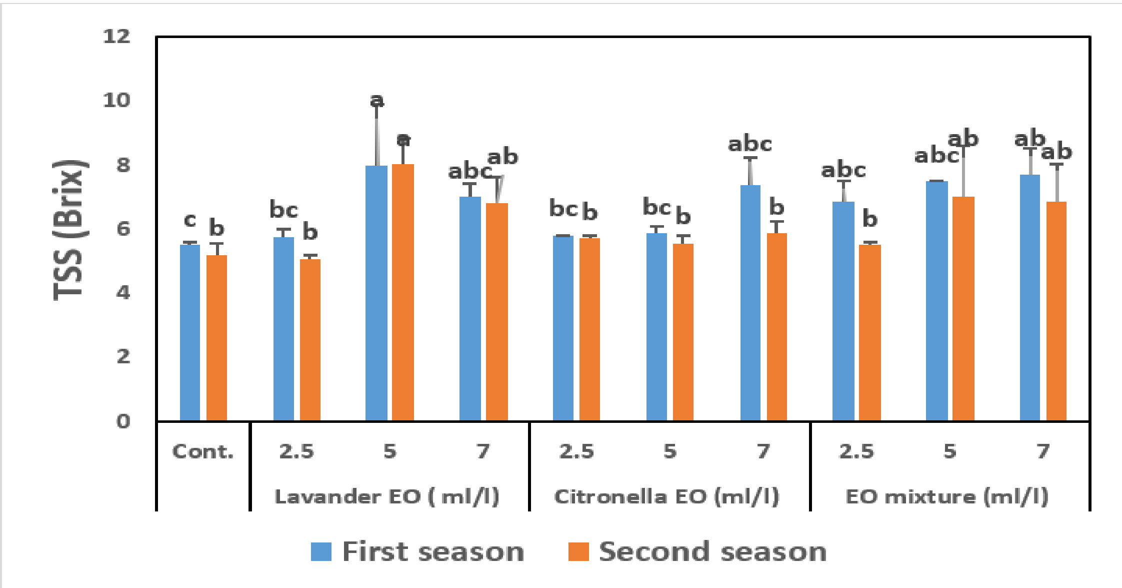

Fig. 1. Effect of foliar application of essential oils on total soluble solids concentration strawberry fruits during both growing seasons of 2022 and 2023.

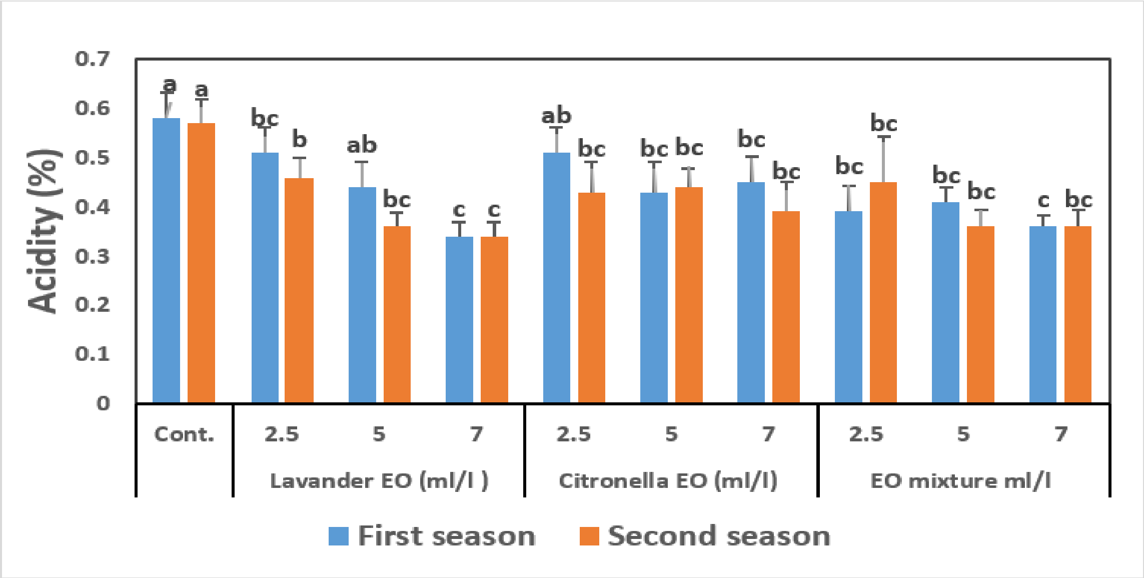

Fig. 2. Effect of foliar application of essential oils on total acidity percentage of strawberry fruits during both growing seasons of 2022 and 2023.

The application of both essential oils also increased the content of anthocyanins, ascorbic acid, and phenolics in strawberry fruits in both seasons (Table 3). The highest anthocyanin content (74.68 and 56.15 mg/100 g FW) was observed from plants sprayed with lavender essential oil at 5 ml/l while the greatest values of ascorbic acid (23.20 and 24.13 mg/ 100 g FW), and total phenolic content (10.3 and 9.37 mg/ g FW) were detected in strawberry fruits obtained from treated plants with lavender essential oil at 7.5 ml/l as compared to the control (Table 3). DPPH radical scavenging activity is considered a good indicator of antioxidant activity. Higher antioxidant activity is indicated by a lower IC_{50} (Shala *et al*., 2024). The highest DPPH radical scavenging activity (32.8 and 35.30 mg/ml), of strawberry fruits were observed after using lavender essential oil at 7.5 ml/l during both growth seasons. On the other hand, spraying plants with other concentrations of both essential oils or their mixture significantly reduced ascorbic acid, total anthocyanin, total phenolic content and DPPH radical scavenging activity, during both growing seasons (Table 3).

The present results and earlier reports showed that spraying of essential oils noticeably increased antioxidant compounds such as ascorbic acid, anthocyanin and phenolic contents which have a great role in the scavenging of free radical oxygen species and thus protecting the plant from its destructive effects. The total phenolic content was greater in plants sprayed with both essential oils than the control which may be due to the role of essential oil in the induction of phenylalanine ammonia lyase (PAL), which is one of the enzymes responsible for phenolic compounds biosynthesis and accumulation (Vermerris *et al*., 2006 and Bill *et al*., 2017). The stimulatory role of essential oils on ascorbic acid, total anthocyanin and total phenolic content are in accordance with previously published results by Farouk *et al*. (2021) who found that jasmine essential oil application resulted in the highest concentrations of phenolics and ascorbic acid percentage in eggplant compared to other treatments also the authors stated that essential oils have a bio-stimulatory effect on secondary metabolites assimilation. Similarly, Hashem *et al*. (2023) found that clove essential oil stimulated plant resistance by increasing phenolic content and antioxidant enzymes in *Carum carvi* plants. Furthermore, Abd El-Khalek *et al*. (2023) found that the highest ascorbic acid content in grape berries was observed after spraying grape clusters with thyme essential oil at 0.2% before harvest compared to the control. In addition, Chaouch *et al*. (2023) reported that *Thymus capitatus* essential oil is a satisfactory eco-friendly and efficient alternative to synthetic chemicals used in vitro, offering protective impacts against oxidative stress via accumulation of hydrogen peroxide content, peroxidases and ROS-scavenging phenolic compounds in strawberry leaves which increase

Table 3. Effect of foliar application of essential oils on total anthocyanin, ascorbic acid, total phenolic content and antioxidant activity of strawberry fruits during both growing seasons of 2022 and 2023.

Treatments	Total anthocyanin (mg/100 g FW)		Ascorbic acid (mg/100 g FW)		Total phenolic content (mg/ g FW)		Antioxidant activity (DPPH IC_{50} mg/ml)	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T0	35.26j	37.59j	17.80b	16.53c	6.50d	5.70g	49.9a	45.43a
T1	38.54i	42.65f	20.20ab	20.70abc	7.3cd	6.67def	49.7a	41.57d
T2	74.68a	56.15a	19.60ab	21.50ab	9.90a	8.47b	38.7f	39.17f
T3	64.84b	50.78b	23.20a	24.13a	10.3a	9.37a	32.8i	35.30h
T4	38.62h	41.67g	20.70ab	19.40bc	7.5cd	6.33f	45.5c	44.30b
T5	47.49f	39.03i	19.20ab	20.60abc	7.8c	6.73de	47.1b	42.47c
T6	52.48e	45.67d	20.30ab	20.50abc	8.3bc	7.03d	40.3e	42.17c
T7	46.36g	41.25h	20.20ab	20.43abc	7.1cd	6.60ef	44.5d	41.37d
T8	52.57d	42.87e	21.10ab	21.00ab	9.2ab	7.50c	36.6g	39.57e
T9	60.37c	47.48c	23.30a	21.63ab	9.70a	7.53c	34.4h	38.63g

Means followed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.
T0 = Control T1= Lavender essential oil at 2.5 ml/l T2=Lavender essential oil at 5 ml/l T3= Lavender essential oil at 7.5 ml/l
T4= Citronella essential oil at 2.5 ml/l T5= Citronella essential oil at 5 ml/l T6=Citronella essential oil at 7.5 ml/l
T7=Mixture of both oils at 2.5 ml/l T8=Mixture of both oils at 5 ml/l T9=Mixture of both oils at 7.5 ml/l

plant tolerance to acclimation stress. Likewise, Kamel *et al*. (2024) found that total phenolic content exhibited significant increase in in globe artichoke with application of thyme oil at 1ml during both seasons. Recently, Górska-Drabik *et al*. (2024) reported that foliar spray of *Tanacetum vulgare* L. essential oil at 4.5% resulted in the highest phenolic content of *Aronia melanocarpa* (Michx.) fruits, while the highest anthocyanin content scored in the fruits of *Aronia melanocarpa* plants received 3% essential oil of *Satureja montana* L. Moreover, foliar spray of *Satureja montana* L. essential oil at 4.5% resulted in the highest vitamin C content in *Aronia melanocarpa* (Michx.) fruits as compared to control. The role of essential oil components in increasing antioxidant activity and total phenolic content in plant fruits may be attributed to essential oil component triggers a signal that resembles a mild stress to the fruit as a defense mechanism, plant fruits produce additional amount of flavonoids and phenolic compounds as well as enhancing antioxidant activity (Wang *et al*., 2007). Furthermore, the enhancement of antioxidant activity in various plants by the application of essential oils as a defense mechanism has been reported (Ben-jabeur *et al*., 2015; Hashem *et al*., 2023; Es-sahm *et al*., 2024 and Kamel *et al*., 2024).

Amino acid and sugars content

Essential oil treated plants reported increased amino acid content and sugars concentrations in plant fruits (Table 4). The greatest content of amino acid (15.63 and 15.43 mg/100g F.W.), fructose (283.7 and 279.5 mg/100g F.W.), glucose (234.27and 214.4 mg/100g F.W.) and sucrose (197.2 and 156.6 mg/100g F.W.) concentrations in strawberry fruits were observed after using lavender essential oil at 7.5 ml/l during both growth seasons compared to control plants, while spraying plants with other concentrations of both essential oils or their mixture significantly reduced total amino acid content and sugars concentration (Table 4).

Our results are in agreement with findings of Wang *et al*. (2007) who stated that strawberry fruits treated with eugenol, thymol and menthol as active ingredients of miscellaneous essential oils maintained higher amounts of fructose and glucose and sucrose as well as increased anthocyanins, total phenolics and enhanced the antioxidant capacity via increasing DPPH scavenging activities of strawberry fruits. Similarly, Souri and Bakhtiarizade (2019) the highest leaf soluble carbohydrates of tomato seedlings resulted from foliar spray of rosemary essential oil at1000 ppm than control plants. Similarly, Mostafa *et al*. (2021) reported that the highest concentration of water-soluble carbohydrates in cucumber leaves was observed in oil-treated plants with peppermint oil or thieves blend oil and oil mixture (lemon + lemongrass + thyme + peppermint in equal proportions) compared to untreated plants in the first and second experiment respectively.

Table 4. Effect of foliar application of essential oils on amino acid and sugar contents of strawberry fruits during both growing seasons of 2022 and 2023.

Treatments	Total amino acid (mg/100g F.W.)		Sugars (mg/100g fresh weight)					
			Fructose		Glucose		Sucrose	
	1st	2nd	1st	2nd	1st	2nd	1st	2nd
T0	11.43e	9.80h	149.4j	124.0e	124.33j	152.2i	115.7j	126.9i
T1	13.37c	11.83d	249.6d	186.3d	199.33g	168.3e	124.2i	138.7f
T2	14.17b	14.47b	277.3b	243.4bc	229.73b	205.7b	179.2c	152.3b
T3	15.63a	15.43a	283.7a	279.5a	234.27a	214.4a	197.2a	156.6a
T4	12.60d	11.43e	196.5i	187.4d	212.47f	157.7h	177.1d	135.4h
T5	13.30c	10.53g	229.6g	207.8d	175.27h	162.5g	163.4g	136.2g
T6	13.33c	11.57de	232.9f	196.3d	228.40d	164.3f	167.9f	138.8e
T7	12.73d	10.90f	218.9h	216.3cd	128.73i	134.3j	146.6h	126.5j
T8	13.47c	12.63c	243.7e	244.5bc	217.27e	175.7d	168.7e	142.8d
T9	14.07b	12.43c	270.5c	255.4ab	228.97c	199.1c	193.0b	148.8c

Means followed by the same letter at each column are not significantly different at the 5% level according to Duncan's multiple range test.

T0 = Control, T1= Lavender essential oil at 2.5 ml/l, T2=Lavender essential oil at 5 ml/l, T3= Lavender essential oil at 7.5 ml/l

T4= Citronella essential oil at 2.5 ml/l T5= Citronella essential oil at 5 ml/l T6=Citronella essential oil at 7.5 ml/l

T7=Mixture of both oils at 2.5 ml/l T8=Mixture of both oils at 5 ml/l T9=Mixture of both oils at 7.5 ml/l

Conclusion

The used essential oils displayed some biostimulation on plant growth and productivity, and biochemical fruit characters under greenhouse conditions, particularly lavender essential oil at higher concentrations which has shown positive effects on vegetative growth characteristics, yield and fruit chemical components with increased antioxidant activity. Furthermore, our outcomes confirm the potential of essential oils in improving strawberry yield and fruit quality. In addition, the increase in total phenolic content and antioxidant activity following essential oil application will reduce oxidative stress via suppressing reactive oxygen species in stressed plant tissues, which in turn will enhance plant resistance to stress as well as benefit human health through its ability to scavenge free radicals. In light of these findings essential oils were proposed as an environmentally friendly plant growth enhancer that could be utilized to stimulate strawberry plants and fruit quality. Further research is required to evaluate the molecular features of essential oils on plant productivity.

References

Abd El-Khalek, A.; U. El-Abbasy and M. Abdel-Hameed (2023). Pre-harvest application of essential oil for maintaining quality of "flame seedless" grapes during cold storage. J. Sustain. Agric. Environ. Sci., 2 (1): 18–28. https://doi.org/10.21608/jsaes.2023.18791 1.1015

Abeysinghe, D.C.; X. Li; C. Sun; W. Zhang; C. Zhou and K. Chen (2007). Bioactive compounds and antioxidant capacities in different edible tissues of citrus fruit of four species. Food Chem.,104:1338–1344. https://doi.org/10.1016/j.foodchem.2007.01.047

AOAC(2000)."International Official Methods of Analysis."in: Association of Official Analytical Chemists; A.O.A.C International. Washington, DC, USA.

Barkaoui, H.; Z. Chafik; R. Benabbas; M. Chetouani; M. El Mimouni and E. Hariri (2022). Antifungal activity of the essential oils of *Rosmarinus officinalis*, *Salvia officinalis*, *Lavandula dentata* and *Cymbopogon citratus* against the mycelial growth of *Fusarium oxysporum* f.sp.Albedinis. Arab. J. Med. Aromat. Plants.,8(1):108–133. https://doi.org/10.48347/IMIST.PRSM/ajmap-v8i1.30676

Ben-jabeur, M.; E. Ghabri; M. Myriam and W. Hamada (2015). Thyme essential oil as a defense inducer of tomato against gray mold and fusarium wilt. Plant Physiol. Biochem., 94: 35–40. https://doi.org/10.1016/j.plaphy.2015.05.006

Bill, M.; L. Korsten; F. Remize; M. Glowacz and D. Sivakumar (2017). Effect of thyme oil vapours exposure on phenylalanine ammonia-lyase (PAL) and lipoxygenase (LOX) genes expression, and control of anthracnose in "Hass" and "Ryan" avocado fruit. Sci. Hortic., 224: 232–237.https://doi.org/10.1016/j.scienta.2017.06.026

Chan, L.K.; P.R. Dewi and P.L. Boey (2005). Effect of plant growth regulators on regeneration of plantlets from bud cultures of *Cymbopogon nardus* L. and the detection of essential oils from the *in vitro* plantlets. J. Plant Biol.,48:142–146.

Chaouch, R.; Z. Kthiri; S. Soufi; M. Ben Jabeur and T. Bettaieb (2023). Assessing the biostimulant effect of micro-algae and thyme essential oil during *in-vitro* and *ex-vitro* rooting of strawberry. South African J. Bot.,162:120–128. https://doi.org/10.1016/j.sajb.2023.08.066

Cheng, G.W. and P.J. Breen (1991). Activity of phenylalanine ammonia- lyase (PAL) and concentrations of anthocyanins and phenolics in developing strawberry fruit. J. Am. Soc. Hortic. Sci.,116:865–869. https://doi.org/10.21273/jashs.116.5.865

Cho, Y.Y.; S. Oh; M.M. Oh and J.E. Son (2007). Estimation of individual leaf area, fresh weight, and dry weight of hydroponically grown cucumbers (*Cucumis sativus* L.) using leaf length, width, and SPAD value. Sci. Hortic.,111(4):330–334.

Dela Cueva, F. and M.A. Balendres (2018). Efficacy of citronella essential oil for the management of chilli anthracnose. Eur. J. Plant Pathol.,152:461–468. https://doi.org/10.1007/s10658-018-1491-y

El-Mougy, N.S. (2009). Effect of some essential oils for limiting early blight (*Alternaria solani*) development in potato field. J. Plant Prot. Res.,49(1):57–62. https://doi.org/10.2478/v10045-009-0008-2

El-Shoraky, F. and A.Y. Shala (2018). Antifungal activity of spearmint and peppermint essential oils against macrophomina root rot of cotton. J. Plant Prot. & Path., Mansoura Univ., 9 (11): 775 – 781. https://doi.org/10.21608/jppp.2018.44061

El Abdali, Y.; A. Agour; A. Allali; M. Bourhia; A. El Moussaoui; N. Eloutassi; A. Mohammed Salamatullah; A. Alzahrani; L. Ouahmane; M.A.M. Aboul-Soud; J.P. Giesy and A. Bouia (2022). *Lavandula dentata* L.: Phytochemical analysis, antioxidant, antifungal and insecticidal activities of its essential oil. Plants.,11,311. https://doi.org/10.3390/plants11030311

ELsayed, S. S. A.; M. D. Sehsah; A.Y. Shala and S. Hamden (2023). Suppression of powdery mildew disease on sugar beet by using some natural substances and essential oils. J. Sustain. Agric. Sci., 49(4): 59–73. https://doi.org/10.21608/jsas.2023.241691.1437

Es-sahm, I.; S. Esserti; J. Dich; A. Smaili; L.A. Rifai; L. Faize; T. Koussa; J.S. Venisse; Y. Benyahia; N. Sawadi; H. Rabib; W. Badri; and M. Faize (2024). Common Bacillus mitigate tomato verticillium wilt and bacterial specks when combined with an essential oil extract. Rhizosphere., 29: 100865. https://doi.org/https://doi.org/10.1016/j.rhisph.2024.100865

Farouk, S.; A.B. Almutairi; Y.O. Alharbi and W.I. Al-Bassam (2021). Acaricidal efficacy of jasmine and lavender essential oil or mustard fixed oil against two-spotted spider mite and their impact on growth and yield of eggplants. Biology,10, 410. https://doi.org/10.3390/biology10050410

Gad El-Kareem, M.R.; M.A. Hussein and A.R. El-shereif (2022). Partial replacement of chemical NPK fertilizers with liquid compost and banana pseudostem sap in “Sewy” date palm (*Phoenix dactylifera* L.). J. Sustain. Agric. Sci., 48(3):33–40. https://doi.org/ 10.21608/jsas.2022.125513.1342

Górska-Drabik, E.; K. Golan; I. Kot; K. Kmiec; M. Poniewozik; K. Dzida and A. Bochniak (2024).The Effect of pre-harvest treatments with *Tanacetum vulgare* L . and *Satureja montana* L . essential oils (EOs) on the yield and chemical composition of *Aronia melanocarpa* (Michx .) Agriculture.,14, 12. https://doi.org/10.3390/ agriculture14010012

Hashem, A.H.; A.M. Abdelaziz; M.M.H. Hassanin; A.A. Al-Askar; H. Abdelgawad and M.S. Attia (2023). Potential impacts of clove essential oil nanoemulsion as bio fungicides against neoscytalidium blight disease of *Carum carvi* L. Agronomy.,13,1114. https://doi.org/10.3390/ agronomy13041114

Hosseini, S.; J. Amini; M.K. Saba; K. Karimi and I. Pertot (2020). Preharvest and postharvest application of garlic and rosemary essential oils for controlling anthracnose and quality assessment of strawberry fruit during cold storage. Front. Microbiol.,11,1855. https://doi.org/10.3389/fmicb.2020.01855

Kamel, S.M.; S.F. El-Gobashy; F.A. Mostafa and M.K. Abd Elhalem (2024). Effective control of root rot enhances seedling production in artichoke using safe compounds. Egypt. J. Agric. Res., 102 (1):4–21. https://doi.org/10.21608/ejar.2024.246485.1462

Kumar, P.; V. Lokesh; P. Doddaraju; A. Kumari; P. Singh; B.S. Meti; J. Sharma; K.J. Gupta and G. Manjunatha (2021). Greenhouse and field experiments revealed that clove oil can effectively reduce bacterial blight and increase yield in pomegranate. Food Energy Secur., 10, e305. https://doi.org/10.1002/fes3.305

Lis-Balchin, M.T. (2012). Lavender.in: K. V. Peter (Ed.), Handbook of Herbs and Spices.vol. 2, Woodhead Publishing Ltd.pp. 329–347. https://doi.org/10.1533/9780857095688.329

Liu, X.-P.; T.E.E. Grams; R. Matyssek and H. Rennenberg (2005). Effects of elevated *p*CO2 and/or *p*O3 on C-, N-, and S-metabolites in the leaves of juvenile beech and spruce differ between trees grown in monoculture and mixed culture. Plant Physiol. Biochem., 43 (2):147–154. https://doi.org/https://doi.org/10.1016/j.plaphy.2005.01.010

Lo Scalzo, R.; T. Iannoccari and C. Summa (2007). The relationship between the composition of different table grape (*Vitis vinifera* L.) extracts and three methods of measuring their free radical scavenging properties. Ital. J. food Sci. ,19 (3): 329–341.

Loko, Y.L.E.; Ms.M. Fagla; P. Kassa; C.A. Ahouansou; J. Toffa; B. Glinma; V. Dougnon; O. Koukoui; S.L. Djogbenou; M. Tamò and F. Gbaguidi (2021). Bioactivity of essential oils of *Cymbopogon citratus* (DC) Stapf and *Cymbopogon nardus* (L.) W. Watson from Benin against *Dinoderus porcellus* Lesne (Coleoptera: Bostrichidae) infesting yam chips. Int. J. Trop. Insect Sci.,41:511–524. https://doi.org/10.1007/s42690-020-00235-3

Mostafa, Y.S.; M. Hashem; A.M. Alshehri; S. Alamri; E.M. Eid; E.S. H.E. Ziedan and S.A. Alrumman (2021). Effective management of cucumber powdery mildew with essential oils. Agriculture.,11,1177. https://doi.org/10.3390/agriculture11111177

Page, A.L.; R.H. Miller and D.R. Keeney (1982). Methods of Soil Analysis - Chemical and Microbiological Properties. Madison, Wisconsin.

Pane, C.; D. Rongai and M. Zaccardelli (2013). Foliar spray application of glucosinolates and essential oils on processing tomato in open field production system. Agric. Sci.,4(3):149–153. https://doi.org/10.4236/as.2013.43022

Parra-Palma, C.; L. Morales-Quintana and P. Ramos (2020). Phenolic content, color development, and pigment−related gene expression: A comparative analysis in different cultivars of strawberry during the ripening process. Agronomy,10, 588. https://doi.org/10.3390/agronomy10040588

Patras, A.; N.P. Brunton; S. Da Pieve and F. Butler (2009). Impact of high pressure processing on total antioxidant activity, phenolic, ascorbic acid, anthocyanin content and color of strawberry and blackberry purées. Innov. Food Sci. Emerg. Technol.,10:308–313. https://doi.org/10.1016/j.ifset.2008. 12.004

Pérez, A.G.; R. Olías; J. Espada; J.M. Olías and C. Sanz (1997). Rapid determination of sugars, nonvolatile acids, and ascorbic acid in strawberry and other fruits. J. Agric. Food Chem.,45 (9): 3545–3549. https://doi.org/10.1021/jf9701704.

Pharmacopoeia, B. (1963). Determination of volatile oil in drugs. London.

Seliem, M.K.; Y.M. Hafez and H.R. El-Ramady (2020). Using nano - selenium in reducing the negative effects of high temperature stress on *Chrysanthemum morifolium* Ramat. J. Sustain. Agric. Sci., 46 (3): 47–59. https://doi.org/10.21608/jsas.2020.23905.1203.

Shala, A.Y.; O.H. Tawfik and T.R. El-Sayed (2024). Effect of gamma irradiation on vegetative growth and biochemical changes of cumin plants. J. Product. Dev.,29(1):35–55. https://doi.org/10.21608/JPD.2024.346236

Snedecor, G. W. and W .G. Cochran.(1980). Statistical Methods, Seventh Edition (Ames, IA: The Iowa State University Press), Seventh Ed. Iowa, USA.

Souri, M.K. and M. Bakhtiarizade (2019). Biostimulation effects of rosemary essential oil on growth and nutrient uptake of tomato seedlings. Sci. Hortic.,243:472–476. https://doi.org/10.1016/j.scienta.2018.08.056

Vermerris, W.; R. Nicholson; W. Vermerris and R. Nicholson (2006). "Biosynthesis of phenolic compounds."in: Phenolic Compound Biochemistry.Springer.pp. 63–149.

Wang, C.Y.; S.Y. Wang; J.-J. Yin; J. Parry and L.L. Yu (2007). Enhancing antioxidant, antiproliferation, and free radical scavenging activities in strawberries with essential oils. J. Agric. Food Chem.,55:6527–6532. https://doi.org/10.1021/jf070429a.

Wei, L.S. and W. Wee (2013). Chemical composition and antimicrobial activity of *Cymbopogon nardus* citronella essential oil against systemic bacteria of aquatic animals. Iran. J. Microbiol.,5(2):147–152.

تأثير الزيوت العطرية على نمو وجودة ثمار الفراولة

عوض يوسف شعله[١]، رانيا شوقي عبدالحميد[٢]، تهاني شعبان عبد الباري[٣]

(١) قسم بحوث النباتات الطبية والعطرية –معهد بحوث البساتين – مركز البحوث الزراعية – الجيزه – مصر

(٢) قسم بحوث إنتاج الخضر تحت ظروف جوية معدله–معهد بحوث البساتين – مركز البحوث الزراعية– الجيزه –مصر

(٣) قسم بحوث البطاطس والخضر خضرية التكاثر–معهد بحوث البساتين – مركز البحوث الزراعية – الجيزه – مصر

المستخلص. تعتبر الزيوت العطرية طريقه فعالة وآمنة بيئيا كمحفزات طبيعية لنمو النبات. تم إجراء التجربة بهدف دراسة تأثير الرش الورقي بالزيوت العطرية المستخلصة من نباتي اللافندر وحشيشة السترونيلا ومخلوط هذه الزيوت على نبات الفراولة النامي تحت البيوت البلاستيكية خلال موسمي النمو ٢٠٢٢/٢٠٢٣. أثبت التحليل الكروماتوجرافى أن ١,٨–سينول (٤٣,٩٥٪) ولينالول (٢٦,٢٧٪) هي المركبات السائدة في زيت اللافندر بينما كان السترونيلال (٢٧,٦٤٪) والجيرانيول (٢٤,٥١٪) من أكثر المركبات وفرة في زيت حشيشة السترونيلا. أدى الرش الورقي للزيوت العطرية إلى زيادة معنوية في ارتفاع النبات، عدد الأوراق، مساحة الورقة، طول الثمرة، قطر الثمرة، صلابة الثمرة، المحصول المبكر، المحصول الكلي وجودة الثمار وأعلى محتوى من الفينولات والأنثوسيانين وحمض الاسكوربيك والمواد الصلبة الذائبة الكلية خاصة بعد استخدام زيت اللافندر بتركيز مرتفع بالمقارنة بالنباتات غير المعاملة بالزيوت العطرية. تقترح هذه الدراسة استخدام زيت اللافندر الفرنسي بمعدل ٧,٥ (مل/لتر) باعتباره نهجًا صديقًا للبيئة لتحسين نمو نبات الفراولة وإنتاجيته وللحصول على جودة أفضل للثمار.

الكلمات المفتاحية: الزيوت الطيارة، الفراولة، اللافندر الفرنسي، حشيشة السترونيلا، الأنثوسيانين، حمض الاسكوربيك.