Exogenous utilization of jasmonic acid and methyl jasmonate stimulates growth and biochemical composition of lavender (*Lavandula angustifolia*) plant

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Background
Lavender (*Lavandula angustifolia*) as an economic herb is used in traditional medicine, perfume, flavoring, and cosmetics. It is classified in the mint family (Lamiaceae) and commonly used as a landscape plant. Monoterpenes and sesquiterpenes are the most common chemical components found in essential oils. Because of these compounds, it is used for antifungal, antibacterial, and antioxidant activities. Secondary metabolite compounds, that is, jasmonic acid (JA) and methyl jasmonate (MeJA), significantly influence secondary metabolism regulation by stimulating the accumulation of phenols, flavonoids, and alkaloids.

Objective
The research aimed to estimate the effect of both JA and MeJA on growth parameters, chemical composition, particularly secondary metabolism, and the composition of volatile oils of *L. angustifolia* Mill plants.

Materials and methods
In the experiment, JA concentrations of 0, 1, 5, and 10 mM and MeJA concentrations of 0, 0.25, 0.50, and 1.0 mM were used as foliar spray applications on *L. angustifolia*. The investigation was performed as a randomized complete block design in three replicates. The parameters collected were different growth parameters, essential oil components using gas chromatography–mass spectrometry, the number of glands and secretory trichome diameter by scanning electron microscope, as well as chemical constituents.

Results and conclusion
The results showed that growth parameters were increased gradually with the increasing of JA and MeJA concentrations. The effects of JA and MeJA at high concentrations were more effective on all the growth parameters, biochemical components, and the number of glands and diameter of secretory trichomes than other concentrations and control plants in both seasons. JA application significantly increased chlorophyll a and b, carotenoids, and N and protein content of lavender plants. MeJA gave the highest values of total sugar, free amino acids, and phenols. Therefore, the results suggested that 10 mM of JA and 1.0 mM of MeJA significantly stimulate lavender plant growth and chemical compounds and volatile oil components, especially linalool and camphor, increasing its value and raising its quality in the perfume and cosmetics industries and various chemical industry applications.

Keywords:
chemical compounds, gas chromatography–mass spectrometry, growth, lavender, oil components, volatile

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Introduction

In recent years, medicinal plants have attracted global interest from all over the world due to their valuable phytochemical components, which are crucial for treating and curing human illnesses [1–3]. *Lavandula angustifolia* Mill is one of the most common species of the mint family (Lamiaceae), usually known as lavender *Lavandula officinalis* Chaix., *L. angustifolia* Mill., or *Lavandula vera* although the correct name is *L. angustifolia* [4]. It originated in the Mediterranean area, although it is commercially cultivated worldwide [5]. It is utilized alone or as an addition in aromatherapy, folk, and traditional medicine [6]. There is a lot of interest in lavender due to its capacity to produce essential oils, which are widely used in perfume, cosmetic, flavoring, and medicinal applications [7]. Moreover, it is widely used as a very important landscape plant [8]. Monoterpenes and sesquiterpenes are the most common chemical components found in essential oils [9]. Lavandula's antifungal, antibacterial, and antioxidant activities are due to these compounds [10]. Furthermore, *L. officinalis* explants produce carotenoids and polyphenols. They play an essential role in human health due to their anti-inflammatory, antioxidant, and antibacterial properties and their ability to regulate metabolism [11]. Trichomes are outgrowths of epidermal on plant surfaces, which act as physical obstructions for herbivorous arthropods. These trichome structures also serve as biochemical factories, and also, they secrete a variety of specialized metabolites, including phenylpropanoids, terpenoids, flavonoids, alkaloids, and sugars [12].

Jasmonate was the name of jasmonic acid (JA) and its derivatives (Jasmontes), plant hormones, or cyclopentanone molecules produced from linolenic acid are called JAs. It is the major precursor of several chemicals in this group, such as methyl jasmonate (MeJA), first identified from *Jasminum grandiflorum* volatile oil [13]. JA is produced from α-linolenic acid, which is a fatty acid formed primarily in the leaves. It occurs mostly in an esterified form as glycerolipid [14]. MeJA is an organic molecule that can influence plant defense responses. MeJA is a plant growth regulator that occurs naturally and plays essential roles in plants, such as seed germination and root growth [15]. They are formed when membrane fatty acids are broken down. Furthermore, the MeJA is produced by the octadecanoic pathway, which is a set of metabolic processes that follow the oxidation of linolenic acid [16]. Also, the MeJA has a major influence on secondary metabolism regulation, as it stimulates the accumulation of phenols, flavonoids, alkaloids, and coumarins [17]. MeJA is a relatively new phytohormone class. MeJA regulates germination and morphogenesis, as well as plant stress responses. The data evidence from studies on MeJA's effect on plant growth yields mixed results. MeJA has both stimulatory and inhibitory effects on development and can increase or decrease bulbing [18].

This work aimed to assess the impact of JA and MeJA application spray on the growth and chemical composition of *L. angustifolia* plants, as well as secretory trichomes.

Materials and methods

The study was conducted in two successive seasons (2021 and 2022), at the Ornamental Horticulture Department, in an open field at the Faculty of Agriculture, Cairo University, Giza, Egypt. Experimental was executed to inspect growth parameters, chemical composition, particularly secondary metabolism, and secretory trichomes of *L. angustifolia* plant under treatments with JA and MeJA.

Planting material and experiment treatments

L. angustifolia seedlings were obtained from the commercial farm-planted seedlings with a length of 7 cm and 8–10 leaves per seedling transplanted in clay pots (35 cm); the soil comprised clay and sand at 1 : 1 v/v, planted two seedlings in each pot. JA concentrations (0, 1, 5, and 10 mM) and MeJA (0, 0.25, 0.50, and 1.0 mM) were used as spray applications three times. The first spray was applied 3 weeks after transplanting, followed by two applications with 15-day intervals. The physical and chemical characteristics of the used experimental soil were determined according to Jackson [19] and are presented in Table 1.

Growth parameters

The growth parameters of different treatments, including the plant height (cm), plant fresh herb and dry weight (g), and leaf area (cm^2), were measured during 2021 and 2022.

Essential oil percentage: was estimated in the fresh herb according to British Pharmacopeia [20]. Essential oil yield/plant (ml)=oil percentage×herb fresh weight/plant. Essential oil yield/per Fadden (l)=oil yield/plant×number of plants per Fadden.

Essential oil components

The samples were analyzed using gas chromatography–mass spectrometry analysis to determine the main components of lavender oil in the first season of 2021, according to Adams [21].

The number of glands and the secretory trichome diameter by scanning electron microscope

Cut out 3–10 mm of lavender leaves in the first season of 2021. Seal the cut faces with glue. The pieces were

Table 1 Physical and chemical analysis of the experimental soil

	Clay%	Silt%	Sand%				Texture			
Physical properties	12.86	13.04	74.10				Sandy loam			
Chemical analysis	pH	EC (dS/m)	Soluble cations (mmol/l)				Soluble anions (mmol/l)			
			Ca^{++}	Mg^{++}	Na^{+}	K^{+}	Co_3	HCO_3	Cl^-	SO_4^-
	7.7	0.76	2.3	1.50	2.30	0.60	–	2.10	2.50	2.10

dS/m, deciSiemens per meter; EC, electrical conductivity.

mounted on a scanning electron microscope stubs with a conductive adhesive tab. Examine the fresh pieces of leaves without coating [22].

Biochemical analysis

Pigment content

The contents of chlorophyll a, chlorophyll b, and total carotenoids (mg/g FW) in the fresh leaves sample were determined according to the method recorded by Saric *et al.* [23].

Macronutrient evaluations in shoot

Nitrogen (%) was determined by using the modified Kjeldahl method according to Cottenie *et al.* [24], protein content determined by multiplying N% by 6.25 [25]. Phosphorus (%) was determined in shoot using the ammonium molybdate method described by Snell *et al.* [26]. Potassium (%) was determined in shoot according to Chapman method [27].

Total sugars, total free amino acid, and total phenols in fresh shoot

The ethanol extract was prepared by cutting 0.5 g of fresh shoots into small pieces, it was crushed in porcelain mortar using about 25 ml of 80% ethyl alcohol, and then was boiled for 10 min, after filtration through a sintered glass silica – filter finally, and the residue was adjusted to 50 ml using ethyl alcohol 70%.

Total sugars (mg/g FW) were assessed using ethanol extract, phenol, and sulfuric acid reagent method described by Dubois *et al.* [28]. Analysis of total free amino acids was determined by a spectrophotometer (JWNWAY 6315) at 570 nm, using glycine as the standard described by Moore and Stein [29]. Total phenols were determined by colorimetric method, using a folin-Ciocalteau reagent, calculated by a spectrophotometer at 650 nm and using gallic acid as the standard described by Swain and Hillis [30].

Statistical analysis

Randomized complete block design and analysis of the collected data with three replicates for each treatment were done by the COSTATV-63 program. The mean values of treatment were compared at 0.05 level of probability using Duncan's multiple-range test of mean separation [31].

Results and discussion

Growth parameters

JA and MeJA generally increase the growth parameters of *L. angustifolia* plants compared with the control plants. Also, growth parameters increased progressively with releasing the concentration of JA and MeJA. Data in Table 2 show that JA treatments improved the plant height, herb fresh and dry weights, and leaf area of lavender plants. The plant height and herb fresh and dry weights increased significantly with increasing addition of JA up to 10 mM in both seasons. The highest values of plant height were 47.00 and 50.00 cm in both seasons, respectively, herb fresh weight 205.33 and 222.33 g in both seasons, respectively, and herb dry weight 68.88 and 73.44 g in the first and second seasons, respectively. The growth characteristics of lavender showed that leaf area increased with increasing addition (0.25, 0.50, and 1.0 mM) of MeJA. Leaf area reached the highest value with 1.0 mM of MeJA that gave 4.34 and 3.17 cm^2 in the first and second seasons, respectively, compared with the control plants.

These findings are in line with Złotek *et al.* [32], who found that using JA could enhance the plant height and dry weight of basil plant. Also, Imano and Tanokora [33] indicated that JA (0.5 mM) increased some physiological parameters of the safflower plant. Furthermore, using JA at a low concentration improved the elongation percentage, plant height, and fresh and dry weights of sorghum plants [34]. The treatment with 0.5, 1.0, and 1.50 mM of JA

Table 2 Growth parameters of *Lavandula angustifolia* as affected by jasmonic acid and methyl jasmonate concentrations during both seasons

	Plant height (cm)		Herb fresh weight (g)		Herb dry weight (g)		Leaf area (cm^2)	
Treatments	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Control	31.0±2.09^{e}	35.66±1.35^{d}	96.33±2.17^{f}	103.66±0.78^{g}	31.68±1.34^{e}	34.53±1.42^{g}	2.10±0.44^{d}	1.44±0.29^{d}
JA 1 mM	37.0±1.25^{c}	38.68±1.78^{c}	123.66±1.32^{e}	130±3.73^{f}	42.13±1.13^{d}	43.4±1.03^{f}	2.66b-±0.22^{d}	2.29±0.063^{bc}
JA 5 mM	34.0±1.29^{d}	39.52±1.60^{c}	149.66±2.11^{d}	156.03±1.78^{e}	48.76±0.91^{c}	50.04±1.07^{e}	4.27±0.28^{a}	3.14±0.341^{a}
JA 10 mM	47.0±0.51^{a}	50.0±2.21^{a}	205.33±0.85^{a}	222.36±3.24^{a}	68.88±2.60^{a}	73.44±1.67^{a}	3.16±0.16^{b}	2.62±0.67^{b}
MeJA 0.25 mM	39.66±2.32^{b}	43.03±2.32^{b}	166.05±1.98^{c}	184.3±0.79^{c}	51.61±1.29^{b}	54.97±1.20^{c}	2.88±0.11^{bc}	2.38±0.16^{bc}
MeJA 0.50 mM	40.01±1.11^{b}	42.33±0.74^{b}	164.1±1.03^{c}	175.05±1.73^{d}	51.08±1.73^{bc}	53.22±0.78^{d}	2.44±0.11^{cd}	2.05±0.28^{c}
MeJA 1.0 mM	45.33±0.85^{a}	49.66±0.83^{a}	172.66±1.94^{b}	191.33±0.95^{b}	51.92±0.62^{b}	59.24±0.98^{b}	4.34±0.40^{a}	3.17±0.35^{a}

The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

Table 3 Essential oil parameters of *Lavandula angustifolia* as affected by jasmonic acid and methyl jasmonate concentrations during both seasons

	Oil %		Oil yield per plant (ml)		Oil yield per feddan (l)	
Treatments	1st	2nd	1st	2nd	1st	2nd
Control	0.22±0.06[c]	0.20±0.05[d]	0.21±0.01[d]	0.20± 0.02[d]	26.04±4.91 [d]	24.96±4.40 [d]
JA 1 mM	0.24±0.14[c]	0.40±0.22[c]	0.29±0.02[d]	0.52±0.02[cd]	29.56±11.38[d]	51.84±17.78[cd]
JA 5 mM	0.63±0.15[b]	0.28±0.11[d]	0.94±0.10[c]	0.46±0.02[d]	82.56±12.25[c]	36.51±8.95[d]
JA 10 mM	0.93±0.32[a]	0.82±0.38[a]	1.84±0.20[a]	1.77±0.10[a]	85.48±25.97[a]	73.36±30.60[a]
MeJA 0.25 mM	0.65±0.23[b]	0.68±0.20[b]	1.07±0.20[c]	1.25±0.02[c]	59.52±18.74[c]	68.54±16.32[c]
MeJA 0.50 mM	0.24±0.06[c]	0.41±0.10[c]	0.36±0.02[d]	0.71±0.01[cd]	28.8±5.12[d]	48.64±8.60[cd]
MeJA 1.0 mM	0.78±0.10[b]	0.70±0.19[a]	1.50±0.10[b]	1.33±0.06[b]	83.36±8.37[b]	69.6±15.24[b]

The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

significantly affected the plant height and leaf area of *Catharanthus roseus* [35]. In the current study, the foliar spray of JA to *L. angustifolia* plants significantly influenced the morphological parameters. Moreover, AL-Huqail and Ali [35] indicated that JA enhanced the growth parameters of roots and shoots of *C. roseus* plants.

Essential oil, essential oil yield per plant, and essential oil yield per feddan

Table 3 reveals that essential oil %, essential oil yield per plant, and essential oil yield per fedden were significantly affected by JA and MeJA. The results indicated that JA at the rate of 10 mM instigated the highest values of essential oil (0.93±0.32 and 0.82 ±0.38% in both seasons, respectively), essential oil per plant (1.84±0.20 and 1.77±0.10 ml in the first and second season, respectively), and the highest induction of essential oil yield per feddan (85.48 ±25.97 and 73.36±30.60 l in the first and second season, respectively). Alternatively, the minimum values of essential oil %, essential oil/plant, and essential oil yield were found from the control plants in both seasons.

In the current study, the JA application positively affected the oil properties of lavender plants. While a small progressive influence of MeJA on plant oil % and oil yield. Similarly, in the study by Złotek *et al.* [32] on basil plants, the highest oil yield (0.78±0.005 ml/ 100 g D.W.) was obtained by stimulation of the basil with 100 μM JA compared with the control. Using the different concentrations of MeJA on *Agastache foeniculum* positively affected essential oil percentage. The level of 0.1 mM improved the essential oil % of *A. foeniculum* [36].

Essential oil component

The data are presented in Table 3. Shows the main constituents of lavender essential oil as identified by gas chromatography–mass spectrometry. Fourteen essential oil compositions have been identified in lavender listed in Table 4. The total identified components of essential oil were 98.44 (control), 98.87 (JA at the rate of 10 mM), and 99.34 (MeJA at 1.0 mM). The four major components were linalool, camphor, ∝pinene, and cyclohexane. The concentrations of these components varied according to different treatments. Linalool and camphor concentrations were increased by using JA and MeJA compared with the control plants.

Table 4 Essential oil composition of *Lavandula angustifolia* as affected by jasmonic acid at 10 mM and methyl jasmonate at 1.0 mM

	Component %		
Component %	Control	JA 10 mM	MeJA 1.0 mM
∝-pinene	4.04	2.59	3.45
Cyclohexane	3.03	2.28	2.69
Cyclohexane	0.66	1.71	2.32
Linalool	55.75	59.90	59.22
Terpinene	1.3	0.65	0.81
Cyclohexanol	0.94	0.94	0.66
Camphor	20.9	26.88	22.68
Ethyl vinyl carbinol	1.14	1.15	1.06
Terpinen-4-ol	1.73	2.81	1.61
Myrtenol	3.56	0.87	0.88
Verbenone	0.58	0.68	0.92
Tetrahydrophenol	0.64	1.19	2.17
2-Pinen-10-ol	1.43	1.05	0.86
Hexyl tiglate	0.74	0.93	1.01
	98.44	98.87	99.34

These results are in agreement with Talebi *et al.* [37] who found that leaf application of MeJA increased the percentage of 1,8-cineole and linalool, while decreased eugenol, α-cadinol, and α-beramoten in the extracted oil in basil (*Ocimum basilicum*). Moreover, Yadegari and Shakerian [38] indicated that using JA and salicylic acid, treatment with JA showed a positive effect in enhancing of limonene, α-pinene thymol, camplore, trans-thujone, camphene, borneol acetate, 1,8-cineole, borneol, carvacrol, caryophyllene, and α-humulene in salvia. Another study showed that treatment with 8 m MeJA released the content of monoterpenoids and total content of the essential oil in lavender [39].

Number of glands per leaf and the diameter of glands

The application of JA and MeJA increased the number of glands and diameter of the secretory trichome on both the adaxial and abaxial surfaces of the leaves. MeJA gave the best values of the number of glands and the number of secretory trichomes on both sides of the leaf (Tables 5 and 6 and Fig. 1). The greatest number of glands was obtained from plants sprayed with 1.0 mM MeJA on both the adaxial (20.66/mm^2 in the first season and adaxial 41.33/mm^2 in the first season). Also, the highest diameter of trichomes was observed in the plants treated with JA 10 mM on both the adaxial (91.20 μm) and abaxial (83.50 μm) leaf surface in Table 4 and Fig. 1. These results agree with Andrys *et al.* [10] that treatment with JA released the number and diameter of trichome in lavender plants. Furthermore, Dong *et al.* [39] revealed that application with MeJA increased in glandular trichome density in lavender.

Table 5 The number of secretory trichomes of *Lavandula angustifolia* as affected by jasmonic acid and methyl jasmonate

	Number of trichomes (per mm^2)	
Treatments	Adaxial surface of leaf	Abaxial surface of leaf
Control	20.0±2.00^{d}	10.0±1.97^{d}
JA 1 mM	25.0±2.00$^{b–d}$	13.0±1.00^{bc}
JA 5 mM	30.09±3.00^{b}	15.0±1.00^{b}
JA 10 mM	40.66±1.52^{a}	20.33±0.577^{a}
MeJA 0.25 mM	27.33±1.52^{bc}	13.66±0.577^{bc}
MeJA 0.50 mM	23.0±1.00^{cd}	11.66±0.577^{cd}
MeJA 1.0 mM	41.33±3.51^{a}	20.66±2.081^{a}

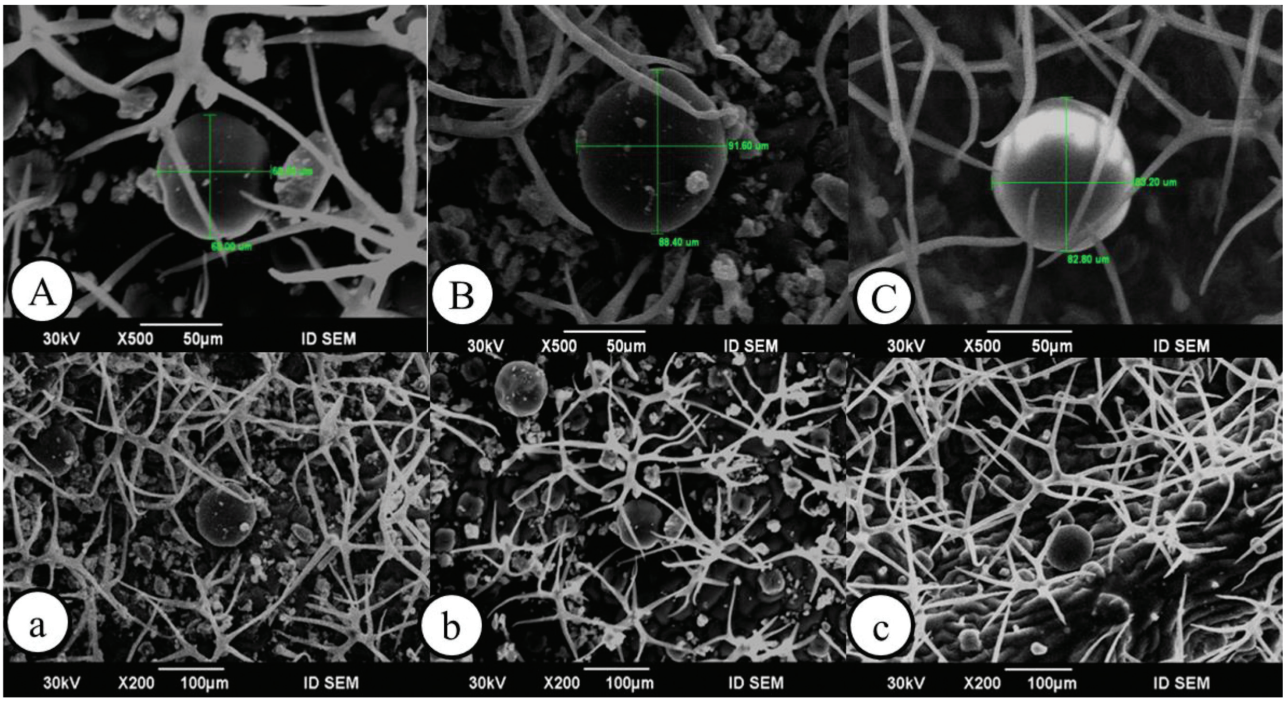
The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

Table 6 Size of secretory trichomes of *Lavandula angustifolia* as affected by different jasmonic acid and methyl jasmonate

	Trichome size (μm)	
Treatments	Adaxial surface of leaf	Abaxial surface of leaf
Control	68.40±1.718^{e}	58.00±2.80^{d}
JA 1 mM	79.60±2.183^{d}	71.40±2.74^{c}
JA 5 mM	85.10±1.90^{c}	80.10±2.74^{ab}
JA 10 mM	91.20±2.109^{a}	83.50±2.11^{a}
MeJA 0.25 mM	81.30±2.033^{d}	78.60±6.58^{ab}
MeJA 0.50 mM	87.60±1.39^{bc}	81.30±0.794^{ab}
MeJA 1.0 mM	89.60±1.74^{ab}	82.20±1.030^{ab}

The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

Figure 1



Trichome size and number on adaxial side of *Lavandula angustifolia* leaf on control (A, a), JA 10 mM (B, b), and MJ 1.0 mM (C, c).

Table 7 Photosynthetic pigments of *Lavandula angustifolia* treated with different jasmonic acid and methyl jasmonate

Treatments	Chlorophyll a (mg/g F.W.)	Chlorophyll b (mg/g F.W.)	Total chlorophyll (mg/g F.W.)	Total carotenoids (mg/g F.W.)
Control	0.340±0.010^{g}	0.127±0.010^{e}	0.468±0.020^{g}	0.076±0.005^{f}
JA 1 mM	1.108±0.025^{d}	0.772±0.070^{b}	1.879±0.010^{d}	0.371±0.017^{d}
JA 5 mM	0.718±0.017^{f}	0.340±0.017^{d}	1.058±0.026^{f}	0.201±0.018^{e}
JA 10 mM	2.120±0.055^{b}	1.074±0.045^{a}	3.194±0.072^{a}	0.674±0.010^{a}
MeJA 0.25 mM	0.822±0.026^{e}	0.375±0.020^{d}	1.197±0.026^{e}	0.209±0.017^{e}
MeJA 0.50 mM	1.862±0.030^{c}	0.526±0.010^{c}	2.388±0.020^{c}	0.539±0.010^{c}
MeJA 1.0 mM	2.306±0.065^{a}	0.717±0.015^{b}	3.0231±0.264^{b}	0.615±0.006^{b}

The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

Table 8 N, P, K, and protein content of *Lavandula angustifolia* as affected by jasmonic acid and methyl jasmonate

Treatments	N%	P%	K%	Protein%
Control	1.22±0.026^{g}	0.104±0.017^{d}	2.06±0.030^{f}	7.625±0.030^{g}
JA 1 mM	1.96±0.052^{d}	0.137±0.010^{bc}	2.77±0.040^{c}	12.25±0.050^{d}
JA 5 mM	1.40±0.036^{f}	0.106±0.010^{d}	2.20±0.030^{e}	8.75±0.050^{f}
JA 10 mM	2.80±0.026^{a}	0.182±0.0264^{a}	3.91±0.072^{a}	17.50±0.050^{a}
MeJA 0.25 mM	1.64±0.026^{e}	0.119±0.264^{cd}	2.48±0.085^{d}	10.25±0.0888^{e}
MeJA 0.50 mM	2.16±0.036^{c}	0.156±0.010^{ab}	2.84±0.045^{c}	13.50±0.655^{c}
MeJA 1.0 mM	2.24±0.020^{b}	0.168±0.020^{a}	2.98±0.096^{b}	14.00±0.176^{b}

The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

Photosynthetic pigments

Generally, chlorophyll a, b, and total carotenoid content were gradually increased with increasing the concentration of both JA and MeJA. The highest increase of chlorophyll recorded with the highest level of MeJA (1.0 mM) compared with the other concentrations and the control (Table 7). However, plants sprayed with JA noticeably increased chlorophyll b, total chlorophyll, and total carotenoids. The highest values of chlorophyll b (1.074±0.045), total chlorophyll (3.194±0.072), and total carotenoids (0.0674±0.010) were obtained from the highest JA level (10 mM) compared with the other concentrations and the control. Our findings agree with Awang *et al.* [40] who found that the greatest pigment content was obtained from JA. Also, the chlorophyll content was significantly decreased in the control plants compared with the JA treatment. Applying JA positively increased the photosynthesis accumulation of sorghum plants [34].

N, P, K, and protein%

Data presented in Table 8 showed that the N, P, K, and protein% were considerably increased with the concentration of JA and MeJA comparable with the untreated plants. The highest values of N and protein% were recorded with the highest JA level (10 mM). In contrast, the lowest values of N and protein% were found with the control plants. Applying of JA also led to a significant increase of P and K%. The data in Table 8 indicated that the JA at the level of 10 mM gave the highest P and K% values.

These findings correspond with the study conducted by the authors. Złotek *et al.* [41] demonstrated that treatment with JA released the content of K, Ni, Zn, Cd, Na, and Mg in lovage plant. According to some research, the improved nutrient uptake and enhanced growth, as well as the production of some phytohormones and the conversion of the soluble form of phosphorus availability to plants, maybe the cause of the increase in the content of some nutrient elements seen in the studied lavender plant [41].

Total sugar mg/g F.W.

Total sugar content in lavender shoots (Table 9) increased with exogenous JA and MeJA foliar application, especially 10 JA and 1.0 mM MeJA, when compared with control plants and other treatments.

These results are in harmony with Noor *et al.* [42] in Glycine max plants, who found increased sugar content with foliar treatment of JA at 100 μmol/l and 0.5–10 μM JA of *Beta vulgaris* plants [42]. In addition, Wang *et al.* [43] and Pandita [44] suggested that JA is usually involved in physiological responses, including the antioxidant activity system, accumulation of amino acids, and soluble sugars. Parmoon *et al.* [45], Tayyab *et al.* [46], and Gao

Table 9 Total sugar, total free amino acid, and total phenols of *Lavandula angustifolia* as affected by jasmonic acid and methyl jasmonate

Treatments	Total sugar mg/g F.W.	Total free amino acid mg/g F.W.	Total phenols mg/g F.W.
Control	7.49±0.125^{g}	1.96±0.060^{e}	0.79±0.015^{e}
JA 1 mM	13.68± 0.45^{d}	2.82±0.195^{d}	1.18±0.060^{c}
JA 5 mM	10.63±0.150^{f}	2.5±0.013^{e}	1.05±0.025^{d}
JA 10 mM	17.93±0.195^{b}	4.18±0.27^{b}	1.37±0.070^{b}
MeJA 0.25 mM	11.21±0.385^{e}	2.64±0.38^{d}	0.99±0.030^{d}
MeJA 0.50 mM	16.21±0.360^{c}	3.43±0.20^{c}	1.25±0.026^{c}
MeJA 1.0 mM	20.12±0.24^{a}	4.87±0.26^{a}	1.59±0.070^{a}

The data are expressed as means±SD of three replications. JA, jasmonic acid; MeJA, methyl jasmonate. Within the mean values column marked with different letters are significantly different according to Duncan's test of Bonferroni correction *P* value less than or equal to 0.05.

et al. [47] found that exogenous MeJA provides the carbohydrate, total soluble sugar, and activities of CAT, POD, and SOD.Total free amino acid mg/g F.W.

Table 9 shows enhanced total free amino acid content in the shoot of lavender, the highest content indicated with treated plants with MeJA at 1 mM (4.87 mg/g F. W.), followed by JA at 10 mM (4.18 mg/g F.W.), but the lowest content of total free amino acid shown with control plants (1.96 mg/g F.W.).

These results are in the same line as many studies such as Sheyhakinia *et al*. [48] in roselle seedlings when used JA at 1 Mm found increased hyperaccumulating metabolites, such as proteins, soluble sugars, starch, and free amino acids. Major *et al*. [49] opinioned that MeJA may alter primary metabolites, including sugar, amino acid, and organic acid, by regulating the balance between defense activities and growth. Abdi *et al*. [50] on peppermint plant showed improved metabolite profiles, such as amino acids and carbohydrates with or without stress when applied 50 μM of MeJA.

Total phenols

Total phenol content (Table 9) improved by applying all concentrations of JA and MeJA. The highest content of total phenols was found when plants were treated with MeJA at 1.0 mM (1.59 mgÌ¸g F.W.), followed by JA at 10 mM (1.37 mgÌ¸g F.W.) when compared with other concentrations and control plants.

A similar trend was observed with Öztürk and Yücedağ [51] and Centin *et al*. [52], who indicated the MeJA applied increased total phenolic compounds in different organs of plant, especially under different stress conditions. Many phenolic compounds created via this pathway are induced by JA and MeJA. Exogenous JA increased secondary metabolites such as total phenols, flavonoids, and anthocyanins [53–55]. The high concentration of MeJA increased the relative content of phenolic compound [56–59].

Conclusions

In summary, the utilization of 10 mM of JA and 1.0 mM of MeJA had a positive effect on the growth parameters and bioactive compounds, oil production, volatile oil components, macroelements, and protein. The current study recommended that application with JA and MeJA increases its economic value and raising its uses in the perfume and cosmetics industries as well as multichemical applications.

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Conflicts of interest

There are no conflicts of interest.

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