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# The effect of water stress, salicylic acid and bio-fertilizer on quality of leaf and seed essential oil, and oil components of coriander

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**ABSTRACT**

A field experiment was conducted to evaluate the effect of salicylic acid (SA) and bio-fertilizer on quality of leaves and seeds essential oils and seeds oil constituents of coriander under different irrigation treatments. The treatments were irrigation intervals (irrigation after 60, 90 and 120 mm evaporation from class A pan) and combination of fertilization (control, 100 kg $ha^{-1}$ Urea, Nitrokara (as biofertilizer), and 50% Urea + Nitrokara) and salicylic acid (0 and 1 mM) that were allocated to main and sub-plots, respectively. Leaves and seeds essential oils were analyzed by gas chromatography mass spectroscopy (GC/MS). Results revealed that (E)-2-decenal was major component in essential oil of coriander leaves, while the main constituent of essential oil in seeds under all treatments was linalool. Water stress increased all major components of leaves essential oil, especially in untreated plants with SA. Application of nitrogen fertilizers, particularly 50% Urea + Nitrokara, had an additive effect on leaves essential oil constituents. Effect of salicylic acid on essential oil constituents of leaves was minimal. Increasing irrigation intervals led to a slight increment in concentration of all major components of essential oil, except γ-terpinene. Application of SA and nitrogen fertilizers (especially 50% Urea + Nitrokara) improved seed essential oil quality by increasing the linalool and γ-terpinene contents. Based on the results of the GC analysis, the major fatty acid in coriander seeds oil was petroselinic acid, followed by oleic, linoleic, palmitic, stearic, myristic and linolenic acids in all treatments. Water deficit increased percentage of petroselinic, oleic and palmitic acids, and reduced linoleic and linolenic acids. The application of nitrogen fertilizers, especially 50% Urea and Nitrokara, decreased stearic acid content, but increased other fatty acids. Exogenous application of salicylic acid led to increment in unsaturated fatty acids of seed oil, except linolenic acid. Therefore, application of bio-fertilizers and salicylic acid could be recommended for improving quality of essential oil and oil components of coriander seeds under different water availabilities.

**Keywords:** Coriander, essential oil, fatty acid, fertilizer, irrigation, salicylic acid.

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## INTRODUCTION

Coriander (*Coriandrum sativum* L.), an annual herb belonging to the Apiaceae family, is a Mediterranean indigenous plant (Purseglove et al., 1981). This species mostly grows in temperate areas around the Mediterranean basin and in India, China, Thailand and Eastern Europe (Pino et al., 1993). It is used as an herbal condiment in many culinary preparations. All parts of the plant are edible, but in cooking mostly the fresh leaves and the dried seeds are used. Coriander plant is cultivated for its seeds, which are used for many purposes including aromatherapy, food, drugs, cosmetics and perfumery. Seeds are used in the treatment of rheumatism, gastrointestinal complaints, flatulence and gastralgia, worms, insomnia, anxiety, loss of appetite and glycemia (Emamghoreishi et al., 2005; Rakhshandeh et al., 2012). The use of coriander seeds as a spice are widespread. Coriander seeds are also used in the preparation of baked goods and tobacco products (Purseglove et al., 1981). Coriander leaves are also enriched with various compounds such as tartaric acid, gallic acid, diosmin, dicoumarin, 4-hydroxycoumarin apigenin, esculin luteolin and vicenin which have various health enhancing functions such as antioxidant, antidiabetic, antimutagenic and antidepressant activities (Kansal et al., 2011, 2012). In industry, the main product from coriander is distilled oil and solvent-extracted oleoresin for aroma and flavor productions (Islam et al., 2009). The quality of coriander is mainly determined by the essential oil content and its composition. Coriander herbal extract (aqueous and ethanol) and essential oil have been shown to functions as natural antioxidant and antimicrobial agents (Peter and Kitts, 2005). This plant contains essential oil in its leaves, stem, flowers and fruits/seeds. Essential oil content in coriander seeds is very different, 0.5 to 2.5%, and it increases as the seed ripens, while its leaves contain less essential oil than the seeds (Mandal and Mandal, 2015). Linalool is the main volatile compound in coriander seeds, typically constituting more than 50% of the total essential oil (Ramadan and Mörsel, 2003). The high concentration of linalool in seed essential oil makes it potentially useful in the medicine and perfumery purposes, respectively. In addition to its use as a scent in domestic products such as soap, detergent, shampoo and lotion, linalool is also used as a chemical intermediate. One common downstream product of linalool is vitamin E. Linalool is also used by pest professionals as a flea, and cockroach insecticide (Lewinshon et al., 2001). Coriander oils are familiar not only in the perfumery, food, beverage and pharmaceutical industries, but also in medicine. They are used as antioxidants, in treatment of nervous disorders, for gut modulation, blood pressure lowering, and diuretic activity, as an anti-diabetic and antimicrobial agent, and in many traditional remedies for various diseases (Azhar and Mazhar, 2003 ; Isabelle et al., 2010). Interest in coriander seed oil has increased since the European Union authorized the use of coriander oil as a food supplement.

Petroselinic acid is an unusual fatty acid that is found primarily in seeds. This fatty acid composes nearly 85% of the total fatty acids of Apiaceae seeds (Angelini et al., 1997). It can be oxidatively cleaved to produce a mixture of lauric acid, a compound useful in the production of detergents, and adipic acid, a $C_6$ dicarboxylic acid used in the synthesis of nylon polymer (Msaada et al., 2009).

The production and composition of secondary metabolites in plants is affected by environmental conditions, physiological characteristics, genetics and evolutionary factors (Selmar and Kleinwächter, 2013). Drought is known as a major abiotic factor that limits plant growth and production in arid and semiarid regions more than other environmental stresses. Drought conditions are normally associated with low precipitation, high evaporative demand, and high temperatures and irradiation, which make the water deficit a multidimensional stress (Larcher, 2000). Water deficit can reduce the duration of the seed-filling period that will have an effect on seed oil content and can influence the composition of its oil (Flagella et al., 2002).

Applying bio-fertilizers such as nitrogen fixing bacteria and phosphate solubilizing microorganisms has led to a decrease in the application of chemical fertilizers and has provided high quality agricultural products (Sharma, 2002). By using bio-fertilizers, quantity and quality of active substances of medicinal plants can be improved (Rashmi et al., 2008; Azzaz et al., 2009). *Azorhizobium caulinodans* is a Gram-negative soil bacterium that has not only the ability to fix nitrogen but also the ability to release phyto-hormones similar to gibberellic acid and indole acetic acid, which could stimulate plant growth, absorption of nutrients, and photosynthesis (Mahfouz and Sharaf Eldin, 2007).

Salicylic acid (SA) is an endogenous growth regulator of phenolic nature which participates in the regulation of physiological processes in plants (He et al., 2005) and has an effective role in the defensive mechanism of plants against biotic and abiotic stresses. The effect of salicylic acid on plant growth under abiotic stresses are related to its role in nutrient uptake, membrane stability, water relations, stomatal regulation, photosynthesis, growth and inhibition of ethylene biosynthesis (Khan et al., 2003).

Despite the widespread use of coriander plant in various industries, combination effect of water stress, and application of salicylic acid and bio-fertilizer was not documented on essential oil and oil components of this medicinal plant. Therefore, main objective of the present research was to investigate the quality of oil and essential oil of coriander under different irrigation regimes, hormonal and fertilization dosages.

## MATERIALS AND METHODS

### Field conditions

The experiment was carried out at the Research Farm of Kermanshah, Iran (latitude 47°34′N, longitude 34°39′E, altitude 1200 m above sea level) in 2015 as split-plot factorial based on randomized complete block design with three replications. Before sowing, physical and chemical properties of the soil were determined. The soil texture was loamy with a pH = 8.09, EC = 0.4 dS $m^{-1}$, total nitrogen = 0.2%, available phosphorus = 14.1 ppm, available potassium = 232 ppm and 0.4% organic carbon.

### Treatments

The irrigation treatment (irrigation after 60, 90 and 120 mm evaporation from class A pan) and combination of fertilization (control, 100 kg $ha^{-1}$ Urea, Nitrokara (as bio-fertilizer), and 50%

Urea + Nitrokara) and salicylic acid (0 and 1 mM) were allocated to main and sub-plots, respectively. Coriander seeds were inoculated with Nitrokara, a bio-fertilizer containing *Azorhizobium caulinodans* bacteria, and sown by hand in 4 × 1.2 m plots with 6 rows and the spacing of 10 cm between the plants and 20 cm between the rows (with a density of 40 seeds per $m^2$) on April 9th 2015. Urea was applied on the basis of soil test (1/3 at sowing date, 1/3 after thinning and 1/3 at vegetative stage). All plots were irrigated immediately after sowing, but subsequent irrigations were carried out according to the treatments. The plants were sprayed twice with salicylic acid (0 and 1 mM) at stages of stem elongation and flowering, using a hand pump sprayer at the time of 07:00 to 08:00 AM, until both sides of the leaves completely became wet. Weeds were controlled by hand during plant growth and development as required.

#### Measurements

At the early flowering stage, 20 plants with healthy and well-grown leaves were harvested from the middle part of each plot. Then, leaves were separated from the stems and dried for about 72 h at room temperature (20 to 25°C). At the physiological maturity, plants of 1 $m^2$ in the middle part of each plot were harvested. Seeds were separated from other parts of plants and similar to leaves, they were dried at room temperature.

#### Extraction of essential oil and determining its components

Air-dried and ground samples from each treatment (100 g of seeds and 20 g of leaves) were mixed with 500 ml distilled water and the essential oil content was determined by hydro-distillation for three hours, using a modified Clevenger-type apparatus (Pino et al., 1996; Ghobadi and Ghobadi, 2012). The extracted essential oil was dried over anhydrous sodium sulphate and stored in a dark glass and kept at a temperature of 4°C, until gas chromatography-mass spectrometry (GC/MS) analysis. The analysis was conducted using a hermoquest-Finnigan Trace GC/MS instrument equipped with a DB-5 fused silica column (60 m × 0.25 mm i.d., film thickness 0.25 µm). The oven temperature was raised from 60 to 250°C at a rate of 5°C/min and then kept at 250°C for 10 min. Transfer line temperature was 250°C. One µl of sample was injected and helium was used as the carrier gas at a flow rate of 1.1 ml/min with a split ratio equal to 1/50. The quadrupole mass spectrometer was scanned over the 40 to 500 *m/z* with an ionizing voltage of 70 eV and an ionization current of 150 µA.

The essential oil components were identified by comparing retention indices (RI) with authentic compounds or with those reported in the literature and by comparison of their mass spectra with the Wiley library or published mass spectra data. RI was calculated by using retention times of n-alkanes ($C_6$-$C_{24}$) that were injected after the essential oil at the same temperature and conditions (Adams, 2007). The relative percentage of the essential oil constituents was expressed by peak area normalization.

#### Oil extraction and analysis of fatty acids methyl esters

In order to determine the seeds oil, 10 g of seed samples were ground and oil percentage was determined using soxhlet apparatus. Fatty acid methyl esters (FAMEs) of the seed oil were analyzed using gas chromatography (South Korea, YL-6100GC) with a flame ionization detector (FID). Analysis of FAME was achieved with the fused silica capillary column BP × 70 with length 30 m × i.d 0.25 mm and film thickness 0.2 µm. Helium was used as a carrier gas at a flow rate of 1.0 ml $min^{-1}$. The oven temperature was held initially at 80°C for 1 min, then increased to 230°C at 5°C $min^{-1}$ and maintained at 230°C for 10 min. The injector and detector temperatures were 250 and 240°C, respectively. The area of each fatty acid peak was expressed as a percentage of the total area. The peaks were identified by retention times and comparing them with authentic standards analyzed under the same conditions.

#### Statistical analysis

The data were analyzed as split-plot factorial based on randomized complete block design with two replications by SAS and MSTAT-C softwares and the means were compared using the Duncan's multiple range test at $p \leq 0.05$.

## RESULTS

Thirty-three and forty-two compounds were identified in essential oil of coriander leaves and seeds under different treatments, respectively that relative percentages of major constituents are shown in Tables 1 and 2.

### Chemical composition of leaves essential oil

Leaves essential oil of coriander has a different chemical constituents from those present in the seeds. (E)-2-decenal (27.19 to 29.33%), decanal (14.09 to 16.21%), cyclodecanol (9.91 to 13.06%), linalool (11.33 to 13.24%), 2-dodecenal (9.39 to 11.47%), 2-decen-1-ol (8.31 to 9.21%) and dodecanal (4.11 to 5.79%) were major components in essential oil of coriander leaves.

According to Table 3, linalool, decanal, cyclodecanol, (E)-2-dodecenal and dodecanal contents were significantly affected by irrigation, fertilization, salicylic acid and all of their interactions. Effects of irrigation, nitrogen fertilizers and interaction of irrigation × fertilization were also significant for (E)-2-decenal. 2-decen-1-ol was only influenced by irrigation, fertilization and interaction of irrigation × salicylic acid (Table 3). (E)-2-decenal and 2-decen-1-ol had the lowest changes under different treatments. Water stress increased all major components of leaves essential oil, especially in untreated plants with SA. Application of nitrogen fertilizers, particularly 50% Urea + Nitrokara, had an additive effect on essential oil constituents of coriander leaves. Effect of salicylic acid on essential oil constituents of leaves was minimal. However, plants treated with SA under well watering had mostly higher components percentage in leaves compared to untreated plants in same irrigation treatment (Table 1).

### Chemical composition of seeds essential oil

According to Table 4, effects of irrigation, fertilization, foliar application of salicylic acid and interactions of irrigation × fertilization, irrigation × salicylic acid, fertilization × salicylic acid, and irrigation × fertilization ×

**Table 1.** Changes in major components of essential oil of coriander leaves under different treatments.

| Treatments | linalool | (E)-2-decenal | decanal | cyclodecanol | (E)-2-dodecenal | 2-decen-1-ol | dodecanal |
|---|---|---|---|---|---|---|---|
| 1: $I_{60}F_0SA_0$ | $11.33^{o}$ | 27.19 | $14.11^{i}$ | $9.91^{r}$ | $9.39^{o}$ | 8.32 | $4.11^{l}$ |
| 2: $I_{90}F_0SA_0$ | $11.73^{lm}$ | 27.55 | $14.53^{k}$ | $10.17^{q}$ | $9.98^{jk}$ | 8.41 | $4.39^{j}$ |
| 3: $I_{120}F_0SA_0$ | $12.02^{hi}$ | 27.91 | $14.87^{ij}$ | $10.35^{p}$ | $10.29^{h}$ | 8.57 | $4.43^{j}$ |
| 4: $I_{60}F_1SA_0$ | $11.63^{n}$ | 27.57 | $14.55^{k}$ | $10.48^{no}$ | $9.57^{n}$ | 8.49 | $4.54^{i}$ |
| 5: $I_{90}F_1SA_0$ | $11.98^{ij}$ | 28.14 | $15.09^{g}$ | $11.15^{j}$ | $10.43^{g}$ | 8.63 | $4.86^{g}$ |
| 6: $I_{120}F_1SA_0$ | $12.44^{e}$ | 28.63 | $15.52^{f}$ | $11.61^{h}$ | $10.72^{c}$ | 8.84 | $5.24^{cd}$ |
| 7: $I_{60}F_2SA_0$ | $11.65^{mn}$ | 28.00 | $14.98^{h}$ | $10.80^{l}$ | $9.87^{lm}$ | 8.61 | $4.52^{i}$ |
| 8: $I_{90}F_2SA_0$ | $12.00^{ij}$ | 28.58 | $15.62^{e}$ | $12.07^{f}$ | $10.37^{gh}$ | 8.85 | $4.97^{f}$ |
| 9: $I_{120}F_2SA_0$ | $12.66^{d}$ | 29.01 | $16.11^{b}$ | $12.22^{de}$ | $10.76^{e}$ | 9.11 | $5.21^{d}$ |
| 10: $I_{60}F_3SA_0$ | $11.99^{ij}$ | 28.13 | $15.14^{g}$ | $11.41^{i}$ | $10.01^{j}$ | 8.85 | $5.00^{f}$ |
| 11: $I_{90}F_3SA_0$ | $12.86^{c}$ | 28.90 | $15.90^{d}$ | $12.44^{c}$ | $11.01^{c}$ | 9.05 | $5.56^{b}$ |
| 12: $I_{120}F_3SA_0$ | $13.07^{b}$ | 29.33 | $16.21^{a}$ | $12.93^{b}$ | $11.38^{a}$ | 9.17 | $5.75^{a}$ |
| 13: $I_{60}F_0SA_1$ | $11.56^{n}$ | 27.25 | $14.09^{l}$ | $10.12^{q}$ | $9.48^{no}$ | 8.31 | $4.23^{k}$ |
| 14: $I_{90}F_0SA_1$ | $11.82^{kl}$ | 27.54 | $14.55^{k}$ | $10.38^{op}$ | $10.04^{j}$ | 8.39 | $4.43^{j}$ |
| 15: $I_{120}F_0SA_1$ | $12.11^{gh}$ | 27.88 | $14.83^{j}$ | $10.54^{n}$ | $10.31^{h}$ | 8.58 | $4.55^{i}$ |
| 16: $I_{60}F_1SA_1$ | $11.87^{k}$ | 27.66 | $14.61^{k}$ | $10.65^{m}$ | $9.78^{m}$ | 8.50 | $4.72^{h}$ |
| 17: $I_{90}F_1SA_1$ | $12.18^{g}$ | 28.23 | $15.14^{g}$ | $11.18^{j}$ | $10.55^{f}$ | 8.50 | $5.00^{f}$ |
| 18: $I_{120}F_1SA_1$ | $12.52^{e}$ | 28.62 | $15.55^{ef}$ | $11.73^{g}$ | $10.89^{d}$ | 8.76 | $5.27^{cd}$ |
| 19: $I_{60}F_2SA_1$ | $11.91^{jk}$ | 28.02 | $14.95^{hi}$ | $10.91^{k}$ | $9.91^{kl}$ | 8.69 | $4.81^{g}$ |
| 20: $I_{90}F_2SA_1$ | $12.13^{g}$ | 28.61 | $15.59^{ef}$ | $12.14^{ef}$ | $10.34^{gh}$ | 8.78 | $5.12^{e}$ |
| 21: $I_{120}F_2SA_1$ | $12.51^{e}$ | 28.99 | $16.00^{c}$ | $12.31^{d}$ | $10.77^{e}$ | 9.03 | $5.32^{c}$ |
| 22: $I_{60}F_3SA_1$ | $12.29^{f}$ | 28.19 | $15.16^{g}$ | $11.58^{h}$ | $10.19^{i}$ | 8.87 | $5.09^{e}$ |
| 23: $I_{90}F_3SA_1$ | $13.03^{b}$ | 28.86 | $15.91^{d}$ | $12.43^{c}$ | $11.12^{b}$ | 8.97 | $5.61^{b}$ |
| 24: $I_{120}F_3SA_1$ | $13.24^{a}$ | 29.32 | $16.18^{ab}$ | $13.06^{a}$ | $11.47^{a}$ | 9.21 | $5.79^{a}$ |

$I_1$, $I_2$, $I_3$: Irrigation after 60, 90 and 120 mm evaporation from class A pan, respectively.
$F_0$, $F_1$, $F_2$, $F_3$: No fertilizer (control), Urea, Nitrokara (bio-fertilizer), and 50% Urea + Nitrokara, respectively.
$SA_0$ and $SA_1$: Non-application of salicylic acid and application of 1mM salicylic acid, respectively.
Different letters at each column indicate a significant difference at $p \leq 0.05$.

salicylic acid were significant for linalool, α-pinene and p-cymene contents. γ-terpinene was influenced by all studied treatments, except interaction of irrigation × salicylic acid. Effects of irrigation, fertilization and foliar application of salicylic acid were also significant for β-pinene (Table 4). Linalool was main component in essential oil of coriander seeds under all treatments (68.81 to 78.04%). γ-terpinene, α-pinene, β-pinene and p-cymene were other major constituents in essential oil. Decreasing water availability led to a slight increment in concentration of all major components of essential oil, except γ-terpinene. Under all irrigation intervals, the lowest percentage of linalool was related to untreated plants. Application of salicylic acid and nitrogen fertilizer (especially 50% Urea + Nitrokara) improved quality of seed essential oil by increasing the percentage of linalool and γ-terpinene. In contrast, α-pinene content was reduced in seed essential oil of plants treated with SA. The maximum percent of linalool (78.04%) was obtained from simultaneous application of SA, 50% Urea and Nitrokara in the plants irrigated with 120 mm evaporation intervals ($I_3$), while the highest γ-terpinene content (6.53%) was observed in plants treated with SA, 50% Urea and Nitrokara under well watering ($I_{60}F_3SA_1$) (Table 2).

## Oil components

Based on the results of the GC analysis, petroselinic acid (69.12 to 72.43%), oleic acid (4.09 to 6.32%), linoleic acid (13.94 to 16.48%), palmitic acid (3.34 to 4.91%), stearic acid (1.27 to 1.74%), myristic acid (0.63 to 0.75%) and linolenic acid (0.64 to 0.95%) were main components in coriander seeds oil.

Petroselinic acid, oleic acid and palmitic acid were affected by all treatments. Interaction of irrigation × fertilization × salicylic acid was also significant for linoleic and stearic acids. Myristic acid was only influenced by fertilization and interaction of irrigation × fertilization. Water deficit, nitrogen fertilizers and foliar application of salicylic acid had a significant effect on linolenic acid content (Table 5). Major component of oil was petroselinic acid in all treatments. The fatty acids content

**Table 2.** Changes in major components of essential oil of coriander seeds under different treatments.

| Treatments | linalool | γ-terpinene | α-pinene | β-pinene | p-cymene |
|---|---|---|---|---|---|
| 1: $I_{60}F_0SA_0$ | 68.81 p | 5.14 kl | 3.33 mn | 0.112 | 0.56 n |
| 2: $I_{90}F_0SA_0$ | 69.53 o | 4.97 mn | 3.65 ij | 0.137 | 0.63 m |
| 3: $I_{120}F_0SA_0$ | 71.00 n | 4.69 o | 3.77 gh | 0.169 | 0.71 jkl |
| 4: $I_{60}F_1SA_0$ | 71.16 n | 5.69 gh | 3.83 fg | 0.151 | 0.65 lm |
| 5: $I_{90}F_1SA_0$ | 73.22 l | 5.21 k | 3.98 de | 0.179 | 0.74 ghijk |
| 6: $I_{120}F_1SA_0$ | 74.51 j | 5.05 lm | 4.01 d | 0.197 | 0.80 efgh |
| 7: $I_{60}F_2SA_0$ | 73.28 l | 5.74 fg | 3.90 ef | 0.168 | 0.69 klm |
| 8: $I_{90}F_2SA_0$ | 74.55 j | 5.63 h | 4.05 cd | 0.226 | 0.78 fghij |
| 9: $I_{120}F_2SA_0$ | 75.19 h | 5.50 i | 4.15 b | 0.241 | 0.85 def |
| 10: $I_{60}F_3SA_0$ | 74.90 i | 6.15 b | 4.12 bc | 0.244 | 0.81 efg |
| 11: $I_{90}F_3SA_0$ | 75.15 h | 5.93 d | 4.20 b | 0.292 | 0.97 bc |
| 12: $I_{120}F_3SA_0$ | 76.27 f | 5.83 ef | 4.55 a | 0.339 | 0.94 c |
| 13: $I_{60}F_0SA_1$ | 71.09 n | 5.37 j | 3.15 o | 0.143 | 0.62 mn |
| 14: $I_{90}F_0SA_1$ | 72.94 m | 5.12 kl | 3.30 n | 0.174 | 0.71 jkl |
| 15: $I_{120}F_0SA_1$ | 73.67 k | 4.95 n | 3.41 lm | 0.201 | 0.79 fghi |
| 16: $I_{60}F_1SA_1$ | 75.21 h | 5.64 h | 3.42 lm | 0.185 | 0.72 ijkl |
| 17: $I_{90}F_1SA_1$ | 76.40 f | 5.47 i | 3.57 jk | 0.215 | 0.81 efg |
| 18: $I_{120}F_1SA_1$ | 76.93 d | 5.22 k | 3.63 ij | 0.237 | 0.87 de |
| 19: $I_{60}F_2SA_1$ | 77.53 b | 6.19 b | 3.50 kl | 0.205 | 0.73 hijk |
| 20: $I_{90}F_2SA_1$ | 76.33 f | 5.88 de | 3.65 ij | 0.266 | 0.81 efg |
| 21: $I_{120}F_2SA_1$ | 77.11 c | 5.62 h | 3.70 hi | 0.281 | 0.95 c |
| 22: $I_{60}F_3SA_1$ | 76.00 g | 6.53 a | 3.69 hi | 0.280 | 0.90 cd |
| 23: $I_{90}F_3SA_1$ | 76.57 e | 6.18 b | 3.81 fg | 0.338 | 1.02 b |
| 24: $I_{120}F_3SA_1$ | 78.04 a | 6.04 c | 3.95 de | 0.382 | 1.31 a |

$I_1$, $I_2$, $I_3$: Irrigation after 60, 90 and 120 mm evaporation from class A pan, respectively
$F_0$, $F_1$, $F_2$, $F_3$: No fertilizer (control), Urea, Nitrokara (bio-fertilizer), and 50% Urea + Nitrokara, respectively
$SA_0$ and $SA_1$: Non-application of salicylic acid and application of 1mM salicylic acid, respectively
Different letters at each column indicate a significant difference at p ≤ 0.05.

**Table 3.** Analysis of variance for major components of essential oil of coriander leaves under different treatments.

| Sources of variance | df | Mean squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Linalool | (E)-2-Decenal | Decanal | Cyclodecanol | (E)-2-Dodecenal | 2-Decen-1-ol | Dodecanal |
| Replication | 1 | 0.003 ns | 0.005 ns | 0.002 ns | 0.004 ns | 0.008 ns | 0.001 ns | 0.0001 ns |
| Irrigation (I) | 2 | 2.521 ** | 3.689 ** | 3.749 ** | 5.168 ** | 4.574 ** | 0.446 ** | 1.327 ** |
| $E_a$ | 2 | 0.002 | 0.002 | 0.005 | 0.003 | 0.005 | 0.003 | 0.002 |
| Fertilizer (F) | 3 | 2.012 ** | 3.475 ** | 3.714 ** | 9.358 ** | 1.813 ** | 0.798 ** | 2.485 ** |
| I×F | 6 | 0.071 ** | 0.048 ** | 0.132 ** | 0.309 ** | 0.069 ** | 0.005 ns | 0.038 ** |
| Salicylic acid (SA) | 1 | 0.273 ** | 0.005 ns | 0.056 ** | 0.185 ** | 0.095 ** | 0.008 ns | 0.155 ** |
| I×SA | 2 | 0.044 ** | 0.005 ns | 0.023 ** | 0.0087 * | 0.039 ** | 0.011 * | 0.010 * |
| F×SA | 3 | 0.010 ** | 0.002 ns | 0.018 ** | 0.0084 * | 0.025 ** | 0.002 ns | 0.0097 * |
| I×F×SA | 6 | 0.006 ** | 0.001 ns | 0.005 * | 0.0079 * | 0.015 ** | 0.002 ns | 0.0085 * |
| $E_b$ | 21 | 0.0015 | 0.0020 | 0.0019 | 0.0024 | 0.0021 | 0.0029 | 0.0018 |
| CV (%) | - | 3.2 | 2.5 | 3.6 | 4.1 | 4.4 | 2.8 | 3.9 |

ns, *,**: No significant and significant at p ≤ 0.05 and p ≤ 0.01, respectively.

of seed oil was affected by water deficit. Increasing irrigation intervals improved percentage of petroselinic, oleic and palmitic acids, and reduced linoleic and linolenic acids. In contrast, changes in stearic acid and myristic acid contents were minimal under irrigation treatments. The application of nitrogen fertilizers,

**Table 4.** Analysis of variance for major components of essential oil of coriander seeds under different treatments.

| Sources of variance | df | Mean squares | | | | |
|---|---|---|---|---|---|---|
| | | linalool | γ-terpinene | α-pinene | β-pinene | p-cymene |
| Replication | 1 | 0.0034 ns | 0.0022 ns | 0.0015 ns | 0.0008 ns | 0.0005 ns |
| Irrigation (I) | 2 | 13.616 ** | 0.794 ** | 0.311 ** | 0.020 ** | 0.148 ** |
| $E_a$ | 2 | 0.003 | 0.001 | 0.002 | 0.000 | 0.000 |
| Fertilizer (F) | 3 | 60.483 ** | 2.579 ** | 0.787 ** | 0.053 ** | 0.219 ** |
| I×F | 6 | 0.852 ** | 0.006 * | 0.012 ** | 0.001 ns | 0.003 ** |
| Salicylic acid (SA) | 1 | 76.255 ** | 0.599 ** | 1.884 ** | 0.018 ** | 0.103 ** |
| I×SA | 2 | 0.542 ** | 0.004 ns | 0.009 * | 0.000 ns | 0.012 ** |
| F×SA | 3 | 1.761 ** | 0.015 ** | 0.017 ** | 0.000 ns | 0.008 ** |
| I×F×SA | 6 | 0.830 ** | 0.020 ** | 0.005 * | 0.000 ns | 0.007 ** |
| $E_b$ | 21 | 0.006 | 0.0021 | 0.0017 | 0.00043 | 0.0008 |
| CV (%) | - | 5.10 | 4.82 | 3.17 | 8.99 | 3.48 |

ns, *,**: No significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

**Table 5.** Analysis of variance for major components of coriander seeds oil under different treatments.

| Sources of variance | df | Mean squares | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Petroselinic acid | Oleic acid | Linoleic acid | Palmitic acid | Stearic acid | Myristic acid | Linolenic acid |
| Replication | 1 | 0.002 ns | 0.001 ns | 0.019 ns | 0.003 ns | 0.001 ns | 0.0015 ns | 0.0006 ns |
| Irrigation (I) | 2 | 2.554 ** | 2.066 ** | 2.123 ** | 1.274 ** | 0.040 * | 0.002 ns | 0.109 ** |
| $E_a$ | 2 | 0.0017 | 0.0014 | 0.022 | 0.004 | 0.0011 | 0.001 | 0.0005 |
| Fertilizer (F) | 3 | 4.586 ** | 2.261 ** | 3.652 ** | 1.305 ** | 0.146 ** | 0.007 ** | 0.018 ** |
| I×F | 6 | 0.019 ** | 0.023 ** | 0.011 ns | 0.009 ** | 0.005 ** | 0.003 ** | 0.002 ns |
| Salicylic acid (SA) | 1 | 8.234 ** | 1.092 ** | 8.670 ** | 1.200 ** | 0.134 ** | 0.000 ns | 0.055 ** |
| I×SA | 2 | 0.057 ** | 0.253 ** | 0.002 ns | 0.035 ** | 0.001 ns | 0.001 ns | 0.001 ns |
| F×SA | 3 | 0.506 ** | 0.075 ** | 0.029 ns | 0.024 ** | 0.011 ** | 0.001 ns | 0.001 ns |
| I×F×SA | 6 | 0.024 ** | 0.140 ** | 0.085 ** | 0.005 ** | 0.001 * | 0.001 ns | 0.001 ns |
| $E_b$ | 21 | 0.0011 | 0.0010 | 0.021 | 0.0006 | 0.0005 | 0.00048 | 0.0009 |
| CV (%) | - | 2.35 | 3.61 | 4.94 | 4.59 | 4.47 | 5.20 | 3.82 |

ns, *,**: No significant and significant at $p \leq 0.05$ and $p \leq 0.01$, respectively.

especially 50% Urea and Nitrokara, decreased stearic acid content, but increased other fatty acids. Exogenous application of salicylic acid led to increment in unsaturated fatty acids of seed oil, except linolenic acid. So that percentage of petroselinic, oleic and linoleic acids in plants treated with SA was higher than untreated plants. In contrast, the lowest palmitic and stearic acids contents were related to the plants sprayed with SA. The concentration of myristic acid was almost stable at the different treatments (Table 6).

## DISCUSSION

Coriander leaves, flowers and seeds exhibit a wide range of pharmacological activities such as antibiotic (Silva et al., 2011) anti-oxidant, anti-diabetic, anti-cholinesterase, anti-helminthic, sedative-hypnotic, anticonvulsant, cholesterol lowering (Wangensteen et al., 2004), anti-cancer, and hepatoprotective (Samojlik et al., 2010). In qualitative and quantitative aspects, the essential oils are chemically unstable and may undergo changes depending on the severity of stress (Sangwan et al., 2001).

Secondary metabolites play a major role in the adaptation of plants to the environment changes (Edreva et al., 2008). (E)-2-decenal and linalool were major components in essential oil of coriander leaves and seeds, respectively (Tables 1 and 2). Linalool, a terpene tertiary alcohol, has antioxidant potency at high concentrations (Krishnakantha and Lokesh, 1993). The presence of bioactive compounds as flavonoids and triterpene in different parts of the plants can be the reason of antimicrobial and antioxidant activities in these

**Table 6.** Changes in fatty acids composition of coriander seeds under different treatments.

| Treatments | Petroselinic acid (C18: $1_{n-12}$) | Oleic acid (C18: $1_{n-9}$) | Linoleic acid (C18: 2 Cis) | Palmitic acid (C16: 0) | Stearic acid (C18: 0) | Myristic acid (C14: 0) | Linolenic acid (C18: 3) |
|---|---|---|---|---|---|---|---|
| 1: $I_{60}F_0SA_0$ | $69.12^{q}$ | $4.09^{n}$ | $14.32^{kl}$ | $3.86^{l}$ | $1.74^{a}$ | 0.63 | 0.81 |
| 2: $I_{90}F_0SA_0$ | $69.75^{p}$ | $4.74^{l}$ | $14.16^{lm}$ | $3.99^{jk}$ | $1.71^{ab}$ | 0.68 | 0.76 |
| 3: $I_{120}F_0SA_0$ | $70.11^{m}$ | $4.89^{k}$ | $13.94^{m}$ | $4.15^{i}$ | $1.66^{bc}$ | 0.67 | 0.70 |
| 4: $I_{60}F_1SA_0$ | $70.00^{n}$ | $4.71^{lm}$ | $15.21^{gh}$ | $3.77^{m}$ | $1.68^{abc}$ | 0.68 | 0.91 |
| 5: $I_{90}F_1SA_0$ | $70.18^{l}$ | $4.99^{j}$ | $14.77^{ij}$ | $4.02^{jk}$ | $1.62^{cde}$ | 0.65 | 0.83 |
| 6: $I_{120}F_1SA_0$ | $70.54^{i}$ | $5.23^{h}$ | $14.53^{jk}$ | $4.37^{fg}$ | $1.63^{cd}$ | 0.67 | 0.75 |
| 7: $I_{60}F_2SA_0$ | $70.25^{k}$ | $5.00^{j}$ | $15.85^{cde}$ | $4.33^{gh}$ | $1.55^{efg}$ | 0.72 | 0.94 |
| 8: $I_{90}F_2SA_0$ | $70.50^{i}$ | $5.58^{e}$ | $15.48^{fg}$ | $4.51^{d}$ | $1.43^{jk}$ | 0.75 | 0.87 |
| 9: $I_{120}F_2SA_0$ | $70.76^{g}$ | $5.01^{j}$ | $14.81^{ij}$ | $4.83^{b}$ | $1.47^{hij}$ | 0.68 | 0.78 |
| 10: $I_{60}F_3SA_0$ | $70.39^{j}$ | $5.32^{g}$ | $15.74^{def}$ | $4.31^{gh}$ | $1.49^{ghij}$ | 0.71 | 0.95 |
| 11: $I_{90}F_3SA_0$ | $70.86^{f}$ | $5.83^{cd}$ | $15.42^{fg}$ | $4.64^{c}$ | $1.52^{fghi}$ | 0.69 | 0.80 |
| 12: $I_{120}F_3SA_0$ | $71.07^{d}$ | $5.96^{b}$ | $14.90^{hi}$ | $4.91^{a}$ | $1.37^{kl}$ | 0.72 | 0.78 |
| 13: $I_{60}F_0SA_1$ | $69.86^{o}$ | $4.65^{m}$ | $15.56^{ef}$ | $3.38^{n}$ | $1.57^{def}$ | 0.61 | 0.77 |
| 14: $I_{90}F_0SA_1$ | $70.42^{j}$ | $4.86^{k}$ | $14.93^{hi}$ | $3.73^{m}$ | $1.53^{fgh}$ | 0.68 | 0.71 |
| 15: $I_{120}F_0SA_1$ | $70.87^{f}$ | $5.08^{i}$ | $14.52^{jk}$ | $3.96^{k}$ | $1.48^{ghij}$ | 0.68 | 0.66 |
| 16: $I_{60}F_1SA_1$ | $70.04^{n}$ | $4.88^{k}$ | $15.94^{bcd}$ | $3.34^{n}$ | $1.61^{cde}$ | 0.71 | 0.88 |
| 17: $I_{90}F_1SA_1$ | $70.68^{h}$ | $5.42^{f}$ | $15.57^{ef}$ | $3.77^{m}$ | $1.57^{def}$ | 0.69 | 0.73 |
| 18: $I_{120}F_1SA_1$ | $70.92^{f}$ | $5.77^{d}$ | $15.23^{gh}$ | $4.07^{j}$ | $1.58^{def}$ | 0.66 | 0.64 |
| 19: $I_{60}F_2SA_1$ | $71.00^{e}$ | $5.10^{i}$ | $16.48^{a}$ | $3.99^{jk}$ | $1.45^{ij}$ | 0.71 | 0.89 |
| 20: $I_{90}F_2SA_1$ | $71.63^{c}$ | $5.55^{e}$ | $16.22^{ab}$ | $4.43^{ef}$ | $1.33^{lm}$ | 0.73 | 0.79 |
| 21: $I_{120}F_2SA_1$ | $71.96^{b}$ | $6.29^{a}$ | $15.87^{cde}$ | $4.65^{c}$ | $1.27^{m}$ | 0.69 | 0.68 |
| 22: $I_{60}F_3SA_1$ | $71.64^{c}$ | $5.19^{h}$ | $16.45^{a}$ | $3.88^{l}$ | $1.48^{ghij}$ | 0.65 | 0.85 |
| 23: $I_{90}F_3SA_1$ | $72.02^{b}$ | $5.86^{c}$ | $16.11^{bc}$ | $4.27^{h}$ | $1.42^{jk}$ | 0.72 | 0.78 |
| 24: $I_{120}F_3SA_1$ | $72.43^{a}$ | $6.32^{a}$ | $15.95^{bcd}$ | $4.46^{de}$ | $1.31^{lm}$ | 0.71 | 0.69 |

$I_1$, $I_2$, $I_3$: Irrigation after 60, 90 and 120 mm evaporation from class A pan, respectively.
$F_0$, $F_1$, $F_2$, $F_3$: No fertilizer (control), Urea, Nitrokara (bio-fertilizer), and 50% Urea + Nitrokara, respectively.
$SA_0$ and $SA_1$: Non-application of salicylic acid and application of 1mM salicylic acid, respectively.
Different letters at each column indicate a significant difference at $p \leq 0.05$.

plants (Rashed and Butnariu, 2014). Increased essential oil content under water stress (Tables 1 and 2) has been attributed to the production of high concentrations of terpenes, isoprenoids and phenylpropanoids by plants (Delfine et al., 2005). Application of nitrogen fertilizer had a positive effect on essential oil components and increased (E)-2-decenal and decanal contents in leaves (Table 1), and linalool and γ-terpinene percentages in seeds (Table 2). The improvement of quantity and quality of essential oil through application of nitrogen fixing bacteria has been also reported in other medicinal plants such as lemon balm (Harshavardhan et al., 2007), hyssop (Koocheki et al., 2009) fennel (Mahfouz and Sharaf Eldin, 2007; Azzaz et al., 2009; Moradi et al., 2011) and dill (Darzi et al., 2012). Leaves and seeds essential oils of plants treated with salicylic acid had higher quality compared with untreated plants. However, effect of salicylic acid on essential oil constituents of leaves was lower than seeds (Tables 1 and 2). The reports indicate that the salicylic acid similar to the stress manipulated quality and quantity of essential oil in some medicinal plants (Rowshan et al., 2010) through its effect on plastid, chlorophyll level and also simulating stress conditions (Nourafcan et al., 2014).

Similar results reported by Shahwar et al. (2012) showed that the major volatile components in coriander seed essential oil were linalool, γ -terpinene, α-pinene, camphor, decanal geranyl acetate, limonene, geraniol, camphene and D-limonene, while the main constituents identified in leaves essential oil were (E)-2-decenal, linalool, (E)-2-dodecenal, (E)-2-tetradecenal, 2-decen-1-ol, (E)-2-undecenal, dodecanal, (E)-2-tridecenal, (E)-2-hexadecenal, pentadecenal, and α-pinene. The linalool content depends on the plant growth stage, environmental condition and location. Overall, the results reported on the chemical composition of the coriander plants during different stages of maturity revealed great differences, occurring during maturation process. It may be suggested that these differences were concomitant with modification in secondary metabolism (Gil et al., 2002; Msaada et al., 2007). So that mature seeds of coriander have the highest amount of this component and have been reported 40% (Machado et al., 1993), 55.6% (Shahwar et al., 2012), 65.8% (Smallfield et al., 2001), 72.3 to 77.7% (Gil et al., 2002) and 72 to 83% (Arak et al., 2007) in different researches. Increment of main components in essential oil of coriander seeds (such as linalool, γ- terpinne and α-pinene) has been reported by Darzi and Hadi (2014) in the presence of bio-fertilizers.

The results of present research showed that the coriander seed oil contains saturated fatty acids (5.24 to 7.40%) such as palmitic, stearic and myristic acids, monounsaturated fatty acids (MUFAs) (73.21 to 78.75%) such as petroselinic and oleic acids, and polyunsaturated fatty acids (PUFAs) (14.58 to 17.43%) such as linoleic and linolenic acids (Table 6). Jaworski and Cahoon (2003) reported that coriander is a good dietary source of polyunsaturated fatty acids (PUFAs). PUFAs cannot be synthesized naturally in mammals; so they are obtained from dietary supplementation. Most PUFAs, especially n-3 fatty acids (Omega 3), are known for reducing the risk of cardiovascular diseases (Walter, 2007), improving insulin sensitivity and reducing lipolysis, triglyceride synthesis and free fatty acid concentration (Rustan et al., 1993). Oleic acid or petroselinic acid, that is a positional isomer of oleic acid, and linoleic acid (LA) are commonly found in plant products and are important precursors of omega 9 and omega 6 unsaturated fatty acids, respectively. Oleic acid plays a role in lowering of blood pressure and LDL levels in the body (Terés et al., 2008), while LA is important in balancing the fatty acid ratio (French et al., 2000). Dietary sources of PUFAs such as coriander have been shown to activate AMP-activated protein kinase which causes expression of proteins that promote fatty acid oxidation and their suppression synthesis in the liver (Suchankova et al., 2005). Coriander seeds contain fatty acid desaturase enzymes which their activity promotes MUFA and probably PUFA synthesis. The fatty acid desaturase enzyme (Δ-4-palmitoyl acyl carrier protein) in coriander catalyses the conversion of saturated fatty acids to unsaturated fatty acids (Jaworski and Cahoon, 2003).

Under the same conditions, the higher percentage of saturated fatty acids over unsaturated fatty acids would increase, because unsaturated fatty acids are obtained from saturated fatty acids (Tohidi Moghadam et al., 2011). Water limitation decreased percentage of unsaturated fatty acids such as linoleic and linolenic acids contents, but increased petroselinic, oleic, palmitic and stearic acids contents (Table 6). The increment in oleic acid under water stress can be attributed to the decreasing activity of Δ-12 desaturase, which reduces the conversion of oleic to linoleic acid (Baldini et al., 2000). Baldini et al. (2000) have established that with the increase in the biosynthesis of the oil, the enzyme Δ–9 desaturase started its activity. This enzyme has been proposed as being responsible for the accumulation of oleic acid (18:1) by desaturing stearic acid (18:0) (Mckeon and Stumpf, 1982). Another enzyme leading to the oleic acid accumulation is Δ–12 desaturase, which catalyses the second desaturation of oleic acid into linoleic acid (Stymme and Appelqvist, 1980). Lee et al. (2008) reported that irrigation did not affect unsaturated fatty acid concentration in soybean, however oleic acid tended to increase and linolenic acid tended to decrease. Dwivedi et al. (1996) also reported that under water stress, linoleic acid content decreased, but stearic acid content increased in peanuts. It has been reported that percentage of saturated fatty acids such as palmitic acid could be increased as a result of water limitation in oilseeds (Mekki et al., 1999; Laribi et al., 2009).

Application of nitrogen fertilizers (especially 50% Urea + Nitrokara) and SA improved oil quality of coriander seeds by increasing of unsaturated fatty acids (petroselinic, oleic and linoleic acids). Nitrogen fertilizers including bio-fertilizers, increased oil quality by decreasing saturated fatty acids and increasing unsaturated fatty acids. Bio-fertilizers are microorganisms that are able to change nutritional elements from useless form to effective and useful compounds and this change is conducted in a biological process. Production expenses of bio-fertilizers are low and they do not cause pollution in the soil and environment (Rahimi-Shokooh et al., 2013). The results are also in agreement with findings of Noreen and Ashraf (2008) in sunflower and they also observed reduction in linolenic acid and increment in linoleic acid content with foliar application of salicylic acid.

## Conclusion

Results revealed that (E)-2-decenal and decanal were major components in essential oil of coriander leaves, while the main constituent of essential oil in seeds under all treatments was linalool. Water stress increased all major compounds of leaves essential oil, especially in untreated plants with SA. Application of nitrogen fertilizers, particularly 50% Urea + Nitrokara, had an additive effect on leaves essential oil constituents. Effect of salicylic acid on essential oil constituents of leaves was minimal. Increasing irrigation intervals led to a slight increment in concentration of all major components of essential oil, except γ-terpinene. Application of SA and nitrogen fertilizers (especially 50% Urea + Nitrokara) improved seed essential oil quality by increasing the linalool and γ-terpinene contents. The major fatty acid in coriander seed oil was petroselinic acid, followed by oleic, linoleic, palmitic, stearic, myristic and linolenic acids in all treatments. Water deficit increased percentage of petroselinic, oleic and palmitic acids, and reduced linoleic and linolenic acids. The application of nitrogen fertilizers, especially 50% Urea and Nitrokara, decreased stearic acid content, but increased other fatty acids. Exogenous application of salicylic acid led to increment in unsaturated fatty acids of seed oil, except for linolenic acid. Therefore, application of bio-fertilizers and salicylic acid can be recommended for improving quality of essential oil and fatty acids components of coriander seeds under different water availabilities.

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## REFERENCES

**Adams** RP, **2007**. Identification of essential oil components by gas chromatography/mass spectrometry. 4th ed.; Allured Publishing: Carol Stream, USA, 804 p.

**Angelini** LG, Moscheni E, Colonna G, Belloni P, Bonari E, **1997**. Variation in agronomic characteristics and seed oil composition of new oilseed crops in central, Italy. Ind Crop Prod, 6: 313-323.

**Arak** E, Orav A, Roal A, **2007**. Composition of the essential oil of *Coriandrum sativum* L. seeds from various countries. Eur J Pharmaceut Sci, 32: 521-522

**Azhar** I, **Mazhar** F, **2003**. Spices as Medicine. CANIZ Printing Agency, Research Institute of Indusyunic Medicine, Karachi, pp: 143-144.

**Azzaz** NA, Hassan EA, Hamad EH, **2009**. The chemical constituent and vegetative and yielding characteristics of fennel plants treated with organic and bio-fertilizer instead of mineral fertilizer. Austr J. Basic Appl Sci, 3(2): 579-587.

**Baldini** M, Giovanardi R, Vannozzi, GP, **2000**. Effects of different water availability on fatty acid composition of the oil in standard and high oleic sunflower hybrids. In: Proceedings of fifteenth International Sunflower Conference, Toulouse, pp: 79-84.

**Darzi** MT, Hadi MRHS, Rejali F, **2012**. Effects of the application of vermicompost and nitrogen fixing bacteria on quantity and quality of the essential oil in dill (*Anethum graveolens*). J Med Plant Res, 6(21): 3793-3799.

**Darzi** MT, **Hadi** MRHS, **2014**. Response of concentration and composition of essential oil of coriander (*Coriandrum sativum* L.) to cattle manure and nitrogen fixing bacteria. Ethno-Pharm Prod, 1(2): 35-42.

**Delfine** S, Loreto F, Pinelli P, Tognetti R, Alvino A, **2005**. Isoprenoids content and photosynthetic limitations in rosemary and spearmint plants under water stress. Agric Ecosyst Environ, 106: 243-252.

**Dwivedi** SL, Nigam SN, Nageswara-Rao RC, Singh U, Rao KVS, **1996**. Effect of drought on oil, fatty acids and protein contents of groundnut (*Arachis hypogaea* L.) seeds. Field Crop Res, 48(2-3): 125-133.

**Edreva** A, Velikova V, Tsonev T, Dagnon S, Gürel A, Aktaş L, Gesheva E, **2008**. Stress-protective role of secondary metabolites: diversity of functions and mechanisms. General Appl Plant Physiol, 34(1-2): 67-78.

**Emamghoreishi** M, Khasaki M, Aazam F, **2005**. *Coriandrum sativum*: evaluation of its anxiolytic effect in the elevated plus-maze. J Ethnopharmacol, 96: 365-370.

**Flagella** Z, Rotunno T, Tarantito E, Caterina RD, Caro AD, **2002**. Changes in seed yield and oil fatty acid composition of high oleic sunflower (*Helianthus annuus* L.) hybrids in relation to the sowing date and the water regime. Eur J Agron, 17: 221-230.

**French** P, Stanton C, Lawless F, O'Riordan EG, Monahan FJ, Caffrey PJ, Moloney AP, **2000**. Fatty acid composition, including conjugated linoleic acid, of intramuscular fat from steers offered grazed grass, grass silage, or concentrate-based diets. J Anim Sci, 78: 2849-2855.

**Ghobadi** ME, **Ghobadi** M, **2012**. Effects of late sowing on quality of coriander (*Coriandrum sativum* L.). Int J Biol Biomol Agric Food Biotechnol Eng, 6(7): 425-428.

**Gil** A, De La Fuente EP, Lenardis AE, Pereira ML, Suarez SA, Arnaldo B, Van Baren C, Di Leo LP, Ghersa CM, **2002**. Coriander essential oil composition from two genotypes grown in different environmental conditions. J Agric Food Chem, 50: 2870-2877.

**Harshavardhan** PG, Vasundhara M, Shetty GR, Nataraja A, Sreeramu BS, Gowda MC, Sreenivasappa KN, **2007**. Influence of spacing and integrated nutrient management on yield and quality of essential oil in lemon balm (*Mellisa officinalis* L). Biomed, 2(3): 288-292.

**He** Y, Liu Y, Cao W, Huai M, Xu B, Huang B, **2005**. Effects of salicylic acid on heat tolerance associated with antioxidant metabolism in Kentucky bluegrass. Crop Sci, 45: 988-998.

**Isabelle** M, Lee BL, Lim MT, Koh WP. Huang D, Ong CN, **2010**. Antioxidant activity and profiles of common vegetables in Singapore. Food Chem, 120: 993-1003.

**Islam** M, Hasan MM, Xiong W, Zhang S, Lei C, **2009**. Fumigant and repellent activities of essential oil from *Coriandrum sativum* (L.) (Apiaceae) against red flour beetle *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). J Pest Sci, 82: 171-177.

**Jaworski** J, **Cahoon** EB, **2003**. Industrial oils from transgenic plants. Curr Opin Plant Biol, 6: 178-184.

**Kansal** L, Sharma A, Lodi S, **2012**. Potential health benefits of coriander (*Coriandrum sativum*): an overview. Int J Pharm Res Dev, 4(2): 10-20.

**Kansal** L, Sharma V, Sharma A, Lodi S, Sharma SH, **2011**. Protective role of *Coriandrum sativum* (coriander) extracts against lead nitrate induced oxidative stress and tissue damage in the liver and kidney in male mice. Int J Appl Bio Pharm Tech, 2(3): 65-83.

**Khan** W, Prithiviraj B, Smith DL, **2003**. Photosynthetic responses of corn and soybean to foliar application of salicylates. J Plant Physiol, 160: 485-492.

**Koocheki** A, Tabrizi L, Ghorbani R, **2009**. Effect of biofertilizers on agronomic and quality criteria of Hyssop (*Hyssopus officinalis*). Iran J Agron Res, 6(1): 127-137.

**Krishnakantha** TP, **Lokesh** BR, **1993**. Scavenging of superoxide anions by spice principles. Indian J Biochem Biophys, 30(2): 133-134.

**Larcher** W, **2000**. Ecofisiologia Vegetal. Rima, São Carlos –São Paulo.

**Laribi** B, Bettaieb I, Kouki K, Sahli A, Mougou A, Marzouk B, **2009**. Water deficit effects on caraway (*Carum carvi* L.) growth, essential oil and fatty acid composition. Ind Crop Prod, 30:372-379.

**Lee** JD, Oliva ML, Sleper DA, Shannon JG, **2008**. Irrigation has little effect on unsaturated fatty acid content in soybean seed oil within genotypes differing in fatty acid profile. J Agron Crop Sci, 194: 320-324.

**Lewinshon** E, Schalechet F, Wilkinson J, Matsui K, Tadmor Y, Nam K, Amar O, Lastochkin E, Larkov O, Ravid U, Hiatt W, Gepstein S, Pichersky E, **2001**. Enhanced levels of the aroma and flavor compound S-linalool by metabolic engineering of the terpenoid pathway in tomato fruits. Plant Physiol, 127: 1256-1265.

**Machado** ASR, De Azevedo EG, Da ponte MN, Sardinha RMA, **1993**. High pressure carbon dioxide extraction from coriander plants/ headspace analysis. J Essential Oil Res, 5: 645-649.

**Mahfouz** SA, **Sharaf Eldin** MA, **2007**. Effect of mineral vs. biofertilizer on growth, yield, and essential oil content of fennel (*Foeniculum vulgare* Mill). Int Agrophysics, 21(4): 361-366.

**Mandal** S, **Mandal** M, **2015**. Coriander (*Coriandrum sativum* L.) essential oil: Chemistry and biological activity. Asian Pac J Trop Biomed, 5(6): 421-428.

**Mckeon** TA, **Stumpf** PK, **1982**. Purification and characterization of the stearoil-acyl carrier protein desaturase and the acyl-acyl protein thioesterase from mature seeds of sunflower. J Biochem, 257(20): 12141-12147.

**Mekki** BB, El-Kholy MA, Mohamad EM, **1999**. Yield, oil and fatty acids contents as affected by water deficit and potassium fertilization in two sunflower cultivars. Egypt J Agron, 21(1): 67-85.

**Moradi** R, Nasiri-Mahallati M, Rezvani-Moghaddam P, Lakzian A, Nejad Ali A, **2011**. The effect of application of organic and biological fertilizers on quantity and quality of essential oil in fennel (*Foeniculum vulgare*). J Hortic Sci, 25(1): 25-33.

**Msaada** K, Hosni K, Ben-Taarit M, Chahed T, Hammami M, Marzouk B, **2009**. Changes in fatty acid composition of coriander (*Coriandrum sativum* L.) fruit during maturation. Ind Crop Prod, 29: 269-274.

**Msaada** K, Hosni K, Taarit MB, Chahed T, Marzouk B, **2007**. Variations in the essential oil composition from different parts of *Coriandrum sativum* L. cultivated in Tunisia. Italian J Biochem, 56(1): 47-52.

**Noreen** S, **Ashraf** M, **2008**. Alleviation of adverse effects of salt stress on sunflower (*Helionthus annus* L.) by exogenous application of salicylic acid: growth and photosynthesis. Pak J Bot, 40(4): 1657-1663.

**Nourafcan** H, Sefidkon F, Khaligi A, Mousavi A, Sharifi M. **2014**. Effects of salicylic acid on quality and quantity of essential oil components *in Lippia citriodora* H.B.K. Int J Biosci, 5(3): 252-259.

**Peter**, YYW, **Kitts** DD, **2005**. Studies on the dual antioxidant and antibacterial properties of parsley (*Petroselinum crispum*) and cilantro (*Coriandrum sativum*) extracts. Food Chem, 97: 505-515.

**Pino** J, Borges P, Roncal E, **1993**. The chemical composition of laurel leaf oil from various origins. Nahrung, 37: 592-595.

**Pino** JA, Rosado A, Fuentes V, **1996**. Chemical composition of the seed oil of *Coriandrum sativum* L. from Cuba. J Essent Oil Res, 8:97-98.

**Purseglove** JW, Brown EG, Green CL, Robbins SRJ, **1981**. Spices. Vol. 2, Longman, London & New York.

**Rahimi-Shokooh** A, Dehghani-Meshkani MR, Mehrafarin A, Khalighi-sigaroodi F, Naghdi-Badi H, **2013**. Changes in essential oil composition and leaf traits of basil (*Ocimum basilicum* L.) affected by bio-stimulators / fertilizers application. J Med Plant, 12(47): 83-92.

**Rakhshandeh** H, Sadeghnia HR, Ghorbani A, **2012**, Sleep-prolonging effect of *Coriandrum sativum* hydro-alcoholic extract in mice. Nat Prod Res, 26: 2095-2098.

**Ramadan** MF, **Mörsel** JT, **2003**. Analysis of glycolipids from black cumin (*Nigella sativa* L.), coriander (*Coriandrum sativum* L.) and niger (*Guizotia abyssinica* Cass.) oilseeds. *Food Chem*, 80: 197-204.

**Rashed** KN, **Butnariu** M, **2014**. Isolation and antimicrobial and antioxidant evaluation of bio-active compounds from *Eriobotrya japonica* stems. Adv Pharm Bull, 4(1): 75-81.

**Rashmi** KR, Earanna N, Vasundhara M, **2008**. Influence of biofertilizers on growth, biomass and biochemical constituents of *Ocimum gratissimum*. L. *Biomed*, 3(2): 123-130.

**Rowshan** V, Khosh Khoi M, Javidnia K, **2010**. Effects of salicylic acid on quality and quantity of essential oil components in *Salvia macrosiphon*. J Biol Environ Sci, 4(11): 77-82.

**Rustan** AC, Hustvedt B, Drevon CA, **1993**. Dietary supplementation of very long-chain n-3 fatty acids decreases whole body lipid utilization in the rat. J Lipid Res, 34: 1299-1308.

**Samojlik** I, Lakić N, Mimica-Dukić N, Daković-Svajce K, Bozin B, **2010**. Antioxidant and hepatoprotective potential of essential oils of coriander (*Coriandrum sativum* L.) and caraway (*Carum carvi* L.) (Apiaceae). J Agric Food Chem, 58: 8848-8853.

**Sangwan** NS, Farooqi AHA, Shabih F, Sangwan RS, **2001**. Regulation of essential oil production in plants. Plant Growth Regul, 34(1): 3-21.

**Selmar** D, **Kleinwächter** M, **2013**. Stress enhances the synthesis of secondary plant products: the impact of stress-related over-reduction on the accumulation of natural products. Plant Cell Physiol, 54: 817-826.

**Shahwar** MK, El-Ghorab AH, Anjum FM, Butt MS, Hussain S, Nadeem M, **2012**. Characterization of coriander (*Coriandrum sativum* L.) seeds and leaves: volatile and non-volatile extracts. Int J Food Properties, 15: 736-747.

**Sharma** AK, **2002**. Biofertilizers for sustainable agriculture. Agrobios, India, 407 p.

**Silva** F, Ferreira S, Duarte A, Mendonça DI, Domingues FC, **2011**. Antifungal activity of *Coriandrum sativum* essential oil, its mode of action against Candida species and potential synergism with amphotericin B. Phytomed, 19: 42-47

**Smallfield** B, John W, Nigel BP, Kenneth GD, **2001**. Coriander spice oil: Effects of fruit crushing and distillation time on yield and composition. J Agric Food Chem, 49: 118-123.

**Stymme** S, **Appelqvist** LA, **1980**. The biosynthesis of linoleate and linolenate in homogenate from developing soya been cotyledons. Plant Sci Lett, 17: 287-297.

**Suchankova** G, Tekle M, Saha AK, Ruderman NB, Clarke SD, Gettys TW, **2005**. Dietary polyunsaturated fatty acids enhance hepatic AMP-activated protein kinase activity in rats. Biochem Biophys Res Commun, 326: 851-858.

**Terés** S, Barceló-Coblijn G, Benet M, Álvarez R, Bressani R, Halver JE, Escribá PV, **2008**. Oleic acid content is responsible for the reduction in blood pressure induced by olive oil. Proc Natl Acad Sci, 105: 13811-13816.

**Tohidi Moghadam** HR, Zahedi H, Ghooshchi F, **2011**. Oil quality of canola cultivars in response to water stress and super absorbent polymer application. Pesq Agropec Trop Goiânia, 41(4): 579-586.

**Walter** CC, **2007**. The role of dietary n-6 fatty acids in the prevention of cardiovascular disease. J Cardiovasc Med, 8: S42-S45.

**Wangensteen** H, Samuelsen AB, Malterud KE, **2004**. Antioxidant activity in extracts from coriander. Food Chem, 88: 293-297.

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