Effect of Triple Superphosphate on Growth, Total Chlorophyll Content, Essential Oil and Fatty Acid Compositions in Shoots of Coriander (*Coriandrum sativum* L.)

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Abstract: The effect of different doses of triple superphosphate (TSP), 100, 200, and 400 kg P ha^{-1} on growth, chlorophyll content, and essential oil and fatty acid composition was evaluated in shoots of coriander (*Coriandrum sativum* L.) grown in a pot experiment under nursery conditions. The application of TSP to 6 weeks-old seedlings induced an increase in shoot height, shoot dry weight, the chlorophyll and total fatty acid contents. However, phosphate fertilizer did not affect the total essential oil content, expressed as % of dry weight. The major constituents of the essential oils are decanal, aromadendrene and α-cadinol. The total content of sesquiterpene hydrocarbons was strongly increased under 200 kg P ha^{-1} (1.9-fold). The essential oil components aromadendrene, cadalene, α-copaene, α-octan-2-ol and n-decanol, (E)-nerolidol, (E,E)-2,4-decadienal, and myrtenyl acetate, were also increased under phosphate fertilization. Threfore, triple superphosphate application induced changes in the composition of essential oils and fatty acids in coriander shoots, and significantly increased the terpenes and total lipid contents.

Keywords: *Coriandrum sativum*, essential oils, fatty acids, sesquiterpene hydrocarbons, total lipids, triple superphosphate.

INTRODUCTION

The medicinal and aromatic plants (MAPs) are recognized as an important source of biologically active compounds. These are commonly used in phytotherapy, perfumery, cosmetic, food and pharmaceutical industries. The MAPS contain volatile aliphatic and aromatic compounds including terpenes and phenolics [1]. The essential oils (EOs) are characterized by their medicinal and cosmetic activities and therefore are used in many industries including pharmaceutical, sanitary, cosmetics, etc. [2-4]. Coriander (*Coriandrum sativum* L.) is one of the most traditional medicinal plants commonly exploited for a wide variety of purposes, which include the use of essential oils as a flavor ingredient [5]. The EOs from different parts of coriander are characterized by antibacterial [6], antioxidant [7], antidiabetic [8], antifungal, acaricides, anti-inflammatory, anti-carcinogenic, and anti-mutagenic activities [9].

Fertilizers are presented as primary sources of plant nutrients nitrogen (N), phosphorus (P) and potassium (K) necessary to enhance the crop growth, development, and production. The phosphorus play an important role in physiological and biochemical processes including photosynthesis, carbohydrate metabolism, and energy transfer processes. It is also a component of sugar phosphates, nucleic acids, nucleotides, coenzymes, and phospholipids [10]. The phosphate rocks (PRs) are used for the production of phosphates fertilizers. In soils, these can lead to the formation of $H_2PO_4^-$ or HPO_4^{2-} associated with changes in soil pH. These anions can react with cationic species involving mainly Ca in alkaline soils, Fe and Al in acid soils, to form indissoluble metal phosphates responsible for low P mobility and bioavailability.

The aim of this study is to evaluate the changes in the content and composition of the essential oils and fatty acids in shoots of coriander grown under different doses of triple superphosphate, in a pot experiment.

MATERIALS AND METHODS

Plant Material and Growing Conditions

The coriander seeds (*Coriandrum sativum* L.) were collected from field-growing plants (autumn) in Menzel Temime (Northeastern Tunisia; latitude 36°46'17.80" N; longitude 10°46'03.38" E). The growing experiments were performed in the Belvedere (Tunis, Tunisia) in pots containing a sandy loam soils prepared by mixing fresh manure, top soil, grass waste, and lined with a 2 cm base of dead leaves. Seeds were sown on October

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27, 2009 at 8 seeds per pot. The seedlings were watered with 150 ml pot^{-1} of tap water twice per week and grown under natural daylight conditions at 14-29/15-23°C day/night.

Triple Superphosphate Treatment and Plant Harvest

Triple superphosphate (TSP) was added on December 9, 2009 to 6 week-old seedlings at a field rate of 0 (no added P), 100 (0.314 g P pot^{-1}), 200 (0.628 g P pot^{-1}) and 400 kg P ha^{-1} (1.256 g P pot^{-1}). The experiment was arranged in 4 blocks with three replicates of each treatment. The control and treated pots were irrigated once per week with 250 ml pot^{-1} with tap water. The plants (apical and basal leaves and stems) were harvested on January 11, 2010, 11 weeks after planting (4 weeks of treatment), weighed, dried at 60°C to weight constancy and weighed again. Growth parameters including shoot height (SH), shoot fresh weight (SFW) and shoot dry weight (SDW) were recorded. The chlorophyll content was determined according to Arnon [11].

Analysis of Essential Oils

Essential oils were isolated from fresh aerial parts of *Coriandrum sativum* L. by a simple laboratory quick-fit hydrodistillation system with distilled water (50 g/500 ml) for 90 min at 100°C [12,13]. The distillate was extracted with 2-methyl-butane (v/v) and dried over anhydrous sodium sulfate (Na_2SO_4), and concentrated under water refrigeration on a Vigreux column. Extraction was performed in triplicates; data are expressed in % (w/w) relative to the total content of essential oil ± SEM (dry weight basis).

Analysis of essential oils was carried out using high resolution gas chromatography (HRGC, Shimadzu GC-2010, Japan) equipped with a flame ionization detector (320°C), a nonpolar RTX-1 column of dimethyl polysiloxane (30 m × 0.32 mm × 0.25 µm, Restek, Bellefonte, PA, USA), and using the following temperature profile setup: injector at 230°C, isotherm 50°C for 10 min, ramped at 2°C min^{-1} to 190°C, then held isothermally for 10 min. Gas chromatography analysis was carried out in split mode (split ratio 1:40), employing N_2 as carrier gas (1.6 ml min^{-1} flow rate). The compounds in the essential oil were identified by comparing the retention times of the chromatogram peaks with those of authentic compounds run under identical conditions, by comparison of relative retention indices [14], and also by co-injection of authentic samples.

Analysis of Fatty Acids

The lipids were extracted from 2 g of triplicate samples of each treatment with chloroform/methanol mixture (2:1, v/v), according to the method of Folch *et al*. [15] modified by Bligh and Dyer [16]. The phospholipases were inactivated by immersing the sample in boiling water for 5 min [17]. The extract was washed with fixing water and kept at +4°C overnight. The aqueous non-lipid phase was removed and the chloroformic phase containing lipids was dried in an N_2 stream at 40°C, resuspended in toluene/ethanol mixture (4:1, v/v), and stored at -20°C.

The lipid extract was trans-esterified in 3% sodium methylate (v/v in methanol), using nonadecanoic acid (C19:0) as an internal standard. The resulting fatty acid methyl esters (FAME) were stored in sealed tubes. Analysis of the FAME was by GC-FID (gas chromatography-flame ionization detector) on a RT-2560 (biscyanopropyl polysiloxane) column (100 m × 0.25 mm × 0.2 µm). The GC injection port was set at 225°C in split mode (split ratio 1:20), with nitrogen as the carrier gas at a constant flow rate of 1.2 ml min^{-1}. The initial oven temperature was held constant at 170°C for 2 min; then the temperature was ramped at 4°C min^{-1} to 240°C and remains constant for 10 min. Fatty acids were identified by comparison of their retention times to those of pure standards. An estimation of the lipid total unsaturation level (double-bond index for fatty acids, DBI) was calculated from the percent values derived from the gas chromatographic data, according to the equation: [(1 × Σmol% monoenoic) + (2 × Σmol% dienoic) + (3 × Σmol% trienoic)] /100.

Statistical Analysis

Means were compared using one-way ANOVA ($P < 0.05$) and Student-Newman-Keuls multiple range tests (SPSS 11.5).

RESULTS AND DISCUSSION

Effect of Triple Superphosphate on Growth Parameters

Triple superphosphate (TSP) applied to the rates of 100, 200 and 400 kg P ha^{-1} lead to a important increase ($P < 0.01$) in shoot height (12.8, 38.7 and 77.4%, respectively), compared to non-treated control plants (Figure **1A**). Similarly, Saharkhiz and Omidbaigi [18] have shown that TSP supply to feverfew (*Tanacetum parthenium* L.) plants resulted in a

consequential increase in plant height. However, this was not considerably affected in Cumin (*Cuminum cyminum* L.) by additions of 20, 40 and 60 kg P ha^{-1}, supplied as TSP [19]. Results also indicate that the high P application significantly increased shoot dry weight, much more pronounced in plants treated with 400 kg P ha^{-1} (42.1%, $P < 0.001$), compared with the control (Figure **1B**). Nevertheless, similar increases by about 24% were observed by the addition of 100 and 200 kg P ha^{-1}. These results suggest that TSP produce an enhancing effect on plant growth. Similar results were reported for *Tanacetum parthenium* L. where the supply of phosphate at 100 kg P ha^{-1} resulted in a significant increase in dry weight [18]. However, seed weight in cumin (*Cuminum cyminum* L.) was reduced with increasing application of TSP [19]. Moreover, TSP application led in significantly higher content of total chlorophylls (31–39%, $P < 0.001$) than in the control plants (Figure **1C**).

Effect of TSP on the Yield and Composition of Essential Oils

The main components of essential oil of aerial parts of *Coriandrum sativum* L., were identified as members of nine groups, including aldehydes (24.1%), sesquiterpene hydrocarbons (16.1%), sesquiterpene alcohols (10.6%), ethers (5.8%), aliphatic alcohols (3.9%), alkanes (3.3%), terpene esters (2.9%),

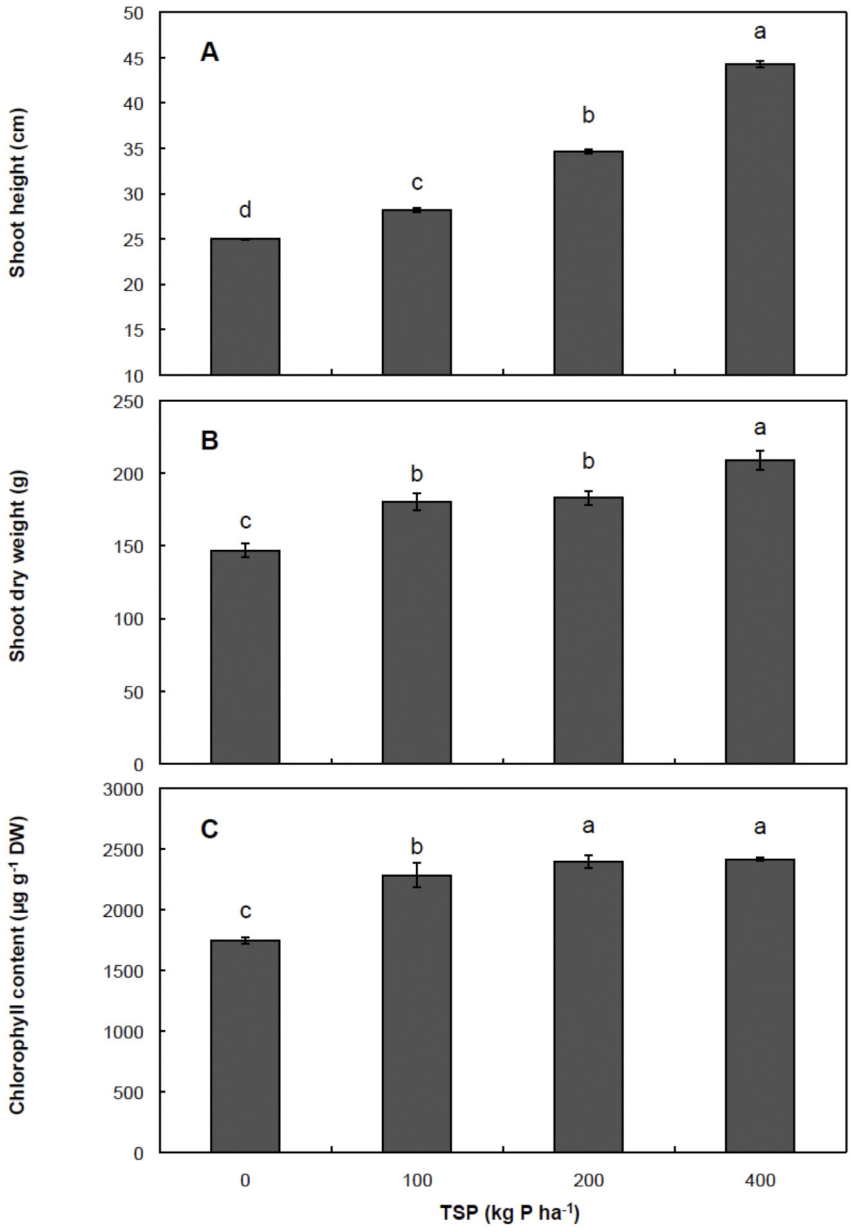

Figure 1: Effect of TSP rate on (**A**) shoot height (SH), (**B**) shoot dry weight (SDW) and (**C**) chlorophyll (Chl) content of coriander (*Coriandrum sativum* L.).

Table 1: The Effect of TSP on the Chemical Composition (%) of Essential Oils in Coriander (*Coriandrum sativum* L.) Shoots

	TSP (kg P ha^{-1})			
	0	**100**	**200**	**400**
Sesquiterpene hydrocarbons	16.10 ± 2.53^{b}	22.01 ± 4.23^{ab}	30.58 ± 0.94^{a}	23.93 ± 1.14^{ab}
Aldehydes	24.09 ± 1.15^{a}	22.07 ± 1.53^{a}	24.59 ± 2.54^{a}	25.33 ± 4.14^{a}
Sesquiterpene alcohols	10.57 ± 0.70^{a}	12.71 ± 3.58^{a}	15.00 ± 1.61^{a}	16.02 ± 4.31^{a}
Terpene esters	2.90 ± 1.32^{a}	3.13 ± 0.85^{a}	4.66 ± 0.50^{a}	5.40 ± 0.25^{a}
Ethers	5.81 ± 1.46^{a}	3.91 ± 0.02^{a}	3.05 ± 0.33^{a}	5.13 ± 0.51^{a}
Aliphatic alcohols	3.89 ± 0.99^{a}	4.14 ± 0.51^{a}	5.94 ± 0.33^{a}	4.52 ± 0.02^{a}
Monoterpene alcohols	1.09 ± 0.31^{a}	1.12 ± 0.13^{a}	1.40 ± 0.18^{a}	1.81 ± 0.29^{a}
Alkanes	3.26 ± 0.77^{a}	ND	ND	ND
Monoterpene hydrocarbons	0.50 ± 0.17^{a}	ND	ND	ND

Data are expressed as mean ± SEM (dry weight basis) of three replicates. Values designated with different letters indicate significant differences within a row at $P < 0.05$ (ANOVA). ND. Not detected.

monoterpene alcohols (1.1%), and monoterpene hydrocarbons (0.5%), as shown in Table **1**. Triple superphosphate at 200 kg P ha^{-1} strongly increased the yield of sesquiterpene-hydrocarbons by 1.9– fold. However, there was no significant effect of TSP treatment on any of the other constituents (Table **1**). No significant changes were found for the total essential oil yield, as % (w/w) relative to dry weight (Figure **2**). The results also showed that TSP application led to changes in the essential oil composition of coriander shoots. Twenty three compounds were identified in the hydrodistillation extract by GC, as shown in Table **2**. The chemical composition of essential oils, expressed as % (w/w) relative of the total oil content revealed that decanal was the major component (18.1%) in the control extract, followed by aromadendrene (8.5%), and α-cadinol (8.3%). Triple superphosphate supply at 200 and 400 kg P ha^{-1} led to a significant increase in aromadendrene (1.6 and 2.0-fold, respectively), while there were no significant differences in decanal and α-cadinol between treatments. Alpha-copaene (4.74%) and octan-2-ol (0.23%) showed 1.8- and 5.6-fold increase at 200 kg P ha^{-1}, whereas (E)-nerolidol (0.96%) showed 2.1-fold increase at 400 kg P ha^{-1}. When TSP was applied at 200 and 400 kg P ha^{-1}, (E,E)-2,4-decadienal (2.72%), decanol (1.65%), cadalene (0.84%), and myrtenyl acetate (0.76%) were increased significantly from 1.6– to 4.6– fold. Although β-pinene, β-caryophyllene, heptadecane, nonadecane, (E)-phytol and heneicosane were found in control extract, they were not detected in any of TSP-treated samples. The effects of TSP on essential oil yield have been previously studied in *Tanacetum parthenium* L. grown under 50, 100, and 150 kg P ha^{-1} [18]. Similar results were obtained in *Origanum majorana* [20], *Ocimum basilicum* [21], and *Nigella sativa* [22]. The essential oil composition has been studied in Tunisian coriander (*Coriandrum sativum* L.) and the major compounds in different plant organs (flowers, leaves, stems and roots) were identified as (E)-2-dodecenal, (E)-2-tridecenal, γ-cadinene, (Z)-myroxide, neryl acetate and eugenol [12]. Aldehydes and alcohols were found to be the major essential oil constituents of *Coriandrum sativum* L. leaves and 2E-decenal, decanal, 2E-decen-1-ol and n-decanol were the major compounds [2]. Many studies have shown changes in the essential oil content and composition under a variety of environmental constraints. Thus, low and moderate salinity conditions were associated with an increase in essential oil content in coriander shoots, while severe stress caused a significant decrease [23]. Salt treatments significantly affected the essential oil in clary sage (*Salvia sclarea* L.) rosette leaves; an increase in the essential oil yield was observed at 25 mM NaCl, but a decrease with increasing salt concentrations [24]. However, this constraint has led to a decrease in essential oil yields in roots and aerial tissues of safflower (*Carthamus tinctorius* L.) which is associated with a significant change in the oxygenated compounds in both organs [25]. In marjoram (*Origanum majorana*) shoots, salinity significantly decreased the yield of essential oil characterized by trans-sabinene hydrate, terpinen-4-ol and cis-sabinene hydrate [26]. Furthermore, recent work has shown that salinity significantly increases the essential oil yield of *Coriander sativum* L. fruits, as well as the content of the major components, linalool and camphor [27]. Moderate water deficit decreased the seed oil yield in

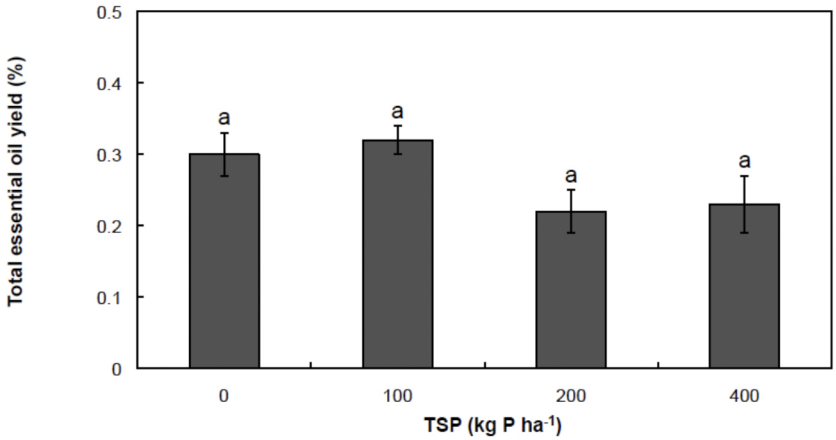

Figure 2: Effect of TSP rate on the total essential oil yield of coriander (*Coriandrum sativum* L.) shoots.

Table 2: The Effect of TSP on the Essential Oil Composition (%) of Coriander (*Coriandrum sativum* L.) Shoots

N	Volatile compounds	RT[a]	RI[b]	TSP (kg P ha^{-1})			
				0	100	200	400
1	β-Pinene	8.87	977	0.50 ± 0.17	ND	ND	ND
2	Octan-2-ol	9.51	988	0.23 ± 0.08^{b}	0.58 ± 0.06^{ab}	1.28 ± 0.32^{a}	0.65 ± 0.38^{ab}
3	Linalool	16.74	1082	1.08 ± 0.31^{a}	1.11 ± 0.15^{a}	1.40 ± 0.17^{a}	1.81 ± 0.36^{a}
4	Decanal	24.61	1183	18.07 ± 1.24^{a}	14.44 ± 2.88^{a}	15.09 ± 2.77^{a}	14.43 ± 1.57^{a}
5	Carvacryl methyl oxyde	28.39	1223	5.81 ± 1.46^{a}	3.91 ± 0.03^{a}	3.05 ± 0.33^{a}	5.13 ± 0.62^{a}
6	Linalyl acetate	29.82	1237	2.14 ± 1.02^{a}	1.87 ± 0.77^{a}	2.25 ± 0.45^{a}	2.88 ± 0.06^{a}
7	Perillaldehyde	30.19	1240	3.30 ± 1.76^{a}	4.54 ± 0.53^{a}	5.13 ± 0.21^{a}	3.70 ± 3.53^{a}
8	Decanol	32.04	1258	1.65 ± 0.30^{b}	2.43 ± 0.21^{ab}	3.20 ± 0.27^{a}	2.94 ± 0.02^{a}
9	(*E,E*)-2,4-decadienal	35.6	1291	2.72 ± 0.40^{c}	3.08 ± 0.46^{c}	4.37 ± 0.26^{b}	7.20 ± 0.03^{a}
10	Myrtenyl acetate	36.8	1309	0.76 ± 0.30^{b}	1.25 ± 0.26^{b}	2.42 ± 0.10^{a}	2.53 ± 0.24^{a}
11	α-Copaene	38.99	1372	4.74 ± 0.67^{b}	6.33 ± 1.44^{ab}	8.62 ± 0.19^{a}	ND
12	β-Caryophyllene	41.53	1425	0.21 ± 0.03	ND	ND	ND
13	Aromadendrene	42.38	1438	8.48 ± 1.25^{c}	11.23 ± 2.54^{bc}	13.73 ± 0.75^{ab}	16.85 ± 0.23^{a}
14	α-Humulene	43.36	1454	1.83 ± 0.58^{a}	2.41 ± 1.51^{a}	4.39 ± 0.85^{a}	4.14 ± 0.40^{a}
15	Cubebol	45.5	1487	0.78 ± 0.08^{a}	1.12 ± 0.35^{a}	1.46 ± 0.18^{a}	0.93 ± 0.43^{a}
16	(*E*)-Nerolidol	48.72	1541	0.96 ± 0.13^{b}	1.43 ± 0.45^{ab}	1.53 ± 0.16^{ab}	2.00 ± 0.26^{a}
17	Ledol	51.63	1589	1.32 ± 0.22^{a}	1.26 ± 0.58^{a}	1.96 ± 0.16^{a}	1.37 ± 0.55^{a}
18	α-Cadinol	54.73	1644	8.29 ± 0.49^{a}	10.02 ± 3.36^{a}	11.49 ± 1.35^{a}	12.66 ± 4.47^{a}
19	Cadalene	55.38	1655	0.84 ± 0.16^{c}	2.04 ± 0.32^{bc}	3.84 ± 0.19^{a}	2.94 ± 1.23^{ab}
20	Heptadecane	57.41	1700	0.21 ± 0.03	ND	ND	ND
21	Nonadecane	68.46	1900	0.35 ± 0.11	ND	ND	ND
22	(*E*)-phytol	76.92	2078	1.23 ± 0.62	ND	ND	ND
23	Heneicosane	77.7	2100	2.70 ± 0.64	ND	ND	ND
	Total identified			71.07	71.38	87.76	86.17

Data are expressed as mean ± SEM (dry weight basis) of three replicates. Values designated with different letters indicate significant differences within a row at $P < 0.05$ (ANOVA). [a] Retention time, [b] Kovats retention index, ND, Not detected.

caraway [28], but increased that in cumin [29]. However, the severe water deficit caused an oil yield reduction in the latter species [29]. The effect of microbial and chemical sources of phosphorus supply

on the yields and chemical composition of essential oil has been examined in rose-scented geranium (Pelargonium species) grown in a sodic soil. Essential oil yields were increased significantly by application of Arbuscular mycorrhizal (AM) fungi, phosphate-solubilizing bacteria (PSB) or P fertilizers. While co-inoculation with AM fungi and PSB increased the contents of monoterpenes, citronellol, geraniol, geranial, and sesquiterpene 10-epi-γ eudesmol, P fertilizers only enhanced the content of a sesquiterpene, the 10-epi-γ eudesmol [30].

Our study showed that application of TSP at different rates resulted in a significant increase in chlorophyll content. By studying the essential oil profiles, of coriander shoots, it was shown that TSP leads to significant increases in sesquiterpene compounds (aromadendrene, α-copaene, cadalene and (E)-nerolidol). Monoterpenes, sesquiterpenes, and phytol, a constituent of chlorophylls, are characteristic metabolites of the terpenoids (or isoprenoids) [31,32]. Plants synthesize a large number of isoprenoid compounds that are diverse in structure and function [33,34]. All terpenoids are synthesized from two C5 isoprenoid precursors: isopentenyl diphosphate (IPP) and dimethylallyl diphosphate (DMAPP) (Figure **3**). Two pathways are used by higher plants for the biosynthesis of IPP and DMAPP: the mevalonate pathway (MVP) in the cytosol and the non-mevalonate, a 2-C-methyl-D-erythritol 4-phosphate (MEP) pathway in the plastids [35-37]. The MEP pathway has been involved in the biosynthesis of essential oils in aromatic plants [38]. The mevalonic acid (MVA) also provides precursors for the monoterpene biosynthesis as has been reported in strawberry fruits and foliage [39]. The 1-deoxy-D-xylulose-5-phosphate reductoisomerase (DXR) and the 1-deoxy-D-xylulose 5-phosphate synthase (DXS) of the MEP pathway, have been shown to play an important role in the regulation of terpenoid biosynthesis in plants [40]. Therefore, up-regulation of the genes involved in the terpene biosynthesis may represent one mechanism leading to enhanced isoprenoid compounds. Hence, overexpression of *DXS* significantly increased the production of essential oil production in lavender leaves and flowers, *via* the MEP pathway [41], and to the increase in the chlorophyll and carotenoid biosynthesis in Arabidopsis [42]. The up-regulation of *DXR* gene resulted in accumulation of large amounts of essential oil in peppermint (*Mentha x piperita* L.) leaves, while *DXR* gene silencing led to decreased essential oil concentration [38]. Thus, the up-regulation of *DXS* and *DXR* genes acting upstream of terpene synthase (*TPS)* gene could result in increased precursor pools, and therefore, lead to enhanced oil yield.

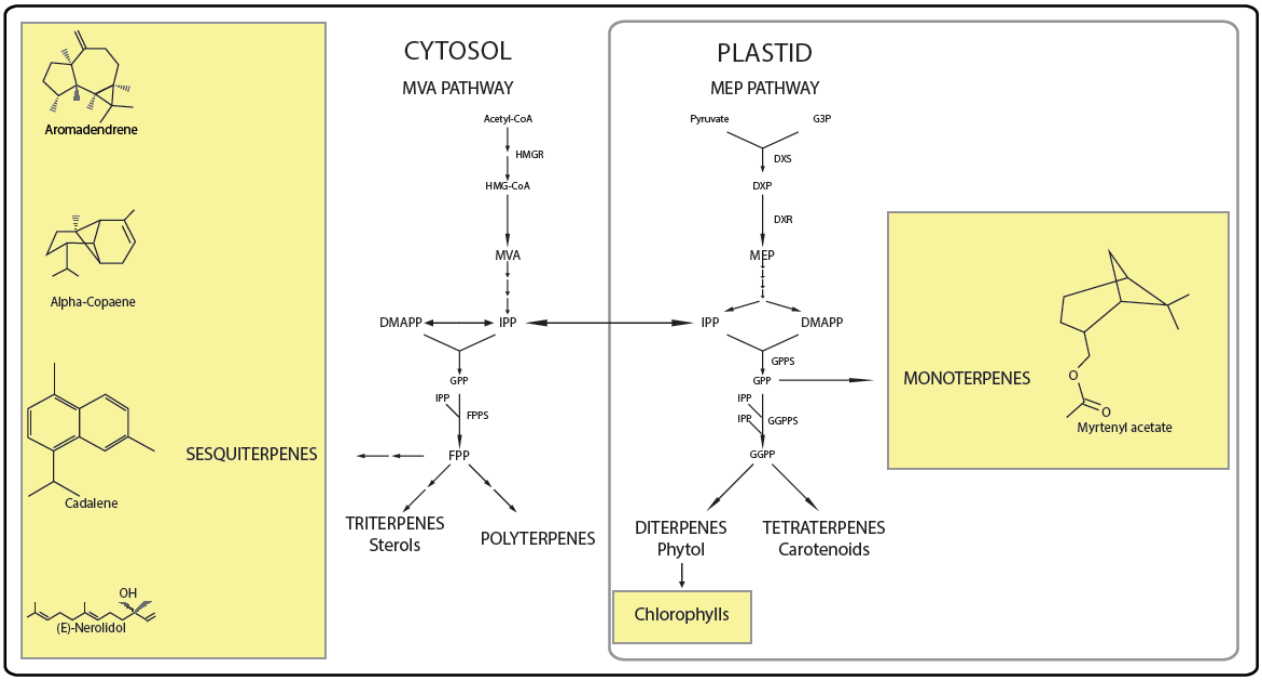

Figure 3: The isoprenoid (terpenoid) biosynthetic pathway in plants. Chemical structures of representative mono- and sesquiterpenes specifically accumulated in response to TSP are highlighted in yellow. FPP, farnesyl diphosphate; FPPS, farnesyl diphosphate synthase; G3P, D-glyceraldehyde 3-P; GGPP, geranylgeranyl diphosphate; GGPPS, geranylgeranyl diphosphate synthase; GPPS, GPP synthase; HMG-CoA, 3-hydroxy-3-methylglutaril-CoA HMGR, 3-hydroxy-3-methylglutaryl CoA reductase.

Effects of TSP on the Composition and Content of Fatty Acids

The fatty acid composition (expressed as % of total FA) of *C. sativum* shoots (Table **3**) is characterized by high unsaturated FAs (81.9%) with the major fatty acids being linolenic acid (31.7%), followed by linoleic (29.2%) and oleic (15.3%) acid, against 17.7% for saturated FA (palmitic, stearic and arachidic). Palmitoleic (C16:1), margaric (C17:0), heptadecenoic (C17:1), stearic (C18:0), petroselinic (C18:1Δ6) and arachidic (C20:0) acids represent the minor components (8.1% of the total FAs). P fertilizer at rates of 100, 200, and 400 kg P ha^{-1} significantly increased ($P < 0.05$) the levels of oleic acid, by 22.6, 28.2 and 19.3%, respectively, while there was no significant percentage change in the linoleic, and linolenic acids. However, arachidic acid was not detected in any of fertilized treated plants, in contrast to control. There were no TSP effects on the mono- (MUFA), poly- (PUFA), total saturated (SFA) and the total unsaturated fatty acids (UFA), as well as on the fatty acid double bond index (DBI). Significant increases ($P < 0.001$) in total fatty acid (TFA) content of 3.7 and 12.2% were observed following the additions of 100 and 400 kg P ha^{-1}, respectively, as shown in Figure **4**. There is a significant ($P < 0.001$) decrease of the TFA content by 38.6% in response to application of 200 kg P ha^{-1}. TSP treatment significantly altered the contents of individual FAs, expressed as mg g^{-1} DW (Table **4**). There was a significant ($P < 0.01$) increase in palmitic acid content of 26.2 and 24.9% (dry weight basis) in pots receiving 100 and 400 kg P ha^{-1}, respectively, whereas a significant ($P < 0.01$) decrease of 24% was observed in plants fertilized at a rate of 200 kg P ha^{-1}. The oleic acid (C18:1Δ9) levels showed significant increases ($P < 0.01$) of 27.5 and 35.7% in plants amended by 100 and 400 kg P ha^{-1}, respectively, whereas they decreased significantly ($P < 0.01$) by 14.7% under 200 kg P ha^{-1}. However, there were no significant differences in linoleic acid (C18:2) content between treatments. Plants supplied with 400 kg P ha^{-1} showed a significant ($P < 0.05$) increase of 16% in linolenic acid (C18:3) content. Moreover, TSP supply induced an increase of TFA content in response to 100 and 400 kg P ha^{-1}. The linolenic acid which is predominant in control plants, showed no significant variation under TSP treatment. It's well-known that plasma membrane exhibits structural changes in response to varied environments, thus maintaining membrane fluidity, and permeability [43]. Salinity was found to influence significantly the FA composition [44,45]. Our results showed that FAs in the extracts of coriander leaves

Table 3: Effect of TSP on the Fatty Acid Composition (% of TFA) of Coriander Shoots

No	Fatty acids	TSP (kg P ha^{-1})			
		0	100	200	400
1	C16:0 (Palmitic acid)	15.56 ± 0.83^{a}	18.91 ± 1.78^{a}	17.78 ± 0.24^{a}	17.11 ± 0.10^{a}
2	C16:1 (Palmitoleic acid)	1.61 ± 0.20^{a}	2.06 ± 0.05^{a}	1.93 ± 0.18^{a}	1.80 ± 0.24^{a}
3	C17:0 (Heptadecanoic acid)	0.29 ± 0.04^{a}	0.56 ± 0.19^{a}	0.54 ± 0.06^{a}	0.40 ± 0.14^{a}
4	C17:1 (Heptadecenoic acid)	0.95 ± 0.12^{a}	1.30 ± 0.20^{a}	0.94 ± 0.06^{a}	1.02 ± 0.42^{a}
5	C18:0 (Stearic acid)	0.56 ± 0.05^{a}	0.87 ± 0.20^{a}	0.81 ± 0.14^{a}	0.77 ± 0.08^{a}
6	C18:1Δ6 (Petroselinic acid)	0.80 ± 0.13^{b}	3.87 ± 0.83^{a}	0.66 ± 0.04^{b}	0.67 ± 0.14^{b}
7	C18:1Δ9 (Oleic acid)	15.34 ± 1.45^{a}	18.81 ± 0.56^{b}	19.66 ± 0.99^{b}	18.30 ± 0.79^{ab}
8	C18:2 (Linoleic acid)	29.23 ± 3.61^{a}	23.17 ± 0.73^{a}	23.71 ± 0.68^{a}	22.12 ± 1.69^{a}
9	C18:3 (Linolenic acid)	31.72 ± 4.73^{a}	31.61 ± 2.46^{a}	32.78 ± 0.77^{a}	32.40 ± 3.37^{a}
10	C20:0 (Arachidic acid)	1.61 ± 1.37^{a}	ND	ND	ND
	SFA	18.03 ± 0.54^{a}	20.34 ± 2.16^{a}	19.14 ± 0.44^{a}	18.28 ± 0.14^{a}
	MUFA	21.03 ± 0.66^{a}	24.87 ± 1.10^{a}	24.37 ± 1.24^{a}	27.20 ± 4.93^{a}
	PUFA	60.95 ± 1.15^{a}	54.78 ± 2.98^{a}	56.49 ± 1.07^{a}	54.52 ± 5.03^{a}
	UFA	81.97 ± 0.54^{a}	79.66 ± 2.16^{a}	80.86 ± 0.44^{a}	81.72 ± 0.14^{a}
	DBI	1.75 ± 0.06^{a}	1.66 ± 0.07^{a}	1.70 ± 0.02^{a}	1.69 ± 0.08^{a}

Data are expressed as mean ± SEM (dry weight basis) of three replicates. Values designated with different letters indicate significant differences within a row at $P < 0.05$ (ANOVA). DBI, double bond index; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; UFA, unsaturated fatty acids. ND, Not detected.

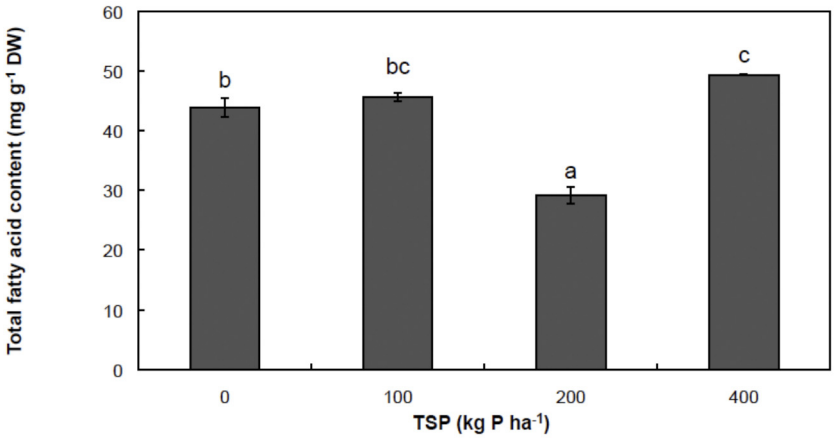

Figure 4: Effect of TSP on the total fatty acid (TFA) content of coriander shoots.

Table 4: Effect of TSP on the Fatty Acid Contents (mg g^{-1} DW) of Coriander Shoots

Fatty acids	TSP (kg P ha^{-1})			
	0	100	200	400
C16:0	6.83 ± 0.75^{b}	8.62 ± 1.36^{c}	5.20 ± 0.52^{a}	8.53 ± 0.11^{c}
C16:1	0.71 ± 0.15^{ab}	0.94 ± 0.01^{b}	0.56 ± 0.08^{a}	0.89 ± 0.20^{b}
C17:0	0.13 ± 0.03^{a}	0.25 ± 0.14^{a}	0.15 ± 0.03^{a}	0.19 ± 0.12^{a}
C17:1	0.41 ± 0.10^{a}	0.59 ± 0.15^{a}	0.27 ± 0.04^{a}	0.50 ± 0.35^{a}
C18:0	0.24 ± 0.05^{a}	0.39 ± 0.15^{a}	0.24 ± 0.08^{a}	0.38 ± 0.07^{a}
C18:1Δ6	1.36 ± 1.73^{a}	1.23 ± 0.96^{a}	0.53 ± 0.60^{a}	3.02 ± 4.63^{a}
C18:1Δ9	6.75 ± 1.33^{a}	8.58 ± 0.62^{b}	5.74 ± 0.07^{a}	9.13 ± 0.63^{b}
C18:2	12.83 ± 2.64^{a}	10.57 ± 0.58^{a}	6.94 ± 0.88^{a}	11.40 ± 5.55^{a}
C18:3	13.93 ± 3.80^{ab}	14.44 ± 2.23^{ab}	9.57 ± 0.79^{a}	16.17 ± 2.81^{b}
C20:0	0.70 ± 1.02^{a}	ND	ND	ND

Data are expressed as mean ± SEM (dry weight basis) of three replicates. Values designated with different letters indicate significant differences within a row at $P < 0.05$ (ANOVA). ND, Not detected.

are predominantly of the polyunsaturated types that are taken to be the main constituents of membrane lipids and precursors of molecules involved in signal transduction [46,47]. The degree of FA unsaturation is involved in maintaining the membrane fluidity, and its different biological functions [48]. Previously, the content of FAs was shown to decrease significantly in Tunisian coriander plants grown under salt treatments [23]. Similarly, the FA content of apical and basal leaves was reduced by salt treatments [49]. Moreover, salt treatment leads to a decrease in total lipid content and to concomitant changes to the FA composition in both roots and shoot, and causing a decrease in degree of FA unsaturation [25]. The FA composition was analyzed in two varieties of an important aromatic plant, marjoram (*Origanum majorana* L.) grown under saline conditions [50]. Salt treatment led to increased FA content in both varieties. Water deficit has shown to induce changes in FA composition of caraway (*Carum carvi* L.) seeds where petroselinic acid was decreased [28]. Petroselinic, palmitic, and linoleic are the major FAs in cumin (*Cuminum cyminum* L.) seeds [29]. The water deficit altered the seed FA profile by increasing the relative content of palmitic acid. Moreover, the lipid content and proportions of FAs (palmitic, stearic and arachidic acids) of clary sage (*Salvia sclarea* L.) rosette leaves showed a significant decrease under salt stress [51].

CONCLUSION

Overall, this study provides new insights about the effect of TSP on the growth, oil yield and oil and fatty acid compositions of coriander. Thus, an increase in the accumulation of terpene metabolites in the essential oil of coriander, after addition of TSP, may be due to activation of the terpene biosynthesis pathways.

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