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***In vitro* evaluation of essential oils from Mediterranean aromatic plants of the Lamiaceae for weed control in tomato and cotton crops**

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ABSTRACT

We studied the potential allelopathic activity of seven essential oils against two crops (tomato and cotton) and 5 weeds (*Amaranthus retroflexus*, *Echinochloa crus-galli*, *Oryza sativa*, *Portulaca oleracea* and *Setaria verticillata*). The essential oils examined originated from *Lavandula stoechas*, *L. angustifolia*, *Mentha spicata*, *Origanum onites*, *O. vulgare* ssp. *hirtum*, *Salvia fruticosa* and *S. pomifera*. In *in-vitro* experiments, we determined the effect of these essential oils and their constituents on seedling emergence and growth of target species. The oils of *M. spicata*, *O. onites* and *O. vulgare* ssp. *hirtum* severely affected both weed and crop species. Among the weeds, *A. retroflexus* was most sensitive, whereas *O. sativa* and *E. crus-galli* were least sensitive. Cotton proved the most sensitive of all species. The essential oils that originated from *Lavandula* and *Salvia* spp. showed good efficacy against *A. retroflexus* and *P. oleracea*, without severely affecting the tomato, hence, they have a high potential to be used as selective herbicides for weed control in tomato fields.

Keywords: Allelopathy, lavender, mint, oregano, sage, seed germination, seedling growth, selective herbicide, stimulation, volatile oils

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INTRODUCTION

Many studies have shown that seedling emergence and growth are affected by the volatile isoprenoid compounds that make the essential oils of aromatic plants (5,14,15,17,19). Mostly inhibitory effects are observed but stimulatory effects are also recorded, particularly at low concentrations (3,9,13). In plant-plant interactions, effects on plant germination and growth depend on the aromatic plant that serves as essential oil-donor; the effects may vary both among and within species of aromatic plants reflecting the quantitative and qualitative differences in essential oil composition of species, populations and even individuals of the same species (4,10,12,15,18). Effects also vary depending on the target species. These results indicate that the use of aromatic plants, essential oils and their constituents as weed control agents is quite promising in a more environmentally friendly agriculture. However, since effects are affected by many factors more research is needed on their activity and their selectivity before their use in practice.

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Of the compounds tested, L-terpineol and geraniol proved good seed germination inhibitors of several weeds without any adverse effect on soybean (17), whereas rosemary essential oils, rich-in-1,8 cineole, are strong germination inhibitors of weed species without adverse effects on germination of pepper (2). Tomato and cotton are major crops of Greece, a country rich in aromatic plants. Therefore, we examined several essential oils produced by Mediterranean aromatic plants for their selectivity on these two crop species and their activity against their weed species. In particular, we studied the effect of three concentrations of essential oils produced by two sage, two lavender, two oregano and one mint species on seed germination and further growth of tomato and cotton, as well as of redroot pigweed, barnyardgrass, purslane, foxtail, and red rice. Effects of essential oils were compared with those produced by the application of individual isoprenoid compounds.

MATERIAL AND METHODS

The seven aromatic plants (family Lamiaceae) used in this study were: *Lavandula angustifolia* Mill., *L. stoechas* L., *Mentha spicata* L., *Origanum onites* L., *O. vulgare* ssp. *hirtum* (Link) Ietswaart, *Salvia fruticosa* Mill. and *S. pomifera* L.. The target test species were 2 annual crops [tomato (*Solanum lycopersicum* L., Solanaceae) and cotton (*Gossypium hirsutum* L., Malvaceae)] and 5 annual weeds [red rice (*Oryza sativa* L., Poaceae), redroot pigweed (*Amaranthus retroflexus* L., Amaranthaceae), purslane (*Portulaca oleracea* L., Portulacaceae), foxtail (*Setaria verticillata* (L.) Beauv., Poaceae) and two biotypes of barnyardgrass (*Echinochloa crus-galli* (L.) Beauv., Poaceae) with awned and awnless spikelets]. In Greece, redroot pigweed and purslane are major weeds in tomato and redroot pigweed, barnyardgrass and foxtail in cotton crop. Red rice is common in rice fields and in rotational crops after rice.

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We also examined the effect of major constituents of the essential oils used: (i). carvacrol, (ii). thujone, (iii). fenchone and (iv). 1,8 cineole, which are known as effective germination and growth inhibitors (21) against tomato, redroot pigweed, foxtail and both types (awned and awnless) of barnyardgrass. The full description of these compounds, commercially provided (Sigma-Aldrich) is given in Table 5. Carvacrol and thujone were applied at rates of 10 µl reflecting their approximate content in *Origanum* and *S. pomifera* essential oils. Fenchone and 1,8 cineole were not tested alone, but as a mixture including rates relative to their concentration in *L. stoechas* essential oil (Table 1). Finally, carvone was tested at a rate similar to carvacrol.

The tomato and cotton seeds, the isoprenoid compounds and lavender were purchased from seed and chemical suppliers (Table 1). The rest of the aromatic plants examined were collected from their naturally growing areas, while, weed-species seeds were collected from the fields of Aristotle University Farm.

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Essential oil isolation and identification

We water-distilled the leaves of aromatic plants (about 20-30 g) for 2 h in a Clevenger apparatus. The essential oils extracted were analyzed by gas chromatography (Varian 3700) as per conditions described previously (24). We identified the major

Table 1. Chemical composition and source of the essential oils used

Plant species	Essential oil constituents	Oil content (%)	Source
<i>Lavandula angustifolia</i> Mill.	Linalool	43	Market
	Linalyl acetate	30	
<i>Lavandula stoechas</i> L.	Fenchone	37	Macedonia,
	1,8-cineole	28	Greece
<i>Mentha spicata</i> L.	Trans-Piperitone oxide	82	Lesvos island, Greece
<i>Origanum onites</i> L.	Carvacrol	72	Lesvos island, Greece
<i>Origanum vulgare</i> L. ssp. <i>hirtum</i> (Link) Ietswaart	Carvacrol	66	Lesvos island, Greece
<i>Salvia fruticosa</i> Mill.	1,8-Cineol	36	Crete island, Greece
	Camphor	17	Greece
<i>Salvia pomifera</i> L.	α -Thujone	48	Crete island, Greece
	β -Thujone	28	Greece

constituents on the basis of references concerning retention times and the chemical profile of each aromatic plant (6,7,8,20,22,23). In addition, we co-chromatographed authentic samples of compounds to cross-check the identity of constituents.

Bioassays

We conducted preliminary experiments (Table 2) at two temperature regimes (15°C and 25°C), with seeds pre- or not exposed to high temperature (65 °C for 48 h). The seed germination test was conducted in dark, using Petri dishes (9 cm, dia) For these experiments, 10 to 50 seeds (Table 2), depending on the species seed size, were placed at the bottom of each Petri dish having two filter papers and 15 ml distilled water. The essential oils or the individual compounds tested were added in a small aluminum container, placed inside the Petri dish, so that there was only aerial contact with the seeds. Following that, the Petri dishes were closed with adhesive tape to avoid escape of the volatile compounds and were incubated for 6 days. A 7 x 4 factorial experiment [7 essential oils x 4 concentrations (0 μ l, 1 μ l, 5 μ l and 10 μ l)] was used for the essential oil treatments and a complete randomized design (CRD) was applied with three replicate Petri dishes for each combined treatment. Taking into account the volume of the Petri dishes, the rates used of 1 μ l, 5 μ l and 10 μ l, correspond to concentrations of 10, 50 and 100 ppm

The individual compounds were tested against one crop and three weed species, at one rate (7 or 8 μ l). A CRD with three replicate Petri dishes for each treatment was used. Analysis of variance was performed on the collected data. For both the essential oil and the compound treatments, LSD tests were used to detect and separate seed germination and seedling length mean treatment differences at $P = 0.05$. For all statistical analyses the Statistica 6.0 (2001) StatSoft Inc. software was used. After statistical analysis, the seed germination and seedling length data were expressed as percentages of the untreated control.

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Table 2. Seed germination and seedling length of control (untreated) samples, at 6-days after sowing

Plant species	Pre-treatment	Temperature (°C)	Number of seeds per Petri dish	Germination (%) [*]	Seedling length (cm) [*]
<i>A. retroflexus</i>	No	25	40	29.2 ± 2.2	5.5 ± 0.21
<i>E. crus-galli</i> (awned)	65°C (48 h)	25	20	86.6 ± 4.4	15.7 ± 0.32
<i>E. crus-galli</i> (awnless)	65°C (48 h)	25	20	25.0 ± 5.0	8.7 ± 1.27
<i>G. hirsutum</i>	No	25	15	73.4 ± 4.0	1.90 ± 0.53
<i>O. sativa</i>	No	25	10	90.0 ± 5.7	2.1 ± 0.23
<i>P. oleracea</i>	65°C (48 h)	25	50	34.0 ± 1.2	2.5 ± 0.04
<i>S. verticillata</i>	65°C (48 h)	25	20	31.7 ± 4.4	9.9 ± 0.85
<i>S. lycopersicum</i>	No	25	20	88.3 ± 3.3	8.2 ± 0.45

^{*}Values are means ± SE of three replicates

RESULTS

The gas chromatography analysis indicated that the main constituents found in the extracted essential oils from the seven species of aromatic plants were linalool (43%) and linalyl acetate (30%) for *L. angustifolia*, fenchone (37%) and 1,8-cineole (28%) for *L. stoechas*, trans-piperitone oxide (82%) for *M. spicata*, carvacrol (72%) for *O. onites*, carvacrol (66%) for *O. vulgare* ssp. *hirtum*, 1,8-cineole (36%) and camphor (17%) for *S. fruticosum*, and a-thujone (48%) and b-thujone (28%) for *S. pomifera* (Table 1).

The germination and seedling length data of seeds grown in the absence of essential oils or of individual compounds (control seeds) indicated considerable differences among weed or crop species (Table 2). In particular, awnless barnyardgrass had the lowest germination (25%) while red rice had the highest (90%). Regarding seedling length, the lowest value (1.9 cm) was recorded for cotton, while the highest (15.7 cm) was for awned barnyardgrass. Given these large among species differences, to make comparisons easier, we decided to express the results of the treatments that we applied as percentages of the untreated control rather than as actual germination or elongation values.

Seed germination was significantly affected by essential oils, concentrations used and their interaction (Table 3). More specifically, even at the lowest rate applied, the essential oils extracted from *M. spicata*, *O. onites* and *O. vulgare* ssp. *hirtum* completely inhibited seed germination of awnless barnyardgrass, foxtail, redroot pigweed, red rice, and tomato, except for the *M. spicata*-1 µl treatment that allowed a few tomato seeds to germinate. Also, all rates of the essential oil extracted from *O. vulgare* ssp. *hirtum*, the two higher rates of the essential oil extracted from *M. spicata* and the highest rate of the essential oil extracted from *O. onites* entirely inhibited seed germination of awned barnyardgrass. In addition, all rates of the essential oil extracted from *M. spicata*, the two higher rates of the essential oil extracted from *O. vulgare* ssp. *hirtum* and the highest rate of the essential oil extracted from *O. onites* caused a hundred percent inhibition of purslane seed germination. However, several of the other four essential oil treatments did not produce a significant inhibitory effect on the target species, whereas in some cases a stimulatory effect was produced instead. In particular, even at the highest rate applied (10 µl), the essential oils extracted from *S. fruticosum*, *S. pomifera*, *L. stoechas*, and

Table 3. Effects of essential oils and their rates on the relative seed germination (% of control) of test crop and weed species, at 6-days after sowing

Treatment		Target species							
Essential oil origin	Rate (µl)	<i>Solanum lycopersicum</i>	<i>Gossypium hirsutum</i>	<i>Oryza sativa</i>	<i>Echinochloa crus-galli</i> (awned)	<i>Echinochloa crus-galli</i> (awnless)	<i>Portulaca oleracea</i>	<i>Setaria verticillata</i>	<i>Amaranthus reroflexus</i>
Control	0	100 a ¹	100 a	100 ab	100 ab	100 a	100 bc	100 b	100 a
<i>Salvia fruticosa</i>	1	96 ab	52 c	100 ab	85 b	86 a	97 bc	132 a	94 a
	5	85 b	27 d	93 ab	106 a	120 a	35 d	58 c	17 c
	10	83 b	27 cd	89 ab	100 ab	120 a	0 e	47 cd	0 d
<i>Salvia pomifera</i>	1	92 ab	24 d	104 a	96 ab	93 a	118 b	74 bc	106 a
	5	88 ab	0 e	96 ab	100 ab	113 a	106 bc	37 cd	14 cd
	10	76 b	0 e	100 ab	98 ab	107 a	82 c	0 d	0 d
<i>Lavandula stoechas</i>	1	100 a	60 b	93 ab	85 b	80 a	67 cd	89 b	106 a
	5	89 ab	60 b	89 ab	85 b	73 a	0 e	89 b	31 c
	10	81 b	54 bc	93 ab	62 c	80 a	0 e	47 c	0 d
<i>Lavandula angustifolia</i>	1	89 ab	30 cd	89 ab	94 ab	100 a	141 a	84 bc	66 b
	5	87 ab	15 de	96 ab	96 ab	93 a	106 bc	42 cd	51 b
	10	74 b	0 e	85 b	75 bc	126 a	88 c	26 d	28 c
<i>Mentha spicata</i>	1	15 c	21 d	0 c	79 bc	0 b	0 e	0 d	0 d
	5	0 d	27 d	0 c	0 d	0 b	0 e	0 d	0 d
	10	0 d	0 e	0 c	0 d	0 b	0 e	0 d	0 d
<i>Origanum onites</i>	1	0 d	42 c	0 c	8 d	0 b	47 d	0 d	0 d
	5	0 d	30 cd	0 c	15 d	0 b	18 e	0 d	0 d
	10	0 d	30 cd	0 c	0 d	0 b	0 e	0 d	0 d
<i>Origanum vulgare ssp. hirtum</i>	1	0 d	58 b	0 c	0 d	0 b	12 e	0 d	0 d
	5	0 d	54 bc	0 c	0 d	0 b	0 e	0 d	0 d
	10	0 d	30 cd	0 c	0 d	0 b	0 e	0 d	0 d

¹Means of the same column followed by the same letters are not significantly different, at the level of 5%, according to Fisher's Protected LSD test.

Table 4. Effects of essential oils and their rates on relative seedling growth (% of control) of crop and weed species, at 6- days after sowing

Treatment		Target species							
Essential oil origin	Rate (µl)	<i>Solanum lycopersicum</i>	<i>Gossypium hirsutum</i>	<i>Oryza sativa</i>	<i>Echinochloa crus-galli</i> (awned)	<i>Echinochloa crus-galli</i> (awnless)	<i>Portulaca oleracea</i>	<i>Setaria verticillata</i>	<i>Amaranthus reroflexus</i>
Control	0	100 a ²	100 bc	100 a	100 a	100 a	100 a	100 b	100 a
<i>Salvia fruticosa</i>	1	84 b	35 bc	57 bc	71 c	73 b	41 d	78 c	63 c
	5	45 d	20 c	55 c	61 cd	62 bc	30 e	33 de	36 d
	10	28 e	6 c	21 e	25 f	30 d	0 j	19 e	0 e
<i>Salvia pomifera</i>	1	111 a	152 a	77 b	87 b	89 ab	54 c	131 a	78 b
	5	77 bc	0 c	52 c	70 c	57 bc	42 d	80 c	52 c
	10	68 c	0 c	64 bc	53 d	46 cd	11 h	0 f	0 e
<i>Lavandula stoechas</i>	1	44 d	30 bc	61 bc	57 d	50 cd	51 c	50 d	57 c
	5	28 e	7 c	27 d	42 e	70 bc	0 j	32 e	30 d
	10	29 e	6 c	8 ef	20 f	45 cd	0 j	4 ef	0 e
<i>Lavandula angustifolia</i>	1	104 a	58 bc	95 a	81 b	82 ab	69 b	102 b	61 c
	5	58 cd	134 b	45 cd	58 cd	42 cd	32 e	46 d	29 d
	10	33 de	0 c	8 ef	19 f	18 de	15 g	18 e	10 e
<i>Mentha spicata</i>	1	5 f	6 c	0 f	4 g	0 e	0 j	0 f	0 e
	5	0 f	14 c	0 f	0 g	0 e	0 j	0 f	0 e
	10	0 f	0 c	0 f	0 g	0 e	0 j	0 f	0 e
<i>Origanum onites</i>	1	0 f	55 bc	0 f	1 g	0 e	25 f	0 f	0 e
	5	0 f	104 bc	0 f	1 g	0 e	27 f	0 f	0 e
	10	0 f	26 bc	0 f	0 g	0 e	0 j	0 f	0 e
<i>Origanum vulgare ssp. hirtum</i>	1	0 f	35 bc	0 f	0 g	0 e	24 f	0 f	0 e
	5	0 f	49 bc	0 f	0 g	0 e	0 j	0 f	0 e
	10	0 f	7 c	0 f	0 g	0 e	0 j	0 f	0 e

¹Zero values of relative seedling growth correspond to no-seedling emergence and hence, no seedling growth.

²Means of the same column followed by the same letters are not significantly different, at the level of 5%, according to Fisher's Protected LSD test.

L. angustifolia did not have any inhibitory effect on seed germination of red rice and awnless barnyardgrass; only a slight effect was induced by the highest rate of *L. angustifolia* on red rice. Also, *L. angustifolia* essential oil did not have any effect on awned barnyardgrass, at any of the rates applied; at the two highest rates it did not have any effect on purslane either. Seed germination of cotton was inhibited by all essential oil treatments tested; compared to the control, it was always between 40% to 100% less. In contrast, treatments of four essential oils (*S. fruticoso*, *S. pomifera*, *L. stoechas*, *L. angustifolia*) either left tomato seed germination unaffected or had only a small effect on it. Two of the essential oils, applied at the lowest rate, led to a significant stimulatory effect of seed germination of foxtail and purslane; they were the essential oils of *S. fruticoso* and *L. angustifolia*, respectively.

Seedling length was significantly affected by essential oils, concentrations tested and their interaction (Table 4). Seedling growth was negatively affected by more treatments than seed germination but the trend regarding the inhibitory effect on this growth parameter was similar to that for the seed germination inhibition.

Regarding the effect of the individual isoprenoid compounds tested on crop and weed species, the ANOVA indicated significant differences among the compounds and the species examined (Table 5). In particular, seed germination of redroot pigweed was entirely inhibited by all compounds, while that of foxtail was similarly affected by thujone, carvacrol and the mixture of fenchone-cineole. In addition, awned barnyardgrass seed germination was fully inhibited by carvone and that of tomato by carvone and carvacrol. Seedling elongation was also affected. Carvone did not induce any inhibitory effect on foxtail, although it significantly reduced its germination.

Table 5. Effects of individual isoprenoid compounds on Relative germination (% of control) and seedling growth (% of control) of tomato and three weed species

Compound	Rate (µl)	<i>Solanum lycopersicum</i>		<i>Echinochloa crus-galli</i> (awned)	
		Germination	Growth	Germination	Growth
Control	0	100 a ¹	100 a	100 a	100 a
(-)-Thujone (tech)	8	44 b	10 b	37 b	13 b
(S)-(+)-Carvone	7	0 c	0 b	0 b	0 b
Carvacrol	7	0 c	0 b	39 b	12 b
1,8 Cineole + (1R)-(-)-fenchone	4 + 3	36 bc	21 b	94 a	22 b
		<i>Setaria verticillata</i>		<i>Amaranthus retroflexus</i>	
Control	0	100 a	100 a	100 a	100 a
(-)-Thujone (tech)	8	0 c	0 b	0 b	0 b
(S)-(+)-Carvone	7	46 b	113 a	0 b	0 b
Carvacrol	7	0 c	0 b	0 b	0 b
1,8 Cineole + (1R)-(-)-fenchone	4 + 3	0 c	0 b	0 b	0 b

DISCUSSION

The high phytotoxicity of the essential oils originated from *M. spicata*, *O. onites* and *O. vulgare* ssp. *hirtum* against weed species makes their use promising for weed control. Their high phytotoxicity against both crop species tested makes them unlikely to be used for selective weed control in these crop but their use remains possible for weed control in uncultivated (non-crop) areas or after selective application (direct application between crop rows).

The efficacy of the oregano essential oils (*O. onites* and *O. vulgare* ssp. *hirtum*) against the weed species was also confirmed by testing carvacrol, their major constituent, which was also found very phytotoxic against the three weeds examined (redroot pigweed, barnyardgrass and foxtail). These results are in agreement with previous findings that some essential oils and isoprenoid compounds had a high inhibitory effect on seedling emergence and growth of six crop and weed species, among which were barnyardgrass and purslane (2). The same work also showed that carvacrol and the essential oil originated from *Satureja montana* had a very high inhibitory effect on the six crop and weed species tested; it is worth mentioning that *Satureja montana* essential oil, which contained 57% of carvacrol, indicated no selectivity (reduced 100% seed germination) on any of the target species (2). This is in agreement with our findings which showed that our two oregano species that contained more than 65% of carvacrol entirely inhibited seed germination of all species examined, even at the lowest rate applied (1 µl). In a further report, carvacrol and the essential oil originated from *Origanum syriacum* (containing 60% of carvacrol) had a strong inhibitory activity on seed germination of tomato and of two amaranth species (5).

The *M. spicata* essential oil that we examined belongs to a relatively common chemotype in Greece (8) that is characterized by the dominance of piperitone oxide (82%). To our knowledge, there is no information regarding the effect of this compound on germination and growth. On the basis of its very high concentration in the *M. spicata* oil that we examined and the high inhibitory activity of this essential oil, we expect piperitone oxide to have a high inhibitory activity.

Redroot pigweed was the most sensitive of the weed species; all essential oils, applied at 5 or 10 µl, and those of *M. spicata*, *O. onites* and *O. vulgare* ssp. *hirtum* applied at 1 µl, completely (or almost) inhibited germination of its seeds. Therefore, all essential oils examined have the potential to be used for its control. Barnyardgrass and red rice were the most resistant weeds; most treatments did not affect germination of their seeds and produced little effect on seedling growth. Therefore, only few of the essential oils examined have the potential to be used for their control. Among the two barnyardgrass types, we can detect a slightly higher sensitivity of the awned one. This is in agreement with results previously reported (16) regarding the propanil-resistant qualities of the two barnyardgrass biotypes.

The high germination and seedling growth reduction of cotton by all essential oils indicate that none of them can be used for selective weed control in this crop. In contrast, the lack of considerable germination reduction of tomato by the essential oils originated from the two sage species (*S. fruticosa* and *S. pomifera*) and the two lavender species (*L. angustifolia* and *L. stoechas*), applied even at the highest rate (10 µl), indicate that these

essential oils have the potential to be used as herbicides for selective weed control in this crop. Severe germination reduction of tomato by *Minthostachys mollis* essential oil, which contained 83.6% pulegone has been reported (1). This compound was not found in appreciable amounts in any of the essential oils that we examined. Based on our and these previous results (1), we can argue that tomato sensitivity is highly dependent on essential oil composition, and that essential oils rich in carvacrol or piperitenone oxide or pulegone severely inhibit tomato germination, whereas those rich in linalool, linalyl acetate, fenchone, 1,8-cineole and camphor do not affect it. Further research providing the evidence required is needed to substantiate this prediction.

Taking into account the lack of considerable germination and seedling elongation reduction of tomato due to *S. pomifera* essential oil, applied at any of the rates examined, along with the extremely inhibitory effect on seed germination and/or further seedling elongation of redroot pigweed and purslane, at the two highest rates, *S. pomifera* essential oil could be recommended as the most promising for selective weed control in tomato. According to our findings, the application rate may range from 10 to 100 ppm. Given that the essential oils of *S. fruticosa*, *Lavandula angustifolia* and *L. stoechas*, at various rates, produced strong inhibitory effects on redroot pigweed and/or purslane germination, these oils could be also regarded as promising candidates for selective control of these two weeds in tomato fields.

There was a fairly good agreement of results taken with essential oils and with individual compounds that are among their major constituents, although both lower and higher than expected activities were recorded. For instance, thujone was more effective in inhibiting tomato seed germination and seedling growth than *S. pomifera* essential oil. One probable reason that can explain such results is the difference of the compounds examined [e.g. (-)-thujone (tech.)] to those naturally occurring in the mixtures of essential oils (e.g. α -thujone and β -thujone participating in *S. pomifera* essential oil). It is well known that structurally similar compounds, like the essential oil constituents that exist in numerous isomeric types, can be very dissimilar functionally, as is the case for 1,4-cineole and 1,8-cineole which have different modes of action and activity (11).

In short, results of this study allow the following conclusions to be drawn: (i) the very good efficacy of the essential oils originated from both species of *Origanum* and from *M. spicata* against both crop and weed species indicates good potential for their possible use either as non-selective herbicides in non-crop areas or as selectively applied post-emergence herbicides (post-emergence directed application); (ii) none of the essential oils examined has the potential to be used for selective weed control in cotton fields; (iii) the fact that the essential oils originated from both species of *Lavandula* and of *Salvia* had a good efficacy against redroot pigweed and purslane, without severely affecting tomato, indicates a high potential of using these essential oils as selective herbicides for weed control in tomato fields.

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