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ORIGINAL PAPER

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SUPPLEMENTARY IRRIGATION AND DRYING METHOD AFFECT THE YIELD AND ESSENTIAL OIL CONTENT AND COMPOSITION OF LAVENDER (*Lavandula angustifolia* Mill.) FLOWERS

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ABSTRACT

This paper presents the results of a study conducted over the period 2016–2017 which was designed to determine to what extent crop irrigation and raw material drying process determine the content and composition of lavender essential oil. In cultivation with irrigation, a higher yield of fresh and yield of air-dried inflorescences was obtained compared to cultivation without irrigation. The use of supplementary irrigation in lavender crops contributed to an increased amount of essential oil (EO) compared to plants without irrigation. The main components of the essential oil were linalyl acetate, linalool, and E-caryophyllene. In EO obtained from plants cultivated with irrigation, the share of oxygenated monoterpenes (OM) was higher and the share of hydrogenated monoterpenes (HM) was lower than in the oil from plants without irrigation. The EO content in lavender flowers dried at a temperature of 30°C was twice higher than in those dried in natural conditions. In 2016 in which the air temperatures were high and a greater number of sunshine hours was recorded in July and August, plants accumulated more EO than in 2017. Study shows that there are prospects for practical application of crop irrigation in lavender cultivation and of raw material preservation method in order to modify EO content and chemical composition.

Key words: *Lavandula angustifolia*, essential oil constituents, irrigation, drying methods, total phenolic acids, DPPH radical scavenging activity

INTRODUCTION

Lavender (*Lavandula angustifolia* Mill.) is a perennial plant native to the Mediterranean area. The genus *Lavandula* comprises more than 60 species and significantly more varieties and hybrids [Ekren et al. 2012]. Lavender (*L. angustifolia* Mill.), spike lavandula (*L. latifolia* Medik.), and lavandin (*Lavandula* × *intermedia* Emeric ex Loisel.) are the species of greatest industrial importance due to the unique biological activity of their EO [Despinasse et al. 2017]. EO is a mixture of many compounds, predominantly mono-, di-, and sesquiterpenes, their oxygen derivatives, and phenylpropane derivatives [Bakkali et al. 2008]. Lavender raw materials and EO constituents exhibit different pharmacological effects, primarily antimicrobial and antifungal, spasmolytic, and choleretic activity [Shafaghat et al. 2012]. The dominant compounds in lavender essential oil are linalyl acetate (25–51%,) linalool (20–45%,), and terpinene-4-ol (0.1–6.0%) [Rapper et al. 2016].

The content of individual compounds in EO varies and depends on many factors, among others biological and agronomic ones, as well as on processing and stor-

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age [Najafian et al. 2012]. Many researchers, in different climate and soil conditions, have evaluated the positive effect of irrigation on yield and quality characteristics of *Lavandula angustifolia* [Karamzadeh 2003], *Ocimum basilicum* [Omidbaigi et al. 2003, Yassen et al. 2003, Bettaieb et al. 2009, Ekren et al. 2012] *Satureja hortensis* [Baher et al. 2002], *Origanum vulgare* [Azizi et al. 2009]. Nonetheless, there is no lack of less optimistic reports on, for example, a reduction in EO content in various *Lamiaceae* species as affected by irrigation [Misra and Sricastatva, 2000, Zehtab-Salmasi at al. 2001, Moeini Alishah et al. 2006, Govahi et al. 2015, García-Caparrós et al. 2019]. EOs are usually produced by enzymes in plant cells in response to drought-induced stress [Kleinwächter et al. 2015]. In the light of existing research, mild water deficit usually causes biochemical changes in plants which allow them to adapt to growth under changed conditions [Alavi-Samani et al. 2015].

The effect of drying process on the essential oil content in herbal materials is quite well documented and unequivocal. The key parameters are temperature and drying time [Blanco et al. 2002]. Volatile EO compounds are very sensitive to the effect of elevated temperature. As reported by Śledź and Witrowa-Rajchert [2013], in the case of many herbal plant species a lower drying temperature (close to ambient temperature) results in the preservation of a larger amount of compounds. In the literature, papers can be found dealing with changes occurring in the chemical composition and proportions of individual oil constituents of the oils of *Laurus nobilis* and *Thymus vulgaris* under the influence of temperature [Sellami et al. 2011, Król and Kiełtyka-Dadasiewicz 2015].

Thus far, there has been a lack of studies investigating the effect of irrigation of lavender crops on the amount and percentage of individual constituents of EO. Technology of preservation of lavender flowers obtained from irrigated plants has not been identified yet. This study made an assumption that preservation of lavender flowers from irrigated plants would not cause a decrease in oil quality relative to non-irrigated plants. Therefore, a study was undertaken to establish to what extent application of additional crop irrigation and variable drying conditions determine the chemical composition of EO.

MATERIALS AND METHODS

Description of the station's location. Agronomic experiences were conducted over the period 2016–2017 in a research station of the University of Life Sciences in Lublin located in south-eastern Poland (51.23°N, 22.56°E). Determination of the chemical composition was made at the Department of Vegetable and Herb Crops, University of Life Sciences in Lublin.

Description of the cultivation method. The experimental material consisted of the herb of lavender (*Lavandula angustifolia* Mill.), the cultivar 'Hidcote Blue Strain'. Seeding material was obtained from the company PNOS Ożarów Mazowiecki.

The experiment investigating the effect of irrigation on fresh herb yield and fresh inflorescence yield was a single-factor one. The experimental factor was crop irrigation with a drip line, while crops grown without additional irrigation were the control treatment.

The experiment regarding yield of air-dried inflorescences and air-dried flowers as well as the chemical composition of raw material and its EO content was a two-factor one. The experimental factors were crop irrigation (crops without additional irrigation were the control treatment) and drying method of lavender inflorescences: in natural conditions and convective drying – in oven. The two-factor experiment was set up as a split-plot design in four replicates.

The area of each plot was 8.0 m^2 (2.0 × 4.0 m). Lavender was grown from transplants at a spacing of (45 × 45) cm. 40 lavender plants were grown per replicate in each treatment.

Crops were grown on a luvisol derived from medium silty loam, which contained in the 0–20 cm layer (in %): sand 35.2, clay 25.8, loam 39; organic matter 1.6, pH in KCl 6.7, Ca 4.5, total N 0.68, P 1.2, K 1.8, Mg 0.9.

To produce transplants, seeds were sown in a greenhouse in plug trays filled with peat substrate (the volume of a single pot was 90 cm^3) in the first 10 days of April in 2016 and 2017, respectively. Plants were fertilized twice with a 0.1% solution of Florovit. Lavender plants were planted in the field on May 5, 2016 and May 8, 2017, respectively.

Before the establishment of the experiment, the macronutrient content in the field was replenished to the following levels (in $mg \cdot dm^{-3}$): 120 N, 80 P, 200 K, 60 Mg. During the growing season, necessary crop management operations were carried out (several times manual weed removal) and the crops were fertilized twice with nitrogen applied as ammonium nitrate with 34% N (a single dose of about 7 kg $N \cdot ha^{-1}$). No crop protection chemicals were used during the cultivation period.

Plants were irrigated using an on-surface system with drip lines (T-Tape 508-20-400), placed next to plant rows. In the period of water scarcity, a drip line with a capacity of 4.0 $dm^3 \cdot m \cdot h^{-1}$ was used at a working pressure of 1.5 bar. Irrigation was applied when the value of soil water potential at a depth of 25–30 cm was equal to or less than –20 kPa. The value of water potential in the soil was measured using a tensiometer (Irrometer, USA). Each dose of water consisted of 15 mm.

Plant material was collected from one-year-old plants. The raw material was harvested once from plants irrigated additionally with a drip line and from non-irrigated ones. Over the experimental period, the lavender herb (leaves and inflorescences) was collected on September 12, at the beginning of plant flowering (in the experiment, 45% of all plants produced inflorescence stems). From among plants that had produced inflorescence stems, leaves and inflorescences were collected separately (from 5 randomly selected plants). Fresh herb yield ($kg \cdot m^{-2}$) and fresh inflorescence yield ($g \cdot m^{-2}$) were calculated based on the weight of leaves and inflorescences. The lavender raw material was collected by hand using a knife, cutting the herb at a height of 3 cm above ground level. Immediately after harvest, drying samples were prepared, separately for irrigated plants and for those without additional irrigation, maintaining the separation between fresh herb yield and fresh inflorescence yield. On the basis of the weight of inflorescences from five plants, after they had been dried, the yield of air-dry inflorescences ($g \cdot m^{-2}$) was calculated. Having been dried, the inflorescence stems were rubbed through sieves to separate flowers from stems. Based on the weight of air-dried flowers, the flower yield was calculated ($g \cdot m^{-2}$).

The plant raw material was dried using two methods: in natural conditions and convectively. Natural drying was performed in a shaded room at a temperature of 20−22°C for 5 days. The convective drying process was carried out in a drying oven in a stream of air at 35°C, flowing parallel to the layer being dried at 0.5 $m \cdot s^{-1}$. During drying, the amount of leaves was 2–2.5 $kg \cdot m^{-2}$ of area, while for inflorescences it was 0.5 $kg \cdot m^{-2}$. The drying process was carried out in complete darkness. After drying, the leaves and inflorescences contained 12–14% of water in 5 successive measurements. Drying of the raw material consisted in gradually increasing the temperature by 5°C each time, to finish at 35°C, with the fans open. The conditioning process lasted 24 hours in order to get rid of water residue, with the fans closed.

Laboratory analysis. 0.25 kg samples were made from air-dry flowers and after grinding them for laboratory analysis, the plant material was kept in air-tight containers. In air-dried lavender flowers, the content of total phenolic acids, expressed as caffeic acid equivalents [Polish Pharmacopoeia 1999] as well as the content of EO and its composition [Polish Pharmacopoeia 2014] were determined. The antioxidant activity of the compounds was expressed as % of DPPH inhibition. The determination was performed according to the method given by Yen and Chen [1995], and the calculation of DPPH inhibition according to the formula given by Rossi et al. [2003]. The quantitative and qualitative composition of the lavender oil obtained from leaves, and developed flowers was determined using gas chromatography and mass spectrometry methods (GC-MS). The qualitative analysis was carried out on the basis of MS Spectral Library (2008). The identity of the compounds was confirmed by their retention indices taken from the literature [Adams 2004] and our own data.

Statistical Processing. The study results were statistically analyzed with two-way analysis of variance (ANOVA), based on a factorial combination of irrigation × drying methods. Means were separated by the least significance difference (LSD) test when the *F*-test was significant. Data were evaluated by HSD Tukey's test at $P < 0.05$. All calculations and analyses were performed using Statistica 10.0 PL software (StatSof Inc., Tulsa, OK, USA).

RESULTS AND DISCUSSION

The fresh herb yield from irrigated crops was significantly ($P < 0.05$) higher by 0.68 $kg \cdot m^{-2}$ than that from crops without additional irrigation (Tab. 3).

The obtained yield of fresh lavender inflorescences from irrigated plants was also higher by 103 g·m^{-2} on average than that from non-irrigated ones. In 2016 higher yields of fresh herb and fresh inflorescences were obtained than in 2017. The year 2016 was characterized by a relatively large total number of sunshine hours and a relatively low amount of rainfall during the intensive flowering period of lavender plants in September (Tab. 1).

The use of additional crop irrigation in 2016 caused a significant increase in fresh herb yield and fresh inflorescence yield, but it had no impact on the percentage of inflorescence yield in herb yield (Tab. 3). Many authors have shown that factors associated with genotypic, climatic, geographic, and seasonal variation can affect the quantity of lavender yield and the content of biologically active substances [Figueiredo et al. 2008, Najafian et al. 2012].

Table 1. Climatic conditions during the experiment in the years 2016–2017 (data from the Meteorological Station in Felin, 51.13°N; 22.37°E)

Year	Month	Temperature (°C)			Precipitation (mm)	Total sunshine hours
		average maximum	average minimum	average diurnal		
2016	May	19.2	8.2	14.3	38	222
	June	22.4	13.0	18.6	43	205
	July	22.0	14.7	18.4	130	170
	August	24.5	13.4	18.8	71	202
	September	22.1	12.1	15.2	11	169
	average/total	22.0	12.3	17.1	59/293	194/968
2017	May	20.6	8.5	14.2	29	198
	June	24.1	13.3	18.6	28	222
	July	23.9	14.5	19.0	108	185
	August	24.5	13.6	20.0	48	201
	September	21.3	10.2	14.0	77	103
	average/total	22.9	12.0	17.2	58/290	182/909

Table 2. Mean square per each source of variation (percentage of total) resulting from analysis of variance

Source of variation	Degree of fredom	YFI	YDI	YDF	EO	TPA	DPPH
Irrigation (I)	1	67.6*	12.7*	23.1*	4.5*	5.7*	2.9*
Drying (D)	1	–	81.3*	63.6*	87.3*	91.1*	39.1*
Year (Y)	1	18.9*	2.9^{NS}	1.0^{NS}	0.7*	0.0 ^{NS}	22.8*
Y × I	3	13.5*	0.0^{NS}	0.2^{NS}	0.4^{NS}	0.0 ^{NS}	0.2 ^{NS}
Y × D	3	–	0.5^{NS}	0.2^{NS}	5.3*	0.0 ^{NS}	0.2 ^{NS}
I × D	3	–	2.5*	12.0*	1.7*	3.3*	34.8*
Total mean square		155330.0	45839.1	28495.5	80.6	12.3	3925.7

YFI – yield of fresh inflorescientia, YDI – yield of dry inflorescientia, YDF – yield of dry flowers, EO – essential oil, TPA – total phenolic acids, DPPH – antioxidant activity by DPPH inhibition. *Indicate significant at $P < 0.05$, NS – not significant

The yield of air-dried inflorescences from irrigated plants was higher by 18 g·m^{-2}, while the flower yield by 19 g·m^{-2} compared to plants without supplementary irrigation (Tab. 4). The yield from irrigated crops was characterized by a higher percentage of flower yield in air-dried inflorescence yield than for non-irrigated crops. The quantity of this yield was dependent on drying method. The yield of air-dried inflorescences and the yield of flowers dried in natural conditions were 3 times higher than of those dried at 30°C. In 2016 and 2017 the highest yields of air-dried inflorescences and air-dried flowers of lavender were obtained from irrigated plants and under natural drying conditions, while the lowest ones from crops without irrigation and using oven drying.

The EO content in the lavender flower raw material ranged 1.11–3.86 ml·100 g^{-1} (Tab. 5). The amount of EO in lavender flowers was similar to the results obtained by Nurzyńska-Wierdak and Zawiślak [2016] as well as by Jianu et al. [2013], but substantially lower than those reported by [Kara and Baydar 2013], which is probably due to the ontogenetic and environmental diversity. Changes in the essential oil content and composition in *Lamiaceae* species under drought conditions have been noted by different researchers [Yassen et al. 2003, Ekren et al. 2012]. According Garcia-Caparros et al. [2019] the increase of EO content under drought conditions may be related to a higher density of oil glands, mainly due to the reduction in leaf area as a consequence of the stress generated by the water deficit. In these studies, the oil content was determined in the flowers.

In the present study, on average 15% more EO was determined in the raw material from irrigated crops than for crops without irrigation. The impact of supplementary irrigation has a small (4.5%) on EO content in the lavender flowers (Tab. 2). The increase of content the EO was related to the increase yield of fresh and yield dry lavender flowers. Drying method has a much greater impact (87.3%) on the amount of EO in the raw material (Tab. 2). The EO content in oven dried lavender flowers was higher by 53% than in those dried in natural conditions (Tab. 5). A higher amount of EO in oven dried herb, compared to drying in natural conditions, has also been found in the case of basil [Calín-Sánchez et al. 2012], oregano [Di Cesare et al. 2004], lemon balm [Argyropoulos and Müller 2014], mint [Blanco et al. 2002], and thyme [Król and Kiełtyka-Dadasiewicz 2015]. As reported by Argyropoulos and Müller [2014], in the case of drying in natural conditions oil losses may also result, among others, from the destruction of skin cells of plant organs

In this study, in 2016 when the temperatures were higher and the number of sunshine hours was greater in July and August, plants accumulated more EO than in 2017 (Tabs. 1 and 5).

The large differences in the amount of EO determined in the samples could also have been resulted from plant tissue hydration at the beginning of the drying process. A higher amount of EO was found in the samples collected from plants additionally irrigated with a drip line and dried at 30°C than for non-irrigated plants dried at ambient temperature (Tab. 5).

The lavender raw material was found to contain a large amount of TPA, which was 0.36–1.38% (Tab. 5). More TPA was determined in flowers from plants grown without irrigation. TPA content was greatly affected (91.1%) by drying method (Tab. 2). Oven drying resulted in a three times higher TPA content than drying in natural conditions. The changes in the content of phenolic compounds in the dried material observed in the present study could have been due to the combined effect of both drying method and crop irrigation. In 2016 and 2017, the TPA content in the raw material obtained from plants grown without irrigation and dried at 30°C was found to be higher by more than 72% than the amount determined in the raw material harvested from irrigated plants and dried in natural conditions.

The present study did not show irrigation and drying method to affect the average value of AA based on the amount of quenched DPPH free radicals in the raw material (Tab. 5). In 2016 the oven dried raw material, with a higher amount of TPA, exhibited the highest AA.

GC/MS analysis allowed identifying 98.89 to 99.76% of EO constituents (Tab. 7). Among the compounds identified in EO, the percentage of oxygenated monoterpenes (OM) was highest, ranging 73.82–80.43% (Tab. 6). Crop irrigation influenced the proportions of EO constituents. EO obtained from irrigated plants contained more OM and less hydrocarbon monoterpenes (HM) than non-irrigated ones. Monoterpenes and sesquiterpenes are the main components

Table 3. Effect of irrigation on yield of fresh herbs, yield of fresh inflorescences and percentage of fresh inflorescences in fresh herb yield

Treatments		YFH ($kg \cdot m^{-2}$)	YFI ($g \cdot m^{-2}$)	YFI in YFH (%)
Irrigation	WI	2.37 ±0.46A*	302 ±68A	12A
	NI	1.69 ±0.20B	199 ±41B	11A
Year	2016	2.20 ±0.61A	278 ±93A	12A
	2017	1.86 ±0.25B	224 ±40B	12A
Irrigation (I) × year (Y)				
WI	2016	2.68 ±0.48a	352 ±59a	13a
	2017	2.07 ±0.15b	252 ±26b	12a
NI	2016	1.72 ±0.24bc	204 ±52bc	11a
	2017	1.66 ±0.16c	224 ±40b	11a
Mean		2.03 ±0.42	251 ±76	12

Treatments: WI – with irrigation, NI – no irrigation. YFH – yield of fresh herbs, YFI – yield of fresh inflorescences, YFI in YFH – percentage of fresh inflorescence yield in fresh herb yield. *Different letters within each column and main factor indicate significant differences ($p < 0.05$)

Table 4. Effect of irrigation and drying method on yield of air-dry inflorescences, yield of air-dried flowers, and percentage of air-dry flowers in air-dried inflorescences

Treatments		YDI ($g \cdot m^{-2}$)	YDF ($g \cdot m^{-2}$)	YDF in YDI (%)
Irrigation	WI	54 ±2A*	39 ±2A	72A
	NI	36 ±2B	20 ±1B	55B
Drying method	O	22 ±0B	13 ±0B	59B
	N	68 ±1A	45 ±1A	66A
Year	2016	49 ±2B	31 ±2A	63A
	2027	41 ±2B	27 ±1B	65A
Year (Y) × irrigation (I) × drying method (D)				
	2016 × WI × O	30 ±4e	17 ±1c	56c
	2016 × WI × N	88 ±3a	67 ±2a	76a
	2016 × NI × O	20 ±4fg	12 ±6cd	60b
	2016 × NI × N	60 ±6c	30 ±5b	50c
	2017 × WI × O	25 ±2ef	16 ±1c	64b
	2017 × WI × N	73 ±5b	57 ±3a	78a
	2017 × NI × O	15 ±4g	9 ±1d	60b
	2017 × NI × N	50 ±5d	28 ±4b	56c
Mean		45 ±5	29 ±2	64

Treatments: WI – with irrigation, NI – no irrigation. Drying method: O – oven, N – natural. YDI – yield of dry inflorescences, YDF – yield of dry flowers, YDF in YDI – percentage of air-dry flower yield in air-dry inflorescence yield. *Different letters within each column and main factor indicate significant differences ($P < 0.05$)

Table 5. Effect of irrigation and drying method on the chemical constituents of lavender flowers and its antioxidant activity (AA)

Treatments		EO (mg 100 g^{-1})	TPA (%)	AA by DPPH inhibition (%)
Irrigation	WI	3.00 ±0.86A*	0.693 ±0.32B	70 ±4A
	NI	2.55 ±1.18B	0.898 ±0.48A	68 ±5A
Drying method	O	3.76 ±0.18A	1.191 ±0.18A	73 ±6A
	N	1.78 ±0.44B	0.400 ±0.07B	64 ±7B
Year	2016	2.87 ±0.94A	0.822 ±0.41A	72 ±6A
	2017	2.68 ±1.15B	0.768 ±0.43B	65 ±8B
Year (Y) × irrigation (I) × drying method (D)				
	2016 × WI × O	3.86 ±0.08a	1.047 ±0.05b	76 ±1ab
	2016 × WI × N	2.20 ±0.08b	0.383 ±0.06d	71 ±2bc
	2016 × NI × O	3.70 ±0.17a	1.380 ±0.03a	79 ±2a
	2016 × NI × N	1.73 ±0.17c	0.480 ±0.07c	64 ±2d
	2017 × WI × O	3.83 ±0.08a	0.976 ±0.05b	65 ±1d
	2017 × WI × N	2.11 ±0.08b	0.366 ±0.05d	69 ±2cd
	2017 × NI × O	3.66 ±0.26a	1.362 ±0.04a	74 ±6ab
	2017 × NI × N	1.11 ±0.13d	0.370 ±0.06d	53 ±3e
Mean		2.77 ±1.05	0.795 ±0.42	69 ±8

Treatments: WI – with irrigation, NI – no irrigation. Drying method: O – oven, N – natural. EO – essential oil, TPA – total phenolic acids, AA – antioxidant activity. *Different letters within each column and main factor indicate significant differences ($P < 0.05$)

Table 6. Effect of irrigation and drying method on the chemical fraction of the essential oils from flowers of *L. angustifolia* plants depending on irrigation and drying method (%)

Compound	WI		NI	
	O	N	O	N
HM	8.26	6.98	11.23	7.40
OM	76.31	80.43	73.82	74.75
HS	11.56	5.70	9.72	4.63
OS	3.63	6.56	4.92	12.11

Treatments: WI – with irrigation, NI – no irrigation. Drying method: O – oven, N – natural. Compounds: HM – hydrocarbon monoterpenes, OM – oxygenated monoterpenes, HS – hydrocarbon sesquiterpenes, OS – oxygenated sesquiterpenes

of lavender EO and are derived from the condensation of isopentenyl diphosphate (IPP) and its allylic isomer, dimethylallyl diphosphate (DMAPP) involving of four monoterpene synthases and five sesquiterpene synthases [Despinasse et al. 2017]. The availability of water for the plant leading to the synthesis of different monoterpenes and sesquiterpenes in the plant. This chance in the composition of the EO may be due to the plants defense strategy as a mechanism to overcome the effect of water deficit conditions as reported by Selmar i Kleinwächter [2013a].

EO extracted from flowers dried at 30°C contained more hydrocarbon compounds HM and hydrocarbon sesquiterpenes (HS) and less oxygenated ones OM and

Table 7. Chemical composition of the essential oil of *L. angustifolia* flowers depending on irrigation and drying method (%)

No	Compound	RI	WI		NI	
			O	N	O	N
1.	Cumene	926	0.16	0.09	0.12	0.07
2.	α-Pinene	933	0.41	0.39	0.35	0.45
3.	Camphene	950	0.07	0.10	0.15	0.40
4.	Verbenene	968	–	0.08	–	0.13
5.	Sabinene	973	–	0.07	0.11	0.11
6.	β-Pinene	978	0.44	0.66	0.48	0.93
7.	1-Octen-3-ol	980	0.11	0.11	0.15	0.17
8.	3-Octanone	986	0.67	0.56	0.38	0.50
9.	Myrcene	990	1.04	0.98	0.96	0.72
10.	Butyl butanoate	997	0.08	0.08	–	–
11.	2-δ-Carene	1009	0.30	0.18	0.20	0.21
12.	Hexyl acetate	1012	0.19	0.25	0.12	0.11
13.	*p*-Cymene	1019	0.12	0.24	0.14	0.39
14.	*ortho*-Cymene	1023	0.53	0.78	0.55	1.04
15.	Limonene	1027	0.58	0.72	0.77	1.29
16.	1,8-Cineole	1030	1.06	0.90	1.17	2.21
17.	(*Z*)-β-Ocimene	1033	2.86	1.82	4.78	1.10
18.	(*E*)-β-Ocimene	1042	1.49	0.78	2.32	0.52
19.	γ-Terpinene	1053	0.15	0.06	0.15	Tr
20.	*trans*-Linalool oxide	1064	0.39	1.46	0.39	0.65
21.	*cis*-Linalool oxide	1079	0.22	1.08	0.37	0.49
22.	Linalool	1093	23.38	18.91	22.23	17.85
23.	1-Octen-3-yl acetate	1095	0.07	1.09	0.09	1.03
24.	*trans*-*p*-Mentha-2,8-dien-1-ol	1100	0.94	–	1.16	0.08
25.	3-Octanol acetate	1111	0.22	0.15	0.07	0.26
26.	*cis*-*p*-Menth-2-en-1-ol	1113	–	0.08	–	0.18
27.	*allo*-Ocimene	1121	0.07	0.08	0.20	0.11
28.	*cis*-Limonene oxide	1123	–	–	–	0.10
29.	*cis*-*p*-Mentha-2,8-dien-1-ol	1127	–	–	–	0.10
30.	*trans*-Sabinol	1132	–	0.32	–	0.57
31.	*cis*-Sabinol	1136	0.22	–	0.29	0.22
32.	Camphor	1143	0.24	0.82	0.32	1.50
33.	Pinocarvone	1158	–	0.51	–	0.35
34.	β-Pinene oxide	1161	0.58	–	0.63	0.28
35.	Borneol	1172	1.01	3.21	1.33	7.14
36.	Terpinene-4-ol	1181	5.25	5.22	4.26	2.70
37.	Cryptone	1188	0.69	1.38	1.33	2.31
38.	γ-Terpineol	1197	2.26	2.04	2.29	2.80
39.	Verbenone	1211	0.18	0.30	0.23	0.41

Table 7 cont.

No	Compound	RI	WI		NI	
			O	N	O	N
40.	*ortho*-Cymene	1223	0.07	0.15	0.13	0.35
41.	Nerol	1228	0.25	0.12	0.25	0.28
42.	Isobornyl formate	1228	–	0.19	–	0.41
43.	Linalyl acetate	1254	28.00	30.90	26.18	22.34
44.	Thymoquinone	1269	–	0.07	–	0.15
45.	Isopulegyl acetate	1276	0.07	–	0.09	–
46.	Neryl formate	1284	–	8.16	–	5.27
47.	Lavandulyl acetate	1288	7.53	–	7.66	–
48.	*p*-Cymen-7-ol	1297	0.18	0.15	0.36	0.40
49.	γ-Terpinen-7-al	1310	–	0.10	–	0.11
50.	Piperitenone	1313	0.07	–	0.09	0.08
51.	*trans*-Verbenyl acetate	1333	–	0.27	–	0.29
52.	Neryl acetate	1361	0.76	1.80	0.81	3.34
53.	Linalyl isobutanoate	1381	1.66	–	1.39	–
54.	7-*epi*-Sesquithujene	1389	0.06	–	0.06	–
55.	*α*-*cis*-Bergamotene	1417	0.07	–	–	–
56.	*E*-Caryophyllene	1425	7.76	3.52	6.22	1.54
57.	*α*-*trans*-Bergamotene	1439	0.22	0.17	0.18	0.07
58.	(*Z*)-β-Farnesene	1458	0.06	0.66	0.07	0.35
59.	(*E*)-β-Farnesene	1462	1.62	–	1.67	–
60.	*α*-Humulene	1465	0.28	–	0.16	–
61.	Germacrene D	1494	0.55	0.19	0.46	0.08
62.	β-Bisabolene	1520	0.14	–	0.06	–
63.	γ-Cardinene	1525	0.42	0.89	0.56	1.42
64.	*trans*-Calamenene	1528	0.10	–	0.08	0.34
65.	β-Sesquiphellandrene	1534	0.10	–	–	0.26
66.	*epi*-Longipinalol	1559	0.18	0.27	0.20	0.57
67.	Caryophyllene oxide	1587	2.48	3.99	2.72	4.37
68.	1,10-*di*-*epi*-Cubenol	1621	0.08	0.24	0.12	0.64
69.	α-Muurolol	1653	1.01	1.95	1.53	5.38
70.	Himachalol	1665	–	0.09	–	0.19
71.	14-*hydroxy*-9-*epi*-(*E*)-Caryphylene	1670	–	–	0.10	0.10
72.	(*Z*)-α-Santalol	1687	0.06	0.09	0.20	0.31
73.	*cis*-14-*nor*-Muurol-5-en-4-one	1703	–	0.12	0.14	0.67
74.	Ni	1752	–	0.08	0.11	0.45
Total identified compounds (%)			99.76	99.67	99.69	98.89

Treatments: WI – with irrigation, NI – no irrigation. Drying method: O – oven, N – natural. RI – non isothermal Kovats retention indices (from temperature-programming, using the definition of Van den Dool and Kratz [1963] for the series of n-alkanes (C6–C40). Tr – traces, content below 0.05%. Ni – unidentified compound oxygenated sesquiterpenes (OS) compared to drying in natural conditions. Argyropoulos and Müller [2014] report that EO losses due to high temperature effects may result, among others, from the destruction of skin cells of plant organs, greater access of atmospheric oxygen, and in effect faster degradation of OM.

In this study, the dominant compound in the investigated EO was Linalyl acetate, whose content ranged 22.34–30.90% (Tab. 7). In terms of quantity, the second ranking compound was Linalool – 17.85–23.38%. *Lavandula angustifolia* is a plant that exhibits high variation in EO chemical composition. Muñoz-Bertomeu et al. (2007) report that in EO originating from Spain 1.8-cineol, linalool and camphor were predominant, accounting for 70% of its composition. In the temperate climate zone, in turn, Nurzyńska and Zawiślak [2016] found linalool and linalyl acetate to have a high percentage (52%) in EO.

In this study, when we compare the composition of EO extracted from flowers collected from irrigated plants with the oil samples from non-irrigated ones, a higher percentage of *trans*- (0.39–1.46 > 0.39–0.65%) and *cis*-Linalool oxide (0.22–1.08 > 0.37–0.49%) can be noted. It can be presumed that additional irrigation leads to decreased thermal degradation and reduced oxidation of linalool during the drying process. This increase of flowers linalool concentration can be ascribed to increase in leaf enzyme activity which is joined to photosynthesis activity and the availability of C-skeletons, which are increased under optimal water conditions [Selmar and Kleinwächter 2013a].

EO originating from plants grown without irrigation, in comparison to EO extracted from irrigated plants, contained larger amounts of (*Z*)-β-ocimene (4.78–1.10 > 2.86–1.82) and (*E*)-β-ocimene (2.32–0.52 > 1.49–0.78), borneol (1.33–7.14 > 1.01–3.21), camphor (0.32–1.50>0.24–0.82), *γ*-cadinene (0.56–1.42>0.42–0.89), α-muurolol (1.53–5.58>1.01–1.95), neryl acetate (0.81–3.34>0.76–1.80), and caryophyllene oxide (2.72–4.37 > 2.48–3.99). The increase the share monoterpenes concentration in lavender EO under drought stress conditions may be explained by the fact that the water scarcity affects stomatal regulation, resulting in reduced photosynthetic capacity and also the uptake of K ions in order to retain and regulate turgidity and stomatal control as reported [Selmar and Kleinwächter 2013b]. According to Kleinwächter et al. [2015] accumulation of monoterpenes is a plant's defense mechanism against damage to cell organelles and serves to maintain ion homeostasis.

OMs are very susceptible to transformations caused by the effects of high temperature and oxygen. In the case of the raw material obtained from irrigated crops, drying at 30°C reduced the content of *p*-cymene (by 50%) and *ortho*-cymene (by 32%) in eo, while in that extracted from non-irrigated plants: *p*-cymene (by 64%), camphene (by 62%), β-pinene (by 48%), *ortho*-cymene and limonene (by 40%), α-pinene (by 22%), compared to drying in natural conditions. At the same time, EO from flowers processed using oven drying, in comparison with drying in natural conditions, was characterized by a higher percentage of 2-δ-Carene (by 40%), (*Z*)-β-ocimene, (by 36%) and (*E*)-β-ocimene (by 48%) for irrigated plants, while in the case of non-irrigated ones the percentage was higher for (*Z*)-Ocimene and (*E*)-β-ocimene (by 78%). In this experiment, drought stress resulted in a decrease in monoterpenes concentration because the levels of drought essayed was too high and modify the nutritional status of this species.

Sesquiterpenes are another group of terpenes being constituents of EO. In the group of HM compounds, convective drying reduced the percentage of the following compounds in EO extracted from the raw material obtained from irrigated crops: 1-octen-3-*yl* acetate (by 93%), *cis*-linalool oxide (by 78%), borneol (by 68%), *ortho*-cymene (by 53%), neryl acetate (by 57%), cryptone (by 50%), and verbene (by 40%), in comparison with natural drying. In the OS group, on the other hand, this method of drying, with regard to both the raw material from irrigated crops and from those grown without irrigation, resulted in a decrease in the *epi*-longipinalol content by respectively 33% and 65%, 1,10-*di*-*epi*-cubenol by 66% and 81%, α-muurolol by 99% and 71%, *(Z)*-α-santalol by 33% and 35% as well as a decrease in the content of *cis*-14-*nor*-muurol-5-*en*-4-*one* by 79% exclusively in the raw material from non-irrigated crops. At the same time, oven drying of the raw material obtained from irrigated crops resulted in higher retention of linalool (by 19%), 3-octanol acetate (by 31%), and nerol (by 52%). A higher content of compounds from the OS group was found in the oil from the oven dried samples, compared to drying in natural conditions, which was as follows for irrigated and non-irrigated plants, respectively: *E*-caryophyllene by 54% and 75%, -*trans*-bergamotene by 22% and 61%, and germacrene D by 65% and 82%.

The above cited literature data and the results obtained in this study show that it is advisable to conduct further research on improvement of agronomic practices (irrigation, fertilization, preservation methods) that allow the chemical composition of plant raw material to be modified. It is even more important because the chemical composition of lavender, in particular the essential oil fraction, continues to be the object of many studies, while research on biologically active metabolites of *L. angustifolia* flowers are still rare.

CONCLUSIONS

In a two-year study, additional irrigation was shown to be useful in the cultivation of *L. angustifolia* crops. In the case of crops with irrigation, a higher yield of fresh and air-dried inflorescences was obtained compared to plants without additional irrigation. The use of supplementary irrigation in lavender crops contributed to an increase in the amount of EO compared to crops without irrigation. EO obtained from plants grown with irrigation contained more OM and less HM than the oil extracted from non-irrigated plants. Among compounds identified in EO, compounds from the OM group had the highest percentage. In EO obtained from irrigated plants, the dominant compounds were *trans*-Linalool oxide and *cis*-Linalool oxide, while in non-irrigated crops (*Z*)-β-ocimene, (*E*)-β-ocimene, borneol, camphor, γ-cadinene, α-urolol, neryl acetate, and caryophyllene oxide.

Drying method had a much greater impact on the amount of EO in the raw material (87.3%). The EO content in lavender flowers dried at a temperature of 30°C was twice higher than in those dried in natural conditions. Oven drying most reduced the content of compounds from the OM and OS groups, while drying in natural conditions the content of compounds from the HM and HS groups. In the case of the raw material obtained from irrigated plants, thermal drying decreased the content of *p*-cymene in EO by more than 50%, while in plants without irrigation the content of *p*-cymene and camphene, compared to drying in natural conditions. At the same time, EO extracted from flowers dried using oven drying, compared to drying in natural conditions, was characterized by a greater percentage of 2-δ-carene, (*Z*)-β-ocimene and (*E*)-β-ocimene in the case of irrigated plants, while for plants without additional irrigation these were (*Z*)-β-ocimene and (*E*)-β-ocimene.

It can be presumed that in the cultivation of *L. angustifolia* soil moisture content and raw material drying temperature are factors that may affect yield and raw material chemical composition. Nonetheless, further research is necessary to improve agronomic practices and raw material stabilization in order to obtain more stable yields.

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