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ORIGINAL PAPER

MINERAL ELEMENTS AND CHEMICAL COMPOSITION OF ESSENTIAL OIL FROM LEAVES AND FLOWERS OF SELECTED LEMON-SCENTED *OCIMUM* SPECIES*

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Abstract

This study aimed to compare the chemical composition of the essential oils obtained from the leaves and flowers of three *Ocimum* species cultivated in north-western Poland. The content of macro- and microelements as well as dry matter in the leaves and flowers of studied basils were also determined. Essential oils were isolated by hydrodistillation in a Clevenger-type apparatus from *Ocimum* × *citriodorum* Vis. (lemon basil), *Ocimum americanum* L. (lime basil) and *Ocimum basilicum* L. (cv. Sweet Dani Lemon) and analyzed by Gas Chromatography – Mass Spectrometry (GC/MS). The principle components of Lemon basil were linalool (35.34% in leaves and 39.54% in flowers), geranial (17.37% in leaves and 8.06% in flowers) and neral (13.56% in leaves and 6.49% in flowers). Geranial (27.67% in leaves and 18.43% in flowers), neral (21.70% in leaves and 14.70% in flowers), caryophyllene oxide (8.83% in leaves and 13.35% in flowers) and linalool (9.68% in leaves and 12.11% in flowers) dominated in Lime basil. Similarly, the Sweet Dani Lemon cultivar was rich in geranial (27.14% in leaves and 11.55% in flowers), neral (20.97% in leaves and 9.42% in flowers) and caryophyllene oxide (8.20% in leaves and 7.12% in flowers). Contents of macroelements in three *Ocimum* species were in the range: P (0.54 - 0.83 g kg^{-1}), K (108.37 - 170.50 g kg^{-1}), Ca (15.38 - 233.53 g kg^{-1}), Mg (1.25 - 15.89 g kg^{-1}) and Na (1.96 - 2.09 g kg^{-1}). The concentration of microelements in the examined samples decreased as follows: Fe > Zn > Mn > Cu. The highest amounts of iron were determined in the leaves and flowers of *O. americanum* L. (500.37 mg kg^{-1} and 543.73 mg kg^{-1}, respectively), while the highest content of zinc was determined in the flowers of *O. basilicum* L. (244.47 mg kg^{-1}) and *O. americanum* L. (227.33 mg kg^{-1}). The leaves of *O. basilicum* L. were the richest in manganese (117.3 mg kg^{-1}), while flowers accumulated the greatest amounts of copper (68.55 mg kg^{-1}).

Keywords: lemon basil, sweet basil, essential oil, GC/MS, linalool, geranial, neral, caryophyllene oxide, macro- and microelements

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INTRODUCTION

Basil (*Ocimum basilicum* L.), belonging to the Lamiaceae family, is one of the most popular herbs, which is grown around the world (Pripdeevech et al. 2010). The plant has many uses, but the most common is flavoring foods such as vegetables, poultry and fish. The edible flowers of basil can be utilized as an attractive addition to salads, jelly, honey, tea and liquor. This aromatic herb is often used in potpourri and sachets as well as an ornamental plant in the flower garden (Makri, Kintzios 2008). Moreover, green parts of basil are also a valuable source of macroelements and microelements, which have a beneficial influence on human health (Majkowska-Gadomska et al. 2014, Filip 2017).

The essential oil distilled from the leaves and flowers of common basil exhibits stimulant, tonic, antidepressant, nematocidal, fungistatic and antiviral activity (Hassanpouraghdam et al. 2010). *O. basilicum* L. extracts are considered to be antimicrobial, insecticidal and useful in a number of medicinal treatments, such as headaches, coughs, diarrhea and kidney malfunctions (Opalchenova, Obreshkova 2003, Dasgupta et al. 2004).

Other *Ocimum* species, such as *O. americanum* L. and *O.* × *citriodorum* Vis., also have an important role in the various branches of industry. Citral (neral plus geranial) rich essential oils, which are obtained from their leaves, are widely used as condiments for meats, salads, nonalcoholic beverages, ice cream, and oral hygiene products (Paulus et al. 2019). They also possess antibacterial, antifungal, insecticidal and hepatoprotective activity (Bernhardt et al. 2015).

The chemical composition and biological activity of essential oils produced from the plants, which belong to the same species may vary significantly depending on the variety, cultivation methods and the geographical region that the plants are grown in (Avetisyan et al. 2017). The amounts of individual constituents may be also different in the oils obtained from the leaves and flowers of the same plant (Chalchat, Ozcan 2008, Türkmen 2021).

Both, the content of bioactive substances and the concentration of mineral elements, determine the quality, medicinal properties and culinary value of basil as a raw material for pharmaceutical, food and cosmetic industries (Kiczorowska et al. 2015, Stojicevic et al. 2019).

Therefore, the aim of this study was to compare the chemical composition of essential oils obtained from the leaves and flowers of *O.* × *citriodorum* Vis., *O. americanum* L. and *O. basilicum* L. cultivated in north-western Poland. The content of macro- and microelements in the leaves and flowers of selected *Ocimum* species was also determined and compared.

MATERIAL AND METHODS

A field experiment was conducted at the Horticultural Experimental Station near Szczecin (53°26′14″N, 14°24′36″E, West Pomeranian Voivodeship, in north-western Poland), which belongs to the West Pomeranian University of Technology in Szczecin. The laboratory part of the experiment was conducted in the Department of Organic and Physical Chemistry and the Department of Horticulture of the West Pomeranian University of Technology in Szczecin. The basil seeds used in the experiment came from the commercial seed companies Chiltern Seeds (https://www.chilternseeds.co.uk/): *O.* × *citriodorum* Vis. (Lemon basil), *O. americanum* L. (Lime basil) and *O. basilicum* L. (cv. Sweet Dani Lemon). The experiment was set in a randomized block design with four replications, on black earth soil of 3rd class of the soil valuation, with pH in H_2O of 7.6, and the following nutrient content: N-NO_3 – 16, P – 132, K – 102, Ca – 38887 and Mg – 203 mg dm^{-3}. This soil is characterized by the lightest mechanical composition in the entire profile and good water permeability. Although the groundwater level is at a depth of 95 cm, the supply of surface soil layers from seepage to meet the needs of shallow-rooting plants is largely limited. Therefore, the yield of plants depends on the amount of rainfall during the growing season. The seeds were sown directly into the open field on 23 May 2018, with 40 cm row spacing. The area of one plot was 1.44 m^2 (1.2 x 1.2 m^2), and of the whole experiment – 30 m^2. For 1.44 m^2 of the field, 0.86 g of seeds were used. Mineral fertilization was quantified according to the results of the chemical analysis of the soil samples and supplemented to those recommended for basil level.

The analysis of hydrothermal conditions in 2018 was carried out according to data obtained from the Institute of Meteorology and Water Management for the IMGW Hydrological and Meteorological Station in Szczecin – Dąbie (Table 1). The weather conditions prevailing during the experiment differed significantly from the multiannual and can be considered as non-specific for the region. High temperatures and a large number of sunny hours were favourable for the cultivation of basil. Soil moisture deficits were compensated by systematic irrigation.

Aerial parts of all lemon basil species were collected at the beginning of flowering, in the middle of August 2018. The plants were cut 10 cm above the ground. An aggregate sample collected from the four replications weighed from 800 to 950 g, depending on the basil species.

Subsequently, the samples of each basil were combined, mixed and dried in a shady and well ventilated place at room temperature. Flowers and leaves were separated manually before drying. Representative samples of each basil (200 g flowers and 200 g leaves) were used for essential oil isolation.

Table 1

Meteorological data from the period of *Ocimum* species growing in 2018 (Institute of Meteorology and Water Management Szczecin-Dąbie)

Year of the study	Months											
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
	Mean daily temperature (C)											
2018	2.7	-1.8	0.5	12.3	16.6	18.5	20.0	20.0	15.4	10.3	4.7	3.9
Multiyear mean 1971-2000	-0.5	-0.1	3.5	9.8	12.9	16.2	17.8	17.4	13.6	9.1	5.3	1.2
Variation 2018	3.2	-1.7	-3.0	2.5	3.7	2.3	2.2	2.6	1.8	1.2	-0.6	2.7
	Total rainfall (mm)											
2018	71.4	5.5	42.9	26.8	22.5	15.0	92.8	21.4	16.3	20.2	11.5	54.8
Multiyear mean 1971-2000	38.6	25.7	34.8	36.0	54.0	59.0	65.0	56.0	46.0	37.5	45.1	44.4
Variation 2018	32.8	-20.2	8.1	-9.2	-31.5	-44.0	27.8	-34.6	-29.7	-17.3	-33.6	10.4
	Insolation (h)											
2018	30.7	126.7	140.1	257.6	349.0	253.6	301.0	269.2	204.0	170.6	66.9	13.5
Multiyear mean1971-2000	32.0	57.0	102.0	150.0	220.0	200.0	220.0	207.0	120.0	94.0	40.0	27.0
Variation 2018	-1.3	69.7	38.1	107.6	129.0	53.6	81.0	62.2	84.0	76.6	26.9	-13.5

Twenty grams of crushed dried flowers and leaves of each basil (separately) in a 1000 ml round-bottomed flask along with 500 ml of distilled water was subjected to hydrodistillation in a Clevenger-type apparatus for 3 h, according to the general method described in the European Pharmacopoeia 8.0. Hydrodistillation was repeated three times.

Next, the essential oil volume collected in the calibrated tube of apparatus was read. After separation, the obtained oil was dried over an anhydrous sodium sulphate, filtrated and stored in an amber vial at low temperature (4°C) prior to GC/MS analysis.

The essential oil content (%) was calculated based on dry weight of plant material (Zhang et al. 2015) and expressed as % (w/w) in Table 2.

Table 2

Essential oil content in the leaves and flowers of three *Ocimum* species

Ocimum species	Essential oil content (% w/w)		
	leaves	flowers	mean
O. × *citriodorum* Vis. Lemon Basil	1.70±0.13*c*	2.81±0.14*d*	2.25±0.62*c*
O. americanum L. Lime Basil	0.48±0.02*a*	0.58±0.16*a*	0.53±0.12*a*
O. basilicum L. cv. Sweet Deni Lemon	0.30±0.05*a*	1.22±0.22*b*	0.76±0.52*b*
Mean	0.83±0.66*a*	1.54±1.00*b*	1.18±0.90

Values are presented as means ± SD (n=3)
Means followed by the same letter are not significantly different at p=0.05.

The qualitative GC/MS analysis of the isolated oils was carried out on an Agilent 7820 A gas chromatograph (Agilent Technologies, Palo Alto, CA, USA) equipped with a cross-linked (5%-phenyl)-methylpolysiloxane HP-5MS capillary column (30 m × 0.25 mm, film thickness 0.25 μm) and coupled with a 5977 E Mass Selective Detector. Helium was used as carrier gas at a flow rate of 1 ml min^{-1}. Samples of 1 μl (20 mg of oil dissolved in 1.5 ml of methylene chloride) were injected in the split mode at a ratio of 5:1. The injector and the transfer line were kept at 280°C. The ion source temp. was 230°C. The initial temperature of the column was maintained at 40°C for 5 min, then increased to 60°C at a rate of 30°C per min, next to 230°C at a rate of 6°C per min (kept constant for 10 min), and then increased to a final temp. of 280°C at a rate of 30°C per minute. The oven was held at this temperature for 30 min. Mass spectra were taken at 70 eV. Scan time and mass range were 2.94 s and 50 - 550 m/z, respectively. Solvent delay time was 4 minute.

The identification of the constituents in each essential oil sample was based on the retention index (RI), computer matching with the NIST/EPA//NIH (2014 version) mass spectral library and authentic compounds (β-pinene, D-limonene, p-cymene, camphor and geraniol) available in our laboratory. The identity of compounds was also confirmed by retention indices from literature data (Babushok et al. 2011) as well as from NIST

Chemistry WebBook (https://webbook.nist.gov/chemistry/). Retention indices (RI) values were calculated for all constituents using a homologous series of n-alkanes (C_7-C_{30}; Supelco, Bellefonte PA, USA) injected in chromatographic conditions equal to samples ones. The relative contents (%) of the individual essential oil components were evaluated from the total peak area (TIC) by the apparatus software (MSD ChemStation).

Dry matter content was assessed by drying the samples at 105°C. The total nitrogen content was determined by the Kjeldahls method, phosphorus by the colorimetric method, potassium, calcium and sodium by flame photometry, and copper, zinc, manganese, iron and magnesium by the method of atomic absorption spectrophotometry (ASA).

Statistical analysis

The results of the study were subjected to the analysis of variance (ANOVA) for the comparison of means, and significant differences were calculated according to the post-hoc Tukey's HSD (honestly significant difference) test at a significance level of p=0.05, using the Statistica 13 (TIBCO Software Inc. StatSoft, Poland). In order to show the differences in the composition of leaves and flowers oils of selected *Ocimum* species, 15 constituents of the content greater than 2% of the essential oil were selected for statistical analysis (Table 3). All the results were expressed as means ± standard deviations (mean ± SD) calculated for the three replications of the experiment.

RESULTS AND DISCUSSION

All isolated essential oils were found to be yellow liquids with characteristic lemon smell. The content of essential oil in dried basil leaves ranged from 0.30% to 1.70% (w/w), while in dried flowers it ranged from 0.58% to 2.81% (w/w) – Table 2. These results indicated that the part of plant had a significant effect on the content of essential oil. Generally, flowers were richer in oil than leaves. Among the examined *Ocimum* species, lemon basil (O. × citriodorum Vis.) was characterized by the highest volatile oil content, both in the leaves and flowers.

The content of basil essential oil depends on many factors, such as plant genotype and variety, date of sowing and harvest time, irrigation or fertilization (Wogiatzi et al. 2011, Nurzyńska-Wierdak 2013), and ranges from 0.2 to 1.9% (Ilic et al. 2019). However, variations in the essential oil content across countries might be attributed to the varied climatic conditions in these regions. A study provided by Marotti et al. (1996) indicated that the essential oil content in herb of ten Italian basil cultivars ranged from 0.3 to 0.8%. Basil originating from Cuba contained from 1.9 to 2.5% of essen-

Table 3

Statistical analysis of the content (%) of the main chemical constituents identified in the essential oils isolated from the leaves and flowers of the three *Ocimum* species

Ocimum species (A)	Plant part (B)	Eugenol	Linalol	Terpinen-4-ol	Nerol	Neral	Geraniol	Geranial	β-Caryophyllene	*trans*-α-Bergamotene	Germacrene D	β-Selinene	Bicyclogermacrene	*trans*-α-Bisabolene	Caryophyllene oxide	1-Tetradecanol
Lemon basil *O.* × *citriodorum* Vis.	leaves	1.7	35.43	3.75	0.13	13.56	0.05	17.37	2.27	5.10	0.68	0.21	0.14	1.95	2.04	0.24
	flowers	2.81	39.54	4.86	6.22	6.49	3.00	8.06	4.55	1.92	2.22	0.12	0.12	4.21	1.70	0.27
Mean		**2.25*c***	**37.44*c***	**4.31*b***	**3.17*b***	**10.02*a***	**1.52a**	**12.72*a***	**3.41b**	**3.51*b***	**1.45b**	**0.16*a***	**0.13*a***	**3.08*b***	**1.87*a***	**0.26*a***
Lime basil *O. americanum* L.	leaves	0.48	9.68	0.10	0.60	21.70	-	27.67	0.93	1.41	-	0.28	0.11	0.89	8.83	1.40
	flowers	0.58	12.11	-	1.78	14.70	-	18.43	1.31	2.83	-	0.21	0.17	1.55	13.35	2.03
Mean		**0.53*a***	**10.89*b***	**0.05*a***	**1.19*a***	**18.20*c***	**-**	**23.05*c***	**1.12a**	**2.12*a***	**-**	**0.25*a***	**0.14*a***	**1.22*a***	**11.09*c***	**1.71*c***
Sweet Dani Lemon *O. basilicum* L.	leaves	0.30	0.83	-	0.91	20.97	0.22	27.14	2.40	1.59	0.39	4.09	2.63	2.72	8.20	1.02
	flowers	1.22	0.51	-	12.69	9.42	5.86	11.55	5.48	2.42	1.72	7.12	5.46	4.86	7.12	0.94
Mean		**0.76*b***	**0.67*a***	**-**	**6.80*c***	**15.20*b***	**3.04b**	**19.34*b***	**3.94c**	**2.01*a***	**1.06a**	**5.61*b***	**4.05*b***	**3.79*c***	**7.66*b***	**0.98*b***
Mean for plant parts	leaves	0.83*A*	15.28*A*	1.29*A*	0.55*A*	18.74*B*	0.09A	24.06*B*	1.87A	2.70*B*	0.36A	1.53*A*	0.96*A*	1.85*A*	6.35*A*	0.89*A*
	flowers	1.54*B*	17.39*B*	1.62*B*	6.90*B*	10.20*A*	2.95B	12.68*A*	3.78B	2.39*A*	1.32B	2.48*B*	1.92*B*	3.54*B*	7.39*B*	1.08*A*

Values are mean ± SD (n=3). Means followed by the same letter are not significantly different at p=0.05.

(-) – not detected

tial oil (Filip 2017), while basil cultivated in middle Africa contained from 0.02 to 2.1% of essential oil (Tchoumbougnang et al. 2006). Beatovic et al. (2015) reported that the amount of essential oil obtained from twelve *O. basilicum* L. cultivars grown in Serbia ranged from 0.65 to 1.90%. A study by Cheliku et al. (2015) showed that the content of essential oil in herbs of five basil (*O. basilicum* L.) cultivars from Albania ranged from 0.11 to 3.40%. Lemon basil (*O. basilicum* var. *citriodorum)* cultivated in Turkey contained from 0.3 to 0.6% and from 0.4 to 0.7% of essential oil in dried leaves and flowers, respectively (Tansi, Nacar 2000). Hydrodistillation of lime basil leaves (*O. americanum* L.) grown in India yielded 0.2% of essential oil (Parida et al. 2014). The essential oil content in the dried aerial parts of two *O. basilicum* L. cultivars from USA ranged from 0.54% (cv. Sweet Dani Lemon) to 1.64% (cv. Mrs. Burns Lemon) – Vieira, Simon (2006).

Generally, the percentage content of basil oil found in the current research (0.30-2.81%) is in good agreement with the literature data. However, flowers and leaves of *O.* × *citriodorum* Vis. cultivated in north-western Poland were richer in essential oil than obtained from the plants cultivated in Turkey. Similarly, the content of essential oil obtained in this study from the leaves of *O. americanum* L. was higher than that obtained from basil grown in India.

The chemical composition of the essential oils isolated from dried leaves and flowers of lemon-scented *Ocimum* species as well as the main classes of the identified constituents are presented in Table 4.

Table 4

Percentage composition of the essential oils from leaves and flowers of three *Ocimum* species

No.	Compound	$RI_{Exp.}$	$RI_{Lit.}$	A		B		C	
				L	F	L	F	L	F
1.	α-Thujene	928	928	0.07	0.16	-	-	-	-
2.	α-Pinene	934	936	0.27	0.53	0.06	0.27	-	0.17
3.	Camphene	949	950	-	0.03	-	-	-	-
4.	Sabinene	975	975	0.03	0.04	-	-	-	-
5.	β-Pinene	977	978	0.14	0.12	0.04	0.13	-	0.06
6.	1-Octen-3-ol	981	980	-	0.11	-	-	-	-
7.	6-Methyl-5-hepten-2-one	989	988	0.03	0.11	0.32	0.35	0.28	0.30
8.	β-Myrcene	992	992	0.31	0.28	0.20	0.14	-	0.13
9.	Octanal	1005	1005	0.09	0.07	-	0.25	-	-
10.	3-Carene	1009	1010	-	0.12	-	0.13	-	0.11
11.	α-Terpinene	1018	1018	0.13	0.13	-	-	-	-
12.	p-Cymene	1026	1026	0.55	0.88	0.03	-	-	-
13.	D-Limonene	1030	1030	-	0.37	0.14	0.18	0.07	0.18
14.	Eycalyptol (1,8-Cineole)	1032	1032	2.09	0.77	0.35	0.31	-	-
15.	Benzeneacetaldehyde	1046	1046	-	0.02	-	-	-	0.09

cont. Table 4

No.	Compound	$RI_{Exp.}$	$RI_{Lit.}$	A		B		C	
				L	F	L	F	L	F
16.	(E)-β-Ocimene	1050	1050	0.02	0.04	-	-	-	-
17.	4-Methyldecane	1056	1057	-	-	0.08	0.13	0.07	0.08
18.	γ-Terpinene	1060	1060	0.43	0.52	-	-	-	-
19.	*cis*-Sabinene hydrate	1069	1070	0.25	0.45	-	-	-	-
20.	*cis*-Linalool oxide	1074	1075	0.49	0.49	0.43	0.61	-	-
21.	1-Octanol	1077	1077	-	-	-	-	-	0.70
22.	*trans*-Linalool oxide	1083	1083	-	-	0.08	0.09	-	0.06
23.	α-Terpinolen	1090	1089	0.55	0.70	1.52	0.80	0.22	0.08
24.	2-Nonanol	1098	1098	-	-	-	-	0.19	0.17
25.	Linalool	1105	1104	35.34	39.54	9.68	12.11	0.50	0.51
26.	α-Pinene oxide	1106	1105	-	-	0.14	0.26	0.17	0.15
27.	Oct-1-en-3-yl acetate	1114	1113	0.42	0.12	0.62	-	-	-
28.	p-Menth-2-en-1-ol	1124	1123	0.20	0.07	-	-	-	-
29.	α-Campholenal	1130	1130	-	-	-	-	-	0.04
30.	4-Acetyl-1-methylcyclohexene	1133	1135	-	0.03	0.07	0.31	0.07	0.13
31.	*trans*-Limonene oxide	1138	1138	-	-	0.08	0.12	0.10	0.08
32.	*trans*-Pinocarveol	1142	1141	0.21	0.11	0.23	0.08	0.31	0.13
33.	(E)-β-Ocimene epoxide (Myroxide)	1144	1143	-	-	-	0.13	-	-
34.	Camphor	1147	1147	0.29	0.15	0.25	0.12	0.13	0.09
35.	(E,Z)-2,6-Nonadienal	1152	1152	0.43	0.24	0.38	0.27	0.75	0.36
36.	Nerol oxide	1156	1155	0.11	0.06	0.11	0.12	0.13	0.20
37.	(Z)-iso-Citral (Isoneral)	1166	1165	0.52	0.13	0.63	0.33	0.42	0.31
38.	Borneol	1169	1168	-	0.06	-	-	-	-
39.	Rose furan oxide	1177	1177	0.33	0.25	0.79	0.58	1.29	0.89
40.	Terpinen-4-ol	1180	1181	3.76	4.86	0.10	-	-	-
41.	iso-Geranial	1184	1184	1.09	0.32	1.26	0.57	0.83	0.52
42.	α-Terpineol	1193	1192	0.42	0.34	1.19	1.67	0.06	0.38
43.	1-Dodecene	1199	1199	-	0.07	0.53	0.30	0.11	0.07
44.	Methyl chavicol (Estragole)	1203	1204	0.03	0.09	0.33	0.63	0.63	-
45.	Decanal	1209	1208	-	-	-	-	0.09	-
46.	Octyl acetate	1212	1213	-	0.42	-	1.50	-	0.98
47.	*trans*-Carveol	1222	1223	0.21	0.07	0.73	0.31	0.36	0.16
48.	*cis*-Carveol	1225	1226	-	0.03	-	0.08	-	0.08
49.	Nerol	1231	1231	0.13	6.22	0.60	1.78	0.91	12.69
50.	Thymol methyl ether	1235	1235	0.14	0.20	0.28	0.18	0.19	0.32
51.	Neral (β-Citral)	1245	1245	13.56	6.49	21.70	14.70	20.97	9.42
52.	Geraniol	1256	1257	0.05	3.00	-		0.22	5.86
53.	p-Menth-1-en-3-one	1258	1259	0.36	-	0.55	0.13	-	-

cont. Table 4

No.	Compound	$RI_{Exp.}$	$RI_{Lit.}$	A		B		C	
				L	F	L	F	L	F
54.	Geranial (α-Citral)	1276	1273	17.37	8.06	27.67	18.43	27.14	11.55
55.	Neryl formate	1283	1284	-	0.13	-	0.39	0.15	0.71
56.	Bornyl acetate	1289	1289	0.16	-	0.22	-	0.04	-
57.	Tridecane	1304	1300	-	0.05	0.28	0.11	0.66	0.37
58.	Methyl geranate	1325	1326	0.01	-	0.07	0.06	0.28	0.14
59.	Bicycloelemene	1334	1335	-	-	-	-	0.13	-
60.	exo-2-Hydroxycineole acetate	1341	1342	-	-	-	0.19	0.10	-
61.	*α*-Cubebene	1355	1354	0.09	0.12	0.07	0.33	0.34	0.42
62.	Eugenol	1361	1360	-	-	-	-	0.25	-
63.	Neryl acetate	1366	1366	0.31	0.44	0.64	1.40	0.61	0.91
64.	3-Methyltridecane	1377	1377	-	-	-	0.28	0.13	-
65.	*α*-Copaene	1382	1382	0.34	0.48	0.62	1.17	1.02	1.18
66.	Geranyl acetate	1385	1385	0.04	0.28	0.14	0.34	0.20	0.58
67.	*β*-Cubebene	1387	1388	0.06	0.23	0.56	0.84	1.13	0.30
68.	*β*-Bourbonene	1391	1391	0.30	0.17	0.65	0.40	0.73	0.36
69.	*β*-Elemene	1396	1397	0.27	0.50	-	0.23	0.62	0.97
70.	Dodecanal	1410	1412	-	-	0.11	-	0.26	-
71.	*α*-Santalene	1420	1420	0.08	0.04	0.05	0.09	0.22	0.06
72.	*β*-Cedrene	1423	1424	-	-	-	-	0.11	-
73.	*β*-Caryophyllene	1427	1428	2.27	4.55	0.93	1.31	2.40	5.48
74.	*β*-Copaene	1437	1437	0.08	0.32	0.02	-	0.10	0.23
75.	*trans*-*α*-Bergamotene	1441	1441	5.10	1.92	1.41	2.83	1.59	2.42
76.	Aromadendrene	1448	1449	0.11	0.13	0.07	0.32	0.12	0.23
77.	Isogermacrene D	1452	1451	0.07	0.15	-	-	0.06	0.12
78.	*trans*-Geranylacetone	1455	1455	-	-	-	-	0.10	-
79.	*α*-Humulene	1462	1462	0.86	1.07	0.31	0.36	0.88	1.27
80.	*γ*-Gurjunene	1471	1472	-	0.06	-	-	-	-
81.	*γ*-Muurolene	1483	1483	-	0.05	-	-	-	0.13
82.	Germacrene D	1490	1489	0.68	2.22	-	-	0.39	1.72
83.	(Z,E)-*α*-Farnesene	1491	1491	-	-	0.28	0.66	0.41	-
84.	*β*-Selinene	1495	1496	0.21	0.12	0.28	0.21	4.09	7.12
85.	Bicyclogermacrene	1504	1503	0.14	0.12	0.11	0.17	2.63	5.46
86.	*α*-Bulnesene	1507	1506	0.04	0.16	-	-	-	-
87.	*β*-Bisabolene	1513	1514	0.15	0.22	0.14	0.45	0.25	0.36
88.	*γ*-Cadinene	1523	1524	0.06	0.18	0.07	0.16	0.26	0.21
89.	7-epi-*α*-Selinene	1527	1526	-	-	-	-	0.16	0.37
90.	*δ*-Cadinene	1530	1530	0.19	0.28	0.11	0.19	0.51	0.48
91.	*trans*-Calamenene	1533	1532	0.04	-	0.08	0.18	-	-

cont. Table 4

No.	Compound	$RI_{Exp.}$	$RI_{Lit.}$	A		B		C	
				L	F	L	F	L	F
92.	*trans*-α-Bisabolene	1547	1547	1.95	4.21	0.89	1.55	2.72	4.86
93.	α-Calacorene	1551	1550	0.11	-	0.37	0.82	0.22	0.20
94.	β-Calacorene	1562	1563	0.06	0.07	0.24	0.44	0.20	0.27
95.	Nerolidol	1567	1567	0.06	0.27	-	-	0.09	-
96.	3-Methylpentadecane	1571	1570	-	-	0.05	0.12	0.04	-
97.	(Z)-3-Hexenyl benzoate	1576	1573	-	-	-	-	0.08	0.06
98.	Dendrasaline	1579	1579	-	-	0.04	0.10	-	-
99.	β-Copaen-4α-ol	1583	1584	0.03	-	0.04	-	0.11	0.03
100.	Caryophyllene oxide	1594	1595	2.04	1.70	8.83	13.35	8.20	7.12
101.	Hexadecane	1601	1600	0.04	-	-	-	0.30	-
102.	α-Humulene oxide	1603	1602	0.03	0.04	0.14	0.30	0.18	0.18
103.	β-Oplopenone	1608	1608	-	-	0.08	0.19	-	-
104.	Tetradecanal	1614	1615	0.02	-	0.10	0.22	0.06	-
105.	Humulene epoxide II	1619	1619	0.31	0.20	1.33	1.59	1.78	1.05
106.	10-epi-γ-Eudesmol	1624	1625	-	0.07	-	-	-	-
107.	1-epi-Cubenol	1628	1627	-	0.11	-	0.34	0.08	0.19
108.	Isospathulenol	1636	1636	0.02	0.04	0.04	0.09	0.15	0.11
109.	γ-Eudesmol	1640	1641	-	-	0.09	0.10	0.27	0.28
110.	τ-Cadinol	1646	1647	0.04	-	0.22	-	0.33	0.29
111.	τ-Muurolol	1650	1651	0.07	0.47	0.16	0.73	0.34	0.34
112.	α-Muurolol	1655	1656	0.06	0.16	0.20	0.43	0.21	0.35
113.	β-Eudesmol	1660	1660	-	-	0.48	0.59	-	-
114.	α-Cadinol	1664	1663	0.30	0.46	1.07	1.22	0.83	1.13
115.	2-Methylhexadecane	1667	1665	-	-	-	0.25	0.11	-
116.	Cadalene	1678	1679	-	-	-	0.13	-	-
117.	1-Tetradecanol	1681	1680	0.24	0.27	1.40	2.03	1.02	0.94
118.	α-Bisabolol	1686	1686	-	0.12	-	-	0.20	0.27
119.	epi-α-Bisabolol	1690	1691	0.10	0.36	0.31	0.87	0.49	0.78
120.	1-Heptadecene	1697	1694	0.07	-	0.02	0.16	0.17	0.29
121.	Heptadecane	1701	1700	-	-	-	0.28	-	-
122.	Pentadecanal	1717	1717	-	-	-	-	-	0.13
123.	(2Z,6E)-Farnesol	1725	1724	-	0.02	-	0.09	-	0.06
124.	Methyl tetradecanoate	1728	1727	-	0.04	-	-	-	0.14
125.	5-Phenyldodecane	1731	1731	-	-	-	-	-	0.09
126.	Oplopanone	1735	1735	-	-	0.01	0.12	-	-
127.	α-Sinensal	1754	1754	-	-	-	0.17	-	-
128.	5-Methylheptadecane	1758	1755	-	-	0.10	0.12	0.26	0.35
129.	2-Methylheptadecane	1764	1764	-	-	-	-	-	0.20

cont. Table 4

No.	Compound	$RI_{Exp.}$	$RI_{Lit.}$	A		B		C	
				L	F	L	F	L	F
130.	(E)-α-Atlantone	1777	1781	0.04	0.13	0.07	0.39	0.15	0.33
131.	Phenanthrene	1782	1784	-	-	-	0.10	-	-
132.	Hexadecanal	1809	1811	-	-	0.09	0.12	-	0.20
133.	Hexahydrofarnesyl acetone	1847	1847	-	0.04	0.09	0.25	0.11	0.10
134.	2-Hydroxycyclopentadecanone	1856	1853	-	-	-	0.07	-	-
135.	Pentadecanoic acid	1872	1872	-	-	-	0.06	0.10	-
136.	(E,E)-Farnesyl acetone	1922	1920	-	-	0.14	0.26	0.19	-
137.	2-Methylanthracene	1933	1930	-	-	-	-	0.03	-
138.	Dibutyl phthalate	1967	1967	-	-	0.15	0.34	1.95	0.08
139.	5-Ethylnonadecane	2035	2034	-	-	0.19	0.18	-	-
140.	3,3-Dimethylnonadecane	2048	2042	-	-	0.03	0.02	0.07	0.07
141.	5-Methyleicosane	2055	2053	-	-	0.07	-	-	-
142.	3-Methyleicosane	2068	2068	-	-	0.05	-	-	-
143.	Heptadecanoic acid	2076	2077	-	-	0.15	0.10	-	-
144.	1-Heneicosene	2090	2090	-	-	-	-	0.03	-
145.	Heneicosane	2107	2100	-	-	0.06	-	-	-
146.	(E)-Phytol	2117	2116	0.16	0.17	0.29	0.20	0.92	0.42
147.	Oleic acid	2146	2147	0.04	-	0.38	0.31	0.22	0.08
148.	5-Methylheneicosane	2154	2153	-	-	0.22	0.17	0.11	-
149.	Docosane	2205	2200	-	-	0.07	0.03	-	-
150.	Eicosanal	2221	2225	-	-	0.09	-	0.11	-
151.	1-Heptadecene	2696	2694	-	-	0.19	-	-	-
152.	5-Methylheptacosane	2749	2749	0.24	-	0.49	-	-	-
153.	2-Methylheptacosane	2765	2762	0.54	-	0.27	-	-	-
154.	3-Methylheptacosane	2772	2772	0.19	-	-	-	-	-
155.	5,13-Dimethylheptacosane	2779	2776	0.14	-	0.09	-	-	-
156.	1-Octacosene	2796	2797	0.14	-	0.15	-	-	-
157.	8-Methyloctacosane	2823	2829	-	-	0.22	-	-	-
158.	1-Nonacosene	2890	2885	-		0.28	-	-	-
	Number of identified compounds			85	89	102	101	96	91
	Monoterpene hydrocarbons			2.50	3.92	1.99	1.65	0.29	0.73
	Oxygenated monoterpenes			77.47	72.61	68.25	55.72	55.99	45.78
	Sesquiterpene hydrocarbons			13.26	17.37	7.26	12.71	21.29	34.22
	Oxygenated sesquiterpenes			3.10	4.15	13.11	20.67	13.41	12.51
	Diterpene alcohols			0.16	0.17	0.29	0.20	0.92	0.42
	Others			2.63	1.59	7.53	8.82	7.67	5.98
	Total identified (%)			99.12	99.81	98.43	99.77	99.57	99.64

$RI_{Exp.}$ – Retention indices relative to n-alkanes (C_7-C_{30}) on a HP-5 MS capillary column
$RI_{Lit.}$ – Literature retention index (Babushok et al. 2011; NIST Chemistry WebBook)
(-) – not detected
A – *O.* × *citriodorum* Vis. Lemon basil, B – *O. americanum* L. Lime basil, C – *O. basilicum* L. cv. Sweet Dani Lemon, L – leares, F – flowers

Eighty-five compounds, corresponding to 99.12% of the chemical constituents in the oil of lemon basil (sample A), were identified. Linalool was the main constituent of essential oil (35.34%), followed by geranial (17.37%), neral (13.56%), *trans-α*-bergamotene (5.10%), terpinene-4-ol (3.76%), *β*-caryophyllene (2.27%) and eucalyptol (2.09%). A total of one hundred and two compounds, corresponding to 98.43% of the chemical constituents in the oil of lime basil (sample B), were identified. Geranial (27.67%) and neral (21.70%) were dominant in the oil. Other abundant constituents were linalool (9.68%) and caryophyllene oxide (8.83%). Ninety-six constituents were identified in the oil isolated from the leaves of the cultivar Sweet Dani Lemon (sample C), representing 99.57% of the separated compounds. Geranial (27.14%), neral (20.97%), caryophyllene oxide (8.20%), *β*-selinene (4.09%) and *trans-α*-bisabolene (2.72%) were found as major essential oil constituents isolated from the leaves. A total of one hundred thirty-six compounds were identified in basil flowers: 89 for lemon basil (99.81% of the total oil), 101 for lime basil (99.77% of the total oil) and 91 for cv. Sweet Dani Lemon (99.64% of the total oil). The main constituents found in the oil of lemon basil (sample A) were linalool (39.54%), geranial (8.06%), neral (6.49%), nerol (6.22%), terpinene-4-ol (4.86%), *β*-caryophyllene (4.55%) and *trans-α*-bisabolene (4.21%). In the oil of lime basil (sample B) geranial (18.43%), neral (14.70%), caryophyllene oxide (13.35%), linalool (12.11%) and *trans-α*-bergamotene (2.83%) were the major components. Nerol (12.69%), geranial (11.55%), neral (9.42%), *β*-selinene (7.12%), caryophyllene oxide (7.12%), geraniol (5.86%) and *β*-caryophyllene (5.48%) dominated in the oil of cv. Sweet Dani Lemon (sample C). Interestingly, the essential oil isolated from the flowers of this *O. basilicum* L. cultivar was poor in linalool (0.51%).

Oxygenated monoterpenes dominated in the essential oils obtained from the leaves of *O.* × *citriodorum* Vis. (77.47%) and *O. americanum* L. (68.25%). Leaf oil of *O. basilicum* L. cv. Sweet Dani Lemon was composed largely of oxygenated monoterpenes (55.99%) and sesquiterpene hydrocarbons (21.29%) – Table 4. Essential oils isolated from the flowers of *O.* × *citriodorum* Vis. and *O. basilicum* L. mainly consisted of oxygenated monoterpenes (45.78-72.61%) and sesquiterpene hydrocarbons (17.37-34.22%), while flower oil of *O. americanum* L. was rich in oxygenated monoterpenes (55.72%) and oxygenated sesquiterpenes (20.67%) (Table 4).

The statistical analysis of the results presented in Table 3 shows some differences between the content of main essential oil constituents in the leaves and flowers of the tested *Ocimum* species.

The highest content of linalool was found in the leaves (35.34%) and flowers (39.54%) of *O.* × *citriodorum* Vis. (lemon basil), while the least content of this constituent was noted in the leaves (0.83%) and flowers (0.51%) of *O. basilicum* L. cv. Sweet Dani Lemon. Moreover, the leaves of *O.* × *citriodorum* Vis. had the highest content of *trans-α*-bergamotene (5.10%). According to the results, the highest content of neral and geranial was found in the leaves of *O. americanum* L. (lime basil), respectively 21.70% and 27.67% and *O. basilicum* L. cv. Sweet Dani Lemon (20.97% and 27.14%). The highest content of *β*-selinene, *trans-α*-bisabolene and bicyclogermacrene was noted for the essential oil isolated from the leaves of *O. basilicum* L. cv. Sweet Dani Lemon (respectively: 4.09%, 2.72% and 2.63%). *O. americanum* L. (lime basil) flowers were characterized by the highest content of geranial (18.43%), neral (14.70%) and caryophyllene oxide (13.35%). When comparing the nerol content, it was shown that its highest value was in the flowers of *O. basilicum* L. cv. Sweet Dani Lemon (12.69%), while its lowest value was noted for *O. americanum* L. – lime basil (1.78%) flowers. The highest content of *β*-selinene (7.12%) and geraniol (5.86%) was recorded for *O. basilicum* L. cv. Sweet Dani Lemon flowers.

The genus *Ocimum* L., which comprises over 150 species rich in essential oils, has been the subject of considerable studies. Linalool, eugenol, methyl chavicol, methyl eugenol and geraniol dominated in the essential oils of different varieties of *O. basilicum* L., while geranial and neral were found to be the main components of *O.* × *citriodorum* Vis. oils (Poonkodi 2016, Tangpao et al. 2018).

The oil obtained from *O. basilicum* var. *citriodorum* cultivated in Turkey contained mainly geranial (49.01%), neral (47.3%) and linalool (5.8%) – Tansi, Nacar (2000). Majdi et al. (2020) found linalool (32.8%), caryophyllene oxide (6.23%), *trans*-α-bergamotene (5.76%), terpinene-4-ol (4.96%), (E)-caryophyllene (4.32%), nerol (3.70%), germacrene D (3.70%) and neral (2.21%) in *O.* × *citriodorum* Vis. oil from Portugal. Vieira and Simon (2006) reported the presence of linalool (46.10%), citral (16.6%) and methyl chavicol (6.4%) as main components of *O. basilicum* L. cv. Mrs. Burns Lemon, while citral (33.6%), spathulenol (11.3%) and *β*-cubebene (7.1%) dominated in the oil of *O. basilicum* L. cv. Sweet Dani Lemon. Citral (29.00-31.30%), *γ*-elemene (2.60-28.00%), spathulenol (13.40-15.00) and linalool (8.90-10.70%) dominated in the essential oil obtained from *O.* × *citriodorum* Vis. grown in USA (Vieira, Simon 2006). Altantsetseg et al. (2012) studied the composition of the essential oils of some *O. basilicum* L. varieties cultivated in the Mongolian Gobi, showing essential oil of lemon basil as rich in geranial (24.70%), neral (19.60%), *τ*-cadinol (11.70%), *β*-caryophyllene (9.90%), 1,8-cineole (8.10%), linalool (8.10%) and *α*-cubebene (6.60%). Nurzyńska-Wierdak (2013) investigated the composition of the essential oils of seventeen sweet basil cultivars grown in an experimental farm in eastern Poland. The lime cultivar contained mainly geranial (25.70%), neral (20.80%), linalool (10.60%), (Z)-*α*-bisabolene (8.00%) and (E)-caryophyllene (6.20%) in the essential oil. Similarly, essential oils of the lemon cultivar and *O. basilicum* var. *citriodorum* were rich in geranial (20.50% and 20.20%, respectively), neral (15.80% and 15.50%), (E)-caryophyllene (10.70% and 10.50%), (Z)-*α*-bisabolene (10.10% and 9.90%) and linalool (9.80% and 9.90%). The main constituents of *O.* × *citriodorum* Vis. from Armenia were nerol (23.00%), geranial (15.77%), methyl chavicol (9.45%), linalool (9.42%) and

β-bisabolene (8.31%) – Avetisyan et al. (2017), while *O.* × *citriodorum* Vis. cultivated in Brazil contained mainly citral (40.00-78.90%), neral (19.40-34.90%), geranial (15.90-46.60%) and linalool (4.20-41.40%) – Paulus et al. (2019).

In the essential oil obtained from the leaves of *O. americanum* L. grown in India, citral (geranial) (47.18%) and β-citral – neral (36.57%) were two major constituents (Parida et al. 2014). Geranial (28.58%), neral (20.16%), linalool (12.15%), nerol (7.15%) and caryophyllene oxide (7.12%) dominated in the essential oil of *O. americanum* L. cultivated in Croatia (Carovic-Stanko et al. 2010).

Essential oil obtained from different parts of *O.* × *citriodorum* Vis. cultivated in north-western Poland was richer in linalool (39.54% in flowers and 35.34% in leaves) as compared with basil cultivated in Turkey (5.80%) – Tansi, Nacar (2000), Portugal (32.80%) – Majdi et al. (2020), USA (8.90-10.70%) – Vieira, Simon (2006), eastern Poland (9.90%) – Nurzyńska-Wierdak (2013) and Armenia (9.42%) – Avetisyan et al. (2017). It was only lemon basil (*O.* × *citriodorum* Vis.) harvested early morning in Brazil (41.38%) – Paulus et al. (2019) that had a higher content of linalool. The content of geranial (8.06% in flowers and 17.37% in leaves) and neral (6.49% in flowers and 13.56% in leaves) found in *O.* × *citriodorum* Vis. in the present study was lover as compared with plants cultivated in eastern Poland (20.20% and 15.50%, respectively for geranial and neral) (Nurzyńska-Wierdak 2013), Turkey (49.01% for geranial and 47.3% for neral) – Tansi, Nacar (2000) and Brazil (19.40-34.90% for neral and 15.90-46.60% for geranial) – Paulus et al. (2019). However, the essential oil of *O.* × *citriodorum* Vis. of Portugal origin contained less neral (2.21%) – Majdi et al. (2020) than determined in our cultivar.

Interestingly, *O. basilicum* L. cv. Sweet Dani Lemon has the lowest content of linalool (0.51% in flowers and 0.50% in leaves) as compared with the cited literature. Moreover, spathulenol, one of the main constituent in the oil of *O. basilicum* L. cv. Sweet Dani Lemon from USA (Vieira, Simon 2006), was not present in our basil oil.

Essential oil isolated from the leaves of *O. americanum* L. cultivated in north-western Poland contained less geranial (27.67%) and neral (21.70%) than reported by Parida et al. (2014). Moreover, caryophyllene oxide (13.35%), which we found as a major component in our study, has not been reported as the main constituent of leaf oil of *O. americanum* L. from India (Parida et al. 2014). The content of linalool (12.11%) which we found in *O. americanum* L. flower oil was almost equal to the amount found by Carovic-Stanko et al. (2010) in the basil oil from Croatia (12.15%). However, our basil was distinguished by a higher content of caryophyllene oxide (8.83% in leaf oil and 13.35% in flower oil) than in oil from the plants of Croatian origin (7.12%) – Carovic-Stanko et al. (2010).

The comparison of our results with the data presented in the literature showed significant differences in the content of main essential oil constituents. This can be attributed to the local climate, soil composition, stage of plant development, occurrence of different chemotypes and nutritional status of the plants as well as improved extraction process of essential oil (Pandey et al. 2020, Sarma et al. 2020).

The data given in Table 5 show that – among the tested *Ocimum* species – a slightly higher content of dry matter was found in the leaves and flowers of *O. americanum* L. (92.55 and 92.42%), while the lowest one was in the leaves of *O. basilicum* L. cv. Sweet Dani Lemon (90.95%). A comparable content of dry matter was noted by Vlaicu et al. (2022) in *O. basilicum* L. from Romania – 91.35%. In the study of Jadczak et al. (2006), the amount of dry matter determined in *O. basilicum* L. cultivated for bunch harvest was much lower (17.5%).

In the present study, among the analyzed macroelements (Table 5), the highest amounts were noted for potassium and calcium. The leaves and flowers of *O.* × *citriodorum* Vis. (lemon basil) were characterized by the highest content of potassium. Slightly lower levels of this macrolement were noted in the leaves and flowers of *O. americanum* L. (lime basil) and *O. basilicum* L. (cv. Sweet Dani Lemon). On the basis of these results, we can conclude that the amount of potassium in the leaves and flowers of lemon-scented basil ranges from 108.37 to 170.50 g kg^{-1}.

The content of calcium determined in this study varied from 101.93 to 233.53 g kg^{-1} in the leaves and from 15.38 to 37.92 g kg^{-1} d.m. in the flowers. The highest amounts of this macroelement was determined in the leaves of *O. basilicum* L. (233.53 g kg^{-1} d.m.), while the lowest content was assessed in the flowers of *O. americanum* L. (15.38 g kg^{-1} d.m.).

The leaves of the tested *Ocimum* species were also characterized by the higher content of total nitrogen (3.72-4.42% d.m.) than the flowers (2.82-3.37% d.m.). Golcz et al. (2006) indicated that the total nitrogen content in basil leaves depended on the cultivar and nitrogen fertilizer dose, and it ranged from 1.24% to 4.13% d.m. Dzida (2010) determined 5.29% d.m. N in *O. basilicum* L. cv. Wala and 5.41% d.m. N in *O. basilicum* L. cv. Kasia. In the study of Seidler-Łożykowska et al. (2006), the total nitrogen content in basil of cv. Wala ranged from 2.42% for conventional to 3.77% for organic growings. The results of our study are generally in agreement with these values.

As regards the microelements (Table 5), their concentrations in the *Ocimum* species we investigated decreased as follows: Fe > Zn > Mn > Cu. The highest amounts of iron were determined in the leaves and flowers of *O. americanum* L. (500.37 mg kg^{-1} d.m. and 543.73 mg kg^{-1} d.m.). A higher content of iron was noted by Licina et al. (2014) in two basil genotypes: Compact – 3576.0 mg kg^{-1} d.m. and Lattuga – 1585.6 mg kg^{-1} d.m., which belong to *O. basilicum* L. Similarly, basil originated from Romania (Vlaicu et al. 2022) had a higher iron content (624.51 mg kg^{-1} d.m.) than determined in our experiment. A higher content of this microelement was also deter-

Table 5

The content of dry matter, macro- and microelements in the leaves and flowers of three *Ocimum* species

Ocimum species (A)	Plant part (B)	Dry matter (%)	N (% d.m.)	Macroelements (g kg^{-1} d.m.)					Microelements (mg kg^{-1} d.m.)			
				P	K	Ca	Mg	Na	Fe	Zn	Cu	Mn
Lemon	leaves	91.22±0.22*a*	3.72±0.01*d*	0.69±0.17*abc*	170.50±11.7*b*	163.87±9.82*d*	1.25±0.04*a*	2.05±0.11*a*	418.03±9.80*b*	153.8±10.21*a*	38.49*a*	81.24±1.89*c*
	flowers	91.25±0.09*a*	3.37±0.02*c*	0.83±0.01*c*	132.5±4.48*b*	33.19±2.37*b*	11.23±0.29*c*	2.09±0.04*a*	435.67±56.21*b*	227.33±3.13*c*	51.62*d*	34.63±0.26*a*
Lime	leaves	92.55±0.12*b*	4.42±0.02*f*	0.54±0./01*a*	111.53±5.05*a*	101.93±2.34*c*	2.09±0.04*a*	1.96±0.04*a*	500.37±3.20*bc*	185.2±9.96*b*	45.93*c*	91.4±3.67*d*
	flowers	92.42±0.41*b*	2.82±0.01*a*	0.59±0.04*ab*	108.37±8.93*a*	15.38±1.56*a*	10.0±0.88*b*	2.48±0.09*b*	543.73±55.53*c*	164.03±3.79*a*	40.08*ab*	38.29±3.23*a*
Sweet Dani Lemon	leaves	90.95±0.16*a*	3.89±0.02*e*	0.56±0.03*ab*	110.7±0.62*a*	233.53±9.73*e*	1.92±0.10*a*	2.00±0.15*a*	270.93±12.97*a*	159.83±12.25*a*	44.15*bc*	117.3±4.50*e*
	flowers	91.37±0.14*a*	3.22±0.01*b*	0.76±0.03*bc*	119.03±3.16*ab*	37.92±1.28*b*	15.89±0.47*d*	2.03±0.06*a*	462.27±18.04*bc*	244.47±5.83*c*	68.55*e*	68.44±1.66*b*
Mean for A	Lemon	91.23±0.15*a*	3.54±0.19*a*	0.76±0.13*b*	151.50±22.63*b*	98.53±71.86*b*	6.24±5.46*a*	2.07±0.07*a*	426.85±37.35*b*	190.57±40.84*b*	45.05*a*	57.94±25.55*a*
	Lime	92.48±0.28*b*	3.62±0.88*b*	0.57±0.40*a*	109.95±6.72*a*	58.66±47.44*a*	6.05±4.37*a*	2.22±0.29*b*	522.05±42.45*c*	174.62±13.41*a*	43.00*a*	64.84±29.26*b*
	Sweet Dani Lemon	91.16±0.27*a*	3.56±0.37*a*	0.66±0.13*ab*	114.87±4.50*a*	135.72±107.32*c*	8.91±7.66*b*	2.02±0.10*a*	366.6±105.74*a*	202.15±47.14*b*	56.35*b*	92.87±26.93*c*
Mean for B	leaves	91.57±0.75*a*	4.01±0.31*b*	0.60±0.11*a*	130.91±30.37*b*	166.44±57.45*b*	1.76±0.39*a*	2.00±0.10*a*	396.44±101.00*a*	166.28±17.22*a*	42.86*a*	96.65±16.39*b*
	flowers	91.68±0.6*a*	3.13±0.24*a*	0.73±0.11*b*	119.97±12.13*a*	28.83±10.41*a*	12.37±2.74*b*	2.20±0.22*b*	480.56±63.40*b*	211.94±36.89*b*	53.41*b*	47.12±16.17*a*

Values are mean ± SD (n=3). Means followed by the same letter are not significantly different at p=0.05.
Lemon – *Ocimum × citriodorum* Vis. (Lemon basil)
Lime – *Ocimum americanum* L. (Lime basil)
Sweet Dani Lemon – cultivar of *Ocimum basilicum* L.

mined by Majkowska-Gadomska et al. (2013) in the leaves of sweet basil – 517.67 mg kg^{-1} d.m., cinnamon basil – 471.76 mg kg^{-1} d.m. and purple basil – 556.88 mg kg^{-1} d.m.

The highest content of zinc was determined in the flowers of *O. basilicum* L. (244.47 mg kg^{-1} d.m.) and *O. americanum* L. (227.33 mg kg^{-1} d.m.), while the highest content of manganese was recorded in the leaves of *O. basilicum* L. (117.3 mg kg^{-1} d.m.). Seidler-Łożykowska et al. (2009) determined lower values of zinc (53-143 mg kg $^{-1}$ d.m.) in the herb of the Polish basil cultivar Kasia in comparison with the *Ocimum* species investigated in our study. Similarly, *O. basilicum* L. originating from Romania (Vlaicu et al. 2022) had a lower content of zinc (54.63 mg kg^{-1} d.m.) than in the basil examined in this experiment. The manganese content assessed by Seidler-Łożykowska et al. (2009) in cv. Kasia basil ranged from 66 to 302 mg kg $^{-1}$ d.m., depending on the location and type of cultivation. The lower values of this micronutrient (37.17 mg kg $^{-1}$ d.m.) were noted in cv. Wala basil (Golcz, Seidler-Łożykowska 2009). The content of manganese in the leaves and flowers of selected *Ocimum* species determined in this study are in agreement with literature data. However, the leaves were richer in this micronutrient.

In the Polish climatic conditions, the content of copper varied from 5 to 20 mg kg^{-1} d.m. (Seidler-Łożykowska et al. 2009). The content of copper determined in this study ranged from 38.49 mg kg^{-1} d.m. (leaves of *O.* × *citriodorum* Vis.) to 68.55 mg kg^{-1} d.m. (flowers of *O. basilicum* L.). Generally, the greatest amount of copper was accumulated by basil flowers.

Based on the obtained results, it can be stated that the analyzed *Ocimum* species are a good source of macro- and microelements beneficial for the consumer health.

CONCLUSIONS

1. The content of essential oils isolated from different parts of selected *O.* species (*O.* × *citriodorum* Vis., *O. americanum* L. and *O. basilicum* L. cv. Sweet Dani Lemon) grown in north-western Poland ranged from 0.30% to 1.70% (w/w) for leaves and from 0.58% to 2.81% (w/w) for flowers.

2. Linalool, neral and geranial were the main constituents in the all analyzed oil samples. However, the percentages of neral and geranial were higher in the essential oils isolated from the leaves, while slightly higher amount of linalool was detected in the oils isolated from the flowers.

3. Essential oils isolated from the leaves of *O. americanum* L. and *O. basilicum* L. cv. Sweet Dani Lemon may be applied commercially, as natural food preservatives, because of the high content of neral and geranial.

4. The *Ocimum* species tested in the experiment were characterized by a high amount of macroelements. The biggest content of potassium was

found in the leaves and flowers of *O. × citriodorum* Vis., calcium in the leaves of *O. basilicum* L. and nitrogen in the leaves of *O. americanum* L.

5. The leaves and flowers of *O. americanum* L. had the highest content of iron, while the highest content of manganese was recorded in the leaves of *O. basilicum* L.

REFERENCES

Altantsetseg S., Skatar S., Javzmaa N. 2012. *Comparative study of constituents of essential oils of Ocimum basilicum* L. *cultivated in the Mongolian Gobi.* Erforsch. Biol. Ress. Mongolei (Halle/Saale), 12: 451-456.

Avetisyan A., Markosian A., Petrosyan M., Sahakyan N., Babayan A., Aloyan S., Trchounian A. 2017. *Chemical composition and some biological activities of the essential oils from basil Ocimum different cultivars.* BMC Complement. Altern. Med., 17:60. DOI: 10.1186/s12906--017-1587-5

Babushok V.I., Linstrom P.J., Zenkevich I.G. 2011. *Retention indices for frequently reported compounds of plant essential oils.* J. Phys. Chem. Ref. Data, 40(4): 043101-1-043101-47. DOI: 10.1063/1.3653552

Beatovic D., Kristic-Milosevic D., Trifunovic S., Siljegovic J., Glamoclija J., Ristic M., Jelacic S. 2015. *Chemical composition, antioxidant and antimicrobial activities of the essential oils of twelve Ocimum basilicum* L. *cultivar grown in Serbia.* Rec. Nat. Prod., 9(1): 62-75.

https://acgpubs.org/doc/201808071238455-RNP-EO_1208-054.pdf

Bernhardt B., Szabo K., Bernath J. 2015. *Sources of variability in essential oil composition of Ocimum americanum and Ocimum tenuiflorum.* Acta Aliment, 44(1): 111-118. DOI: 10.1556//AAlim.44.2015.1.11

Carovic-Stanko K., Orlic S., Politeo O., Strikic F., Kolak I., Milos M., Satovic Z. 2010. *Composition and antibacterial activities of essential oils of seven Ocimum taxa.* Food Chem., 119(1): 196-201. DOI: 10.1016/j.foodchem.2009.06.010

Chalchat J.C., Ozcan, M.M. 2008. *Comparative essential oil composition of flowers, leaves and stems of basil (Ocimum basilicum* L.*) used as herb.* Food Chem., 110: 501-503. DOI: 10.1016//j.foodchem.2008.02.018

Cheliku N., Karanfilova I.C., Stefkov G., Karapandzova M., Bardhi N., Qjazimi B., Kulevanova S. 2015. *Essential oil composition of five basil cultivar (Ocimum basilicum) from Albania.* Maced. Pharm. Bull., 61(2): 11-18. http://bulletin.mfd.org.mk/volumes/Volume%20 61_2/61_2_002.pdf

Dasgupta T., Rao A.R., Yadava P.K. 2004. *Chemomodulatory efficacy of basil leaf (Ocimum basilicum) on drug metabolizing and antioxidant enzymes, and on carcinogen-induced skin and forestomach papillomagnesis.,* Phytomedicine, 11(2-3): 139-151. DOI: 10.1078/0944--7113-00289

Dzida K. 2010. *Nutrients content in sweet basil (Ocimum basilicum L.) herb depending on calcium carbonate dose and cultivar.* Acta Sci. Pol., Hort. Cult., 9(4): 143-151. https:////czasopisma.up.lublin.pl/index.php/asphc/article/view/3436

European Pharmacopoeia, 8.0. Strasbourg, Council of Europe. 2013, Vol. 1, 273-274.

Filip S. 2017. *Basil (Ocimum basilicum* L.*) a source of valuable phytonutrients.* Int. J. Clin. Nutr. Diet., 3: 118. DOI: 10.15344/2456-8171/2017/118

Golcz A., Politycka B., Seidler-Łożykowska K. 2006. *The effect of nitrogen fertilization and stage of plant development on the mass and quality of sweet basil leaves (Ocimum basilicum* L.*).* Herba Pol., 52(1/2): 22-30. http://www.herbapolonica.pl/magazines-files/7320204-3.pdf

Golcz A., Seidler-Łożykowska K. 2009. *Content of microelements in raw materials of basil (Ocimum basilicum* L.*), savory (Satureja hortensis* L.*) and marjoram (Origanum majorana* L.*)*

collected in the different stages of plant development. Nauka Przyr. Technol., 3(3): 74. http://www.npt.up-poznan.net/pub/art_3_74.pdf

Hassanpouraghdam M.B., Gohari G.R., Tabatabatei S.J., Dadpou M.R. 2010. *Inflorescence and leaves essential oil composition of hydroponically grown Ocimum basilicum* L. J. Serb. Chem. Soc., 75(10): 1361-1368. DOI: 10.2298/JSC100311113H

Jadczak D., Błaszczuk A., Rekowska E. 2006. *Effect of covering on the content of macroelements in yield of basil (Ocimum basilicum* L.*) cultivated for a bunch harvest.* J. Elem., 11(2): 135-141.

Kiczorowska B., Klebaniuk R., Bąkowski M., Al-Yasiry A.R.M.H. 2015. *Culinary herbs – the nutritive values and content of minerals.* J. Elem., 20(3): 599-608. DOI: 10.5601/jelem.2014.19.4.739

Licina V.D., Jelacic S.C., Beatovic D.V., Antic Mladenovic S.B. 2014. *Mineral composition of different basil (Ocimum spp.) genotypes.* Hem. Ind., 68(4): 501-510. http://www.ache.org.rs/HI/2014/No4/HEMIND_Vol68_No4_p501-510_Jul-Aug_2014.pdf

Majdi Ch., Pereira C., Dias M.I., Calhelha R.C., Aives M.J., Rhourri-Frih B., Charrouf Z., Barros L., Amaral J.S., Ferreira I.C.R.R. 2020. *Phytochemical characterization and bioactive properties of Cinnamon basil (Ocimum basilicum cv. Cinnamon) and Lemon basil (Ocimum x citriodorum).* Antioxidants, 9: 369. DOI: 10.3390/antiox9050369

Majkowska-Gadomska J., Wierzbicka B., Dziedzic A. 2014. *The effect of seedling planting time on macroelement and microelement concentrations in basil (Ocimum basilicum* L.*) leaves.* Pol. J. Environ. Stud., 23(1): 125-129.

Makri O., Kintzios S. 2008. *Ocimum* spp. *(Basil): Botany, cultivation, pharmaceutical properties, and biotechnology.* J. Herbs Spices Med., 13(3): 123-150. DOI: 10.1300/J044v13n03_10

Marotti M., Piccaglia R., Giovanelli E. 1996. *Differences in essential oil composition of basil (Ocimum basilicum* L.*) Italian cultivar related to morphological characteristic.* J. Agric. Food Chem., 44: 3926-3929. DOI: 10.1021/jf9601067

Nurzyńska-Wierdak R. 2013. *Morphological and chemical variability of Ocimum basilicum (Lamiaceae).* Mod. Phytomorphol., 3: 115-118. https://www.phytomorphology.com/articles//morphological-and-chemical-variability-of-ocimum-basilicum-l-lamiaceae.pdf

Nurzyńska-Wierdak R. 2013. *Does mineral fertilization modify essential oil content and chemical composition in plants?* Acta Sci. Pol., Hort. Cult., 12(5): 3-16. https://czasopisma.up.lublin.pl/index.php/asphc/article/view/2932

Opalchenova G., Obreshkova D. 2003. *Comparative studies on the activity of basil – an essential oil from Ocimum basilicum* L. *– against multidrug resistant clinical isolates of the genera Staphylococcus, Enterococcus and Pseudomonas by using different test methods.* J. Microbiol. Meth., 54(1): 105-110. DOI: 10.1016/S0167-7012(03)00012-5

Pandey S.K., Sarma N., Begun T., Lal M. 2020. *Standardization of different drying Methods of fresh patchouli (Pogostemon cablin) leaves for high essential oil yield and quality.* J. Essent. Oil Bear. Plants, 23(3): 484-492. DOI: 10.1080/0972060X.2020.1798289

Parida R., Sandeep S., Sethy B.K., Sahoo S., Mohanty S. 2014. *Chemical composition, antioxidant and antimicrobial activities of essential oil from lime basil (Ocimum americanum): a potent source of natural antioxidant.* Int. J. Pharm. Sci., 6(7): 487-490.

Paulus D., Valmorbida R., Ramos C.E.P. 2019. *Productivity and chemical composition of the essential oil of Ocimum × citriodorum* Vis. *according to ontogenetic and diurnal variation.* J. Appl. Res. Med. Aromat. Plants, 12: 59-65. DOI: 10.1016/j.jarmap.2018.12.004

Poonkodi K. 2016. *Chemical composition of essential oil of Ocimum basilicum* L. *(Basil) and its biological activities – an overview.* J. Crit. Rev., 3(3): 56-62. http://www.jcreview.com//admin/Uploads/Files/61c71dfc2097a5.05022958.pdf

Pripdeevech P., Chumpolsri W., Suttiarporn P., Wongpornchai S. 2010. *The chemical composition and antioxidant activities of basil from Thailand using retention indices and comprehensive two-dimensional gas chromatography.* J. Serb. Chem. Soc., 75(11): 1503-1513. DOI: 10.2298/JSC100203125P

Sarma N., Begun T., Pandey S.K., Gogoi R., Munda S., Lal M. 2020. *Chemical profiling of leaf essential oil of Lantana camara* Linn. *from north-east India.* J. Essent. Oil Bear. Plants, 23(5): 1035-1041. DOI: 10.1080/0972060X.2020.1838333

Seidler-Łożykowska K., Kozik E., Golcz A., Mieloszyk E. 2006. *Macroelements and essential oil content in the raw material of the selected medicinal plant species from organic cultivation.* J. Res. Appl. Agric. Eng., 51(2): 161-163. (in Polish)

Seidler-Łożykowska K., Mordalski R., Kucharski W., Golcz A., Kozik E., Wójcik J. 2009. *Economic and qualitative values of the raw material of chosen species of medicinal plants from organic farming*. Part II. *Yield and quality of sweet basil herb (Ocimum basilicum* L.*).* Acta Sci. Pol., Agric, 8(3): 29-35.

Stojicevic A.S., Antic M.P., Jelacic S.C., Solevic Knudsen T.M. 2019. *Chemical composition of the essential oils of three Ocimum basilicum* L. *cultivar from Serbia.* Not. Bot. Horti. Agrobo., Cluj-Napoca, 47(2): 347-351. DOI: 10.15835/nbha47111250

Tansi S., Nacar S. 2000. *First cultivation trials of lemon basil (Ocimum basilicum var. citriodorum) in Turkey*. Pak. J. Biol. Sci., 3(3): 395-397. DOI: 10.3923/pjbs.2000.395.397

Tangpao T., Chung H-H., Sommano S.R. 2018. *Aromatic profiles of essential oils from five commonly used Thai Basils.* Foods, 7(11): 175. DOI: 10.3390/foods7110175.

Tchoumboungnang F., Zollo P.H.A., Avlessi F., Alitonou G.A., Sohounhloue D.K., Ouamba J.M., Tsomambet A., Okemy-Andissa N., Dagne E., Agnaniet H., Bessiere J.M., Menut C. 2006. *Variability in the chemical composition of the essential oils of five Ocimum species from Tropical African Area.* J. Essent. Oil Res., 18: 194-199. DOI: 10.1080/10412905.2006.9699064

Türkmen M. 2021. *The effect of different phenological periods and harvest times on the essential oil ratio and components of basil genotypes.* J. Essent. Oil Bear. Plants, 24(1): 94-109. DOI: 10.1080/0972060X.2021.1894243

Vieira R.F., Simon J. 2006. *Chemical characterization of basil (Ocimum spp.) based on volatile oils.* Flavour Frag. J., 21: 214-221. DOI: 10.1002/ffj.1513

Vlaicu P.A., Untea A.E., Turcu R.P., Saracila M., Panaite T.D., Cornescu G.M. 2022. *Nutritional composition and bioactive compounds of basil, thyme and sage plant additives and their functionality on broiler thigh meat quality.* Foods., 11(8): 1105. DOI: 10.3390/foods11081105

Wogiatzi E., Papachatzis A., Kalorizou H., Chouliara A., Chouliaras N. 2011. *Evaluation of essential oil yield and chemical components of selected basil cultivar.* Biotechnol. Biotec. Eq., 25(3): 2525-2527. DOI: 10.5504/BBEQ.2011.0067

Zhang D.Y., Yao X.H., Duan M.H., Wei F.Y., Wu G.H., Li L. 2015. *Variation of essential oil content and antioxidant activity of Lonicera species in different sites of China.* Ind. Crop. Prod., 77: 772-779. DOI: 10.1016/j.indcrop.2015.09.048