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ORIGINAL PAPER

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DOES PRESERVATION MODIFY THE ESSENTIAL OIL CONTENT AND CHEMICAL COMPOSITION OF LEAF CELERY (*Apium graveolens* L. var. *secalinum* Alef.)?

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ABSTRACT

Preservation of spice plants usually leads to changes in the structure and content of biologically active substances. The present study determined the effect of lyophilization and convection drying on the content and chemical composition of the essential oil from leaves of two leaf celery cultivars. Compared to lyophilization, convection drying allows a larger amount of essential oil to be retained in leaves of leaf celery (respectively by 0.48 and 0.21%). The oil obtained from the material preserved using the convection method had higher amount of limonene, γ-terpinene, (Z)-β-ocimene and β-selinene than that extracted from the lyophilized material, whereas the essential oil from freeze-dried celery had more myrcene and 9H-purin-6-ol than oil from convection-dried celery.

Key words: lyophilization, convection drying, quality of celery leaves, limonene, myrcene

INTRODUCTION

Preservation of food products using physical, chemical and biotechnological methods is designed to extend their shelf life, while in the case of aromatic products, also to maintain their taste and smell. Among various food preservation methods, freezing and drying are the most known ones and, at the same time, these methods do not incorporate additional preserving substances. An additional advantage that speaks for these processing forms is high level of retention of the original nutritional value compared to fresh products. Both these methods slow down the speed of chemical reactions and natural biological processes and inhibit microbial growth, not allowing fermentation processes, mold and decay [Ratti 2001, Zhang et al. 2006]. Drying at an elevated temperature can cause adverse changes in plant material: oxidation of vitamins and pigments, losses in essential oil, and changes in texture [Asekun et al. 2007, Vega-Gálvez et al. 2008, Ayyobi et al. 2014]. An alternative solution, in particular in the case of thermo-labile products, is to use low processing temperature and to shorten the process time. Lyophilization, which is dehydration by sublimation of a frozen product, is such a method and it is recommended for food products [Ratti 2001, Di Cesare et al. 2003, Ciurzyńska et al. 2011] as well as for improvement of the stability of pharmaceutical and biotechnological preparations [Tsinontides et al. 2004]. Due to the phase transition of ice directly into water vapor without passing through the liquid phase, the most valuable components: vitamins, proteins, and mineral nutrients, do not degrade and a product's properties, such as smell,

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taste and color, are preserved [Shofian et al. 2011, Ali et al. 2016].

The method for drying herbs and spices can significantly affect their chemical composition, aroma and biological activity [Díaz-Maroto et al. 2002, Di Cesare et al. 2003, Díaz-Maroto et al. 2004, Mangkoltriluk et al. 2005, Pirbalouti et al. 2013, Prusinowska and Śmigielski 2015]. Chan et al. [2009] report that lyophilization is the best drying method to preserve the high antioxidant activity of rhizomes of the *Zingiberaceae* family plants. Drying results in essential oil losses, but they are substantially higher in the case of convection drying compared to freeze-drying [Lisiewska and Kmiecik 1997, Polak et al. 2009]. Usai et al. [2011] assessed that freezing is the best method, while air drying is the worst method for stabilization of the rosemary oil chemical composition. High-pressure freeze-drying of lemon balm leaves is recommended due to significant retention of volatile substances [Antal et al. 2014]. Lisiewska and Kmiecik [1998] showed that essential oil losses are higher for convection drying than in the case of freeze-drying of chive leaves. An inverse relationship was however demonstrated for lovage leaves [Rosłon et al. 2013]. Freeze-drying of thyme herb and its drying at a temperature of 50°C were characterized by significant essential oil yield and retention of the herb's color compared to other drying methods [Rahimmalek and Goli 2013]. Rosłon et al. [2013] report that the phthalide content in the lovage essential oil increases under the influence of freezing, thermal drying and lyophilization.

Essential oil is the most important component accumulated in all celery organs, which imparts the desired sensory characteristics to the plant. Leaf celery accumulates 0.41−0.72% of essential oil in leaves, depending on irrigation and harvest time [Rożek et al. 2012]. Monoterpenes are the main fraction of the leaf celery essential oil, with limonene and myrcene being predominant among them [Saleh et al. 1985, Rożek et al. 2016]. Phthalides, which give characteristic aroma and an intensive smell to the plant and which exhibit anti-inflammatory, antitumor and insecticidal properties, are an important group of essential oil constituents [Saleh et al. 1985, Sellami et al. 2011, Sowbhagya 2014]. Sipailiene et al. [2005] revealed that the celery leaf extract contains significant amounts of myrcene and some sesquiterpenes and exhibits greater antibacterial activity than the root extract, which is primarily abundant in carvone. The leaf celery essential oil shows activity against larvae of Schistosoma masoni, a parasite causing schistosomiasis which is, apart from malaria, the most important parasitic health problem at the global scale [Saleh et al. 1985]. The present study determined the content and chemical composition of the essential oil obtained from leaves of two leaf celery (*Apium graveolens* L. var. *secalinum* Alef.) cultivars harvested at two times and preserved using convection drying (35°C) and lyophilization.

MATERIALS AND METHODS

The study material consisted of leaves of field-grown leaf celery (*Apium graveolens* L. var. *secalinum* Alef.) obtained in 2012 from crops grown at the Felin Experimental Farm of the University of Life Sciences in Lublin (Poland; 51°22'N, 22°64'E). The experimental factors were as follows: A. cultivar (a = 2); a_1 – 'Amsterdam' (PlantiCo Zielonki), and a_2 – 'Safir' (Bejo Zaden); B. harvest time (b = 2); b_1– July 15, b_2 – October 13; C. drying method (c = 2); c_1 – convection drying, c_2 – lyophilization. At the set harvest dates, two-kilogram samples of leaves were collected. After harvest, the leaves were washed, drip dried and cut into 1 cm pieces that were subsequently lyophilized at 0.0003 millibar/h and a temperature of –50°C [Lisiewska and Kmiecik 1998] in an Alpha 1–4 sublimator. Convection drying was carried out using forced air circulation in a chamber dryer at the temperature of 35°C. The preserved plant material was steam distilled to assess the essential oil content. The indirect method of hydro-distillation of the plant material in a Clevenger-type apparatus with an addition of 0.5 ml xylene was used, according to European Pharmacopoeia 7 [2010]. Portion of 50 g of the plant material was weighed, transferred to a 1 dm^3 round-bottom flask, adding 450 ml of distilled water, and heating to a boiling point. The distillation was carried out for 3 hours. After this time, the heating was turned off, the oil was cooled down and its content was read out on the scale; the obtained value was expressed as the oil content per 100 g of plant material. Such achieved results were statistically analyzed by two-way analysis of variance (ANOVA), determining the significance of differences at p = 0.05

[Oktaba 1986]. The oil samples were used for qualitative evaluation by GC/MS. The oil was stored in a dark glass container at –10°C until chromatographic separation. The qualitative and quantitative composition of the oil was determined by means of gas chromatography and mass spectrophotometry. A Varian 4000 Mass Spectrometer equipped with a VF-5 ms column (length 30 m, diameter 0.25 mm, and film thickness 0.25 mm) was used for the assay. The carrier gas was helium at a constant flow rate of 0.5 ml/min. 1 µl was injected (1 µl of sample in 1000 µl hexane). Recorded range: 40–1000 m/z, scan rate 0.8 sec/scan. The retention indices were determined based on a series of alkanes (C_6–C_{40}) [Van Den Dool and Kratz 1963]. The injector temperature was 220°C. A temperature gradient of 60°C was applied for 5 minutes, and then a temperature increment from 60 to 246°C (3°C/min), whereas 246°C was applied for 10 minutes. The identity of compounds was also confirmed based on the retention indices according to Adams [2004].

RESULTS AND DISCUSSION

Essential oil content. Cultivar, harvest time, preservation method and the interactions of the studied factors were shown to have a significant effect on the essential oil content in leaves of leaf celery (Tab. 1). The average essential oil content in the preserved plant material investigated was 0.34%. Leaves of the leaf celery cultivar 'Safir' contained more essential oil (0.36%) than leaves of cv. 'Amsterdam' (0.32%). Saleh et al. [1985] report that fresh aerial parts of Egyptian leaf celery contain 0.09–0.14% of essential oil, depending on the location. The studies by Rożek et al. [2012, 2016] show that cv. 'Safir' plants accumulate 0.44–0.54% of essential oil in their leaves. Significantly higher essential oil content was obtained from leaves harvested in July (0.42%) compared to the October harvest (0.27%) (Tab. 1). This confirms the results of studies by Rożek et al. [2012, 2016] demonstrating higher essential oil content in leaves of the leaf celery cultivar 'Safir' at the earlier than at later harvest dates. The obtained results indicate that the process of essential oil accumulation in leaves of leaf celery plants is subject to different variations and that the selection of cultivar and harvest time is of key importance for the aromatic value of plant material.

Freeze-drying of common celery (*Apium graveolens* L.) leaves is a good method for color retention [Polak et al. 2014]. Results of the present study reveal significant differences in the essential oil content in convection- and freeze-dried leaves of leaf celery. The highest essential oil content was found in the dried material obtained using the convection method

Table 1. Essential oil content in dried leaf celery leaves (%)

Cultivar (A)	Harvest time (B)	Drying method (C)	
		convection drying	freeze-drying
Amsterdam	July 15th	0.55	0.28
	October 13th	0.42	0.05
Safir	July 15th	0.50	0.33
	October 13th	0.45	0.17
Mean (A)	Amsterdam	0.32	
	Safir	0.36	
Mean (B)	July 15th	0.42	
	October 13th	0.27	
Mean (C)		0.48	0.21

$LSD_{0.05}$ A – 0.03; B – 0.03; C – 0.03; A × B – 0.07; A × C – 0.07; B × C – 0.07; A × B × C – n.s.

(0.48%), whereas it was half as low in the freeze-dried material (0.21%) (Tab. 1). Aromatic herbs containing essential oils are particularly sensitive to drying and technological processes. Investigations of various essential oil plant materials do not clearly point out to one of the drying methods compared. Freeze-drying causes higher essential oil losses than convection drying [Rosłon et al. 2013]. The material freezing process itself can also contribute to lower essential oil content in lyophilized plant material. According to Rosłon et al. [2013], freezing can cause a decrease in the oil content in lovage leaves by even up to 71.3%. Osińska et al. [2012] also draw attention to the lower oil content in parsley leaves after freezing. Lisiewska and Kmiecik [1997], on the other hand, obtained higher essential oil content in chive leaves after freeze-drying relative to convection drying, but it was conducted at a temperature not recommended for essential oil materials (50°C). Drying and storage of rosemary leaves have a strong impact on their sensory characteristics, which are extremely important to the consumer [Diaz-Maroto et al. 2007]. Hoffman [2007] proves that conventionally dried materials, compared to freeze-dried ones, can have less intensive and less typical aroma (in comparison with the standard material) than lyophilized materials. In turn, Diaz-Maroto et al. [2004] report that lyophilization does not cause significant changes in the taste of basil. The study by Chan et al. [2009] proves the stability of the antioxidant properties of ginger leaves and tea after lyophilization. Di Cesare et al. [2003] showed that blanching and/or drying (convection drying at 50°C and freeze-drying) damaged the oil glands of basil. Milder conditions required for lyophilization cause small damage to the oil glands and thus resulting in better retention of volatile substances [Di Cesare et al. 2003]. Obtained results, regarding drying of leaf celery leaves, indicate that the optimal temperature for drying essential oil-containing herbs (35°C) better retains volatile substances than lyophilization.

Essential oil chemical composition. Table 2 presents the essential oil chemical composition of leaf celery depending on the factors studied. The essential oil extracted from celery leaves contained 67–108 compounds. In all samples of the investigated essential oil, the following main compounds were identified: limonene (38.73–50.08%), myrcene (18.01–36.37%), β-selinene (2.00–4.51%), γ-terpinene (<0.05–3.42%), 6-butyl-1,4-cycloheptadien (0.90–3.32%), and E-caryophyllene (1.76–2.57%). Moreover, 9H-purin-6-ol (0.88–7.52%) and kessane (0.18–1.88%) were found in larger amounts; the occurrence and content of these compounds were dependent on the cultivar, harvest time and drying method. Among all the 108 identified compounds contained in the oils, 27 occurred regularly in all combinations (limonene, myrcene, β-selinene, γ-terpinene, α-pinene, β-pinene, sabinene, caryophyllene oxide, camphene, (E)-β-ocimene, para-mentha-2,4(8)-dien, epoxymyrcene (6,7), octen-3-yl acetate (1), octanol acetate (3), trans-limonene oxide, 6-butyl-1,4-cycloheptadien, (3Z,5E)-1,3,5-undecatrien, cis-para mentha-(1,7),8-dien-2-ol, carvone, myrtenyl acetate, 8-epi-dictamnol, (Z)-β-farnesene). The other constituents changed depending on the experimental factors (Tab. 2). These findings are largely in agreement with results obtained by other authors [Saleh et al. 1985, Wolski et al. 2001, Rożek 2007, Polak et al. 2009, Rożek et al. 2013], which may indicate relatively stable chemical composition of the leaf celery essential oil.

The limonene content in the oil obtained from leaves of both studied cultivars was comparable, but the myrcene content in the oil extracted from cv. 'Safir' was lower (24.59%) than in that obtained from cv. 'Amsterdam' leaves (30.99%) (Fig. 1). Limonene is one of the most frequently found components of essential oils. It is biosynthesized from geranyl pyrophosphate, and its wide spread is primarily attributed to its precursor role in the biosynthesis of other monoterpenes [Erasto and Viljoen 2008]. Myrcene, derived from geranyl diphosphate, is also a frequent essential oil component that makes an important contribution to the scent of flowers of many plant species [Dudareva et al. 2003]. The study by Dudareva et al. [2003] proves that snapdragon (*Antirrhinum majus* L.) flowers emit the following 3 main odorous components: myrcene, (E)-ocimene and methyl benzoate, and that their emission is regulated developmentally and changes under the control of the circadian clock. The study by Rożek et al. [2016] demonstrates that the essential oil extracted from leaves of the celery cultivar 'Safir' contains 54.04–58.29% of limonene and 19.51–27.65% of myrcene, depending on plant irrigation. When studying the effect of fertilization on celery yield, El-Sayed et al. [2011]

showed differences in the myrcene content in the essential oil even up to 50%, whereas the limonene content was at the similar level. It can therefore be presumed that the celery essential oil composition is associated not only with genetic and ontogenetic, but also environmental variation. This is also confirmed by the analysis results of the essential oil extracted from leaves harvested at two times: in summer and in autumn (Tab. 2, Fig. 1). The essential oil extracted from leaves harvested in July was characterized by a higher number of components than oil obtained from the October harvest. Differences were found not only in the case of main components, limonene and myrcene, but also for the other constituents. Furthermore, in the case of compounds such as: Z-β-ocimene, γ-terpinene, E- caryophyllene, α-selinene, kessane, 9H-purin-6-ol, and Z-ligustilide, they were shown to be absent in the oil samples obtained from leaves collected in July or October (Tab. 2), which could have been attributable to ontogenetic variation. El-Zaeddi et al. [2016] demonstrated changes in the content of some essential oil constituents (including limonene and myrcene) in leaves of fennel, coriander, parsley and mint harvested at different times. These authors report that proper harvest time of the above-mentioned spice herbs is extremely important with regard to the essential oil content and sensory quality of the plant material.

Drying method modified the qualitative composition of investigated celery essential oil. The oil extracted from convection-dried leaves contained more limonene and less myrcene than the freeze-dried material. In the oil obtained from the freeze-dried material, there was more 9H-purin-6-ol (2.6%) and less γ-terpinene, (Z)-β-ocimene and β-selinene compared to the convection-dried plant material. In the oils extracted from celery (*Apium graveolens* L.) lyophilizates, Polak et al. [2009b] found the presence of 19 odorous compounds from the monoterpene fraction (myrcene, limonene, β-ocimene) and from the phthalide fraction (3-n-butylphthalide, sedanolide, cis-sedanolide). These authors noted that the monoterpene content decreased compared to the fresh material, whereas the percentage of phthalides in lyophilizates increased. In the present study, the (Z)-ligustilide content in the oil was determined only in some samples, while the other phthalides were found in trace amounts (Tab. 2). Phthalides, which determine the specific aroma of celery, are poorly volatile compounds and their content largely depends on the type of plant material investigated [Wolski et al. 2001]. In the opinion of Abascal et al. [2005],

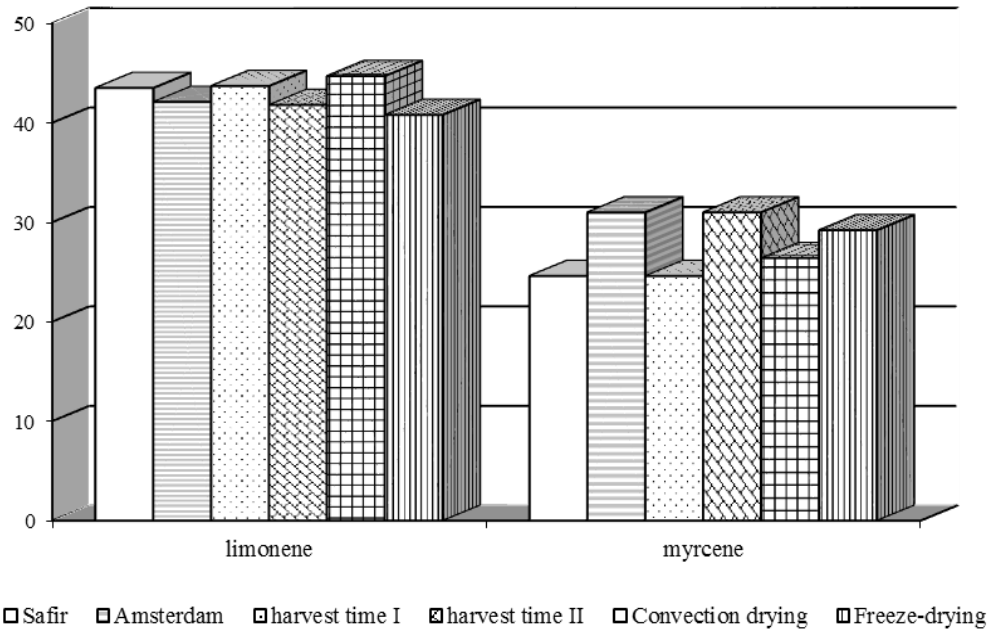

Fig. 1. Main compounds of leaf celery essential oil (%) – average values

Table 2. Chemical composition of leaf celery essential oil (%)

No	Compound	RI	Convection drying				Freeze-drying			
			'Amsterdam'		'Safir'		'Amsterdam'		'Safir'	
			July*	October*	July*	October*	July*	October*	July*	October*
1	α-thujene	928	tr.	tr.	0.09	tr.	tr.	tr.	tr.	–
2	α-pinene	936	0.67	0.59	0.29	0.17	0.34	0.32	0.16	0.12
3	camphene	954	0.13	0.14	tr.	tr.	0.06	tr.	tr.	tr.
4	sabinene	977	0.40	0.29	0.42	0.16	0.24	0.14	0.18	0.15
5	β-pinene	983	0.46	0.48	1.47	0.42	0.32	0.26	0.33	0.24
6	**myrcene**	997	**18.01**	**27.99**	**26.17**	**33.26**	**25.96**	**26.39**	**28.27**	**36.27**
7	**limonene**	1045	**50.08**	**43.93**	**46.13**	**38.79**	**39.97**	**39.84**	**38.73**	**44.73**
8	(Z)-β-ocimene	1047	2.65	–	–	–	–	–	–	–
9	(E)-β-ocimene	1052	0.09	0.12	0.18	0.21	0.13	0.08	0.21	0.30
10	γ-terpinene	1065	1.44	tr.	3.42	tr.	0.55	tr.	1.06	tr.
11	epoxymyrcene (6,7)	1098	0.05	0.08	0.08	0.09	0.11	0.07	0.10	0.13
12	trans-para-mentha-2,4,diene-1-ol	1122	–	0.06	–	tr.	–	0.09	–	tr.
13	allo-ocimene	1133	0.18	–	0.26	–	0.12	–	0.19	–
14	cis-limonene oxide	1137	0.15	–	0.10	–	0.16	–	0.12	–
15	trans-limonene oxide	1146	0.15	0.10	0.14	0.07	0.20	0.08	0.16	tr.
16	6-butyl-1,4-cycloheptadiene	1165	2.15	2.56	1.38	1.29	2.38	3.32	1.36	0.90
17	(3Z,5E)-1,3,5-undecatriene	1180	0.08	tr.	0.05	tr.	0.12	0.06	0.06	0.05
18	terpinene-4-ol	1191	0.07	–	0.06	–	0.05	–	tr.	–
19	trans-carveol	1213	tr.	–	tr.	–	0.05	–	tr.	–
20	cis-para menth-(1,7), 8-dien-2-ol	1232	0.05	tr.	tr.	0.05	0.07	0.11	0.06	tr.
21	carvone	1257	0.10	tr.	0.09	tr.	tr.	tr.	tr.	0.05
22	trans-sabinene hydrate acetate	1262	–	0.12	–	0.10	–	0.13	–	0.06
23	cis-verbenyl acetate	1264	tr.	–	tr.	–	0.06	–	0.07	–
24	trans-pinocarvyl acetate	1306	tr.	–	0.05	–	tr.	–	tr.	–
25	carvacrol	1315	0.08	–	tr.	–	tr.	–	tr.	–
26	terpinen-4-ol acetate	1331	–	tr.	–	tr.	–	tr.	–	0.12
27	cis-pinocarvyl acetate	1339	–	0.23	–	0.18	–	0.31	–	0.11
28	trans-carvyl acetate	1340	0.24	–	0.15	–	0.27	–	0.23	
29	myrtenyl acetate	1350	tr.	tr.	tr.	0.15	tr.	tr.	0.11	0.12
30	anisyl formate	1364	–	0.07	–	tr.	–	0.08	–	0.06
31	1-pentanone	1370	0.13	–	0.07	–	tr.	–	tr.	–
32	Z-β-damascenone	1385	–	0.10		0.12		0.36		0.34
33	E-β-damascenone	1388	0.10	–	0.06	–	0.12	–	0.12	–
34	β-elemene	1395	0.09	–	0.09	–	0.08	–	0.13	–
35	methyl eugenol	1412	0.17	–	0.13	–	tr.	–	tr.	–
36	8-epi-dictamnol	1415	tr.	0.08	tr.	0.09	tr.	0.35	tr.	0.24
37	E-caryophyllene	1429	1.85	–	2.03	–	1.76	–	2.57	–
38	(Z)-β-farnesene	1456	0.07	tr.	tr.	tr.	0.08	tr.	0.07	0.27
39	α-humulene	1465	0.19	–	0.25	–	0.18	–	0.30	–
40	gamma-curcumene	1484	0.33	–	0.28	–	0.22	–	0.18	–

41	(AR)-curcumene	1489	0.25	–	0.18	–	0.21	–	0.27	–
42	β-selinene	1500	2.89	3.30	2.10	4.51	2.46	3.41	2.75	2.00
43	α-selinene	1506	0.40	–	0.49	–	0.34	–	0.63	–
44	β-curcumene	1517	0.10	–	0.05	–	0.09	–	tr.	–
45	kessane	1541	1.88	–	0.18	–	1.51	–	0.59	–
46	liguloxide	1549	0,07	–	tr.	–	tr.	–	tr.	–
47	elemicin	1559	0.08	–	0.07	–	tr.	–	tr.	–
48	(E)-nerolidol	1568	tr.	–	tr.	–	tr.	–	tr.	–
49	caryophyllene oxide	1595	0.23	0.15	0.24	0.08	0.21	–	0.40	–
50	tujanopsan-2-α-ol	1609	0.07	–	tr.	–	0.05	–	tr.	–
51	2,6,6-trimethylundeca-1,3-dien-9-yn-5-one	1623	0.22	–	0.21	–	0.23	–	0.26	–
52	(Z)-asarone	1662	0.12	–	0.06	–	tr.	–	tr.	–
53	14-hydroxy-α-humulene	1674	–	tr.	–	tr.	–	0.11	–	tr.
54	eremoligenol	1685	0.06	–	tr.	–	0.05	–	tr.	–
55	bulnesol	1700	tr.	–	tr.	–	0.05	–	tr.	–
56	9H-purin-6-ol	1755	2.55	–	0.88	–	7.52	–	2.91	–
57	(Z)-ligustilide	1759	0.35	–	0.84	–	–	–	0.56	–
58	1,2-benzenedicarboxylic acid	1872	0.06	–	0.06	–	0.09	–	0.16	–
59	cembrene	1953	0.06	–	0.14	–	0.08	–	0.12	–
60	dibuthyl phthalate	1968	tr.	–	tr.	–	0.05	–	0.08	–
61	(Z)-falcarinol	2058	tr.	–	0.19	–	tr.	–	tr.	–

* time of harvest, tr. – <0.05%

The following compounds are marked in all samples in trace amounts: nonane, tricyclene, santolina trenie, benzaldehyd, heten-2-on, N-octanal, α-phellandrene, Δ-2-carene, α-terpinene, Δ-3-carene, terpinolene, para-mentha-2,4(8)-diene, α-piene oxide, perillene, linalool, octen-3-yl acetate (1), (Z)-myroxide, trans-verbenol, 1,6,10-dodectriene, verbenol, meta-cymen-8-ol, cis-sabinene hydrate acetate, α-terpineol, myrtenol, cis-carveol, pentanoic acid, 2-methyl, methyl ester, linalyl acetate, nopol, bornyl acetate, neoiso-3-thujyl acetate, azulene, para-mentha1,5-dien-8-ol, citronellyl acetate, cis-carvyl acetate, β-copaene, 7-epi-sesquithujene, α-trans-bergamotene, α-acoradiene, 9-epi-(E)-caryophyllene, (E)-methyl isoeugenol, guaiol, (3Z)-butylidene phthalide, α-pentyl-benzenemethanol, cyclopentanone,3,4-bis (methylene), 14-oxy-α-muurolene, diazinone, 2-pentadecanone

each drying method may affect the content of aromatic compounds, but freeze-drying has the greatest impact on the proportions between individual essential oil components. The content of individual essential oil components may depend not only on the drying method used, but also on the selection of drying parameters [Hossain et al. 2010, Ghasemi et al. 2013]. Very frequently, freeze-drying results in a change in the percentage of individual essential oil components [Díaz-Maroto et al. 2002, Abascal et al. 2005]. The study by Diaz-Maroto et al. [2002a] reveals that drying of laurel leaves at a temperature of 45°C and at ambient temperature caused almost no loss in the amount of volatile substances compared to the fresh material, whereas freezing and lyophilization caused a substantial loss in leaf aroma and resulted in an increase in the content of some oil constituents (eugenol, elemicin, spathulenol and β-eudesmol). Usai et al. [2011] report that freezing is the best method for preserving the thyme oil composition, but worse results were obtained with regard to lyophilization. On the other hand, however, in the case of lyophilization, the content of thymol and carvacrol, the most important constituents of the thyme aroma, was better preserved [Usai et al. 2011]. The study by Rosłon et al. [2013] showed that the content of α-terpinyl acetate, (Z)-ligustilide, (Z)-butylidenephthalide, (E)-butylidenephthalide and (E)-ligustilide in the essential oil extracted from lovage leaves increased under the influence of the stabilization methods used (freezing, thermal drying and lyophilization). In the stabilized material, these authors also found the presence of trans-p-menth-2-en-1-ol, cis-β-elemene and butylphthalide – compounds that were not present in the fresh material.

CONCLUSIONS

1. Cultivar and harvest time cause differences in the essential oil content of leaf celery. Compared to freeze-drying, convection drying allows a larger amount of essential oil to be retained in leaves of leaf celery.

2. Quality of lyophilized leaves of leaf celery is dependent on the cultivar. Freeze-dried leaves of cv. 'Safir' better retain the essential oil than cv. 'Amsterdam' leaves. In the case of convection drying, cultivar selection is of lesser importance for essential oil retention.

3. Limonene content in the oil obtained from leaves of both cultivars studied was at similar level, but in the oil extracted from cv. 'Safir", there was less myrcene than in that obtained from cv. 'Amsterdam'. The essential oil extracted from leaves of celery plants harvested in July was characterized by a greater number of components than that obtained from the October harvest.

4. Compared to lyophilization, convection drying contributes to the retention of a larger amount of limonene, γ-terpinene, (Z)-β-ocimene and β-selinene in the leaf celery essential oil. On the other hand, freeze-drying allows a larger amount of myrcene and 9H-purin-6-ol to be retained in the oil than in the case of convection drying.

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