ISSN 1644-0692
www.acta.media.pl
Acta Sci. Pol. Hortorum Cultus, 15(1) 2016, 149-159

THE CHEMICAL COMPOSITION OF THE ESSENTIAL OIL OF LEAF CELERY (*Apium graveolens* L. VAR. *Secalinum* ALEF.) UNDER THE PLANTS' IRRIGATION AND HARVESTING METHOD

Ewa Rożek, Renata Nurzyńska-Wierdak, Andrzej Sałata, Piotr Gumiela
University of Life Sciences on Lublin

Abstract. Qualitative and quantitative composition of the essential oil is subject to different types of variability. The aim of this study was to determine the effect of irrigation and harvest date on the content and composition of essential oil distilled from leaves, petioles and leaf blades of *Apium graveolens* L. var. *secalinum* Alef. Drip irrigation was carried out twice in the third 10 days of July and twice in the third 10 days of August. A single dose of water was 20 mm. The raw material was harvested on September 7 and October 17, thus collecting leaves after 120 and 161 days of plant growth, respectively. Irrigation increased the concentration of volatile substances in leaf blades (0.68%) and decreased the content of these components in petioles (0.24%). Celery leaves harvested in October contained significantly less essential oil (0.34%) compared to those collected in the first 10 days of September (0.53%). Monoterpenes proved to be the main fraction in the essential oil of leaf celery, limonene and myrcene being predominant among them. Most limonene (75.77%) was found in petioles of irrigated plants. Leaves of irrigated plants contained more limonene and less myrcene compared to leaves of non-irrigated plants. More myrcene and less limonene were determined in leaves harvested in September than in those harvested in October.

Key words: Apiaceae, environmental variability, monoterpenes, limonene, myrcene

INTRODUCTION

Leaf celery (*Apium graveolens* L. var. *secalinum* Alef.) is one of the three botanical varieties within the species *Apium graveolens* L. This is a biennial plant of the family

Corresponding author: Renata Nurzyńska-Wierdak, Department of Vegetable Crops and Medicinal Plants, Faculty of Horticulture and Landscape Architecture, University of Life Sciences in Lublin, Leszczyńskiego 58, 20-068 Lublin, Poland; e-mail: renata.nurzynska@up.lublin.pl

Apiaceae, which does not form a bulbous hypocotyl and is grown for its aromatic leaves. The commercial value of celery is increased due to the possibility of preservation of raw material by freezing or drying it. The celery cultivation method has a significant effect on plant growth. Plants grown from seedlings have a shallow root system and 50–60 cm high rosettes consisting of several dozen up to more than one hundred leaves [Rożek 2006, 2007a, b]. All parts of this plant contain an aromatic essential oil and therefore they are used mainly as a seasoning in raw, frozen and dried form. The active substances of celery exhibit, among others, antibacterial [Bonjar 2004, Mahdi 2011, Baananou et al. 2013], antifungal [Afec et al. 1995], antiparasitic [Saleh et al. 1985], and antioxidant activity [Momin and Nair 2002, Yildiz et al. 2008, Nagella et al. 2012]. The celery fruit contains 2–3% of essential oil, while the leaves 0.09–0.43% [Rożek 2007a]. The following are mentioned among the main constituents of the essential oil of celery: limonene, selinene, α- and β-pinene, and myrcene [Saleh 1985, Papamichail et al. 2000, Sowbhagya et al. 2007, Rożek 2007a]. The chemical composition of the essential oil depends on harvesting method and determination method [Papamichail et al. 2000, Sowbhagya et al. 2007]. The characteristic scent of the oil is associated with the presence of phthalides [Zheng et al. 1993], compounds that show antitumor [Zheng et al. 1993], larvicidal, nematicidal, and fungicidal activity [Momin and Nair 2002]. The proportion of the most important group of celery oil compounds, phthalides, can be increased by using appropriate modifications of oil extraction methods [Jain et al. 2003]. The research demonstrates that celery has a wide range of medicinal applications and can be used as a stand-alone medication or a component of combined medications in the treatment of various conditions, and also as a supporting agent [Asif et al. 2011, Al-Saaidi et al. 2012, Salman et al. 2013].

The content and chemical composition of the essential oil of celery and other aromatic plant species are dependent on a number of factors: genetic, ontogenetic and environmental as well as agronomic factors (fertilization, irrigation, cultivation method, and harvesting method) [Benbelaid et al. 2013, Nurzyńska-Wierdak et al. 2014, Aćimović et al. 2015]. It is important to well plan and carry out irrigation in order to maximize vegetable yields, at the same time minimizing environmental effects [Kuşçu et al. 2009, Chidankumar et al. 2010, Paul et al. 2013]. Irrigation of crop plants, in particular during a period of prolonged drought and on light soils, increases the uptake and use of soil nutrients. Water deficit reduces plant photosynthesis and disturbs metabolic processes, which is sometimes associated with an adverse change in the concentration of active substances [Pirzad et al. 2006, Kołodziej 2008, Azimi et al. 2012]. Not all essential oil plant species exhibit a similar response to drought stress. Water deficit significantly reduced the growth parameters of rosemary plants, at the same increasing the essential oil content [Hassan et al. 2013]. Water stress significantly affected the essential oil content in anise plants [Aloghareh et al. 2013]. On the other hand, an increase in time intervals in irrigation of *Carum copticum* L. plants (Apiaceae) did not have an effect on their essential oil content [Vahidipour et al. 2013]. An increase in seedling planting density and irrigation of plants significantly increased the yield of leaf celery [Rożek 2007b, Rożek et al. 2013]. Time of raw material harvest significantly modifies the yield and composition of essential oil of various herbal plants [Rożek et al. 2013, Nurzyńska-Wierdak et al. 2014, Singh et al. 2014], which is affected by both ontogenetic and environmental factors. The essential oil derived from the oregano herb harvested at the initial stage of flowering had the highest number of components compared to the oil distilled from the herb harvested during the other growth stages [Nurzyńska-Wierdak 2009]. In the available literature, information is scarce on the effect of agronomic treatments on the content and chemical composition of the essential oil of leaf celery. On the other hand, however, reports on strong biological activity of the components of celery appear in the literature [Al-Snafi 2014, Hassanen et al. 2015]. Given the above data, the present study was conducted to determine the effect of irrigation and harvest date on the content and composition of the essential oil distilled from leaves, petioles and leaf blades of *Apium graveolens* L. var. *secalinum* Alef.

MATERIALS AND METHODS

A field experiment was established at the Felin Experimental Farm of the University of Life Sciences in Lublin in 2010. The field study was carried out on grey-brown podzolic soil derived from loess deposits, with a humus content of 1.7%. Seeds of leaf celery (*Apium graveolens* L. var. *secalinum* Alef.) cv. 'Safir' (producer: the company Bejo Zaden) were sown in a greenhouse on March 5. After the first true leaves appeared, the seedlings were transplanted into seedling trays. At the 5–7 leaf stage, the seedlings were planted in the field at a spacing of 25 × 20 cm. The experiment was established as randomized block design with four replications. Before planting, fertilization was applied at the following rates on a per hectare basis: 100 kg N (calcium nitrate), 53 kg P (triple superphosphate), and 125 kg K (potassium sulfate). In the middle of the growing period, top dressing was applied in the form of calcium nitrate at a rate of 50 kg N ha^{-1}. The plants were weeded by hand (in rows) and mechanically (in interrows). Crop protection treatments were applied against celery septoriosis, alternately using the fungicides Amistar 250 SC (azoxystrobin) and Bravo 500 SC (chlorothalonil) at the following rates, respectively: 0.8 l ha^{-1} and 1.8 l ha^{-1}. The plants were irrigated using drip irrigation lines four times at critical periods of water deficit: twice in the third 10 days of July and twice in the third 10 days of August. A single dose of water was 20 mm. The control plants were not watered. This gave conditions on the plantations is not irrigated, where plants use some of the rainwater on contained in the soil. During the growing season average rainfall in each month was similar to the long-term average.The following harvest dates were used: September 7 and October 17, thus collecting leaves after 120 and 161 days of plant growth, respectively. The plant material was dried in a drying oven at a temperature of 35°C and subsequently 3 fractions were separated: leaf blades, petioles, and whole leaves.

The essential oil content and chemical composition in the raw material were determined. The essential oil content was determined by direct steam distillation, according to Polish Pharmacopoeia VIII [2010]. Leaves of irrigated and non-irrigated plants harvested on September 7 and the individual fractions of leaves collected on September 7 and October 17 were subjected to chromatographic analysis. The qualitative composition of the essential oil was determined by gas chromatography coupled with a mass detector using the Varian 4000 GC/MS system with a VF column – 5 ms (DB-5 equivalent). The injector temperature was 250°C and 1 μl of the solution was injected (1 μl of sample per 1000 μl hexane). The temperature was increased to 50°C during 1 minute and then it was increased from 50 to 250°C (4°C per 1 minute); 250°C was maintained for 10 minutes. Helium (He) was used as carrier gas, at a constant flow of 0.5 ml·min.$^{-1}$. A Varian 4000 MS/MS detector was used at a scan rate of 0.8 seconds per scan. The Kovats retention indices were determined based on a range of *n* – alkanes from C_6 to C_{40} [Van Den Dool and Kratz 1963]. The qualitative analysis was carried on the basis of MS spectra, which were compared with data available in the literature [Adams 2004]. The identity of the compounds was confirmed by their retention indices, taken from the literature [Adams 2004] and our own data. The results on the essential oil content in celery leaves were statistically analyzed by two-way cross-classification analysis of variance, evaluating the significance of differences by Tukey's range test and performing LSD calculations at a significance level of $\alpha \geq 0.05$.

RESULTS AND DISCUSSION

Essential oil content. Weather conditions during the growing season are the major factor that modifies the essential oil content in celery leaves. Under their influence, the oil content can increase even twice [Rożek 2007a]. The essential oil content in leaf celery depending on irrigation and harvest date is shown in Table 1. Irrigation is an important factor that affects yield quantity and quality of celery [Breschini and Hartz 2002] and other leafy vegetables [Chidankumar et al. 2010]. Nevertheless, the information concerning the effect of irrigation on essential oil content and yield is divergent. Irrigation deficit increases the essential oil content of rosemary [Hassan et al. 2013] and anise [Aloghareh et al. 2013], whereas the oil content is highest under conditions when plants are well supplied with water [Aloghareh et al. 2013]. The essential oil content and yield of chamomile were lowest at 100 and 55% soil water capacity [Pirzad et al. 2006]. In turn in peppermint, which is a plant with high moisture requirements, the lack of water inhibits essential oil accumulation [Kołodziej 2008]. Similar relationships found in celery, a plant with similarly high water requirements, would also suggest this. However, the obtained results indicate that the irrigation of plants did not affect the essential oil content in celery leaves (tab. 1). In comparing the essential oil content in the individual leaf parts, on the other hand, irrigation was found to increase the concentration of volatile substances in leaf blades (0.68%) and to decrease it in petioles (0.24%). This phenomenon can be linked with a possible function of essential oil to prevent too rapid transpiration and a way to maintain a positive water balance. But harvest date had a major effect on the leaf oil content. Celery leaves harvested in October contained significantly less essential oil (0.34%) compared to those collected in the first 10 days of September (0.53%). This corroborates the results of the previous study [Rożek et al. 2013], showing that earlier leaf celery harvest dates (August–September) are more favorable to obtain a highly aromatic raw material than later harvest times (October).

The individual parts of the celery leaf were characterized by varying contents of essential oil (tab. 1). More than twice more oil was determined in leaf blades (on average 0.66%) compared to petioles (on average 0.26%). Hence, the oil in whole leaves was determined to be at a much higher amount than in petioles alone. These differences are of great practical importance: while stalk celery (*A. graveolens* var. *dulce*) is grown for its edible fleshy leaf stalks, in leaf celery (*A. graveolens* var. *secalinum*) whole leaves are the marketable part.

Table 1. The effect of irrigation and harvest time on essential oil content in the leaf blades, petioles and leaves of leaf celery 'Safir' (%)

Harvest time	Irrigated plants			Non-irrigated plants			Mean
	leaf blades	petioles	leaves	leaf blades	petioles	leaves	
07.09	0.75	0.30	0.50	0.88	0.26	0.50	0.53a
17.10	0.50	0.25	0.30	0.47	0.22	0.28	0.34b
Mean	0.63a	0.28c	0.40b	0.68a	0.24c	0.39b	
Mean		0.44a			0.44a		

Essential oil composition. In the essential oil of leaf celery, the presence of 37 chemical compounds was shown, out of which three were not identified (tab. 2). The main constituents of the oil extracted from whole leaves of leaf celery were the following: limonene (54.04–58.29%), myrcene (19.51–27.65%), 1,2 ethanediol, 1-phenyl (5.62–7.17%), furan, 2-(2-propenyl) (2.25–2.27%), Z-β-ocimene (1.45–1.85%), trans-β--guaiene (1.35–1.92%), 2,5 pyrrolidinedione (1.0–1.87%), 6-butyl-1,4-cycloheptadiene (1.03–1.68%), γ-terpinene (1.02–1.18%). This corroborates the results of the previous study [Rożek et al. 2013], showing that the monoterpene fraction is predominant in the essential oil of *A. graveolens* var. *secalinum,* similarly as in *A. graveolens* [Asif et al. 2011, Al-Snafi 2014].

The soil moisture level can cause changes in the contents of the essential oil constituents. The 125% field water capacity contributed to an increase in the myrcene content and a decrease in the limonene concentration in basil oil [Khalid 2006]. Irrigation deficit resulted in an increase in the concentration of α-pinene, 1,8-cineole and borneol as well as in a decrease in the percentage of linalool and camphor in rosemary oil [Hassan et al. 2013]. The level of transformation of p-cymene to phenolic compound thymol increased under water stress conditions [Aziz et al. 2008]. Similar modifications in the chemical composition of the celery oil were demonstrated in the present study. The oil from irrigated plants contained more limonene, 1,2 ethanediol, 1-phenyl, furan, 2-(2-propenyl), Z-β-ocimene, and 6-butyl-1,4-cycloheptadiene, while that from non-irrigated plants more myrcene and trans-β--guaiene. The content of the two main constituents, limonene and myrcene, depending on the plant part and irrigation varied greatly. The limonene content ranged 45.94–75.77%, while the myrcene content 6.56–37.51%. Leaf blades contained less limonene and more myrcene compared to petioles. Both leaf blades and petioles of irrigated plants contained more limonene and less myrcene compared to non-irrigated plants. Similar relationships (except for the cultivar 'Gewone Snij' at the second harvest date) were revealed in the previous study on other leaf celery cultivars [Rożek et al. 2013], which shows the greater effect of environmental variation relative to genetic variation. Likewise, Moro et al. [2011] found an increase in the limonene concentration in the oil of hyssop plants as affected by irrigation. Moreover, Kołodziej [2008] revealed a slight increase in the concentration of limonene and β-myrcene in peppermint oil as affected by irrigation of plants. Additionally, the limonene content in chamomile essential oil decreased with poorer water supply to plants [Pirzad et al. 2006]. The highest limonene content was found in petioles of irrigated plants (75.77%) (tab. 2). At the same time, petioles in this treatment contained least myrcene (6.56%). These changes may result from the course of the biosynthesis of terpenoids. Three compounds: α-thujene, α-terpinene, and caryophyllene oxide, occurred in trace amounts. Water stress conditions can significantly influence the essential oil composition.

Table 2. The effect of irrigation on the chemical composition of essential oil of leaf celery 'Safir' (%)

Compound	IR	Leaf blades		Petioles		Leaves	
		NI	I	NI	I	NI	I
α-Thujene	932	–	–	tr.	–	–	–
α-Pinene	939	0,18	0.42	0.85	1.11	0.44	0.62
Camphene	955	–	0.09	0.17	0.24	0.10	0.14
Sabinene	977	0.09	0.12	0.28	0.33	0.18	0.19
β-Pinene	982	0.16	0.17	0.37	0.50	0.25	0.27
Myrcene	991	37.51	25.67	20.97	6.56	27.65	19.51
α-Tetrapinene		–	–	tr.	–	–	–
Cymene	1028	tr.	0.05	0.19	0.56	0.11	0.2
Limonene	1031	45.94	53.48	55.60	75.77	54.04	58.29
(Z)-β-Ocimene	1036	1.21	1.59	2.38	1.72	1.45	1.85
(E)-β-Ocimene	1048	–	–	0.05	–	–	–
γ-Terpinene	1059	0.35	0.36	2.63	2.57	1.18	1.02
6-Butyl-1,4-cycloheptadiene	1160	1.32	1.59	0.67	0.59	1.03	1.68
β-Elemene	1395	–	0.08	–	–	–	–
E-Caryophyllene	1429	0.73	0.65	0.79	0.30	0.79	0.63
α-Trans bergamotene	1441	–	0.31	–	–	–	0.15
α-Guaiene	1445	–	0.07	–	–		tr
α-Humulene	1469	0.07	0.08	0.07	–	0.06	0.06
γ-Curcumene	1490	0.10	0.11	tr.	–	0.10	0.12
Germacrene D	1496	–	0.28	–	–	–	0.15
Trans-β guaiene	1505	1.59	1.27	2.60	1.32	1.92	1.35
α-Selinene	1512	0.18	0.11	0.13	tr	0.15	0.10
Germacrene A	1516	–	0.06	–	–	–	tr
γ-Cardinene	1527	–	0.11	–	–	–	0.05
Kessane	1544	0.53	0.59	1.62	1.03	0.82	0.75
Liguloxide	1552	–	–	0.06	–	–	–
Caryophyllene oxide	1594	–	–	tr.	–	–	–
α-Santoline alkohol	1654	0.11	–	0.29	–	0.15	–
Cadinol	1656	–	0.35	–	0.10	–	0.23
2,5 Pyrrolidinedione	1671	0.75	1.37	1.37	2.28	1.00	1.87
Apiol	1692	–	0.10	–	tr	–	0.23
n.i.	1697	0.53	1.06	0.94	0.51	0.61	0.92
1,2-Ethanediol, 1-phenyl	1735	5.63	6.77	4.83	3.54	5.62	7.17
Furan, 2-(2-propenyl)	1742	2.91	3.08	2.88	0.85	2.26	2.27
Z-ligustilide	1751	–	–	0.05	–	–	–
n.i.	1767	–	–	–	tr	–	0.10
n.i.	1838	0.10	–	tr	–	0.10	–

NI – non irrigated, I – irrigated, tr. – trace < 0.05%, n.i. – compound not identified

The chemical composition of the essential oil of various aromatic plant species is affected by the time of raw material harvest [Nurzyńska-Wierdak 2013, Zawiślak 2013, Wesołowska et al. 2014]. Irrigation of leaf celery contributes to increased leaf yield [Rożek 2007b], which indicates the high moisture requirements of this species. Celery leaf harvest date caused significant differences in the essential oil composition (tab. 3). The concentration of the main oil constituent, limonene, was from 40.91 to 59.76%, depending on the type of raw material and harvest date. The oil distilled from leaf blades collected on September 7 contained more limonene (45.94%) compared to the later harvest (40.91%). An opposite relationship was shown in the case of the oil obtained from petioles and whole leaves. The results of the previous study [Rożek et al. 2013] demonstrate that the proportion of limonene generally decreases at a later leaf harvest time, while an opposite relationship was found only for one celery cultivar in one year of the study. As influenced by harvest date, the limonene concentration may increase [Bai et al. 2009] or may not vary substantially [Yu et al. 2011]. The proportion of the above-mentioned biocomponent is most clearly dependent on genetic, ontogenetic and environmental factors and therefore its concentration in the oil can be significantly modified.

Table 3. Influence of harvest time on the chemical composition of the essential oil of leaf celery 'Safir'(%)

Compound	IR	Leaf blades		Petioles		Leaves	
		7.09	17.10	7.09	17.10	7.09	17.10
α-Thujene	932	–	–	tr.	tr	–	–
α-Pinene	939	0,18	0.41	0.85	1.03	0.44	0.94
Camphene	955	–	0.10	0.17	0.26	0.10	0.22
Sabinene	977	0.09	0.09	0.28	0.29	0.18	0.21
β-Pinene	982	0.16	0.17	0.37	0.52	0.25	0.37
Myrcene	991	37.51	27.89	20.97	7.45	27.65	15.84
α-Tetrapinene		–	–	tr.	–	–	–
Cymene	1028	tr–.	tr	0.19	0.31	0.11	0.14
Limonene	1031	45.94	40.91	55.60	59.76	54.04	56.05
(Z)-β-Ocimene	1036	1.21	2.43	2.38	2.76	1.45	2.28
(E)-β-Ocimene	1048	–	–	0.05	tr	–	–
γ-Terpinene	1059	0.35	0.51	2.63	2.88	1.18	1.71
6-Butyl-1,4-cycloheptadiene	1160	1.32	2.36	0.67	1.08	1.03	1.34
Trans carvyl acetate	1343	–	–	tr.	0.07	tr.	–
β-Elemene	1395	–	–	–	0.09	–	–
E-Caryophyllene	1429	0.73	0.81	0.79	1.01	0.79	0.84
α-Humulene	1469	0.07	0.05	0.07	0.08	0.06	–
γ-Curcumene	1490	0.10	0.15	tr.	0.08	0.10	0.12
Trans-β-guaiene	1505	1.59	–	2.60	–	1.92	–
β-Selinene	1507	–	1.59	–	3.07	–	2.15
α-Selinene	1512	0.18	0.09	0.13	0.14	0.15	0.10
Kessane	1544	0.53	0.71	1.62	1.89	0.82	1.17
Liguloxide	1552	–	–	0.06	0.06	–	–
Caryophyllene oxide	1594	–	–	tr.	0.06	–	–
α-Santoline alkohol	1654	0.11	–	0.29	0.71	0.15	–
Cadinol	1656	–	0.39	–	–	–	0.44
2,5 Pyrrolidinedione	1671	0.75	–	1.37	1.69	1.00	–
n.i.	1675	–	0.65	–	–	–	0.65
n.i.	1697	0.53	0.57	0.94	0.70	0.61	0.56
1,2-Ethanediol, 1-phenyl	1735	5.63	7.87	4.83	6.44	5.62	5.65
Furan, 2-(2-propenyl)	1742	2.91	–	2.88	6.79	2.26	8.83
Z-ligustilide	1751	–	tr	0.05	0.13	–	–
n.i.	1767	–	0.42	–	0.51	–	0.38
n.i.	1838	0.10	0.08	tr	0.05	0.10	–

tr. – trace < 0.05%, n.i. – compound not identified

The myrcene content in the oil obtained from leaf blades, petioles and whole leaves was higher in the raw material harvested on September 7 compared to that harvested on October 17. The high variation in the content of this constituent in the oil samples analyzed (7.45–37.51%) should be noted. The previous study [Rożek et al. 2013] showed that the percentage of myrcene in the oil distilled from celery leaves harvested in August and October can increase or decrease, depending on weather conditions. The studies of other authors [Inan et al. 2011, Zawiślak 2013] reveal multidirectional changes in the myrcene content in the essential oil of plants harvested at particular growth stages. The direction of such changes seems to be primarily associated with the plant species, but also with environmental conditions during the plant growth and development period.

Interesting relationships were found regarding the percentage of Z-ligustilide in the oil samples analyzed (tab. 3). This compound belongs to the group of phthalides, the oil fraction that gives the characteristic aroma and intense scent to the plant. Apart from their sensory characteristics, these compounds are distinguished by their unique biological activity [Zheng et al. 1993, Momin and Nair 2002]. The content of Z-ligustilide was found only in petioles, in which it was higher in samples from the raw material collected in October compared to that from September (respectively, 0.13 and 0.05%). Likewise, in the previous study [Rożek et al. 2013] a higher percentage of Z-ligustilide was found in the oil from the raw material collected at the later harvest dates. The fraction of phthalides in the essential oil of lovage was more than twice higher when it was sown in late autumn than in the case of planting seedlings [Rosłon et al. 2013]. This may suggest the direction and intensity of biosynthesis of these components and also indicate the optimal time of raw material harvest.

CONCLUSIONS

1. Irrigation of celery plants caused changes in the essential oil content in the individual leaf parts. Leaf blades of irrigated plants accumulated more oil than non-irrigated plants, conversely than petioles.

2. Plants harvested in September had a higher concentration of essential oil than those harvested in October.

3. Monoterpenes proved to be the dominant fraction in the leaf celery oil. The main constituents of the oil were limonene and myrcene. Celery leaf blades contained less limonene and more myrcene compared to petioles.

4. Irrigation modified the essential oil composition of leaf celery. Leaves of irrigated plants contained more limonene and less myrcene compared to leaves of non-irrigated plants.

5. Leaf blades of celery harvested in September contained more limonene and myrcene than in the case of celery harvested in October. Petioles collected in September accumulated more myrcene and less limonene compared to other petioles.

REFERENCES

Aćimović, M.G., Dolijanović, Ž.K., Oljača, S.I., Kovačević, D.D., Oljača, M.V. (2015). Effect of organic and mineral fertilizers on essential oil content in caraway, anise and coriander fruits. Acta Sci. Pol. Hortorum Cultus, 14, 1, 95–103.

Adams, R.P. (2004). Identification of essential oil compounds by gas chromatography/quadrupole mass spectroscopy. Allured Pub. Corp., USA.

Afec, U., Carmeli, S., Aharoni, N. (1995). Columbianetin, a phytoalexin associated with celery resistance to pathogens during storage. Phytochemistry, 39(6), 1347–1350.

Aloghareh, R.R., Tahmasebi, B.K., Safari, A., Armand, R., Odivi, A.G. (2013). Changes in essential oil content and yield components of anise (*Pimpinella anisum* L.) under different irrigation regimes. Intl. J. Agri. Crop Sci., 6, 7, 364–369.

Al-Saaidi, J.A.A., Alrodhan, M.N.A., Ismael, A.K. (2012). Antioxidant activity of n-butanol extract of celery (*Apium graveolens*) seed in streptozotocin-induced diabetic male rats. Res. Pharm. Biotech., 4, 2, 24–29.

Al-Snafi, A.E. (2014). The Pharmacology of *Apium graveolens*. A review. IJPRS 3, 1, 671–677.

Asif, H. M. , Akram, M., Usmanghani, K., Akhtar, N., Shah, P.A., Uzair, M., Ramzan, M., Ali Shah, S.M., Rehman, R. (2011). Monograph of *Apium graveolens* Linn. J. Med. Plant. Res., 5, 8, 1494–1496.

Azimi, J., Pirzad, A., Hadi, H. (2012). Effect of increasing severity of drought stress on morphology and essential oil of pot marigold. IJPAES, 2, 4, 11–17.

Aziz, E.E., Handawi, S.T., Din, E.E., Azza, Omer, E.A. (2008). Effect of soil type and irrigation intervals on plant growth, essential oil yield and constituents of *Thymus vulgaris* plant. American-Eyrasian J. Agric. Environ. Sci., 4, 4, 443–450.

Baananou, S., Bouftira, I., Mahmoud, A., Boukef, K., Marongiu, B., Boughattas, N.A. (2013). Antiulcerogenic and antibacterial activities of *Apium graveolens* essential oil and extract. Nat. Prod. Res., Form. Nat. Prod. Lett., 27, 12, 1075–1083.

Bai, J., Baldwin, E., Plotto, A., Manthey, J.A., McCollum, G., Irey, N., Luizo, G. (2009). Influence of harvest time on quality of ʽValencia' oranges and juice. Proc. Fla. Stare Hart. Soc., 122, 308–315.

Benbelaid, F., Abdouna, M.A., Khadir, A., Bendahou, M. (2013). Drying effect on yield and antimicrobial activity of essential oils. Int. J. Med. Arom. Plants, 3, 1, 93–101.

Bonjar, S., (2004). Evaluation of antibacterial properties of some medicinal plants used in Iran. J. Ethnopharm., 94, 301–305.

Breschini, S.J., Hartz, T.K. (2002). Drip irrigation management affects celery yield and quality. HortScience, 37, 6, 894 – 897.

Chidankumar, C.S., Chandraju, S., Nagendraswamy, G., Nagendraswamy, R. (2010). Comparative study on the growth and yields of leafy vegetables irrigated by distillery spentwash in normal and spentwash treated soil. Sugar Tech., 12, 1, 9–14

Hassan, F.A.S, Bazaid, S., Ali, E.F. (2013). Effect of deficit irrigation on growth, yield and volatile oil content on *Rosmarinus officinalis* L. plant. J. Med. Plants Stud., 1, 3, 12–21.

Hassanen, N.H.M., Eissa, A.M.F., Hafez, S.A.M., Mosa E.A.M. (2015). Antioxidant and antimicrobial activity of celery (*Apium graveolens*) and coriander (*Coriandrum sativum*) herb and seed essential oils. Int. J. Curr. Microbiol. App. Sci., 4, 3, 284–296.

Inan, M., Kirpik, M., Kaya, A., Kibici, S. (2011). Effect of harvest time on essential oil composition of *Thymbra spicata* L. growing in flora of Adıyaman. Adv. Environ. Biol., 5, 2, 356–358.

Jain, M.P., Sama, J.K., Jain, S.M., Sharma, V.K., Singh, B. (2003). An improved method for the recovery of essential oil from Celery seeds. Indian J. Chem. Technol., 10, 370–372.

Khalid, K.A. (2006). Influence of water stress on growth, essential oil, and chemical composition of herbs (*Ocimum* sp.). Int. Agroph., 20, 289–296.

Kołodziej, B. (2008). The effect of drip irrigation and Asahi SL application on peppermint yield and quality. Herba Pol., 54, 43–51.

Kuşçu, H., Çetin, B., Turhan, A. (2009). Yield and economic return of drip-irrigated vegetable production in Turkey. New Zealand J. Crop Hortic. Sci., 37, 51–59.

Mahdi, O.S. (2011). Evaluation of inhibitory activity of extracts of *Apium graveolens*, *Coriandrum sativum* and *Cuminum cyminum* against number of pathogenic bacteria. Kufa J. Vet. Med. Sci., 2, 2, 37–50.

Momin, R.A., Nair, M.G. (2002). Antioxidant, cyclooxygenase and topoisomerase inhibitory compounds from *Apium graveolens* Linn. seeds. Phytomedicine, 9, 312–318.

Moro, A., Zalacain, A., de Mendoza, J.H., Carmona, M. (2011). Effects of agronomic practices on volatile composition of *Hyssopus officinalis* L. essential oils. Molecules, 16, 4131–4139.

Nagella, P., Ahmad, A., Kim, S.J., Chung, I.M. (2012). Chemical composition, antioxidant activity and larvicidal effects of essential oil from leaves of *Apium graveolens*. Immunopharmacol. Immunotoxicol., 34, 2, 205–9.

Nurzyńska-Wierdak, R. (2009). Herb yield and chemical composition of common oregano (*Origanum vulgare* L.) essential oil according to the plant's developmental stage. Herba Pol., 55(3), 55–62.

Nurzyńska-Wierdak, R., Bogucka-Kocka, A. Szymczak, G. (2014). Volatile constituents of *Melissa officinalis* L. leaves depending on plant age. Nat. Prod. Comm., 9, 5, 703–706.

Papamichail, I., Louli V., Magoulas, K. (2000). Supercritical fluid extraction of celery seed oil. J. Supercrit. Fluids, 18, 213–226.

Paul, J.C., Mishra, J.N., Pradhan, P.L., Panigrahi, B. (2013). Effect of drip and surface irrigation on yield, wateruse-efficiency and economics of capsicum (*Capsicum annum* L.) grown under mulch and non mulch conditions in eastern coastal India. Europ. J. Sustain. Develop. 2, 1, 99–108.

Pirzad, A., Alyari, H., Shakiba, M.R., Zehtab-Salmasi, S., Mohammadi, S.A. (2006). Essential oil content and composition of German chamomile (*Matricaria chamomilla* L.) at different irrigation regimes. J. Agron., 5, 3, 451–455.

Polish Pharmacopoeia VII (2006). Polskie Towarzystwo Farmaceutyczne, Warszawa.

Rosłon, W., Osińska, E., Wajs-Bonikowska, A. (2013). Effect of plantation establishment and raw material stabilization on the usefull traits of lovage leaves (*Levisticum officinale* Koch.). Acta Sci. Pol. Hortorum Cultus, 12, 1, 141–155.

Rożek, E. (2006). Uprawa selera listkowego *Apium graveolens* var. *secalinum* Alef. z siewu nasion wprost na pole. Folia Hort., 18(2), 107–112.

Rożek, E. (2007a). Content of some chemicals and essential oil in leaves of leaf celery *Apium graveolens* L.var. *secalinum* Alef. Herba Pol., 53(3), 213–217.

Rożek, E. (2007b). Reaction of leaf celery (*Apium graveolens* L.var. *secalinum*) to planting density and irrigation. Veget. Crops Res. Bull., 66, 69–77.

Rożek, E., Nurzyńska-Wierdak, R., Kosior, M. (2013). Efficiency of some agrotechnical treatments in quantity and quality yield modification of leaf celery (*Apium graveolens* L. var. *secalinum* Alef.). Acta Sci. Pol. Hortorum Cultus, 12, 6, 227–239.

Saleh, M.M., Zwaving, J.H., Malingre, T.M., Bos, R. (1985). The essential oil of *Apium graveolens* var. *secalinum* and its cercaricidal activity. Pharm. Weekbl. Sci., 7, 277–279.

Salman, H.R., Al-Khafaji, B.A., Mohammed, N.J. (2013). Effect of *Apium graveolens* leaves and stalks in reducing the side effects of doxorubicin in male rabbits. Med. J. Babylon, 10, 1, 46–74.

Singh, S., Haider, S.Z., Chauhan, N.K., Lohani, H., Sah, S., Yadav, R.K. (2014). Effect of time of harvesting on yield and quality of *Melissa officinalis* L. in Doon Valley, India. Indian J. Pharm. Sci., 76, 5, 449–452.

Sowbhagya, H.B, Sampathu, S.R., Krishnamurthy, N. (2007). Evaluation of size reduction on the yield and quality of celery seed oil. J. Food Eng., 80, 1255–1260.

Vahidipour, T.H., Vahidipour, H.R., Baradaran, R., Seqhatoleslami, M.J. (2013). Effect of irrigation and nitrogen fertilizer on grain yield and essential oil percentage of medicinal plant Ajowan. Intl. J. Agron. Plant. Prod., 4, 5, 1013–1022.

Van Den Dool, H., Kratz, P.D. (1963). A generalization of the retention index system including linear temperature programmed gas-liquid partition chromatography. J. Chromat., 11, 463–471.
Wesołowska, A., Grzeszczuk, M., Jadczak, D. (2014). Influence of harvest term on the content of carvacrol, p-cymene, γ-terpinene and β-caryophyllene in the essential oil of *Satureja montana*. Not. Bot. Horti. Agrobo., 42, 2, 392–397.
Yildiz, L., Baskan, K.S., Tütem, E., Apak, R. (2008). Combined HPLC-CUPRAC (cupric ion reducing antioxidant capacity) assay of parsley, celery leaves, and nettle. Talanta, 77, 304–313.
Yu, S., Chen, Y., Zhang, L., Shan, M., Tang, Y., Ding, A. **(**2011). Quantitative comparative analysis of the bio-active and toxic constituents of leaves and spikes of *Schizonepeta tenuifolia* at different harvesting times. Int. J. Mol. Sci., 12, 6635–6644.
Zawiślak, G. (2013). The chemical composition of essential hyssop oil depending on plant growth stage. Acta Sci. Pol. Hortorum Cultus, 12, 3, 161–170.
Zheng, G-q., Kenney, P.M., Zhang, J., Lam, L.K.T. (1993). Chemoprevention of benzo[*a*]pyrene – induced forestomach cancer in mice by natural phthalides from celery seed oil. Nutr. Canc., 19, 1, 77–86.

SKŁAD CHEMICZNY OLEJKU ETERYCZNEGO SELERA LISTKOWEGO (*Apium graveolens* L. VAR. *Secalinum* ALEF.) POD WPŁYWEM NAWADNIANIA ROŚLIN I METODY ZBIORU

Streszczenie. Badania miały na celu określenie wpływu nawadniania i terminu zbioru na zawartość i kompozycję olejku eterycznego destylowanego z liści, ogonków liściowych i blaszek liściowych *Apium graveolens* L. var. *secalinum* Alef. Nawadnianie kroplowe przeprowadzono dwukrotnie w trzeciej dekadzie lipca i dwukrotnie w trzeciej dekadzie sierpnia. Jednorazowa dawka wody wynosiła 20 mm. Zbiór surowca przeprowadzono 7 września i 17 października, zbierając liście odpowiednio po 120 i 161 dniach wegetacji roślin. Nawadnianie zwiększało koncentrację substancji lotnych w blaszkach liściowych (0,68%) oraz zmniejszało zawartość tych składników w ogonkach liściowych (0,24%). Liście selera zbierane w październiku zawierały istotnie mniej olejku eterycznego (0.34%) w porównaniu ze zbieranymi w pierwszej dekadzie września (0.53%). Główną frakcją olejku eterycznego selera listkowego okazały się monoterpeny, wśród których dominował limonen i mircen. Najwięcej limonenu (75,77%) stwierdzono w ogonkach liściowych roślin nawadnianych. Liście roślin nawadnianych zawierały więcej limonenu i mniej mircenu w porównaniu z liśćmi roślin nienawadnianych. Więcej mircenu i mniej limonenu oznaczono w liściach zebranych we wrześniu.

Słowa kluczowe: Apiaceae, zmienność środowiskowa, monoterpeny, limonen, mircen

Accepted for print: 20.12.2015

For citation: Rożek, E., Nurzyńska-Wierdak, R., Sałata, A., Gumiela, P. (2016). The chemical composition of the essential oil of leaf celery (*Apium graveolens* L. var. *Secalinum* alef.) under the plants' irrigation and harvesting method. Acta Sci. Pol. Hortorum Cultus, 15(1), 149–159.