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Research Article

Antimicrobial Activity and Analysis of the Essential Oils of Selected Endemic Edible Apiaceae Plants Root from Caspian Hyrcanian Region (North of Iran)

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ABSTRACT

Background: Different endemic species of Apiaceae that widely grow in Hyrcanian region have long been used as spices and herbal remedies. Chemical compositions and bioactivity of many of these plants have not been studied scientifically. The volatile constituents and antimicrobial activity of four edible Apiaceae plants—*Elaeosticta glaucescens* Boiss, *Malabaila secacul* (Mill.) Boiss, *Caucalis platycarpos* L., and *Eryngium caucasicum* Trautv—roots were investigated.

Methods: Gas chromatography/mass spectrometry (GC–MS) and gas chromatography/flame ionization detection (GC–FID) methods were used for chemical investigation. Antimicrobial potential of the volatile compositions of these roots were investigated using the disc diffusion method on four microorganisms including *Staphylococcus aureus*, *Escherichia coli*, *Pseudomonas aeruginosa*, and *Bacillus subtilis.*

Results: The best minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of these species were revealed for *B. subtilis* and *S. aureus* (500 µg/mL for MIC and MBC) followed by *E. caucasicum* and *C. platycarpus*, respectively. The main compounds of *E. caucasicum* root essential oil were hexyl isovalerate (11.0%) and hexyl valerate (10.1%). *E. glaucescens* root essential oil was mainly composed of 3(10)-caren-4-ol, acetoacetic acid ester (9.8%), octyl isovalerate (8.9%), and octyl acetate (5.7%). In *C. platycarpos* root, hexyl isovalerate (9.2%) and n-octyl isobutyrate (8.5%) were constituted the major compositions of the essential oil while n-hexyl isobutyrate (8.5%) and hexyl hexanoate (7.8%) were predominant compounds in *M. secacul*.

Conclusion: The essential oils of *E. caucasicum* and *C. platycarpus* roots were contained high amount of short chain fatty acid esters (SCFAE) and trans- pinocarvyl acetate. They exhibited moderate antibacterial activity.

Introduction

Natural essential oils have long served as food additive, beverages, food preservative and therapeutic remedies. These versatile uses in addition to the diverse secondary metabolites of the essential oils caused a significant attention for use of them in various field such as pharmaceutical, cosmeceutical, and food industries.[1-3] Defence against different pathogens as a natural important role of these constitutions in plants caused that essential oils to be considered historically as the unique antibacterial, and antifungal source.[4] Folklore uses of these constitutions as natural antimicrobial agents, antibacterial properties of them and global antibiotic resistance caused a wide investigation on the antimicrobial properties of different essential oils compositions.[5-8]

Apiaceae plants family are well known as therapeutic and edible plants with massive biodiversity and distribution in Europe, North America, Asia, and Africa.[9] Different genera of this family cultivated for long time as edible herbs as foodstuff or traditional medicine such as *Heracleum spp.* (hogweed), *Petroselinum crispum* (parsley), *Foeniculum vulgare* (fennel), and *Apium graveolens* (celery).[10-13] Wide diversity of this family caused various endemic usage of them as regional vegetables or spices in different places of world for example *Eryngium foetidum* (long coriander) in Mediterranean region, *Myrrhis odorata* (cicely), *Levisticum officinale* (lovage), and *Pastinaca sativa* (parsnip) in Europe, *Bunium persicum* (black zira), *Daucus carota* (wild carrot) and *Echinophora sibthorpiana* (Tarhana herb) in Asia and Middle East.[14-16]

From the secondary metabolites content perspective, this family is one of the important source for volatile secondary metabolites (many different constituents with

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diverse chemical classes have been isolated from the essential oils of this family).[17-19] With regard to the antibacterial potential of Apiaceae plants essential oils and edible endemic backgrounds of them, antibacterial activity screening constituted an important part of phytochemical investigation in this family.[20, 21]

Hyrcania region is one of the five regions of Iran phytogeographical zone which is also known as "Euro-Siberian" or "Euxino-Hyrcanian". This geographical region consists of many old growth forests and endemic species of plants. This unique ecosystems, contribute significantly valuable territorial/ ethno-medical applications for local people.[22,23] Among the territorial plants, many Apiaceous endemic species have been used as common spices among Hyrcanian people. Among them, the four plants, *Elaeosticta glaucescens* Boiss (locally called Shividak), *Eryngium caucasicum* (locally called Avieh or Choochakh), *Caucalis platycarpos* (Bur parsley, Jafari-e-derakhshan), and *Malabaila secacul* (Persian hogweed, golpar-e-vahshi) were collected from the wild population as vegetables and sold commonly in local markets. In Hyrcanian folklore nutrition traditions they are used as food flavouring additive with anti-spoil properties.[24] Although, historical and traditional uses emphasized this potential but no studies have been conducted on their essential oils chemical constituents and antimicrobial activity of them against food-borne bacteria until now. The present study analyses the chemical components and antibacterial activity of these plants roots essential oils.

Materials and Methods

Plant material

The roots of wild growing population of *E. glaucescens*, *M. secacul*, *C. platycarpos*, and *E. caucasicum* were collected during the May 2016 from Saravan rural district (Saqalaksar Lake; 37°9′20″N 49°31′36″E) in Guilan province, Iran. For all species Voucher specimens were authenticated by Dr. Ardalan Pasdaran in the Research and Development Centre of Plants and Medicinal Chemistry, Guilan University of Medical Sciences with voucher specimen no. 2585, 2586, 2587, and 2588, deposited in the Herbarium of Pharmacognosy, Faculty of Pharmacy, Guilan University of Medical Sciences, Rasht, Iran.

Extraction of the essential oils

All plant roots were dried at laboratory temperature (25 °C) for one week. After drying using air-oven at 110 °C for 4 h, samples weight loss were calculated and used for moisture content determination based on the Association of Official Agricultural Chemists (AOAC) method.[25] All four species dried samples were finely grounded and 500 g of each of them were subjected to hydrodistillation (HD) for 3 h using a Clevenger apparatus. Anhydrous sodium sulphate (Na_2SO_4) was used for samples dehydration. Samples were stored at 4 °C for future analysis by gas chromatography/flame ionization detection (GC–FID) and gas chromatography–mass spectrometry (GC–MS).

Analysis of the Essential Oils

A Shimadzu GC-MS-QP5050A instrument with DB-5 column (methyl silicon, 0.25 µm film thickness and 60 m × 0.25 mm internal diameter) was used for essential oils analysis. Helium at a flow rate of 1.3 mL/min was used as the carrier gas. Firstly, the column temperature was kept at 50 °C, for3 min, and then temperature increased to 300 °C at a rate of 5 °C/min. In final step, the column temperature was kept at 300 °C for 5 min. The split ratio was modified at 1:33 and 270ºC was adjusted for injector temperature. The injection volume was 1 µL. The electron impact (EI) quadropolar system with 70 eV ionization energy was used for GC/MS detection. Ion source and quadrupole detector temperatures were adjusted at 200 and 100ºC. Solvent delay was 2 min and amu scan was arranged 30–600 and EM voltage of 3,000 volts. Resolution was 2,000 amu/s. The relative retention times, mass spectra fragmentation pattern based on Kovats indices, and the NIST NBS54K Library computer matching were used for the essential oil components identification.[26-28] An Agilent 6890 apparatus with a FID detector were used for the essential oil components quantization (area %). During this analysis the FID detector's temperature was arranged at 300 ºC. The same elution order and column as with GC–MS with a simultaneous auto-injector were used for applying a same operational conditions. For each separated compounds relative percentage amounts were calculated from FID chromatograms.

Antimicrobial assay (Disk Diffusion Assay)

For antibacterial activity evaluation, four standard strains include *E. coli* (ATCC 25922), *S. aureus* (ATCC 6538), *B. subtilis* (ATCC 6051), and *P. aeruginosa* (ATCC 9027) were used. All micro-organisms were grown on nutrient agar at the ideal temperature 30 °C for *B. subtilis* and *S. aureus* also 37 °C for *P. aeruginosa* and *E. coli*. 5 mm diameter filter paper disc (Whatman's No. 1) containing 600, 900, and 1,200 µg/disk doses of the essential oils were used on the surface of the agar plates which were seeded by bacteria (0.2 mL of each bacterial culture) overnight.[29] Penicillin (10 µg/disk) was used as positive control. In all cases just paper disk with 1200 µg after overnight incubation at suitable temperature were shown appropriate inhibition zone which it was reported based on millimetres.

Determination of minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC)

The minimum inhibitory concentration (MIC) of the all roots essential oils were determined by using broth dilution method.[30,31] For preparing the final essential oils concentration (100, 250, 500, or 1000 µg/mL), 19.6 mL of the sterile Mueller–Hinton broth (MHB) and 200 µL aliquot of bacterial suspension (with at 10^5 CFU/mL) was added to each duplicate 50-mL Erlenmeyer flasks.

After incubation in a shaker incubator at 35 °C, 0.1 mL aliquot of each flask turbidity were measured at 540 nm after 0, 6, 12, 18, 24, and 36 h. MIC was considered at the lowest concentration which no bacterial growth occurred in flask. For determination of the minimum bactericidal concentration (MBC), 1–2 µL of the bacterial suspensions were sub-cultured into 100 µL of MHB (24 h at 35 °C). Similar to MIC, the lowest concentration which no visible bacterial growth occurred was considered as MBC. All experiments for each essential oil at each test concentration were conducted in triplicate.

Statistical analysis

All experiments were repeated for three times for the maximum randomized effect achievement. SPSS 10.0 software package was used for all statistical analysis. The results showed significant difference at p <0.05 level.

Results and Discussion

Considering the large number of Apiaceae plants (over 300 genera and 3000 species) also inter and intra-genera chemo-biodiversity of this family, analysis of the essential oil compositions could present a valuable approach for resolving different subjects such as taxonomical classification and biological activity prediction.[32-35]

Table 1. Major constituents of the volatile oils of *M. secacul, E. glaucescens, E. caucasicum* and *C. platycarpus* roots.

	Chemical compounds	RI[a]	RI[b]	HD (%)[c]			
				E. caucasicum	*C. platycarpus*	*M. secacul*	*E. glaucescens*
1	2,4-Dimethyl-Hexane	729	736	-	-	1.8	0.7
2	1-Hexanol	864	869	-	5.0	1.2	4.5
3	β-Pinene	981	980	1.1	0.6	0.6	0.8
4	1-Octanol	1078	1070	2.0	0.5	2.4	3.8
5	n-Hexyl isobutyrate	1151	1150	0.9	0.8	8.5	5.5
6	Hexyl butyrate	1191	1190	7.3	5.8	6.8	3.4
7	Octyl acetate	1210	1196	3.0	2.6	6.3	5.7
8	Hexyl isovalerate	1241	1241	11.0	9.2	3.7	3.8
9	2-Decenal	1255	1261	6.1	0.8	-	0.7
10	Hexyl valerate	1298	1290	10.1	7.6	-	3.5
11	trans- pinocarvyl acetate	1298	1298	6.6	6.4	-	0.8
12	n-Octyl isobutyrate	1348	1350	4.0	8.5	-	2.8
13	2-Decenoic acid, methyl ester	-	1352	-	-	-	1.4
14	α-Copaene	1376	1374	1.3	2.8	0.5	0.6
15	Hexyl hexanoate	1381	1380	1.0	4.0	7.8	3.6
16	Decyl acetate	1408	1407	2.8	1.9	2.3	0.6
17	(Z)- Caryophyllene	1407	1408	0.8	1.3	1.3	0.5
18	β- Cedrene	1419	1410	-	3.8	1.4	0.8
19	(E)-α- Bergamotene	1438	1411	-	0.6	1.2	0.5
20	Octyl 2-methylbutanoate	1430	1419	-	2.0	-	4.0
21	Octyl isovalerate	1440	1438	6.8	-	5.0	8.9
22	α- Himachalene	1448	1449	-	-	1.5	0.6
23	(E)-β- Farnesene	1458	1454	1.0	1.5	0.8	1.0
24	(E)-β- Bisabolene	1509	1512	-	0.7	-	3.1
25	Hexyl octanoate	1580	1581	1.3	-	7.3	4.1
26	Caryophyllene oxide	1583	1584	1.8	1.5	1.5	0.6
27	(Z)- Nuciferol	1727	1728	-	1.5	0.8	1.3
28	3(10)-Caren-4-ol,acetoacetic acid ester	-	1740	2.0	5.5	6.7	9.8
29	Octyl octanoate	1779	1779	7.0	5.0	-	0.6
30	Hexahydrofarnesyl acetone	1845	1842	5.7	2.9	8.2	3.8
31	Z-falcarinol	2038	2035	5.6	-	0.6	1.4
	Monoterpene hydrocarbons			1.1	1.4	0.6	0.8
	Oxygenated monoterpenes			16.7	6.4	-	0.8
	Sesquiterpene hydrocarbons			3.1	10.7	6.7	6.1
	Oxygenated sesquiterpenes			1.8	1.5	1.5	0.6
	Aliphatic esters			59.6	50.3	55.9	52.0
	Others			6.9	13.9	13.5	17.4
Total percentage				89.2	82.8	78.2	77.7

[a] Retention indices given in literature (NIST on non-polar HP-5 or DB-5 capillary columns).
[b] Retention indices with respect to C5–C28 n-alkanes calculated on non-polar DB-5 capillary column.
[c] Percentage calculated by GC-FID on non-polar DB-5 capillary column.

Table 2. Zone of Inhibition of the essential oils of *M. secacul, E. glaucescens, E. caucasicum* and *C. platycarpus* roots.

	E. caucasicum	***C. platycarpus***	***M. secacul***	***E. glaucescens***	**Penicillin**	**10 µg/disk**
E. coli	5-7 [a]	- [b]	6-8	5-8	-	
P. aeruginosa	7-9	5-8	7-9	6-8	12-18	
S. aureus	17-19	12-15	7-10	8-11	25-29	
B. subtilis	15-18	13-16	5-8	10-12	28-31	

[a] Inhibition zones are given as minimum and maximum inhibition zones in diameter (mm) around the disks impregnated at 1200 µg/disk doses. [b] Not active.

Table 3. MIC and MBC of the essential oils[a] of *M. secacul, E. glaucescens, E. caucasicum* and *C. platycarpus* roots.

Bacterial strain	*E. caucasicum*		*C. platycarpus*		*M. secacul*		*E. glaucescens*	
	MIC (µg/mL)	MBC (µg/mL)	MIC (µg/mL)	MBC (µg/mL)	MIC (µg/mL)	MBC (µg/mL)	MIC (µg/mL)	MBC (µg/mL)
E. coli	500	>1000	500	>1000	1000	>1000	1000	>1000
P. aeruginosa	>1000	>1000	1000	>1000	1000	>1000	1000	>1000
S. aureus	500	1000	500	1000	1000	>1000	1000	>1000
B. subtilis	500	500	500	500	1000	>1000	1000	>1000

[a] Essential oils were dissolved in 1% Tween 20 and then added in liquid media with test bacteria.

In present study, volatile oils of *E. glaucescens, M. secacul, C. platycarpos*, and *E. caucasicum* roots were extracted based on the hydrodistillation method. Four yellowish oils were yielded *E. glaucescens* 1.9 v/w, *M. secacul* 0.8 v/w, *C. platycarpos* 1.3 v/w, and *E. caucasicum* 1.1 v/w on the basis of dry weight (500 g). The hexyl isovalerate was predominant composition of *E. caucasicum* (11.0 %) and *C. platycarpos* (9.2%) roots essential oils. Other main compositions of the *E. caucasicum* were identified as hexyl valerate (10.1%), hexyl butyrate (7.3%), and octyl octanoate (7.0%), respectively. For *C. platycarpos* root secondly and thirdly major volatile compounds were *n*-octyl isobutyrate (8.5%), and hexyl valerate (7.6%). In the essential oil of *M. secacul* root, n-hexyl isobutyrate (8.5%), hexahydrofarnesyl acetone (8.2%) and hexyl hexanoate (7.8%) were also determined as major compounds. In contrast to the other species, 3(10)-caren-4-ol, acetoacetic acid ester (9.8%) was constituted the first major volatile compounds in root essential oil of *E. glaucescens* which continued by octyl isovalerate (8.9%) and octyl acetate (5.7%).

Many parts of Apiaceous plants include seeds, flowers and roots produce high amounts of volatile and non-volatile compositions. Therefore, studying the major and minor compounds of them could represent an important path for investigation on the chemotaxonomic markers. Beside to the monoterpenes, short chain fatty acids esters (SCFAE) constituted the characteristic compartments of the Apiaceae family chemical compounds. The *β*-pinene was common monoterpene in all species, while *α*-copaene and (E)-*β*- farnesene were constituted the common sesquiterpenes in all of them. Besides, 3(10)-caren-4-ol, acetoacetic acid ester was the common predominant monoterpene ester in the four investigated plants (Table 1).

Different categories of the volatile compounds such as terpenes, alcohols, and short chain fatty acid esters have shown antibacterial activity against the wide range of pathogenic bacteria. The antibacterial effect of the essential oils and their chemical contents can present a valuable source for developing new antibiotics. Although, the structure diversity, water solubility, hydrogen-bound capacity and molecular weight of essential oils constituents can affect their antibacterial potentials.

In this study, we used a disk diffusion assay for determination of the inhibition zone around the each essential oils (Table 2). Results of the inhibition zone measurement compared to the penicillin showed that two Gram-negative bacteria (*E. coli* and *P. aeruginosa*) were more resistant against the investigated essential oils compared to the *B. subtilis* and *S. aureus* as Gram-positive bacteria. Since the paper disk assay and inhibition zone determination methods could not accurately reflect antimicrobial potential, MIC and MBC were also, assessed as the complementary methods for these essential oils antibacterial effectiveness. The MIC and MBC results were in accordance with the paper disk assay. The essential oil of *E. caucasicum* and *C. platycarpos* roots exhibited the better antibacterial potential compared to the *M. secacul* and *E. glaucescens* on the *E. coli* and *B. subtilis* (Table 3). *E. coli* and *B. subtilis* were affected by the essential oils of *E. caucasicum* and *C. platycarpos* with MIC and MBC of 500 µg/mL. The essential oils of *M. secacul* and *E. glaucescens* roots did not show an acceptable activity. According to the previous researches, besides to the oxygenated sesquiterpenes, hydrocarbons and fatty alcohols, SCFAEs also can show suitable antibacterial effects.[36] This study was not design to evaluate the antimicrobial activity of the pure compounds of the essential oils. But, several previous studies can be found in the literature reporting antimicrobial properties for SCFA and pinocarvyl acetate. Among them Aldunate *et al.* have suggested that short chain fatty acids exhibit antimicrobial activity for oral or vaginal microorganisms.[37,38] Also, Ricke, has discussed the possibility and challenges of the use of short chain fatty acids as antimicrobials against foodborne bacteria. One hypothesis is that short chain fatty acids and their esters could easily penetrate to the bacteria lipid membrane. also, SCFA represent a potential acid stress exposure to foodborne pathogens bacteria.[39]

Although, in this study antibacterial activity effect was not very distinctive, it seems that the observed potent antimicrobial effects for E. *caucasicum* and *C. platycarpos* might be related to the higher amount of SCFAE such as hexyl isovalerate and hexyl valerate in their roots essential oils. On the other hand, antibacterial activity of these four plants may be ascribed by other constitutions.

For example, the activity of *E. caucasicum* and *C. platycarpos* root essential oils may be attributed to the presence of *trans*-pinocarvyl acetate and some alcohols such as Z-falcarinol and 1-hexanol. These constitutions may act in synergistic manner with SCFAE such hexyl isovalerate.[40]

Various investigations showed that SCFAE can be considered as a valuable chemo-marker in different genus of Apiaceae family for example some reports on *Ferula* genus showed that conjugated isovalerate observed as a same SCFAE in essential oils of this genus.[41,42] Although,

we could not found any study on these four plants but some researches have reported data on *C. orientalis* and *C. leptophylla* volatile constitutions. Spathulenol (30.8 %), caryophyllene oxide (11.1 %), *trans*-α-bergamotene (10.4%), and germacrene D (8.9%) were major compounds in *C. leptophylla* essential oil while sabinene (16.5 %), α-pinene (11.0%), and myrcene (7.0%) were predominant in *C. orientalis.*[43] In both plants SCFAE made up the minor portion of the essential oil which was in contrast with the present study on *C. platycarpos* root essential oils.

Finding biomarkers for essential oils of *Eryngium* genus were more complicated but almost in many members of this genus oxygenated and non-oxygenated sesquiterpenes were the main compartment.[44-47] Previous studies on *Malabaila* genus showed that butyric acid conjugates such as hexyl butyrate, and octyl butyrate made up the main constitutions in essential oil of this genus which relatively in line with our results about *M. secacul* root volatile compounds.[48,49] Several investigations on other genus such as *Heracleum* also showed that octyl conjugated of butyric, acetic, and octanoic acids constitute the main SCFAE in essential oils of *Heracleum* genus.[50-54] This similarity in major SCFAE of both genus may reflect the pervious viewpoint about Tordylieae tribe of Apiaceae which also showed close phylogenetic characters.[55,56]

Conclusion

Overall, the results showed that the *E. caucasicum* and *C. platycarpos* roots essential oils were more active against Gram-positive bacteria. Our research antibacterial findingswas in accordance with ethno-application of these plants as anti-putrefaction additive in foods.

E. caucasicum and *C. platycarpos* root essential oils had a high amount of SCFAE and *trans*- pinocarvyl acetate which might play a role in the observed antibacterial activity of them. The essential oils of *M. secacul* and *E. glaucescens* roots did not show an acceptable activity.

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Conflict of interests

The authors claim that there is no conflict of interest.

References

1. Burt S. Essential oils: their antibacterial properties and potential applications in foods-a review. Int J Food Microbiol. 2004;94(3):223-53. doi:10.1016/j.ijfoodmicro.2004.03.022
2. Hamedi A, Mohagheghzadeh A, Rivaz S. Hydrodistilled volatile constituents obtained from the roots of *Operculina turpethum*. Phcog J. 2014;6(2):36-7. doi:10.5530/pj.2014.2.6
3. Hamedi A, Sakhteman A, Ahmadi F, Sohrabpour M, Zarshenas M. Authentication and quality control of some polyherbal oils used in Persian Traditional Medicine (PTM). Res J Pharmacogn. 2017;4(1):9-22.
4. Levin DA. The chemical defenses of plants to pathogens and herbivores. Annu Rev Ecol Evol Syst. 1976;7(1):121-59. doi:10.1146/annurev.es.07.110176.001005
5. Juteau F, Masotti V, Bessiere JM, Dherbomez M, Viano J. Antibacterial and antioxidant activities of *Artemisia annua* essential oil. Fitoterapia. 2002;73(6):532-5. doi:10.1016/S0367-326X(02)00175-2
6. Ebrahimi SN, Hadian J, Mirjalili M, Sonboli A, Yousefzadi M. Essential oil composition and antibacterial activity of *Thymus caramanicus* at different phenological stages. Food Chem. 2008;110(4):927-31. doi:10.1016/j.foodchem.2008.02.083
7. Wang W, Li N, Luo M, Zu Y, Efferth T. Antibacterial activity and anticancer activity of *Rosmarinus officinalis* L. essential oil compared to that of its main components. Molecules. 2012;17(3):2704-13. doi:10.3390/molecules17032704
8. Velázquez-Nuñez MJ, Avila-Sosa R, Palou E, López-Malo A. Antifungal activity of orange (*Citrus sinensis* var. *valencia*) peel essential oil applied by direct addition or vapor contact. Food Control. 2013;31(1):1-4. doi:10.1016/j.foodcont.2012.09.029
9. Helal IE, Galala A, Saad HE, Halim AF. Chemical composition and α-amylase inhibitory activity of *Apium leptophyllum* essential oils. J Am Sci. 2015;11(4):204-9.
10. Jeyabalan J, Aqil F, Soper L, Schultz DJ, Gupta RC. Potent Chemopreventive/Antioxidant Activity Detected in Common Spices of the Apiaceae Family. Nutr Cancer. 2015;67(7):1201-7. doi:10.1080/01635581.2015.1075051
11. Arai S, Osawa T, Ohigashi H, Yoshikawa M, Kaminogawa S, Watanabe M, et al. A mainstay of functional food science in Japan—history, present status, and future outlook. Biosci Biotechnol Biochem. 2001;65(1):1-13. doi:10.1271/bbb.65.1
12. Diao WR, Hu QP, Zhang H, Xu JG. Chemical composition, antibacterial activity and mechanism of action of essential oil from seeds of fennel (*Foeniculum vulgare* Mill.). Food Control. 2014;35(1):109-16. doi:10.1016/j.foodcont.2013.06.056
13. Zhang H, Chen F, Wang X, Yao HY. Evaluation of antioxidant activity of parsley (*Petroselinum crispum*) essential oil and identification of its antioxidant constituents. Food Res Int. 2006;39(8):833-9. doi:10.1016/j.foodres.2006.03.007
14. Ehsani A, Hashemi M, Naghibi SS, Mohammadi S, Khalili Sadaghiani S. Properties of *Bunium Persicum* Essential Oil and its Application in Iranian White Cheese Against *Listeria monocytogenes* and *Escherichia coli* O157: H7. J Food Saf. 2016;36(4):563-70. doi:10.1111/jfs.12277

15. Akgül A, Chialva F. Constituents of the essential oil of *Echinophora tenuifolia* L. subsp. *sibthorpiana* (Guss.) Tutin from Turkey. Flavour Fragr J. 1989;4(2):67-8. doi:10.1002/ffj.2730040206
16. Guil-Guerrero JL, Rodríguez-García I. Lipids classes, fatty acids and carotenes of the leaves of six edible wild plants. Eur Food Res Technol. 1999;209(5):313-6. doi:10.1007/s002170050501
17. Sahebkar A, Iranshahi M. Biological activities of essential oils from the genus *Ferula* (Apiaceae). Asian Biomedicine. 2010;4(6):835-47. doi:10.2478/abm-2010-0110
18. Rasooli I, Allameh A. Caraway (*Carum carvi* L.) Essential Oils. In: Preedy V, editor. Essential Oils in Food Preservation, Flavor and Safety. Amsterdam: Elsevier; 2016. p. 287-93. doi:10.1016/B978-0-12-416641-7.00032-8
19. Bagci E, Dogan G. Composition of the essential oils of two Umbelliferae herbs (*Artedia squamata* and *Malabaila secacul*) growing wild in Turkey. J Essent Oil Bear Pl. 2015;18(1):44-51. doi:10.1080/0972060X.2014.1001184
20. Lo Cantore P, Iacobellis NS, De Marco A, Capasso F, Senatore F. Antibacterial activity of *Coriandrum sativum* L. and *Foeniculum vulgare* Miller var. vulgare (Miller) essential oils. J Agric Food Chem. 2004;52(26):7862-6. doi:10.1021/jf0493122
21. Oroojalian F, Kasra-Kermanshahi R, Azizi M, Bassami M. Phytochemical composition of the essential oils from three Apiaceae species and their antibacterial effects on food-borne pathogens. Food Chem. 2010;120(3):765-70. doi:10.1016/j.foodchem.2009.11.008
22. Aćimović MG, Kostadinović LM, Popović SJ , Dojčinović NS. Apiaceae seeds as functional food. J Agric Sci. 2015;60(3):237-46. doi:10.2298/JAS1503237A
23. Mohamadipour S, Hatamzadeh A, Bakhshi D, Pasdaran A. Antimicrobial activities of *Caucalis platycarpos* L. and *Eryngium caucasicum* Trautv. essential oils. Aust J Crop Sci. 2018;12(8):1357-62. doi:10.21475/ajcs.18.12.08.PNE1277
24. Khoshbakht K, Hammer K, Pistrick K. *Eryngium caucasicum* Trautv. cultivated as a vegetable in the Elburz Mountains (Northern Iran). Genet Resour Crop Evol. 2007;54(2):445-8. doi:10.1007/s10722-006-9121-5
25. Cunniff P. Official methods of analysis of AOAC International. Gaithersburg: Association of Official Agricultural Chemists; 1996.
26. Ashour ML, El-Readi M, Youns M, Mulyaningsih S, Sporer F, Efferth T, et al. Chemical composition and biological activity of the essential oil obtained from *Bupleurum marginatum* (Apiaceae). J Pharm Pharmacol. 2009;61(8):1079-87. doi:10.1211/jpp/61.08.0012
27. Senatore F, Napolitano F, Ozcan M. Composition and antibacterial activity of the essential oil from *Crithmum maritimum* L.(Apiaceae) growing wild in Turkey. Flavour Fragr J. 2000;15(3):186-9. doi:10.1002/1099-1026(200005/06)15:3<186::aid-ffj889>3.3.co;2-9
28. Stahl-Biskup E, Wichtmann EM. Composition of the essential oils from roots of some Apiaceae in relation to the development of their oil duct systems. Flavour Fragr J. 1991;6(4):249-55. doi:10.1002/ffj.2730060402
29. Pasdaran A, Delazar A, Nazemiyeh H, Nahar L, Sarker SD. Chemical composition, and antibacterial (against *Staphylococcus aureus*) and free-radical-scavenging activities of the essential oil of *Scrophularia amplexicaulis* Benth. Rec Nat Prod. 2012;6(4):350-5.
30. Kim J, Marshall MR, Wei C-i. Antibacterial activity of some essential oil components against five foodborne pathogens. J Agric Food Chem. 1995;43(11):2839-45. doi:10.1021/jf00059a013
31. Baydar H, Sağdiç O, Özkan G, Karadoğan T. Antibacterial activity and composition of essential oils from *Origanum*, *Thymbra* and *Satureja* species with commercial importance in Turkey. Food Control. 2004;15(3):169-72. doi:10.1016/S0956-7135(03)00028-8
32. Angiosperm Phylogeny Website. Version 14, July 2017. http://www.mobot.org/MOBOT/research/APweb/
33. Kapetanos C, Karioti A, Bojović S, Marin P, Veljić M, Skaltsa H. Chemical and principal-component analyses of the essential oils of *Apioideae* taxa (Apiaceae) from Central Balkan. Chem Biodivers. 2008;5(1):101-19. doi:10.1002/cbdv.200890000
34. Kanani MR, Rahiminejad MR, Sonboli A, Mozaffarian V, Kazempour Osaloo S, Nejad Ebrahimi S. Chemotaxonomic significance of the essential oils of 18 *Ferula* species (Apiaceae) from Iran. Chem Biodivers. 2011;8(3):503-17. doi:10.1002/cbdv.201000148
35. Tkachenko KG. Constituents of essential oils from fruit of some *Heracleum* L. species. J Essent Oil Res. 1993;5(6):687-9. doi:10.1080/10412905.1993.9698308
36. Pasdaran A, Hamedi A. Natural Products as Source of New Antimicrobial Compounds for Skin Infections. In: Kon K, Rai M, editors. The Microbiology of Skin, Soft Tissue, Bone and Joint Infections. Academic Press; 2017. p. 223-53. doi:10.1016/b978-0-12-811079-9.00014-8
37. Aldunate M, Tyssen D, Latham C, Ramsland P, Perlmutter P, Moench T, et al. Vaginal concentrations of lactic acid potently inactivate HIV-1 compared to short chain fatty acids present during bacterial vaginosis. AIDS Res Hum Retroviruses. 2014;30(S1):A228. doi:10.1089/aid.2014.5499.abstract
38. Aldunate M, Srbinovski D, Hearps AC, Latham CF, Ramsland PA, Gugasyan R, et al. Antimicrobial and immune modulatory effects of lactic acid and short chain fatty acids produced by vaginal microbiota

associated with eubiosis and bacterial vaginosis. Front Physiol. 2015;6:164. doi:10.3389/fphys.2015.00164
39. Ricke S. Perspectives on the use of organic acids and short chain fatty acids as antimicrobials. Poult Sci. 2003;82(4):632-9. doi:10.1093/ps/82.4.632
40. Langeveld WT, Veldhuizen EJ, Burt SA. Synergy between essential oil components and antibiotics: a review. Crit Rev Microbiol. 2014;40(1):76-94. doi:10.3109/1040841X.2013.763219
41. Sadraei H, Asghari G, Hajhashemi V, Kolagar A, Ebrahimi M. Spasmolytic activity of essential oil and various extracts of *Ferula gummosa* Boiss. on ileum contractions. Phytomedicine. 2001;8(5):370-6. doi:10.1078/0944-7113-00052
42. Rahmani B, Zabarjad Shiraz N, Masnabadi N, Masoudi S, Monfared A, Larijani K, et al. Volatile Constituents of *Alococarpum erianthum* (DC) H. Riedl & Kuber. *Ferula ovina* (Boiss.) Boiss. and *Pimpinella affinis* Ledeb. Three Umbelliferae Herbs Growing Wild in Iran. J Essent Oil Res. 2008;20(3):232-5. doi:10.1080/10412905.2008.9700000
43. Masoudi S, Fathollahi R, Taherkhani M, Valadkhani Z, Baradari T, Cheraghi M, et al. Volatile Constituents of the Aerial parts of *Torilis leptophylla* (L.) Reichenb., *Thecocarpus meifolious* Boiss., Leaves of *Xanthogalum purpurascens* Ave. Lall. and Flowers of *Astrodaucus orieintalis* (L.) Drude. Four Umbelliferae Herbs from Iran. J Essent Oil Bear Pl. 2012;15(6):934-42. doi:10.1080/0972060X.2012.10662596
44. Palá-Paúl J, Brophy JJ, Pérez-Alonso MJ, Usano J, Soria SC. Essential oil composition of the different parts of *Eryngium corniculatum* Lam.(Apiaceae) from Spain. J Chromatogr A. 2007;1175(2):289-93. doi:10.1016/j.chroma.2007.10.061
45. Palá-Paúl J, Copeland LM, Brophy JJ, Goldsack RJ. Essential oil composition of *Eryngium rosulatum* PW Michael ined.: A new undescribed species from eastern Australia. Biochem Syst Ecol. 2006;34(11):796-801. doi:10.1016/j.bse.2006.06.009
46. Sefidkon F, Dabiri M, Alamshahi A. Chemical composition of the essential oil of *Eryngium billardieri* F. Delaroche from Iran. J Essent Oil Res. 2004;16(1):42-3. doi:10.1080/10412905.2004.9698648
47. Cavaleiro C, Gonçalves MJ, Serra D, Santoro G, Tomi F, Bighelli A, et al. Composition of a volatile extract of *Eryngium duriaei* subsp. *juresianum* (*M. Laínz*) M. Laínz, signalised by the antifungal activity. J Pharm Biomed Anal. 2011;54(3):619-22. doi:10.1016/j.jpba.2010.09.039
48. Akhlaghi H. Chemical composition of the essential oil from stems and flowers of *Malabaila secacul* (Miller) Boiss. from northeast Iran. J Essent Oil Bear Pl. 2010;13(1):135-8. doi:10.1080/0972060X.2010.10643802
49. Vuckovic I, Vujisic L, Todosijevic M, Stesevic D, Milosavljevic S, Trifunovic S. Volatile constituents of different plant parts and populations of *Malabaila aurea* Boiss. from Montenegro. Rec Nat Prod. 2014;8(2):148.
50. Najafabadi RE, Mohammadi M, Yousefi M, Habibi Z. Chemical composition and antibacterial activity of essential oils from flowers, seeds and stems of *Heracleum rechingeri* (Manden) from Iran. J Essent Oil Bear Pl. 2011;14(6):746-50. doi:10.1080/0972060X.2011.10643998
51. Ebadollahi A, Zavieh EA, Nazifi A, Sendi JJ, Farjaminezhad M, Samadzadeh A, et al. Chemical composition and bio-pesticidal values of essential oil isolated from the seed of *Heracleum persicum* Desf. ex Fischer (Apiaceae). Span J Agric Res. 2014;12(4):1166-74. doi:10.5424/sjar/2014124-6527
52. Ušjak LJ, Petrović SD, Drobac MM, Soković MD, Stanojković TP, Ćirić AD, et al. Chemical composition, antimicrobial and cytotoxic activity of *Heracleum verticillatum* Pančić and *H. ternatum* Velen.(Apiaceae) essential oils. Chem Biodivers. 2016;13(4):466-76. doi:10.1002/cbdv.201500151
53. Tkachenko KG. Constituents of essential oils from fruit of some *Heracleum* L. species. J Essent Oil Res. 1993;5(6):687-9. doi:10.1080/10412905.1993.9698308
54. Radjabian T, Salimi A, Rahmani N. Essential-oil composition of the fruits of six *Heracleum* L. species from Iran: Chemotaxonomic significance. Chem Biodivers. 2014;11(12):1945-53. doi:10.1002/cbdv.201400085
55. Pimenov M, Ostroumova T. The genus *Malabaila* Hoffm.(Umbelliferae: Tordylieae): A carpological investigation and taxonomic implications. Feddes Repert. 2008;105(3-4):141-55. doi:10.1002/fedr.19941050304
56. Logacheva M, Valiejo-Roman C, Pimenov M. ITS phylogeny of West Asian *Heracleum* species and related taxa of Umbelliferae–Tordylieae WDJ Koch, with notes on evolution of their psbA-trnH sequences. Plant Syst Evol. 2008;270(3-4):139-57. doi:10.1007/s00606-007-0619-x