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Comparative Chemical Analysis of Essential Oils of *Lavandula angustifolia* Cultivated in Seorak and Jiri Mountains of Korea

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A B S T R A C T

Lavender (*Lavandula angustifolia*, Lamiaceae) is the most popular aromatic plant globally and its essential oil (EO) has various cosmetic and therapeutic industrial applications. This study aimed to understand and compare the EO compositions of *L. angustifolia* grown in two different geographically remote locations (Seorak Mountain and Jiri Mountain) in Korea. The EO yields from the aboveground parts of lavender at the flowering stage were 0.04 ± 0.01% (Mt. Seorak) and 1.20 ± 0.38% (Mt. Jiri), while the EO colors were orange (Mt. Seorak) and pale yellow (Mt. Jiri). In total, 44 compounds were identified in the steam-distilled EOs of *L. angustifolia* cultivated in Mt. Seorak (35 compounds) and Mt. Jiri (30 compounds) using gas chromatography−mass spectrometry analysis. Among these, 21 compounds were detected in the EOs of both Seorak and Jiri samples, with linalool and linalyl formate being the most abundant compounds. Particularly, the amounts of linalool (46.15 ± 0.09%) and linalyl formate (39.81 ± 0.15%) were higher in the EOs isolated from the Jiri sample than in the EOs isolated from the Seorak sample (28.72 ± 0.35% and 27.53 ± 0.42%, respectively). Further, considerable amounts of β-caryophyllene and isoborneol were found in the EOs of both samples. High levels of linalool and linalyl formate in the EO may be associated with the pleasant aroma and high quality of lavender.

Keywords: Essential oils, *Lavandula angustifolia*, Lavender, Linalool, Linalyl formate

Introduction

The genus *Lavandula* comprises about 39 species worldwide. Among them, *L. angustifolia* Mill. (Lamiaceae) is an important perennial aromatic plant and is native to the Mediterranean region. The strong aromatic characteristics of *L. angustifolia* refer to its plant leaves, stalks and flowers covered with glands (Zuzarte et al., 2010). It is extensively cultivated in different regions of the World, especially for essential oil (EO) (Akgün et al., 2000). In folk medicines, *L. angustifolia* is used to treat various ailments such as stress, rheumatism, epilepsy, gastrointestinal disorders, pain, anxiety and nervous disorders (Hajhashemi et al., 2003; Koulivand et al., 2013). Further, this plant has been widely used in aromatherapy, cosmetics, eco-friendly pesticide, liqueurs and beverages, in addition to pharmaceutical and perfumery industries. Previous scientific studies reported that *L. angustifolia* has various therapeutic properties such as antibacterial, sedative, spasmolytic and antiviral activities (Cavanagh and Wilkinson, 2002; Piccaglia, 1998; Woronuk et al., 2011).

The chemical composition of the essential oil of *L. angustifolia* is chiefly characterized by a high percentage of linalool and linalyl acetate with a considerable amount of terpinene-4-il and lavandula acetate. This oil also contains eucalyptol (1,8-cineol) and camphor as well as trace amounts of other components (Pokajewicz et al., 2021). Previous studies found that there has been massive variation in the concentration of major components in the essential oil of *L. angustifolia*, linalool (25 − 54%) and linalyl acetate (21 − 45%) (Caputo et al., 2016; Carrasco et al., 2016). In China, linalyl acetate (28.89%) was the most abundant component in the essential oil from the dry inflorescences of *L. angustifolia* followed by linalool (24.30%) and caryophyllene (7.89%) (Chen et al., 2020). The variation in the composition of essential oils may be attributed to various biotic and abiotic factors. The chemical components of essential oil from plants were determined primarily by their genotype. The secondary influences are environmental factors, ontogenic factors and morphogenetic futures (Détár et al., 2020; Landmann et al., 2007). The quality of the essential oil of lavender has been determined by the origin of lavender oil, pleasant aroma and desired chemical components (Beale et al., 2017; Bejar, 2020). The steam distillation method is commonly used for extracting essential oil from lavender which helps the enrichment of volatiles (Détár et al., 2020; Dong et al., 2020).

In the present study, the *L. angustifolia* plants were selected from two different geographically remote locations such as Seorak Mountain (Northern part of South Korea) and Jiri Mountain (Southern part of South Korea). Mainly, *L. angustifolia* is commercially cultivated for more than 10 years as a crop for essential oil in Seorak and Jiri Mt. regions. However, there has been no information on EO of *L. angustifolia* in Jiri Mountain and Seorak Mountain. Therefore, *L. angustifolia* might have been adapted gradually to Korean climatic conditions. Hence, the chemical composition might be changed in *L. angustifolia*. Further, there is no detailed study on the essential oil chemical composition of *L. angustifolia* cultivated in Seorak and Jiri mountains. Hence, the present study aimed to compare the essential oil composition of *L. angustifolia* cultivated in Seorak and Jiri mountains by gas chromatography-mass spectrometry (GC-MS) analysis.

Materials and Methods

Essential oil

The aerial parts of *L. angustifolia* were collected at Jeollabuk-do ARES Herb & Wild Plants Experiment Station, Namwon, Jeollabuk-do; N 35°25'02.47 E 127°31'34.12 (Jiri mountain) and at Lavender Village Farm, Goseong, Gangwon-do; N 38°20'55.03" E 128°24'53.78" (Seorak mountain), South Korea. The *L. angustifolila* was harvested at the flowering stage in June 2022 and air dried at 50°C. Then, the essential oil was isolated from *L. angustifolia* by steam distillation method. The steam distillation was performed at 100°C for 90 min. The essential oil isolation was carried out in triplicates and the yield (%) was calculated as volume (mL) of the isolated oil per 100 g of the dry weight material. The isolated essential oil was dried using anhydrous sodium sulfate and stored at 4°C for further analysis.

Gas chromatography-mass spectrometry (GC-MS) analysis

The identification of the essential oil components from *L. angustifolia* was performed using a Varian CP3800 gas chromatograph coupled with a Varian 1200L mass detector (Varian, CA, USA). The GC-MS was equipped with a VF-5MS polydimethylsiloxane capillary column (30 m × 0.25 mm × 0.25 μm). The oven temperature was started at 50°C and then programmed to 250°C at a rate of 5°C/min. The injector temperature was 250°C and the ionization detector temperature was 200°C. Helium was the carrier gas (1 mL/min) and the injected volume of the sample was 1 μL with a split ratio of 10:1. For mass spectra, an electron ionization system with ionization energy of 70 eV was used. The mass range was 50 − 500 *m/z*. The determination of the percentage composition of each component was based on the normalization of GC peak areas. The identification of the essential oil components was based on the comparison of their retention indices (RIs) relative to a homologous series of n-alkanes (C_8-C_{22}) and mass spectra from the National Institute of Standards and Technology (NIST, 3.0) library and literature data (Adams, 2007). Calculation of the peak area of each compound relative to the total peak area of the whole chromatograph presented the percentage of each essential oil constituent.

Results

The EO was extracted from aerial parts of *L. angustifolia* by steam distillation from Seorak and Jiri Mountains and the yields were 0.04 ± 0.01% and 1.27 ± 0.38%, respectively. The color of Seorak EO was orange, but Jiri Mt.' EO was pale yellow. The EOs chemical composition of *L. angustifolia* from the Seorak and Jiri Mountains was presented in Table 1.

In total, 44 components were identified in the essential oils of *L. angustifolia* from Seorak and Jiri by the GC-MS technique. In these, 21 compounds were detected in both Seorak and Jiri samples. Further, 14 components were identified only in the essential oil of *L. Angustifolia* from Seorak Mountain. Whereas 9 components were identified only in the essential oil of *L. angustifolia* from Jiri Mountain.

The essential oil of *L. angustifolia* from Seorak Mountain contains a total of 35 different components, which accounted for 84.23% of the total essential oil. The essential oil of *L. angustifolia* (Seorak Mt.) contains 10 monoterpenoids, 7 monoterpenes, 7 sesquiterpenes, 4 sesquiterpenoids, 3 alcohols, 3 esters and 1 ketone. Among them, linalool (28.72 ± 0.35%) is the most abundant compound in the essential oil of *L. angustifolia* (Seorak Mt.) followed by linalyl formate (27.53 ± 0.42%). β-caryophyllene (9.32 ± 0.12%), lavandulyl acetate (4.24 ± 0.06%), β-ocimene (3.83 ± 0.08%), isoborneol (1.93 ± 0.02%), α-terpineol (1.35 ± 0.04%) and caryophyllene oxide (1.04 ± 0.05%) were also detected in considerable amount in this essential oil. The rest of the components were identified with less than 1%.

Table 1. Chemical components of essential oils of *L. angustifolia* cultivated in Seorak and Jiri mountains

No.	Compound Name	RI[a]	RI[b]	Area (%)[c]		Formula	Classification
				Seorak Mt.	Jiri Mt.		
1	α-Pinene	920	939	0.26 ± 0.01	-	$C_{10}H_{16}$	Monoterpene
2	Camphene	939	954	0.21 ± 0.01	0.08 ± 0.00	$C_{10}H_{16}$	Monoterpene
3	1-Octen-3-ol	970	972	0.07 ± 0.01	0.10 ± 0.01	$C_8H_{16}O$	Alcohol
4	β-Pinene	978	979	0.84 ± 0.02	0.24 ± 0.01	$C_{10}H_{16}$	Monoterpene
5	3-Octanone	982	983	0.23 ± 0.01	0.52 ± 0.01	$C_8H_{16}O$	Alcohol
6	3-Octanol	986	991	-	0.22 ± 0.01	$C_8H_{18}O$	Alcohol
7	Butyl butyrate	990	993	0.06 ± 0.02	-	$C_8H_{16}O_2$	Ester
8	3-Carene	1002	1011	0.78 ± 0.04	0.02 ± 0.01	$C_{10}H_{16}$	Monoterpene
9	o-Cymene	1020	1026	-	0.06 ± 0.01	$C_{10}H_{14}$	Monoterpene
10	D-Limonene	1027	1029	-	0.06 ± 0.00	$C_{10}H_{16}$	Monoterpene
11	1,8-Cineole	1029	1031	-	0.18 ± 0.01	$C_{10}H_{18}O$	Monoterpenoid
12	β-Ocimene	1036	1050	3.83 ± 0.08	0.43 ± 0.01	$C_{10}H_{16}$	Monoterpene
13	γ-Terpinene	1057	1059	0.19 ± 0.01	-	$C_{10}H_{16}$	Monoterpene
14	(E)-p-2-Menthen-1-ol	1069	1140	0.05 ± 0.00	-	$C_{10}H_{18}O$	Monoterpenoid
15	Hexyl acetate	1075	1009	-	0.21 ± 0.01	$C_8H_{16}O_2$	Ester
16	Terpinolene	1082	1088	0.23 ± 0.01	-	$C_{10}H_{16}$	Monoterpene
17	Linalool	1101	1102	28.72 ± 0.35	46.15 ± 0.09	$C_8H_{18}O$	monoterpenoid
18	1-Octen-3-yl-acetate	1107	1112	0.46 ± 0.01	0.22 ± 0.00	$C_{10}H_{18}O_2$	Ester
19	Camphor	1139	1146	0.39 ± 0.01	-	$C_{10}H_{16}O$	Ketone
20	Lavandulol	1156	-	0.42 ± 0.00	0.05 ± 0.00	$C_{10}H_{18}O$	Alcohol
21	Isoborneol	1161	1160	1.93 ± 0.02	1.22 ± 0.01	$C_{10}H_{18}O$	Monoterpenoid
22	Terpinen-4-ol	1168	1177	-	0.33 ± 0.03	$C_{10}H_{18}O$	Monoterpenoid
23	Thymol	1171	1290	-	0.14 ± 0.03	$C_{10}H_{14}O$	Phenol
24	Hexyl butyrate	1180	1191	-	0.45 ± 0.00	$C_{10}H_{20}O_2$	Ester
25	α-Terpineol	1181	1188	1.35 ± 0.04	-	$C_{10}H_{18}O$	Monoterpenoid
26	Eucarvone	1194	1150	0.03 ± 0.01	0.05 ± 0.00	$C_{10}H_{14}O$	Monoterpenoids
27	Nerol	1206	1229	0.18 ± 0.00	-	$C_{10}H_{18}O$	Monoterpenoid
28	Bornyl formate	1223	-	0.08 ± 0.00	0.07 ± 0.02	$C_{11}H_{18}O_2$	Monoterpenoid
29	Linalyl formate	1246	1246	27.53 ± 0.42	39.81 ± 0.15	$C_{11}H_{18}O_2$	monoterpenoid
30	Phellandral	1267	-	0.10 ± 0.00	-	$C_{10}H_{16}O$	Monoterpenoid
31	Lavandulyl acetate	1283	1290	4.24 ± 0.06	-	$C_{12}H_{20}O_2$	Ester
32	Coumarin	1313	1434	-	0.09 ± 0.00	$C_9H_6O_2$	Ketone
33	β-Caryophyllene	1410	1419	9.32 ± 0.12	3.09 ± 0.03	$C_{15}H_{24}$	Sesquiterpene
34	Teresantalol	1416	-	0.14 ± 0.01	0.08 ± 0.00	$C_{10}H_{16}O$	Monoterpenoid
35	α-Bergamotene	1425	1434	0.27 ± 0.00	0.08 ± 0.00	$C_{15}H_{24}$	Sesquiterpene
36	β-Santalene	1440	1459	0.06 ± 0.01	-	$C_{15}H_{24}$	Sesquiterpene
37	β-Farnesene	1447	1442	0.55 ± 0.01	1.22 ± 0.02	$C_{15}H_{24}$	Sesquiterpene
38	β-Sesquiphellandrene	1452	1522	0.06 ± 0.00	-	$C_{15}H_{24}$	Sesquiterpene
39	β-Cubebene	1476	1388	0.27 ± 0.03	0.07 ± 0.01	$C_{15}H_{24}$	Sesquiterpene
40	Butylated hydroxytoluene	1499	1515	0.09 ± 0.01	0.12 ± 0.01	$C_{15}H_{24}O$	Sesquiterpenoid
41	γ-Cadinene	1510	1513	0.17 ± 0.00	0.08 ± 0.00	$C_{15}H_{24}$	Sesquiterpene
42	β-Caryophyllene oxide	1579	1583	1.04 ± 0.05	0.78 ± 0.02	$C_{15}H_{24}O$	Sesquiterpenoid
43	τ-Cadinol	1637	1640	0.21 ± 0.01	-	$C_{15}H_{26}O$	Sesquiterpenoid
44	Bergamotenol	1918	-	0.05 ± 0.01	-	$C_{15}H_{24}O$	Sesquiterpenoid
			Total	**84.23**	**96.22**		
			Yield (w/w)	**0.04 ± 0.01**	**1.20 ± 0.38**		

[a]RI, retention indices relative to *n*-alkanes (C7-C30) on the VF-5ms column.

[b]RI, comparison of retention indices with those reported in the literature.

[c]Area values a e mean of three replicate determinations (n = 3) ± standard deviation.

In the case of *L. angustifolia* essential oil from Jiri Mountain, 30 different compounds were identified from 96.22% of the total oil. In this essential oil, 6 monoterpenes, 8 monoterpenoids, 4 alcohols, 5 sesquiterpenes, 3 esters, 2 sesquiterpenoids, 1 phenol and 1 ketone were identified. Similar to the essential oil isolated Seorak Mountain, linalool (46.15 ± 0.09%) and linalyl formate (39.81 ± 0.15%) were the most abundant component in the essential oil of *L. angusifolia* from Jiri Mountain. However, the concentration of linalool and linalyl formate was higher in Jiri sample than Seorak sample. Further, β-caryophyllene (3.09 ± 0.03%), isoborneol (1.22 ± 0.01%) and β-farnesene (1.22 ± 0.02%) were detected in significant level.

Discussion

L. angustifolia is one of the most important medicinal and aromatic plants and its essential oil is used in the perfumery, cosmetics and therapeutic industries (Despinasse et al., 2020). The essential oil of *L. angustifolia* has a strong fragrance due to the presence of many aromatic components. Apart from flavor and fragrance purposes, *L. angustifolia* essential oil possesses numerous biological properties such as antioxidant, anti-depressant, anti-inflammatory, antimicrobial, relieving neuropathic pain, toxoplasma activity, antileishmanial activity, cardioprotective, antimutagenic, neuroprotective and anxiolytic properties (Cavanagh and Wilkinson, 2002; Miastkowska et al., 2021). *L. angustifolia* essential oil is a potential alternative in food and industrial production due to its highly acclaimed properties in various fields. Although many studies reported on the essential oil composition of *L. angustifolia* growing in different parts of the world, significant variations were observed in its composition both quantitatively and qualitatively. The concentration of major essential oil components invariably differs according to geographical locations (Demasi et al., 2018).

In the present study, a total of 44 components were identified in the essential oils of *L. angustifolia* both from Seorak and Jiri Mountains. In these, 12 monoterpenoids, 9 monoterpenes, 8 sesquiterpenes, 5 esters, 4 sesquiterpenoids, 4 alcohols, 2 ketones and 1 phenol were identified. A recent study found that alcohols (38.14%), esters (37.41%), alkenes (17.28%) and ketones (1.18%) were major components in the essential oil of *L. angustifolia* in China (Guo and Wang, 2020). In this study, the predominant components in the essential oils of *L. angustifolia* are linalool, linalyl formate and β-caryophyllene. Similarly, Adaszyńska et al. (2013) reported that the primary component of essential oil from five varieties of *L. angustifolia* was linalool (23.9 − 15.8%). However, Mekonnen et al. (2019) found that eucalyptol (52.36%), camphor (11.91%), γ-terpinene (8.78%) and endoborneol (7.59%) were identified as major components in the essential oil from fresh leaves and flowers of *L. angustifolia* cultivated in Ethiopia. The main constituents in the essential oil of *L. angustifolia* cultivated in Belgrade were 1,8-cineole (7.1 − 48.4%), linalool (0.1 − 38.7%), borneol (10.9 − 27.7%), β-phellandrene (0.5 − 21.2%) and camphor (1.5 − 15.8%). In the essential oil of *L. angustifolia* from Algeria, linalool (22.35%), linalyl acetate (21.80%), trans-ocimene (6.16%) and 4-terpineol (5.19%) were major components (Djenane et al., 2012). Major components, linalool and linalyl acetate were mainly responsible for the pleasant aroma of *L. angustifolia* essential oil (Łyczko et al., 2019).

A high amount of linalool (46.15 ± 0.09%) and linalyl formate (39.81 ± 0.15%) were detected in the essential oil of *L. angustifolia* from Jiri Mountain compared to that of the essential oil from Seorak Mountain. According to previous studies, linalyl acetate was one of the predominant components in the essential of *L. angustifolia*. However, linalyl formate was identified as the second major component in the essential oils of *L. angustifolia* from both Seorak and Jiri Mountains. Linalool is an important fragrant compound that is commonly perceived as a pleasant aroma with physiological effects on human beings like inducing calmness and enhancing sleep. Linalool is present in the essential oils of more than 200 plant species of different families (Stashenko and Martínez, 2008). The linalool-rich essential oil exhibited various biological activities and enhanced the specific scent of cosmetic products (Kamatou and Viljoen, 2008). The previous study found that the essential oil components (monoterpene and sesquiterpene hydrocarbons and oxygenated monoterpenes) of *L. angustifolia* had strong antimicrobial activities (Bogdan et al., 2021; Hussain et al., 2008; Ruberto and Baratta, 2000).

The essential oil of *L. angustifolia* from Poland contained 22.7% of monoterpenes, whereas, the essential oil of *L. angustifolia* collected from Ukraine contained only 5.8% of monoterpenes. This variation in the same species of *L. angustifolia* is due to different geographical origins of the plant (Białoń et al., 2019). Lakušic et al. (2014) reported the seasonal variations in the chemical composition of the essential oils obtained from the same individual of *L. angustifolia* cultivated in Belgrade. Another study indicated that the latitude (sea distance) and altitude influenced on the essential oil composition of *L. angustifolia*. In particular, latitude had an influence on morphological as well as phytochemical traits (Demasi et al., 2018). Previously, numerous studies demonstrated that the variation in the essential oil composition is highly influenced by genetic variability of the species, plant parts, developmental stage, in addition to various abiotic factors, including season, soil, climate, etc. (Rathore et al., 2022). It is well-known that the interaction between the plant and environment mostly contributes to the expression of phytochemicals (Demasi et al., 2018). These factors influence the biosynthetic pathways of the plant and affect the concentration of the main constituents (Al-Badani et al., 2017). In the present study, the variation of the chemical components between *L. angustifolia* essential oils from Seorak and Jiri Mountain might be due to the geographical locations and agronomic factors such as fertilizer application and weather.

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References

Adams, R. P. (2007) Identification of essential oil components by gas chromatography/mass spectrometry. *Vol. 456.* pp. 1-811. Allured Publishing Co.: Carol Stream, IL, USA.

Adaszyńska, M., Swarcewicz, M., Dzięcioł, M., Dobrowolska, A. (2013) Comparison of chemical composition and antibacterial activity of lavender varieties from Poland. Nat Prod Res 27:1497-1501.

Akgün, M., Akgün, N. A., Dinçer, S. (2000) Extraction and modeling of lavender flower essential oil using supercritical carbon dioxide. Ind Eng Chem Res 39:473-477.

Al-Badani, R. N., Da Silva, J. K. R., Setzer, W. N., Awadh Ali, N. A., Muharam, B. A., Al-Fahad, A. J. (2017) Variations in essential oil compositions of *Lavandula pubescens* (lamiaceae) aerial parts growing wild in Yemen. Chem Biodiver 14:10.1002/cbdv.201600286.

Beale, D. J., Morrison, P. D., Karpe, A. V., Dunn, M. S. (2017) Chemometric analysis of lavender essential oils using targeted and untargeted GC-MS acquired data for the rapid identification and characterization of oil quality. Molecules 22:1339.

Bejar, E. (2020) Adulteration of english lavender (*Lavandula angustifolia*) essential oil. J. Pharm. Biomed Anal 199:114050.

Białoń, M., Krzyśko-Łupicka, T., Nowakowska-Bogdan, E., Wieczorek, P. P. (2019) Chemical composition of two different lavender essential oils and their effect on facial skin microbiota. Molecules 24:3270.

Bogdan, M. A., Bungau, S., Tit, D. M., Zaha, D. C., Nechifor, A. C., Behl, T., Chambre, D., Lupitu, A. I., Copolovici, L., Copolovici, D. M. (2021) Chemical profile, antioxidant capacity and antimicrobial activity of essential oils extracted from three different varieties (Moldoveanca 4, Vis Magic 10 and Alba 7) of *Lavandula angustifolia*. Molecules 26:4381.

Caputo, L., Souza, L. F., Alloisio, S., Cornara, L., De Feo, V. (2016) Coriandrum sativum and *Lavandula angustifolia* essential oils: Chemical composition and activity on central nervous system. Int J Mol Sci 17:1999.

Carrasco, A., Martinez-Gutierrez, R., Tomas, V., Tudela, J. (2016) *Lavandula angustifolia* and *Lavandula latifolia* essential oils from Spain: Aromatic profile and bioactivities. Planta Medica 82:163-170.

Cavanagh, H. M. A., Wilkinson, J. M. (2002) Biological activities of lavender essential oil. Phytother Res 16:301-308.

Chen, X., Zhang, L., Qian, C., Du, Z., Xu, P., Xiang, Z. (2020) Chemical compositions of essential oil extracted from *Lavandula angustifolia* and its prevention of TPA-induced inflammation. Microchem J 153:104458.

Demasi, S., Caser, M., Lonati, M., Cioni, P. L., Pistelli, L., Najar, B., Scariot, V. (2018) Latitude and altitude influence secondary metabolite production in peripheral alpine populations of the Mediterranean species *Lavandula angustifolia* Mill. Front Plant Sci 9:983.

Despinasse, Y., Moja, S., Soler, C., Jullien, F., Pasquier, B., Bessière, J. M., Baudino, S., Nicolè, F. (2020) Structure of the Chemical and Genetic Diversity of the True Lavender over Its Natural Range. Plants 9:1640.

Détár, E., Németh, É. Z., Gosztola, B., Demján, I., Pluhár, Z. (2020) Effects of variety and growth year on the essential oil properties of lavender (*Lavandula angustifolia* Mill.) and lavandin (*Lavandula x intermedia* Emeric ex Loisel.). Biochem Syst Ecol 90:104020.

Djenane, D., Aïder, M., Yangüela, J., Idir, L., Gómez, D., Roncalés, P. (2012) Antioxidant and antibacterial effects of *Lavandula* and *Mentha* essential oils in minced beef inoculated with *E. coli* O157:H7 and *S. aureus* during storage at abuse refrigeration temperature. Meat Sci 92:667-674.

Dong, G., Bai, X., Aimila, A., Aisa, H. A., Maiwulanjiang, M. (2020) Study on lavender essential oil chemical compositions by GC-MS and improved pGC. Molecules 25:3166.

Guo, X., Wang, P. (2020) Aroma characteristics of lavender extract and essential oil from *Lavandula angustifolia* Mill. Molecules 25:5541.

Hajhashemi, V., Ghannadi, A., Sharif, B. (2003) Anti-inflammatory and analgesic properties of the leaf extracts and essential oil of *Lavandula angustifolia* Mill. J Ethnopharmacol 89:67-71.

Hussain, A. I., Anwar, F., Sherazi, S. T. H., Przybylski, R. (2008) Chemical composition, antioxidant and antimicrobial activities of basil (*Ocimum basilicum*) essential oils depends on seasonal variations. Food Chem 108:986-995.

Kamatou, G. P., Viljoen, A. M. (2008) Linalool-a review of a biologically active compound of commercial importance. Nat Prod Commun 3:1183-1192.

Koulivand, P. H., Ghadiri, M. K., Gorji, A. (2013) Lavender and the nervous system. Evid Based Complement Alter Med 2013:681304.

Lakušic, B., Lakušic, D., Ristic, M., Marčetic, M., Slavkovska, V. (2014) Seasonal variations in the composition of the essential oils of *Lavandula angustifolia* (Lamiacae). Nat Prod Commun 9:859-862.

Landmann, C., Fink, B., Festner, M., Dregus, M., Engel, K. H., Schwab, W. (2007) Cloning and functional characterization of three terpene synthases from lavender (*Lavandula angustifolia*). Arch Biochem Biophys 465: 417-429.

Łyczko, J., Jałoszyński, K., Surma, M., Masztalerz, K., Szumny, A. (2019) HS-SPME analysis of true lavender (*Lavandula angustifolia* Mill.) leaves treated by various drying methods. Molecules 24:764.

Mekonnen, A., Tesfaye, S., Christos, S. G., Dires, K., Zenebe, T., Zegeye, N., Shiferaw, Y., Lulekal, E. (2019) Evaluation of skin irritation and acute and subacute oral toxicity of *Lavandula angustifolia* essential oils in rabbit and mice. J Toxicol 2019:5979546.

Miastkowska, M., Kantyka, T., Bielecka, E., Kałucka, U., Kamińska, M., Kucharska, M., Kilanowicz, A., Cudzik, D., Cudzik, K. (2021) Enhanced Biological Activity of a Novel Preparation of *Lavandula angustifolia* Essential Oil. Molecules 26:2458.

Piccaglia, R. (1998) Aromatic plants: a world of flavouring compounds. Agro Food Ind Hi-Tech 9:12-15.

Pokajewicz, K., Białoń, M., Svydenko, L., Fedin, R., Hudz, N. (2021) Chemical composition of the essential oil of the new cultivars of *Lavandula angustifolia* mill. bred in Ukraine. Molecules 26:5681.

Rathore, S., Mukhia, S., Kapoor, S., Bhatt, V., Kumar, R., Kumar, R. (2022) Seasonal variability in essential oil composition and biological activity of *Rosmarinus officinalis* L. accessions in the western Himalaya. Sci Rep 12:1-13.

Ruberto, G., Baratta, M. T. (2000) Antioxidant activity of selected essential oil components in two lipid model systems. Food Chem 69:167-174.

Stashenko, E. E., Martínez, J. R. (2008) Sampling flower scent for chromatographic analysis. J Sep Sci 31:2022-2031.

Woronuk, G., Demissie, Z., Rheault, M., Mahmoud, S. (2011) Biosynthesis and therapeutic properties of *Lavandula* essential oil constituents. Planta Med 77:7-15.

Zuzarte, M. R., Dinis, A. M., Cavaleiro, C., Salgueiro, L. R., Canhoto, J. M. (2010) Trichomes, essential oils and in vitro propagation of *Lavandula pedunculata* (Lamiaceae). Ind Crop Prod 32:580-587.