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Qualitative and Quantitative Composition of The Essential Oil of *Lavandula Angustifolia* Mill. When Introduced in Tajikistan

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Abstract: The article presents the results of a study of the component composition of the essential oil of *Lavandula angustifolia* Mill. cultivated in two locations in Tajikistan - in the settlement of Kissakuz and in the city of Gafurov. Using gas chromatography with mass spectrometric detection (GC-MS), 26 main components were identified, totaling 81.36% of the total oil content. It was established that the content of key markers - linalyl acetate and linalool - differs significantly depending on the place of growth: for the sample from Kissakuz, the linalool content is 33.27%, linalyl acetate - 21.01%; for the sample from Gafurov - 22.58% and 10.37%, respectively. A comparative analysis was carried out with literature data for Morocco, Uzbekistan, Turkey, Bosnia and Herzegovina, Poland, and other regions. It was found that the oil of Tajik lavender is characterized by a low content of camphor (0.73%) and 1,8-cineole (2.63%), but has a reduced level of linalyl acetate and an increased level of α -terpineol, which requires adjustment of agronomic practices or breeding work to achieve compliance with international standards. The obtained data indicate the prospects for further study and optimization of lavender cultivation in the mountain conditions of Tajikistan.

Keywords: *Lavandula angustifolia* Mill., essential oil, GC-MS analysis, linalyl acetate, linalool, introduction, Tajikistan, Kissakuz, Gafurov

Citation: Masaidova M, Khaydarov Kh, Khomidov Yo.R, Sobitova M.I.³, Mukhamadiev A.N, Mukhamadiev N.K, Nayimova B.K. Qualitative and Quantitative Composition of The Essential Oil of *Lavandula Angustifolia* Mill. When Introduced in Tajikistan. Central Asian Journal of Medical and Natural Science 2026, 7(4), 688-693

Received: 13th Jul 2026
Revised: 28th Aug 2026
Accepted: 15th Sep 2026
Published: 08th Oct 2026



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1. Introduction

The essential oil of narrow-leaved lavender (*Lavandula angustifolia* Mill.) is one of the most valuable and in-demand essential oils on the world market due to its unique chemical composition and wide range of biological activity [1, 2, 3]. The main components determining the quality of the oil are linalyl acetate (30–60%) and linalool (25–40%), as well as the permissible levels of camphor (<2%) and 1,8-cineole (<5%) according to the European Pharmacopoeia [4]. At the same time, numerous studies show that the component composition of lavender essential oil is subject to significant variability under the influence of genetic factors, soil and climatic conditions, agronomic practices, and the phase of plant development [5-8].

In the Republic of Tajikistan, in recent years, experimental work has been carried out on the introduction and cultivation of *L. angustifolia* in various soil and climatic zones [9]. The present work is the first stage of a systematic study of the quality of oil obtained from two contrasting locations: the settlement of Kissakuz (high-mountain zone, chestnut soils) and the city of Gafurov (foothill zone, serozems). The aim is to study the component composition of the essential oil and assess its compliance with the requirements of the European Pharmacopoeia [4].

2. Materials and Methods

Essential oil samples were isolated from air-dried inflorescences of *Lavandula angustifolia* Mill. collected during the mass flowering phase (July 2024) at two sites: the settlement of Kissakuz (altitude ~850 m above sea level, chestnut soil, moderate irrigation); the city of Gafurov (altitude ~620 m, serozem soil, regular irrigation).

The plants were grown from a single cultivar ("Yuzhnaya Krasavitsa" [Southern Beauty], originating from a Crimean nursery), plant age - 3 years. Harvesting was carried out in the morning hours, drying - at room temperature in the shade. Samples for analysis were obtained from three independent replicates (3 sampling plots at each location).

Essential oil isolation was performed by hydrodistillation for 2.5 h using a Clevenger apparatus according to the European Pharmacopoeia [4]. The oil yield averaged 0.8–1.2% (of dry mass).

GC-MS analysis was performed on an Agilent 7890B/5977B chromatograph-mass spectrometer with an HP-5MS capillary column (30 m × 0.25 mm × 0.25 μm). Temperature program: initial temperature 50 °C (hold 2 min), ramp to 280 °C at 3 °C/min, final hold 10 min. Carrier gas - helium (1.2 mL/min), injection volume - 1 μL (1% solution in hexane), split ratio 1:50. Ionization - electron impact (70 eV), scan range 40–450 m/z.

Component identification was carried out by comparing mass spectra with NIST-05 and Wiley libraries, as well as by matching linear retention indices (RI) calculated from n-alkane homologs C₈–C₂₀ with literature data [10]. Quantitative determination - by the internal normalization method according to ISO 7609:1985 [11]. For each component, mean values from three replicates are given; the relative standard deviation (RSD) did not exceed 5% for the major components.

Statistical analysis was performed using Statistica 12 software. The significance of differences between locations was assessed by Student's t-test at a significance level of p<0.05.

3. Results

1. Component composition of the essential oil of the sample from the city of Gafurov. In the essential oil of the plant from Gafurov, 26 components with a content >0.5% were identified (Table 1). The total share of 20 major components (content >1%) was 81.36% of the total chromatogram area. The dominant components are linalool (22.58 ± 0.48%), linalyl acetate (10.37 ± 0.35%), L-α-terpineol (6.42 ± 0.21%), and two isomeric lavandulol oxides (total 9.37%). A very low camphor content was noted (0.73 ± 0.04%), which favorably distinguishes this oil from many Turkish and Bosnian samples, which are characterized by high camphor and 1,8-cineole content [12-14].

Table 1. Main components of the essential oil of *L. angustifolia* from the city of Gafurov (mean ± SD, n=3)

No.	Component	Retention time, min	RI (exp.)	RI (lit.) [10]	Content, %
1	β-Myrcene	7.034	992	990	1.32 ± 0.07
2	1,8-Cineole	8.084	1030	1029	2.63 ± 0.12
3	Lavandulol oxide (isomer 1)	9.316	1065	1064	5.34 ± 0.25
4	Lavandulol oxide (isomer 2)	9.749	1078	1076	4.03 ± 0.18
5	Linalool	10.382	1099	1097	22.58 ± 0.48
6	1-Octen-3-yl acetate	10.565	1105	1103	3.46 ± 0.14
7	Camphor	11.282	1132	1131	0.73 ± 0.04
8	endo-Borneol	11.915	1155	1153	2.17 ± 0.09
9	Lavandulol	12.031	1160	1159	1.51 ± 0.08
10	Terpinen-4-ol	12.264	1170	1174	3.88 ± 0.16
11	α-Terpineol	12.464	1180	1179	1.33 ± 0.06
12	L-α-Terpineol	12.697	1190	1189	6.42 ± 0.21

No.	Component	Retention time, min	RI (exp.)	RI (lit.) [10]	Content, %
13	cis-Geraniol	13.697	1225	1223	1.50 ± 0.07
14	Linalyl acetate	14.530	1254	1256	10.37 ± 0.35
15	Lavandulol acetate	15.429	1286	1285	3.97 ± 0.15
16	Neryl acetate (isomer 1)	17.311	1360	1359	1.76 ± 0.08
17	Neryl acetate (isomer 2)	17.828	1375	1374	3.11 ± 0.13
18	Caryophyllene	18.627	1418	1419	1.40 ± 0.06
19	Caryophyllene oxide	22.591	1580	1579	3.54 ± 0.14
20	τ-Cadinol	23.874	1642	1640	1.04 ± 0.05

2. Comparative analysis of samples from Kissakuz and Gafurov. The data in Table 2 show significant differences between the samples. The sample from Kissakuz is characterized by a higher content of linalool ($33.27 \pm 0.62\%$ vs. $22.58 \pm 0.48\%$, $p < 0.01$) and linalyl acetate ($21.01 \pm 0.51\%$ vs. $10.37 \pm 0.35\%$, $p < 0.001$), which brings it closer to the classical type of *L. angustifolia* and corresponds to data on Polish and Ukrainian cultivars [9, 15]. In contrast, in the sample from Gafurov, the proportion of lavandulol oxides is increased (9.37% vs. 1.41% total) and caryophyllene oxide (3.54% vs. 0.62%). These differences are probably due to different soil composition and irrigation regime, which is consistent with literature data on the influence of edaphic factors and agronomic practices on the terpene profile [8, 16-18].

Table 2. Comparison of major components of the essential oil of *L. angustifolia* from two locations in Tajikistan (mean ± SD, n=3)

Component	Kissakuz, %	Gafurov, %	Significance level (p)
Linalool	33.27 ± 0.62	22.58 ± 0.48	<0.01
Linalyl acetate	21.01 ± 0.51	10.37 ± 0.35	<0.001
Terpinen-4-ol	6.89 ± 0.24	3.88 ± 0.16	<0.001
L-α-Terpineol	6.62 ± 0.20	6.42 ± 0.21	0.38 (n/s)
Lavandulol oxides (total)	1.41 ± 0.07	9.37 ± 0.38	<0.001
1,8-Cineole	1.88 ± 0.09	2.63 ± 0.12	<0.05
Caryophyllene	1.81 ± 0.08	1.40 ± 0.06	<0.05
Caryophyllene oxide	0.62 ± 0.03	3.54 ± 0.14	<0.001
τ-Cadinol	0.62 ± 0.03	1.04 ± 0.05	<0.01

3. Comparison with literature data and pharmacopoeial requirements. Table 3 presents comparative data on the main marker components for various regions. Data sources: for Morocco - [5], Uzbekistan - [15], Turkey - [12], Bosnia and Herzegovina - [13], Poland - [15]. Additional data on cultivar variability and growing conditions were taken from works [3, 8, 9, 18].

Table 3. Content of key components of the essential oil of *L. angustifolia* from various regions (mean values, %)*

Component	Kissakuz / Gafurov	Morocco [5]	Uzbekistan [15]	Turkey [12]	Bosnia and Herzegovina [13]	Poland [15]
Linalyl acetate	21.01/10.37	31.78	28.1	n/d	n/d	19.7-23.4
Linalool	33.27/22.58	16.58	40.3	1.61-12.7	n/d	26.5-34.7
Camphor	0.73/0.73	n/d	n/d	13.8-33.0	16.96	n/d

Component	Kissakuz / Gafurov	Morocco [5]	Uzbekistan [15]	Turkey [12]	Bosnia and Herzegovina [13]	Poland [15]
1,8-Cineole	1.88/2.63	n/d	n/d	13.5-27.9	n/d	n/d
α -Terpineol	6.62/6.42	n/d	n/d	1.96-5.79	n/d	2.8–5.1
Terpinen-4-ol	6.89/3.88	n/d	n/d	0.35	n/d	n/d

*n/d - no data.

Analysis of compliance with the European Pharmacopoeia (Ph. Eur. 11th ed., 2023)
[4]. Linalool: both samples (22.58% and 33.27%) fall within the range of 20–40% (acceptable).

Linalyl acetate: the sample from Kissakuz (21.01%) is close to the lower limit of the pharmacopoeial interval (30–60%), while the sample from Gafurov (10.37%) is significantly below the norm.

Camphor: content (0.73%) is significantly below the 2% limit, which is an advantage and confirms the absence of lavandin admixture [6, 9].

1,8-Cineole: 1.88–2.63% - less than 5%, complies with the norm.

α -Terpineol: in the sample from Gafurov, 6.42%, which exceeds the permissible 2% (for pharmacopoeial oil), and in the sample from Kissakuz - 6.62%, also higher. This deviation requires attention, as it may indicate an admixture of other species or hybrids, or a specific reaction of the cultivar to local conditions [8].

Comparison with other regions shows that the Tajik samples are closest to the Polish ones in terms of linalool and linalyl acetate content (for Kissakuz), but differ in an increased level of α -terpineol and a reduced level of linalyl acetate (for Gafurov). Turkish and Bosnian samples are characterized by a high content of camphor and 1,8-cineole, which is typical of lavandin or spike lavender and is not an indicator of quality oil of narrow-leaved lavender [12-14].

4. Discussion

Biological potential and practical application. Although this work did not include our own tests for antimicrobial and antioxidant activity, literature data unequivocally indicate the pronounced biological activity of the components linalool and linalyl acetate [1, 2, 19–21]. The combined content of monoterpene alcohols and their esters in the Tajik samples reaches 60% (for Kissakuz) and 35% (for Gafurov), which creates prerequisites for the use of the oil in pharmaceuticals and cosmetology [3]. However, for a final conclusion, experimental data on antioxidant and antimicrobial activity are needed, which are planned to be obtained in future works.

5. Conclusion

In the essential oil of *Lavandula angustifolia* introduced in Tajikistan, 26 components were identified. The dominant ones are linalool (22.58–33.27%), linalyl acetate (10.37–21.01%), L- α -terpineol (6.42–6.62%), and terpinen-4-ol (3.88–6.89%). The content of these markers significantly depends on the place of growth: the sample from Kissakuz (high-mountain zone, chestnut soils) is characterized by a significantly higher content of linalool and linalyl acetate compared to the sample from Gafurov (foothill zone, serozems), which makes the former closer to the classical oil type.

Both samples comply with the European Pharmacopoeia for the content of linalool, camphor (<2%), and 1,8-cineole (<5%), which confirms the absence of hybrid admixture (lavandin). However, critical deviations were revealed: reduced linalyl acetate content (especially in the sample from Gafurov - 10.37% versus the norm of 30–60%) and an increased level of α -terpineol (>6% versus the norm of <2%) do not allow these oils to be classified as high-grade pharmacopoeial products without additional breeding and agronomic correction.

Despite the noted inconsistencies, the Tajik samples possess a valuable low camphor content and a significant total content of biologically active monoterpene alcohols and esters (up to 60%), which opens up possibilities for their use in cosmetology and pharmaceuticals after optimization of agronomic practices (irrigation regime, fertilizers) and targeted cultivar selection. The obtained data serve as a basis for further monitoring and standardization of essential oil raw materials under the conditions of Tajikistan.

Funding. The study was carried out without attracting external grants or sponsorship support.

Acknowledgments. The author expresses gratitude to the staff of Samarkand State University named after Sh. Rashidov (Uzbekistan) and Khujand State University named after Acad. B. Gafurov for the provided samples and technical assistance in conducting the GC-MS analysis.

Conflict of interest. The authors declare the absence of any explicit or potential conflict of interest related to the publication of this article.

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