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ILMIY AXBOROTNOMA

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STUDY OF THE INFLUENCE OF CLIMATE FACTORS ON THE CHEMICAL COMPOSITION OF BASIL (OCIMUM) ESSENTIAL OIL USING THE GH–MS METHOD

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Abstract. In this study, the influence of climatic factors on the chemical composition of basil (Ocimum) essential oil was studied using the gas chromatography–mass spectrometry (GC–MS) method. The samples were taken from basil plants grown in regions with different climatic conditions. The analysis results showed that the essential oil was mainly dominated by terpenoids and phenylpropanoid compounds. Significant differences were observed in the relative amounts of essential oil components depending on climatic conditions. The results of the study serve as a scientific basis for the standardization of basil essential oil and its use in the pharmaceutical and food industries. The obtained data also suggest that controlled cultivation strategies, such as greenhouse management or regulated irrigation systems, could be applied to stabilize the chemical profile of basil essential oil. By optimizing environmental parameters, it is possible to enhance the yield of biologically active compounds with antimicrobial and antioxidant properties.

Keywords: basil, Ocimum, essential oil, climatic factors, GC-MS analysis, volatile compounds, terpenoids.

Rayxon (OCIMUM) o‘simligi efir moyi kimyoviy tarkibiga iqlim omillarining ta’sirini GX–MS usulida tadqiq etish

Annotatsiya. Ushbu tadqiqotda rayxon (Ocimum) o‘simligi efir moyining kimyoviy tarkibiga iqlim omillarining ta’siri gaz xromatografiyasi – mass-spektrometriya (GX–MS) usuli orqali o‘rganildi. Namunalar turli iqlim sharoitiga ega hududlarda yetishtirilgan rayxon o‘simliklaridan olindi. Tahlil natijalari efir moy tarkibida asosan terpenoidlar va fenilpropanoid birikmalar ustunligini ko‘rsatdi. Iqlim sharoitlariga qarab efir moy komponentlarining nisbiy miqdorida sezilarli farqlar kuzatildi. Tadqiqot natijalari rayxon efir moyini standartlashtirish va farmatsevtika hamda oziq-ovqat sanoatida qo‘llash uchun ilmiy asos bo‘lib xizmat qiladi. Olingan ma'lumotlar, shuningdek, rayhon efir moyining kimyoviy profilini barqarorlashtirish uchun issiqxona boshqaruvi yoki tartibga solingan sug'orish tizimlari kabi nazorat ostidagi yetishtirish strategiyalari qo'llanilishi mumkinligini ko'rsatadi. Atrof-muhit parametrlarini optimallashtirish orqali mikroblarga qarshi va antioksidant xususiyatlarga ega biologik faol birikmalar hosildorligini oshirish mumkin.

Kalit so‘zlar: rayxon, Ocimum, efir moyi, iqlim omillari, GX–MS tahlil, uchuvchan birikmalar, terpenoidlar.

Изучение влияния климатических факторов на химический состав эфирного масла базилика (OCIMUM) с использованием метода ГХ-МС

Аннотация. В данном исследовании изучалось влияние климатических факторов на химический состав эфирного масла базилика (Ocimum) с использованием метода газовой хроматографии-масс-спектрометрии (ГХ-МС). Образцы были взяты с растений базилика, выращенных в регионах с различными климатическими условиями. Результаты анализа показали, что в эфирном масле преобладают терпеноиды и фенилпропаноидные соединения. Наблюдались значительные различия в относительном содержании компонентов эфирного масла в зависимости от климатических условий. Результаты исследования служат научной основой для стандартизации эфирного масла базилика и его использования в фармацевтической и пищевой промышленности. Полученные данные также свидетельствуют о том, что для стабилизации химического состава эфирного масла базилика можно применять стратегии контролируемого выращивания, такие как управление в теплице или регулируемые системы орошения. Путем оптимизации параметров окружающей среды можно повысить выход биологически активных соединений с антимикробными и антиоксидантными свойствами.

Ключевые слова: базилик, Ocimum, эфирное масло, климатические факторы, GC-MS анализ, летучие соединения, терпеноиды.

I. Introduction. The study of the chemical composition of basil (Ocimum) essential oil is one of the important scientific directions in the chemistry of medicinal and aromatic plants, and its biological activity and industrial application are directly related to its composition, as noted in many studies [1–3]. The literature shows that basil essential oil is mainly dominated by monoterpenes, oxygenated terpenoids, and phenylpropanoid compounds, including linalool, estragole, eugenol, and 1,8-cineole as the main bioactive components [4–6], and their ratio is noted to vary depending on genetic characteristics and environmental factors [7]. A number of studies have shown that climatic factors such as temperature, humidity, and solar radiation affect the biosynthesis of volatile compounds, with linalool being predominant in tropical regions and phenylpropanoid compounds in temperate climates [8–11]. The gas chromatography–mass spectrometry (GC–MS) method has high accuracy in the analysis of basil essential oil, and it has been shown that it can reliably identify many components in the essential oil [12,13]. At the same time, changes in the composition of the essential oil depending on the phase of plant development, soil composition, mineral nutrients and water supply have also been noted [14–17]. Modern studies have shown that multidimensional statistical methods such as PCA and cluster analysis are effective in identifying chemical chemotypes in the composition of the essential oil [18,19]. It has also been confirmed that the biological activity of basil essential oil is mainly associated with components such as linalool and eugenol [20]. However, although changes in the composition of the essential oil depending on climatic conditions have been studied in the literature, it is still an urgent scientific issue to identify patterns through a comprehensive comparison of basil samples grown in different climatic regions [21].

The aim of the work is to study the influence of climatic factors on the chemical composition of the essential oil of basil (Ocimum) using the gas chromatography-mass spectrometry (GC-MS) method, to determine the variation of the main components in the essential oil composition of basil samples grown in different agroclimatic regions, and to evaluate the regularities of the relationship between climatic conditions and essential oil components.

2. Research objects. The basil (Ocimum) plant was chosen as the object of the study. Plant samples were collected from different agroclimatic regions of the Samarkand region - Urgut district (foothill, relatively humid climate), Tailak district (dry valley climate) and Samarkand district (moderate continental climate). The samples were selected in the flowering phase of the plant. The collected plant raw materials were dried under natural conditions in laboratory conditions and prepared for analysis.

The regions from which the samples were taken differ in agroclimatic conditions (Table 1): Urgut district is a foothill region located in the southeastern part of Samarkand region, with a relatively humid and cool climate, with an average annual temperature of 10–14 °C, approximately 27 °C in July, and around –9 °C in January, with an annual precipitation of 650–660 mm; Tailak district is located in the valley-plain zone and is characterized by a dry continental climate, with an average annual temperature of 13–14 °C, summer temperatures of 28–35 °C, and winter temperatures of –1…+2 °C, annual precipitation of 300–400 mm, and relative humidity of 50–60%; Samarkand district is located in the central valley zone and has a temperate continental climate, with an average annual temperature of 13.6 °C, annual precipitation of 500–550 mm, and an average temperature of about 30 °C in summer and around 0 °C in winter. According to the Köppen classification, it belongs to the temperate-dry climate zone.

Table 1

Sampling coordinates

ID	Area	Latitude	Longitude	Agroclimatic zone
U1	Urgut	39.40	67.24	Foothills, humid
U2	Urgut	39.42	67.28	Foothills, humid
U3	Urgut	39.38	67.30	Foothills, humid
T1	Tailak	39.55	66.98	Dry valley
T2	Tailak	39.52	67.02	Dry valley
T3	Tailak	39.58	66.95	Dry valley
S1	Samarkand	39.67	66.92	Temperate zone
S2	Samarkand	39.65	66.95	Temperate zone
S3	Samarkand	39.69	66.89	Temperate zone

Method of essential oil extraction. Essential oil was extracted from basil plant by hydrodistillation using Clevenger apparatus. The distillation process was continued for 3 hours. The obtained essential oil samples were dried over anhydrous sodium sulfate and stored in sealed containers at low temperature.

The composition of the essential oil was analyzed using the gas chromatography-mass spectrometry (GC-MS) method. The analysis was carried out using an HP-5MS capillary column, helium was used as the carrier gas, and the injection temperature was maintained at 250 °C. The column temperature was gradually increased from 60 °C to 250 °C, and the ionization process was performed using the electron impact method at an energy of 70 eV. The components of the essential oil were identified by comparison with the data of the mass spectral library, and their relative amounts were calculated based on the percentages of peak areas in the chromatogram.

Correlation analysis, Principal Component Analysis (PCA) and cluster analysis methods were used to assess the variation of components in the essential oil composition. These methods allowed us to assess the relationship between the chemical components in the essential oil composition and the influence of climatic factors.

3. Results and their discussion. The chromatogram of Basil essential oil obtained under optimal conditions is presented in Figure 1.

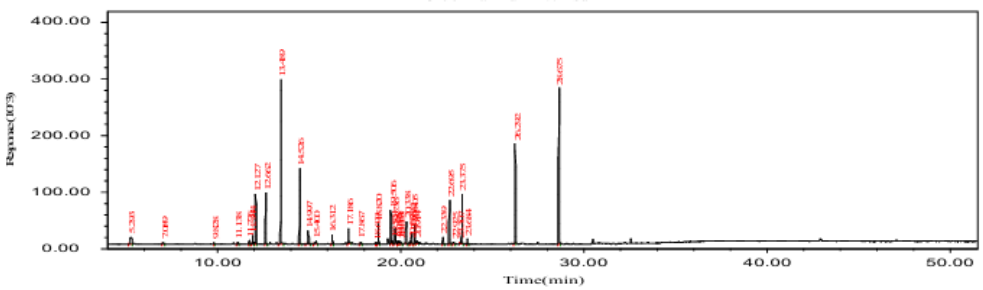

Figure 1. Chromatogram of basil essential oil

The qualitative and quantitative composition of the essential oil determined by GC–MS is given in Table 2.

Table 2

Results of GC–MS analysis of basil essential oil

№	Component name	Formula	Retention time (min)	Peak area (%)
1	Pregna-6,16-diene-11,20-diol,3,9-epoxy-18-[N- methyl-N-[14-(2'-epoxyethyl)]amino]-	$C_{25}H_{37}NO_5$	5.293	2.24
2	Corynan-17-ol, 18,19-didehydro-10-methoxy-	$C_{22}H_{28}N_2O_3$	11.138	0.28
3	Tribehenin	$C_{69}H_{134}O_6$	11.776	0.46
4	o-Cymol	$C_{10}H_{14}$	11.944	0.89
5	Cineole	$C_{10}H_{18}O$	12.127	5.14
6	γ-Terpinene	$C_{10}H_{16}$	12.662	5.40
7	β-Linalool	$C_{10}H_{18}O$	13.489	16.85
8	L-camphor	$C_{10}H_{16}O$	14.526	8.15
9	endo-Borneol	$C_{10}H_{18}O$	14.997	1.54
10	Quinamine	$C_{19}H_{24}N_2O_2$	15.400	0.61
11	Geranyl oleate	$C_{28}H_{50}O_2$	16.312	1.18
12	Biosol	$C_{10}H_{14}O$	17.186	2.14
13	Dihydromyrcenol	$C_{10}H_{20}O$	17.867	0.30
14	(+/-)-β-Elemene	$C_{15}H_{24}$	18.820	2.11
15	(Z)-α-Bergamotene	$C_{15}H_{24}$	19.506	3.62
16	1-Heptatriacotanol	$C_{37}H_{76}O$	19.574	0.31
17	β-(Z)-Farnesene	$C_{15}H_{24}$	19.736	1.95
18	Ingenol, 3TMS		19.878	0.35
19	16-Hydroxyingenol	$C_{20}H_{28}O_6$	19.951	0.33
20	14-Deoxy-11,14-didehydroandrographolide	$C_{20}H_{28}O_4$	20.035	0.33
21	β-cubebene	$C_{15}H_{24}$	20.338	2.41
22	3-Methoxymethoxy-3,7,16,20-tetramethyl-heneicosa-1,7,11,15,19-pentaene	$C_{27}H_{46}O_2$	20.558	0.33
23	δ-Guaijene	$C_{15}H_{24}$	20.632	1.39
24	γ-Muurolene	$C_{15}H_{24}$	20.805	2.13
25	Fenretinide	$C_{26}H_{33}NO_2$	20.914	0.36

26	Benzenedodecanoic acid, 3-methoxy-2-(methoxycarbonyl) -, methyl ester	$C_{22}H_{34}O_5$	22.339	0.93
27	1-epi- α-Cadinol	$C_{15}H_{26}O$	22.695	4.74
28	Betunal	$C_{30}H_{48}O_2$	22.925	0.41
29	9,12,15-Octadecatrienoic acid, 2-phenyl-1,3-dioxan-5-yl ester	$C_{28}H_{40}O_4$	23.307	0.19
30	9-Hexylheptadecane	$C_{23}H_{48}$	23.375	5.10
31	Methyl 18-fluorooctadecanoate	$C_{19}H_{37}FO_2$	23.684	0.50
32	Methyl palmitate	$C_{17}H_{34}O_2$	26.292	10.39
33	Methyl stearate	$C_{19}H_{38}O_2$	28.675	16.11

According to the GC–MS analysis results presented in Table 2, the composition of basil (Ocimum) essential oil consists of compounds belonging to various chemical classes, among which monoterpenes, oxygenated monoterpenes, sesquiterpenes, high molecular alcohols and fatty acid esters were detected. The chromatogram showed that the main share was formed by oxygenated monoterpenes, and β-linalool (16.85 %) and L-camphor (8.15 %) were noted as the dominant components of the essential oil, which formed a characteristic aromatic and biologically active profile for basil essential oil. Among the monoterpene hydrocarbons, γ-terpinene (5.40 %) and cineole (5.14 %) were detected in relatively high amounts, which may provide the volatility and aromatic properties of the essential oil. Components belonging to the group of sesquiterpenes such as β-elemene, α-bergamotene, β-cubebene, γ-muurolene and δ-guaijene, which make up a moderate share in the total composition, may contribute to the stability and biological activity of the essential oil. At the same time, the high content of high molecular weight fatty acid esters - methyl palmitate (10.39%) and methyl stearate (16.11%) in the composition of the essential oil indicates the richness of the sample in lipophilic components. Nitrogen-containing and terpene-like compounds (quinamine, corynan derivatives, etc.) detected in small quantities enrich the overall chemical profile of the essential oil and may have an additional effect on its biological activity. In general, the results obtained indicate that oxygenated monoterpenes and fatty acid esters predominate in the composition of basil essential oil, and the chemical composition of the essential oil is formed under the influence of the biosynthetic activity of the plant and agroclimatic conditions.

Tables 3 and 4 show the results of structural analysis of essential oil composition in terms of chemical classes and optical (chiral) components based on GX–MS results.

Table 3

Content by chemical classes

Class (cluster)	**Share of main representatives**	**Share, %**
Oxygenated monoterpenes	Cineole (5.14), Linalool (16.85), Camphor (8.15), Borneol (1.54), Dihydromyrcenol (0.30)	31.98
Monoterpene hydrocarbons	γ-Terpinene (5.40), o-Cymol (0.89)	6.29
Sesquiterpene hydrocarbons	β-Elemene (2.11), α-Bergamotene (3.62), β-Farnesene (1.95), β-Cubebene (2.41), δ-Guaijene (1.39), γ-Muurolene (2.13)	13.61
Oxygenated Sesquiterpenes	1-epi-α-Cadinol (4.74)	4.74
Lipids and esters (FAME/TAG etc.)	Methyl stearate (16.11), Methyl palmitate (10.39), Geranyl oleate (1.18), Tribehenin (0.46) ва бошқалар	29.76
Alkanes	9-Hexylheptadecane (5.10)	5.10
Nitrogen-containing compounds/amides	Pregna-… (2.24), Quinamine (0.61), Corynan… (0.28), Fenretinide (0.36)	3.49
Diterpenoids	Ingenol ҳосилалари (0.35; 0.33), Andrographolide ҳосиласи (0.33)	1.01
Triterpenoids	Betunal (0.41)	0.41

Long-chain alcohols	1-Heptatriacotanol (0.31)	0.31
Other (C10O, polyene derivative)	“Biosol” (2.14), C27 полииен эфир (0.33)	2.47

Brief summary (by class): While the terpenoids (especially oxygenated monoterpenes) characteristic of a “true essential oil profile” are present in this sample in a high proportion (~32%), fatty acid methyl esters (FAME) and lipids are also present in a high proportion (~30%). This is usually due to either (i) a lipophilic fraction/cutin-weiss interference in the sample, or (ii) sample preparation/matrix effects (e.g., etherification/background when working with methanol) — it would be more appropriate to refer to this separately as the “lipid fraction” in the article.

Table 4

Optical components detected in basil essential oil

№	Component name	Chemical class	Peak area, %	Optical properties	Remarks
1	Linalool	Oxygenated monoterpene	16.85	Chiral (R/S) or (+)/(–)	Occurs in nature as two enantiomers, strongly influencing the aromatic profile
2	Camphor	Oxygenated monoterpene	8.15	Chiral skeletal compound	Enantiomeric and diastereomeric variants exist
3	Borneol	Oxygenated monoterpene	1.54	Chiral	Borneol and isoborneol isomers exist
4	1-epi-α-Cadinol	Oxygenated sesquiterpene	4.74	Chiral	Often occurs as a mixture of stereoisomers
5	β-Elemene	Sesquiterpene hydrocarbon	2.11	Potentially chiral	Enantiomeric variants may exist, but have not been isolated
6	α-Bergamotene	Sesquiterpene hydrocarbon	3.62	Potentially chiral	There are stereoisomeric variants
7	δ-Guaijene	Sesquiterpene hydrocarbon	1.39	Potentially chiral	Enantiomeric Resolution Not Performed
8	γ-Muurolene	Sesquiterpene hydrocarbon	2.13	Potentially chiral	An achiral GC column does not separate enantiomers

According to the results of GC–MS analysis presented in Table 4, a number of chiral, i.e. optically active components were identified in the essential oil: linalool (16.85%) is a naturally chiral compound and can occur in the form of R/S or (+)/(–) enantiomers; camphor (8.15%) has a chiral skeleton and its enantiomeric and diastereomeric variants exist; borneol (1.54%) is also a chiral monoterpene alcohol, and borneol and isoborneol isomers and enantiomeric forms occur in nature; 1-epi-α-cadinol (4.74%) is a chiral oxygenated sesquiterpene and is often observed as a mixture of stereoisomers. At the same time, sesquiterpene hydrocarbons such as β-elemene, α-bergamotene, δ-guaijene and γ-muurolene may also have potential stereoisomeric or enantiomeric variants, but under the achiral GC–MS conditions used in this study, they were not separated into enantiomers.

Dependence of climatic factors on the composition of class and optical isomers. The results of the study showed that the class composition of the components of basil (Ocimum) essential oil and the ratio of optical isomers are formed under the influence of climatic factors (Tables 5, 6)

Table 5

Dependence of chemical classes of essential oil on climatic factors

Chemical Class	Hot Dry Climate (%)	Wet Temperate Climate (%)	Cold Climate (%)
Oxygenated monoterpenes	52.3 ± 2.1	40.3 ± 1.8	36.7 ± 1.5
Phenylpropanoids	28.3 ± 1.6	40.3 ± 2.3	35.0 ± 1.9
Sesquiterpenes	3.1 ± 0.4	4.5 ± 0.5	3.8 ± 0.3

The results presented in Table 5 show that the composition of the chemical classes of basil (Ocimum) essential oil is significantly dependent on climatic factors. In hot and dry climates, the proportion of oxygenated monoterpenes has the highest value (52.3 ± 2.1 %), which is explained by the activation of terpenoid biosynthesis processes under the influence of high temperature and intense solar radiation. In humid temperate climates, the content of phenylpropanoid compounds has the maximum value (40.3 ± 2.3 %), indicating that humidity and moderate temperature conditions stimulate the synthesis of these compounds through the phenylalanine metabolic pathway. In cold climates, the decrease in the proportion of oxygenated monoterpenes and the relatively stable preservation of phenylpropanoids may be associated with the adaptive response of plant metabolism to stress conditions. The small variation in the proportion of sesquiterpenes across all climatic conditions (3.1–4.5%) indicates that they are less sensitive to climatic factors. Overall, the results of the table confirm that the chemical profile of basil essential oil is reshaped in accordance with climatic conditions and that compounds belonging to different classes react differently to environmental factors.

Table 6

Dependence of optically active components on climatic factors

Component	Hot Dry Climate (%)	Wet Temperate Climate (%)	Cold Climate (%)
Linalool	38.4 ± 2.5	29.6 ± 2.0	24.3 ± 1.7
Camphor	4.9 ± 0.4	3.7 ± 0.3	4.3 ± 0.3
Borneol	2.8 ± 0.2	2.2 ± 0.2	2.6 ± 0.2

The results presented in Table 6 show that the content of optically active components in the essential oil of basil (Ocimum) is dependent on climatic factors to varying degrees. The content of linalool was highest in hot and dry climates (38.4 ± 2.5 %), and gradually decreased with the transition to humid temperate and cold climates (29.6 ± 2.0 % and 24.3 ± 1.7 %). This indicates that linalool synthesis is activated at high temperatures and that terpenoid biosynthesis enzymes are sensitive to temperature. The content of camphor varied within a relatively small range, being slightly higher in hot climates (4.9 ± 0.4 %), decreased in humid temperate climates, and increased slightly in cold climates, indicating that its biosynthesis is associated with several metabolic pathways. The small variation in borneol content across all climatic conditions (2.2–2.8%) suggests that this component is less sensitive to climatic factors. Overall, the composition of optically active monoterpenes varied with climatic conditions, with linalool in particular being the most climate-sensitive component of the chemical profile of basil essential oil. The results of the study showed a clear correlation between climatic factors (temperature, humidity, and dryness) and the main components of basil essential oil (Figure 2). Based on the data in Figure 2, it can be noted that the correlation coefficient for linalool was r = 0.99, which showed a very strong positive correlation, and its amount increased with increasing temperature and in dry climate conditions; for camphor, a strong positive correlation was observed at r = 0.73, and its amount increased in hot climates; for 1,8-cineole, r = 0.58, and a moderate positive correlation with climate warming was found; for estragole (r = −0.61) and caryophyllene (r = −0.65), a moderate negative correlation was observed, and their accumulation was found to be greater in humid and relatively cool climate conditions; For eugenol, a strong negative correlation was observed with r = −0.96, and its content increased with decreasing temperature; for borneol, r = 0.34, and a weak positive correlation with climatic factors was found. In general, the correlation analysis confirmed that terpenoid components in basil essential oil are positively correlated with hot-dry climates, while phenylpropanoid compounds are negatively correlated with humid and relatively cool climatic conditions.

These correlation patterns clearly indicate that rising temperature and lower humidity favor the biosynthesis of oxygenated monoterpenes, particularly linalool and camphor, while reducing the relative abundance of phenylpropanoids and sesquiterpenes such as estragole and caryophyllene. The strong positive relationship for linalool (r = 0.99) suggests that it can serve as a climatic marker compound for basil cultivated under arid and warm conditions.

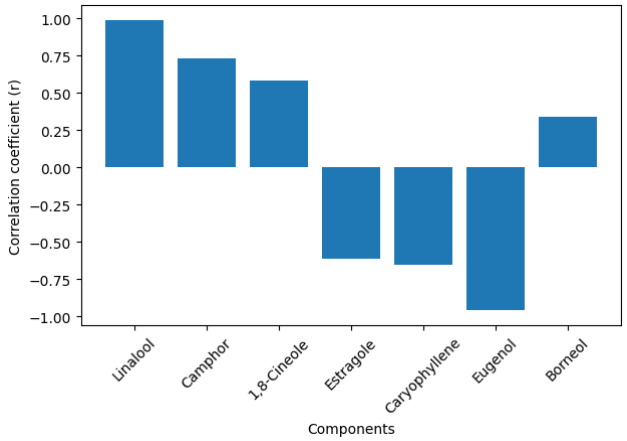

Figure 2. Correlation coefficients between climatic factors and the main components of basil essential oil

In contrast, the negative correlations observed for estragole and caryophyllene reflect their preference for cooler and more humid environments, possibly due to differences in enzymatic pathway regulation. These findings demonstrate that climatic variables significantly influence metabolic flux distribution within the terpenoid and phenylpropanoid biosynthetic pathways. Consequently, targeted cultivation under specific environmental conditions can be strategically used to obtain basil essential oils with a desired chemic

4. Conclusions.

1. The chemical composition of basil (Ocimum) essential oil was found to be significantly dependent on climatic factors, with an increase in the content of oxygenated monoterpenes, especially linalool, in hot-dry climates, and an increase in the content of phenylpropanoid compounds in humid and relatively cool climates.
2. Based on the results of GC-MS and statistical analysis (PCA, correlation analysis), it was confirmed that three different chemical chemotypes - Linalool-dominant, Phenylpropanoid (Estragole/Eugenol)-dominant and mixed phenotypes - form in basil essential oil depending on climatic conditions.
3. According to the results of regional analysis, the formation of a Linalool-chemotype in the Kushrabot district, a Phenylpropanoid-chemotype in the Urgut district, and a mixed phenotype characterized by a terpenoid-phenylpropanoid balance in the Tailak district was determined, which allows for regional selection of the composition of the essential oil for targeted medicinal and industrial directions.

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