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Research article

CHARACTERIZATION OF OREGANO (*Origanum vulgare* L.) ESSENTIAL OIL OBTAINED FROM RAW MATERIAL HARVESTED IN ROMANIA, TURKEY, MACEDONIA, AND SPAIN

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Abstract

Oregano (*Origanum vulgare* L.) is considered to be one of the most commercially valuable aromatic plants on the global market. The objective of this study is to characterise oregano essential oil derived from raw materials sourced from multiple countries, with a view to identifying the most efficacious plant material in terms of both quality and quantity. In the present study, essential oils were extracted from 11 plant materials, including oregano leaves from Romania, North Macedonia, Turkey, and Spain, using the Clevenger method. The composition of the essential oils was characterised using a gas chromatography-flame ionisation detector (GC-FID) method, while their physicochemical properties, including density, refractive index, and optical rotation, were also characterised. It was found that the Romanian raw material has a carvacrol concentration of over 70%, and that the Turkish material produces more essential oil under the same processing conditions. This suggests that the yield is directly related to the geographical area. A comprehensive analysis of the results indicates that Turkish oregano essential oils demonstrate the highest efficiency in terms of quantity, while the superior quality of Romanian essential oils ensures their versatility in applications.

1. Introduction

Annually, foodborne diseases are responsible for a significant number of mortalities on a global scale (Moghimi *et al.*, 2016). Long-term use of artificial antibacterial food additives and preservatives has negative consequences and changes the natural form of food. This result emphasizes how important it is to use naturally occurring chemicals agents. To guarantee food safety, it is essential to reduce the amount of artificial antibacterial agents and other additives in food (Enayatifard *et al.*, 2021; Saffarian *et al.*, 2024). It is evident that these challenges necessitate a modification in industrial policy with a view to enhancing the significance of the social, food and environmental components (Arslan *and* Bayrakçi, 2016). The potential of essential oils as a natural remedy is promising, as they demonstrate a wide range of antimicrobial, insecticidal (Kosakowska *et al.*, 2024) and antioxidant (Tița *et al.*, 2022) properties. These are secondary metabolites rich in terpenoids, which are highly popular and extensively utilised in medicine, pharmacy, food, and cosmetics. Numerous experts have studied the biological activities of these compounds. At present, approximately 300 types of essential oils are employed in the cosmetic, food, and pharmaceutical industries, as well as in aromatherapy and alternative medicine (Moghrovyan *and* Sahakyan, 2024). In recent years, Romanian entrepreneurs have focused on cultivating aromatic and medicinal plants. Until recently, the cultivation of vegetables and other plants endemic to the Romanian region was commonplace. However, in recent years, there has been an increase in the cultivation of crops specific to the Mediterranean region (Bătușaru, 2019; Tița *et al.*, 2020).

Oregano (*Origanum vulgare* L.) is considered to be one of the most commercially valuable aromatic plants worldwide, with over 60 species using the name in commerce. These plants have similar aromatic profiles (Zinno *et al.*, 2023), characterised mainly by compounds such as carvacrol and thymol (Stojanović *et al.*, 2024). The genus *Origanum* belongs to the family *Lamiaceae*. *Origanum vulgare* is the most prevalent and widely utilised species. The natural distribution of the species encompasses Europe, the Middle East, and Central China (Raal *et al.*, 2024).

Oregano essential oil has been demonstrated to be amongst the most efficacious agents, possessing both antimicrobial and antioxidant properties (Fernandez *et al.*, 2018). Studies have shown how effective oregano essential oil is as a flavoring and antioxidant in functional meals and nutraceuticals (Loizzo *et al.*, 2009), a property that contributes to the retardation of the oxidation process of lipids (Handl *et al.*, 2008). It is evident that oregano constitutes a valuable source of essential oil, which renders it a promising candidate for extensive utilisation within the food industry. This is particularly salient in contexts where there is an imperative for the adoption of natural alternatives, with a view to ensuring food safety and quality (Tița *et al.*, 2024).

The essential oil extracted from this plant has been shown to possess antioxidant properties and antimicrobial effects, attributable to the presence of terpenoids and phenolic compounds, including thymol, carvacrol, γ-terpinene, p-cymene, sabinene, caryophyllene, germacrene, and spathulenol (Saffarian *et al.*, 2024). It is also a natural antimicrobial agent against various foodborne pathogens, including *Salmonella*, *Escherichia coli*, and *Listeria monocytogenes* (Moghrovyan *and* Sahakyan, 2024). A recently published study revealed that *Origanum vulgare* essential oil exerts antioxidant and anti-inflammatory activity and protects renal tissue DNA from exposure to aflatoxin B1 (Hassan *et al.*, 2023). A further study has demonstrated the capacity of oregano oil to curtail the rate of increase in peroxide value during the frying process of potato chips. The stability of potato chips during storage was enhanced by the incorporation of essential oils into the frying medium (Houhoula *et al.*, 2003). A further study was conducted on four commercial varieties of oregano from Argentina, observing positive changes in terms of the sensory effect of extra virgin olive oil and the disappearance of rancid notes (Asensio *et al.*, 2012). Edible films composed of milk proteins and containing 1% (w/v) oregano essential oil were applied to slices of beef. This process resulted in the stabilisation of the lipid oxidation process (Oussalah *et al.*, 2004).

The objective of the present study is to characterise oregano essential oil derived from raw materials originating from multiple countries. The objective of this study is to ascertain the most efficient and effective plant material (raw material) in terms of quality (the provision of an essential oil with high structural properties) and quantity (good extraction/yield). In the laboratory, a total of 11 plant materials were examined, including oregano leaves (*Origanum vulgare* L.) from the following regions: Romania-RO, North Macedonia-MK, Turkey-TR, and Spain-SP, from which essential oil was extracted using the Clevenger method. The composition of the essential oils was characterised using a gas chromatography-flame ionisation detector (GC-FID) method, while their physicochemical properties, including density, refractive index, and optical rotation, were also characterised.

2. Materials and methods

2.1. Materials

2.1.1. Obtaining oregano essential oil and calculating distillation yield

The plant material utilised in the production process is sourced from partner companies Esentivia SRL in Romania (Solina Romania SRL), Macedonia (Herba Natura LCC), Turkey (İnan Tarım ECODAB), and Spain (Esencias Martinez Lozano S.A.). The aerial part of the plant (the herb) was utilised in the distillation process. In order to obtain and characterize essential oils at the laboratory level from this standpoint, the analysis method described in SR EN ISO 6571:2008 (hydrodistillation method) was employed to determine the essential oil content in the plant material. The Neo Clevenger distillation apparatus is utilised in this process. The indicated volume of water and two boiling stones (manufactured by Carl Roth) are then placed in the distillation flask. The apparatus's condenser is connected to the cooling water. The addition of 1 ml of xylene (manufactured by Merck Milipore) was followed by the initiation of distillation for a duration of 30 minutes. The following step involves the removal of the heat source for a period of 10 minutes. Thereafter, the xylene should be brought to the lower meniscus, and the volume of xylene measured. The tap must be opened and the upper meniscus of the xylene brought to 0 (zero). The sample, which has been weighed beforehand, should then be placed on the filter paper, which should then be placed in the flask together with the paper. The distillation process should then be continued. Following the conclusion of the distillation process, it is imperative to remove the heat source for a duration of 10 minutes. Subsequently, the lower meniscus should be adjusted to zero, and the organic phase above (xylene in conjunction with the additional volatile oil) should be examined (ISO 6571, 2008). The result is expressed in mL/100g of product and is calculated using formula 1.

$$RA = 100 \times (V_1 - V_0) \times 100/M \times (100-U) \quad (1)$$

Where:

RA – distillation yield, mL essential oil/100 grams of product;

V_0 - volume of xylene, in mL;

V_1 - volume of xylene and essential oils, in mL;

M - sample mass, in g;

U - water content of the sample, in %.

2.2. Methods

2.2.1. Experimental design

The experimental design for characterizing essential oils extracted from plant materials comprises the steps shown in figure 1.

2.2.2. Determination of the physicochemical parameters of oregano essential oil

The density (g/mL, at 20°C) of all essential oils obtained was determined using a high-performance digital densimeter (Anton Paar brand, model DMA4500M) (Anton Paar, 2019).

The refractive index (nD at 20°C) of essential oils was determined by means of a refractometer (Abbemat 300/350, manufactured by Anton Paar) (Anton Paar, 2015).

The optical rotation (αD°) of essential oils was determined using an automatic polarimeter, MCP 100, manufactured by Anton Paar (Anton Paar, 2022).

2.2.3. Determination of the composition of oregano oil by GC-FID method

The chromatographic profile of essential oils obtained in the laboratory was determined by means of a gas chromatograph with a flame ionization detector (GC-FID), model 7890B (manufacturer: Agilent Technologies, USA). The capillary columns employed in this study were procured from Sigma-Aldrich, specifically the Supelco type. The operational methodology is comprehensively delineated in the paper published in 2024 (Opruța *et al.*, 2024).

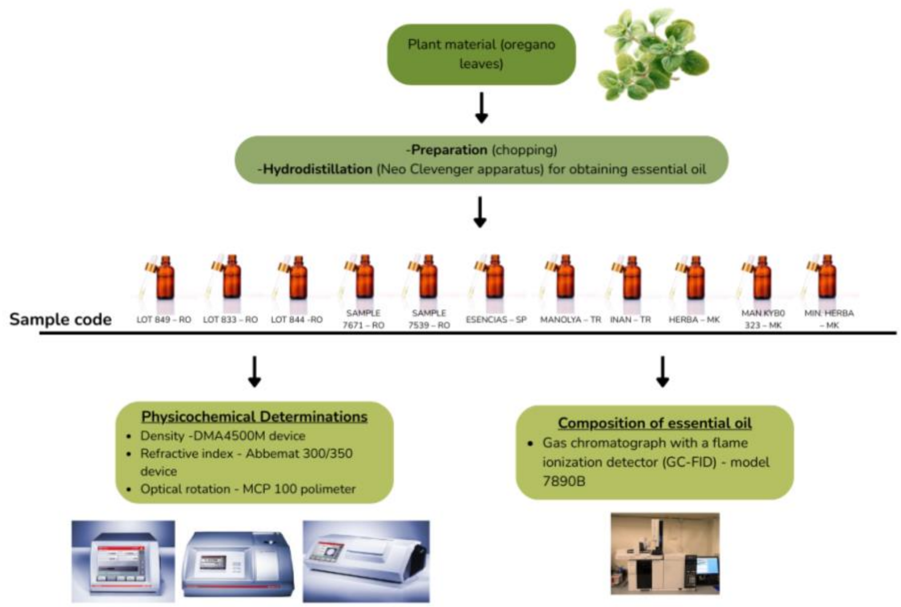

Figure 1. Experimental design for characterizing essential oils extracted from plant materials

2.3. Data analysis

Minitab software version 14 was used to statistically process the data derived from physicochemical analyses. The mean values were compared, and the results were evaluated using One-Way ANOVA and Tukey's Test at a significance level of 5% ($p < 0.05$). Three measurements were taken for each sample.

3. Results and discussions

3.1. Obtaining samples of oregano essential oil. Calculating distillation yield

Subsequent to distillation, the following samples of oregano essential oil were obtained, depending on the country of origin of the plant, as demonstrated in table 1.

Table 1. Oregano essential oil samples: coding, country of origin of the plant, and distillation yield

Sample code	Country	Distillation yield [mL/100g]
LOT 849-RO	Romania	1.50
LOT 833-RO	Romania	1.34
LOT 844-RO	Romania	1.40
SAMPLE 7671-RO	Romania	1.60
SAMPLE 7539-RO	Romania	1.70
ESENCIAS-SP	Spain	1.40
MANOLYA-TR	Turkey	1.95
INAN-TR	Turkey	2.10
HERBA-MK	Macedonia	1.35
MAN.KYB0323-MK	Macedonia	1.60
MIN. HERBA-MK	Macedonia	2.00

From a quantitative perspective, the extraction yield for the samples analysed exhibited variation, ranging from 1.34 mL/100 g of raw material (Lot 833-RO) and 2.10 mL/100 g of raw material (LOT INAN-TR), with an average extraction yield (mL/100 g) was 1.51 for the Romanian batches, 1.40 for the Spanish batch, 2.03 for the Turkish batches, and 1.80 for the Macedonian batches.

3.2. Determination of the physicochemical parameters of oregano essential oil

As illustrated in table 2, the findings derived from the physicochemical analyses of the oregano essential oil samples are presented.

Table 2. Physicochemical characteristics of oregano essential oil samples

Item	Sample	Value (mean±SD)
Density [g/cm^3]	LOT 849-RO	$0.95103 \pm 0.0000577^{egh}$
	LOT 833-RO	$0.96203 \pm 0.0000577^{a}$
	LOT 844-RO	$0.95117 \pm 0.0001530^{efg}$
	SAMPLE 7671-RO	$0.95143 \pm 0.0001150^{ef}$
	SAMPLE 7539-RO	$0.95107 \pm 0.0000577^{egh}$
	ESENCIAS-SP	$0.95207 \pm 0.0001150^{de}$
	MANOLYA-TR	$0.95803 \pm 0.0000577^{b}$
	INAN-TR	$0.95113 \pm 0.0000577^{egh}$
	HERBA-MK	$0.95657 \pm 0.0001150^{bc}$
	MAN.KYB0323-MK	$0.95337 \pm 0.0000577^{cd}$
	MIN. HERBA-MK	$0.95907 \pm 0.0000577^{ab}$
Refractive index	LOT 849-RO	$1.5131 \pm 0.0000577^{bc}$
	LOT 833-RO	$1.5030 \pm 0.0000577^{cf}$
	LOT 844-RO	1.5141 ± 0.0001150^{a}
	SAMPLE 7671-RO	$1.5135 \pm 0.0000577^{ab}$
	SAMPLE 7539-RO	1.5132 ± 0.0000577^{b}
	ESENCIAS-SP	$1.5121 \pm 0.0001150^{bcd}$
	MANOLYA-TR	$1.5110 \pm 0.0000577^{ce}$
	INAN-TR	$1.5132 \pm 0.0000577^{bc}$
	HERBA-MK	$1.5080 \pm 0.0000577^{cf}$
	MAN.KYB0323-MK	$1.5089 \pm 0.0000577^{cef}$
	MIN. HERBA-MK	$1.5111 \pm 0.0000577^{cde}$
Optical rotation [°]	LOT 849-RO	-0.3667 ± 0.0577^{a}
	LOT 833-RO	-1.5667 ± 0.0577^{ef}
	Lot 844-RO	-0.4333 ± 0.0577^{a}
	SAMPLE 7671-RO	-1.0330 ± 0.0577^{c}
	SAMPLE 7539-RO	-0.6000 ± 0.0000^{b}
	ESENCIAS-SP	-1.0333 ± 0.0577^{cd}
	MANOLYA-TR	-1.0667 ± 0.1155^{def}
	INAN-TR	-0.4333 ± 0.0577^{a}
	HERBA-MK	-1.0333 ± 0.0577^{cde}
	MAN.KYB0323-MK	-4.4333 ± 0.0577^{ef}
	MIN. HERBA-MK	-2.0667 ± 0.1155^{ef}

Results are presented in the form of mean ± standard deviation (n = 3). In each column, values with different lowercase letters are significantly different ($p < 0.05$). The results in the same column followed by the same lowercase letters are not significantly different ($p > 0.05$).

The content of carvacrol in oregano oil is influenced by the extraction yield, with a direct proportional relationship (under the same technological conditions). It has been observed that oregano oils with the highest carvacrol % values also have a higher refractive index and density (Zinno *et al.*, 2023). The density of the oregano oil samples, derived from raw materials cultivated in Romania, ranges from 0.9510 to 0.9620 g/cm^3. The density of the Spanish sample is measured at 0.9520 g/cm^3, while those from Turkey and Macedonia have densities of 0.9511 g/cm^3 and 0.9590 g/cm^3, respectively. As with density, the highest refractive index values are recorded in the Romanian oil samples, 1.5030 - 1.5140. Therefore, utilising the established values of these parameters, as determined in the laboratory, we can predict the variation in carvacrol content during the industrial distillation process until its conclusion, without the necessity of conducting a substantial number of GC-FID analyses (which are more costly and time-consuming than refractive index/density analyses).

3.3. Determination of the composition of oregano oil by GC-FID method

As illustrated in table 3, the main components of the oregano oil samples are presented. It has been observed that all oil samples contain the major component, carvacrol, with a percentage ranging from 70 to 79%. The material purchased from North Macedonia has been found to contain the highest percentage of carvacrol (79.12%). The quality of oregano oils, depending on their field of use, is evaluated based on their carvacrol content, a natural organic component responsible for their excellent antimicrobial properties (Youssefi *et al.*, 2019). Consequently, oils derived from Romanian raw materials exhibit an average carvacrol concentration of 72.80%, while those from Spain, Turkey, and North Macedonia display concentrations of 71.94%, 75.44%, and 75.48%, respectively. Carvacrol has been demonstrated to possess antibacterial properties, particularly against gram-positive strains of S. aureus. This mechanism is characterised by the destruction of the biophysical properties of bacterial cell membranes (Selvaraj *et al.*, 2020). Other studies reinforce the results obtained in the current study. In a study conducted by Raal *et al.*, a carvacrol content of 68.5% was demonstrated for the oregano sample from Turkey (Raal *et al.*, 2024). Zinno *et al.* report a content of carvacrol ranging from 80.59% to 84.70% in three samples of oregano cultivated in Sicily, Italy (Zinno *et al.*, 2023).

Table 3. Profile of the main components of oregano essential oil samples

Item	LOT 849-RO	LOT 833 - RO	LOT 844 - RO	SAMPLE 7671-RO	SAMPLE 7539-RO	ESENCIAS-SP	MANOLYA-TR	INAN-TR	HERB-MK	MAN. KYB0323-MK	MIN. HERB-MK
GC area	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**	**%**
alpha-thujene	0.777	0.783	0.750	0.750	0.787	0.800	0.590	0.141	0.763	0.910	0.319
alpha-pinene	0.933	0.942	0.907	0.907	0.911	1.058	0.442	0.518	0.745	0.485	0.573
camphene	0.210	0.209	0.202	0.202	0.208	0.106	0.162	0.339	0.098	0.180	0.285
1-Octen-3-ol	0.710	0.714	0.703	0.703	0.692	0.818	0.145	0.157	0.918	0.165	0.231
beta-pinene	0.176	0.190	0.172	0.172	0.177	0.154	0.080	0.092	0.148	0.100	0.130
beta-myrcene	1.509	1.571	1.536	1.536	1.526	1.432	1.217	0.738	2.025	1.389	0.816
alpha-terpinene	0.812	0.768	0.819	0.819	0.736	1.191	0.921	0.701	1.510	1.052	0.762
para-cymene	6.372	6.608	6.399	6.399	6.525	7.130	2.591	3.492	7.192	2.819	5.002
gamma-terpinene	6.080	6.196	5.968	5.968	6.081	6.326	3.677	2.334	6.463	4.476	2.097
linalool	0.498	0.494	0.535	0.535	0.494	0.912	4.599	5.896	0.148	4.155	1.380

terpinolene	0.088	0.109	0.676	0.089	0.112	0.210	0.692	1.417	0.147	0.792	1.210
alpha-terpineol	0.650	0.663	0.210	0.676	0.641	0.770	0.566	0.818	0.608	0.729	0.908
carvacryl methyl ether	0.250	0.247	0.251	0.251	0.262	0.000	0.105	0.101	0.096	0.128	0.122
thymol	2.940	3.100	2.979	2.979	2.958	2.930	1.367	0.887	1.726	2.795	0.746
carvacrol	72.959	72.277	72.713	72.713	73.230	71.944	75.640	75.254	70.802	71.858	79.120
beta-caryophyllene	2.033	2.080	2.018	2.018	2.064	2.107	0.829	1.374	2.905	1.091	2.052
alpha-humulene	0.465	0.471	0.460	0.460	0.465	0.116	0.040	0.067	0.190	0.058	0.104
beta-bisabolene	0.227	0.284	0.229	0.229	0.280	0.279	1.927	1.221	0.285	2.364	0.225
Total majority components	**97.7**	**97.7**	**97.5**	**97.4**	**98.1**	**98.3**	**95.6**	**95.5**	**96.8**	**95.5**	**96.1**

The main compounds (thymol, carvacrol, γ-terpinene, p-cymene) have been shown to possess potent antibacterial and antifungal properties. As demonstrated in the extant literature, there are numerous mechanisms that have been identified as being responsible for the activity of these compounds. One such example is the disruption of metabolism within the cell (Kotan *et al.*, 2014). The thymol content in samples from Romania varies between 2.94 and 3.10%, while in samples from Macedonia the variation is greater, between 0.746 and 2.795%. A comparable thymol content, amounting to 2.91%, has been documented by Kosakowska et al. for oregano cultivated in Central Europe (Kosakowska *et al.*, 2024).

A significant marker for flavoring applications is the component carvacryl-methyl-ether (CME). Despite the fact that it is not a component with high concentrations in oregano oil, it is one of the compounds that gives this oil its herbaceous and spicy note (Politeo *et al*., 2024; Naef *et al.*, 2002).

Figure 2. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) LOT 849-RO
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

Figure 3. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) LOT 833-RO
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

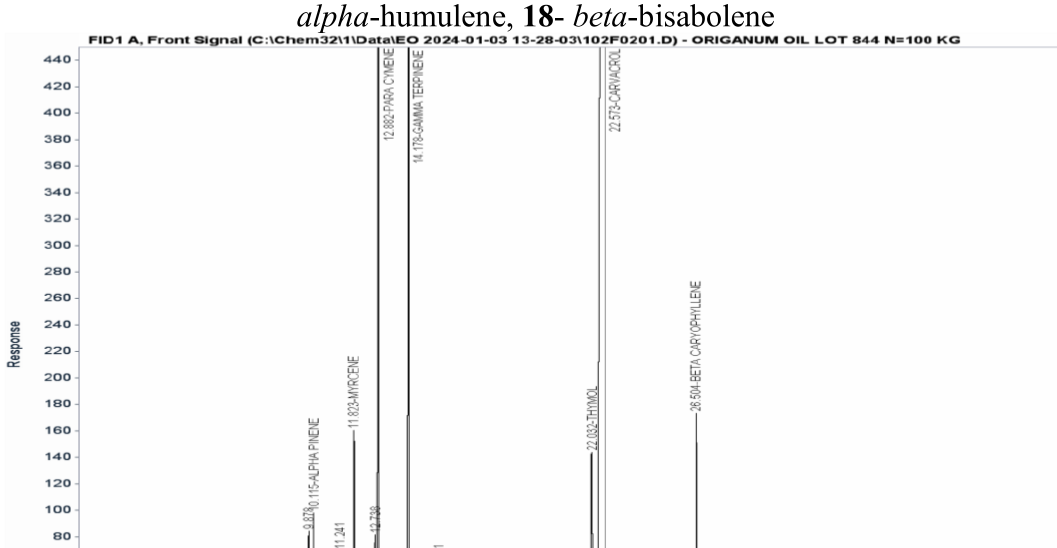

Figure 4. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) LOT 844-RO
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

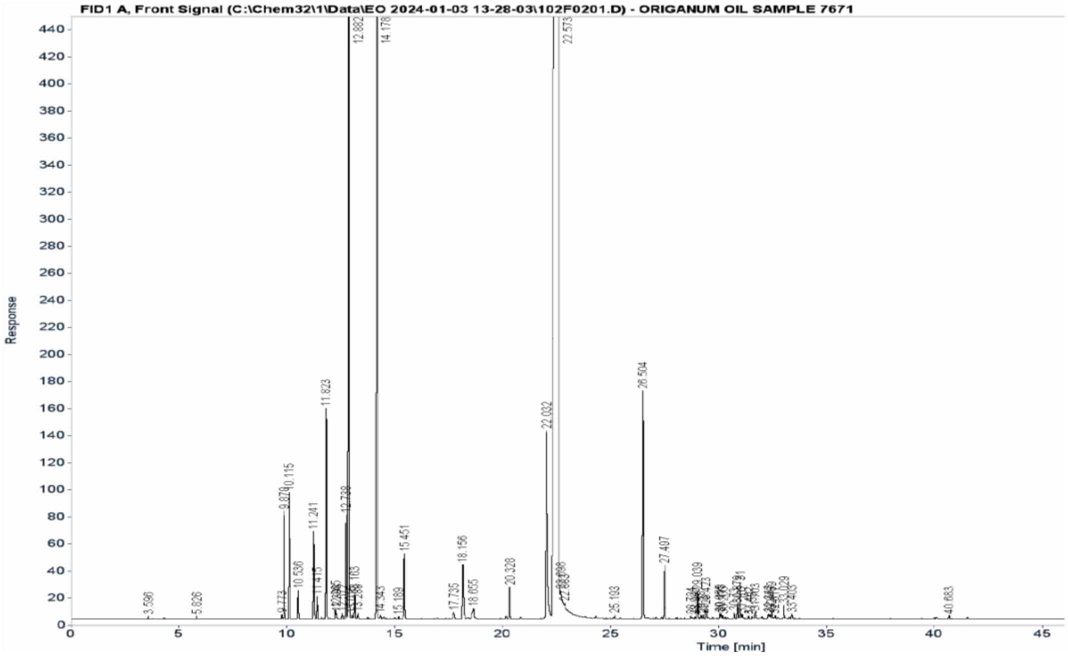

Figure 5. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) SAMPLE 7671-RO

1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

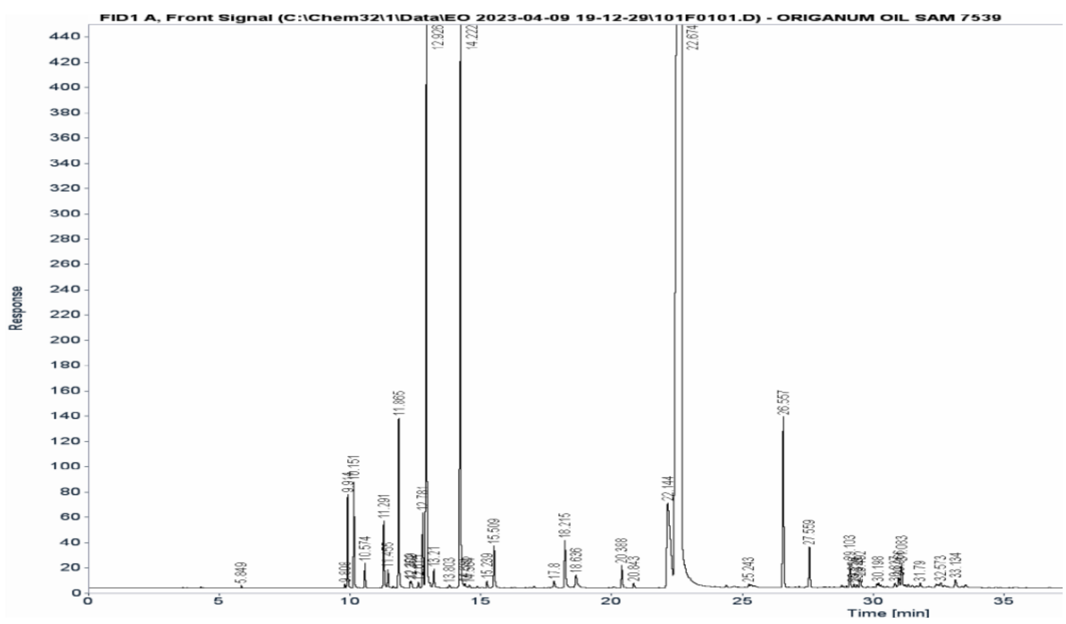

Figure 6. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) SAMPLE 7539-RO

1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

Figure 7. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) ESENCIAS-SP
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

Figure 8. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) MANOLYA-TR
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

Figure 9. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) INAN-TR
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

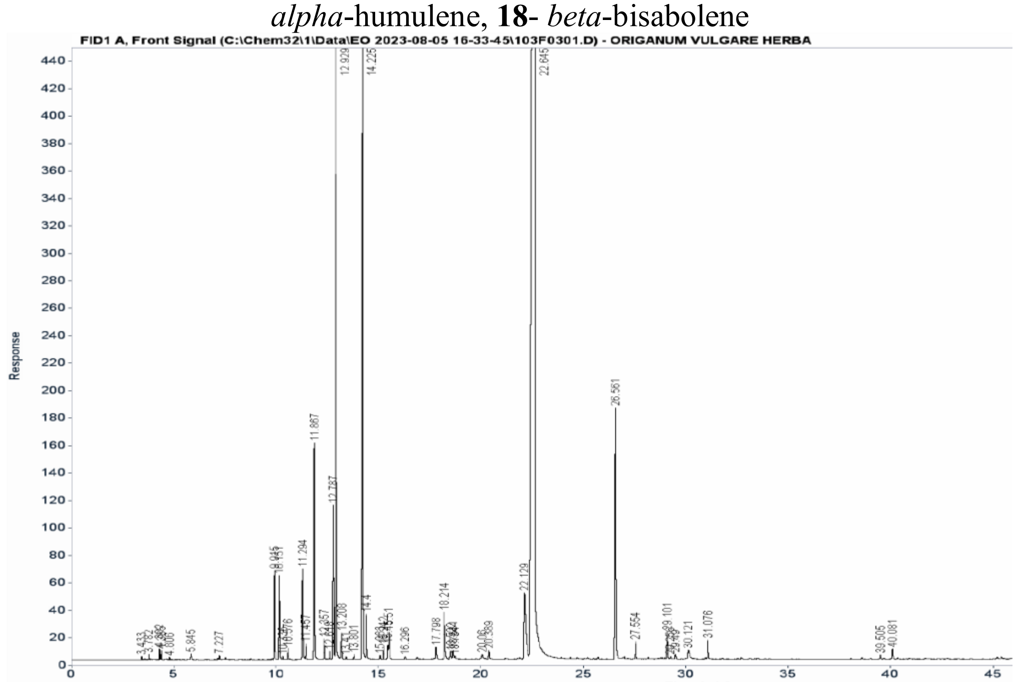

Figure 10. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) HERBA-MK
1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

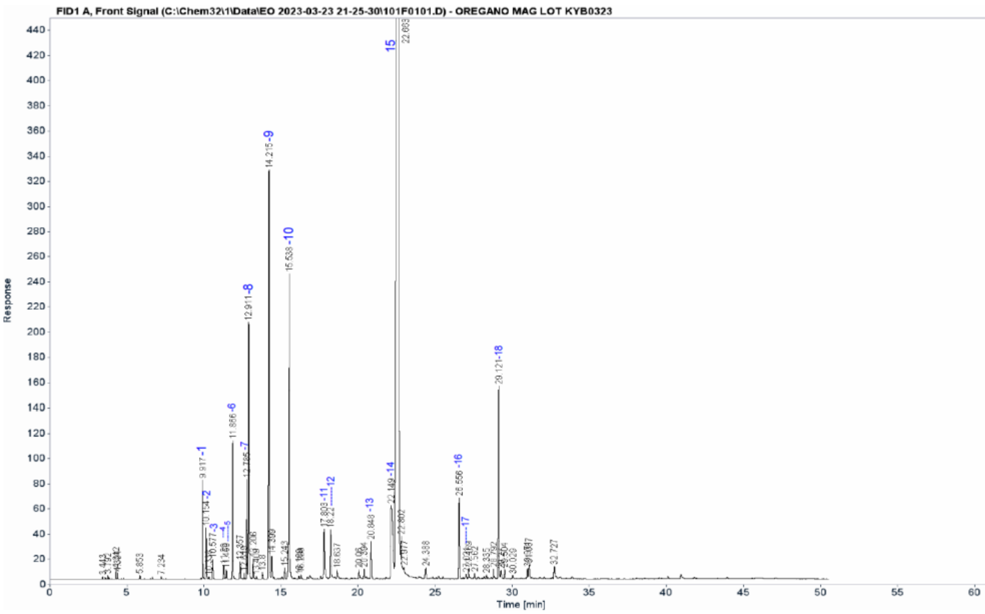

Figure 11. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) MAN.KYB0323-MK

1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

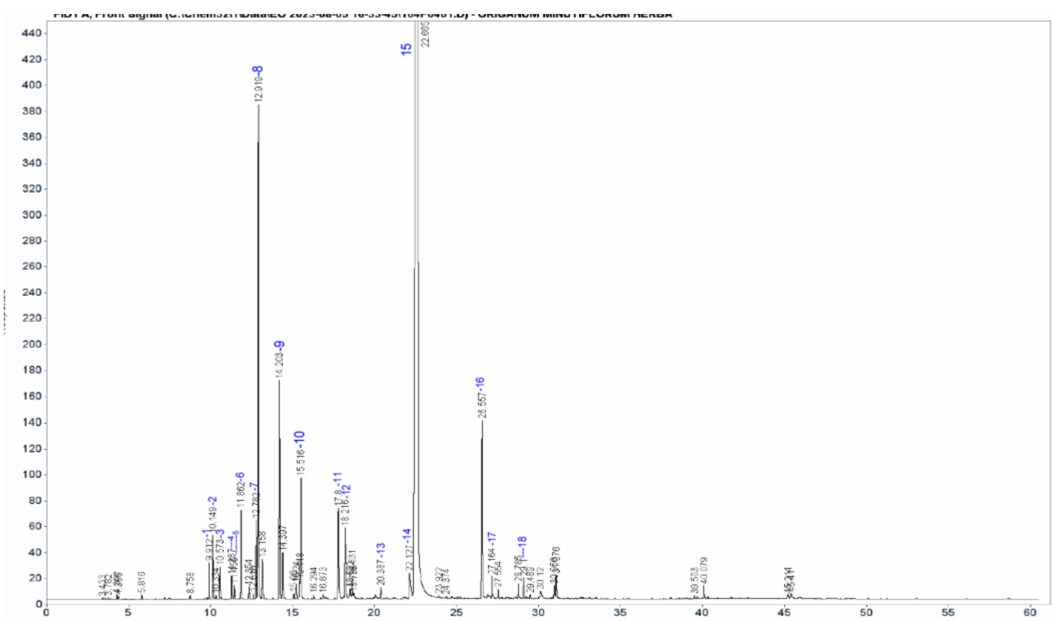

Figure 12. GC-FID gas chromatogram for oregano oil (*Origanum vulgare* L.) MIN. HERBA-MK

1- *alpha*-thujene, **2**- *alpha*-pinene, **3**- camphene, **4**- 1-Octen-3-ol, **5**- *beta*-pinene, **6**- *beta*-myrcene, **7**- *alpha*-terpinene, **8**- *para*-cymene, **9**- *gamma*-terpinene, **10**- linalool, **11**- terpinolene, **12**- *alpha*-terpineol, **13**- carvacryl methyl ether, **14**- thymol, **15**- carvacrol, **16**- *beta*-caryophyllene, **17**- *alpha*-humulene, **18**- *beta*-bisabolene

It has been observed that the oil obtained from Spanish raw material does not contain this substance, while the oil obtained from Macedonian raw material contains it in quantities ranging from 0.096 to 0.128%. Oregano oils obtained from Romanian raw materials demonstrate the highest values in CME, which is why, from an organoleptic perspective, they are optimally suited for the production of flavourings for food products.

It is an established fact that the higher the concentration of this particular compound, the higher the quality of the essential oil. This is due to the fact that the presence of this component is an indication of the naturalness and authenticity of oregano oil.

Figures 2-12 show the GC-FID gas chromatograms for the 11 oregano essential oil samples (figure 2 – LOT 849-RO; figure 3 – LOT 833-RO; figure 4 – LOT 844-RO; figure 5 – SAMPLE 7671-RO; figure 6 – SAMPLE 7539-RO; figure 7 – ESENCIAS-SP; figure 8 – MANOLYA-TR; figure 9 – INAN-TR; figure 10 – HERBA-MK; figure 11 – MAN.KYB0323-MK; figure 12 – MIN. HERBA-MK).

The examination of the samples showed a relationship between the fluctuation in the concentration of the secondary component, carvacrol, and the concentration of the main component, gamma-terpinene. With an R^2 value of 0.728, this association was found to have a high degree of confidence. From a compositional standpoint, the gamma-terpinene content stays constant in respect to the carvacrol concentration if the steam distillation process follows the specified specifications.

Figure 13. Correlation between *gamma*-terpinene concentration and carvacrol concentration for oregano essential oil samples

Figure 14. Variation in carvacrol content depending on distillation yield

With an average concentration of gamma-terpinene of 5.060% and carvacrol of 72.713% for the examined samples, the confidence coefficient R shows high reliability, as shown in figure 13. This remark relates to oils made from a variety of plant components. Conversely, it is noteworthy that there is a correlation between the extraction yield values and the content of the primary constituent of interest (carvacrol). A high R^2 value of 0.6984, which shows a strong correlation between the variables, supports this link, as seen in figure 14. Carvacrol concentrations are highest in samples derived from Turkish plant material with the highest extraction yields (INAN-TR) and Macedonian material (MIN.HERBA-MK).

4. Conclusions

The highest quantity of carvacrol has been identified in oregano essential oils derived from raw materials originating from Macedonia (MIN. HERB-MK) and Turkey. This characteristic lowers their dosage in combinations with antibacterial and antioxidant qualities, which lowers the recipe's production cost. Research has revealed that Romanian raw materials contain a carvacrol concentration of over 70%, while simultaneously exhibiting a higher content of carvacryl methyl ether, the key component that renders the oil suitable for use in flavouring mixtures. The purpose of this is to accentuate the herbaceous, spicy note of the finished product. It was also observed that the Turkish raw material produced a greater quantity of essential oil under the same processing conditions, suggesting that the yield is directly related to the geographical area from which the plant material originates. A comprehensive analysis of the results indicates that Turkish oregano essential oils demonstrate the highest efficiency in terms of quantity, while the superior quality of Romanian essential oils ensures their versatility in applications. In the future, we plan to conduct additional studies to improve the distillation line and perform further industrial tests with raw materials from areas in Romania.

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