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Comparative Extraction Methods for Chemical Profile of Various Essential Oils and Extracts Obtained from Pelargonium graveolens Leaves

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Abstract

The study investigates the chemical composition of essential oils and extracts derived from the air-dried and freeze-dried/lyophilized leaves of *Pelargonium graveolens*, commonly known as rose-scented geranium. This analysis aims to compare the differences in chemical constituents between the two drying methods and their impact on the overall quality and characteristics of the essential oils and extracts. This study focuses on two common methods of leaf drying: air-drying and freeze-drying, and their subsequent effect on the chemical constituents of the essential oils and extracts. Essential oils were extracted using hydrodistillation, while extracts were obtained using solvent extraction methods and Supercritical fluid extraction. The chemical composition of the oils and extracts was analyzed using Gas Chromatography-Mass Spectrometry (GC-MS). The analysis results revealed significant differences in the chemical profiles of the essential oils and extracts from the air-dried and freeze-dried/ lyophilized leaves. The study identified the main compounds in *P. graveolens* essential oil and extract using GC-MS, highlighting β-Citronellol as predominant. The chemical profile of the oil and the other extracts varies significantly depending on the drying method of the plant material, with notable compounds such as Citronellyl formate and Epizonaren in air-dried samples, and 3,7-Guaiadiene and 1-Linalool in lyophilized samples. The most important identified active compounds are Geraniol, Citronellol and menthone. Extraction efficiency varies based on solvent and geographical origin of the material, emphasizing the importance of solvent choice in optimizing the extraction for specific applications.

Keywords: Pelargonium; GC-MS; Hydrodistillation, Supercritical Fluid Extraction, Essential Oil

Abbreviations: GC-MS: Gas Chromatography-Mass Spectrometry; EO: Essential Oil; HX: Hexane; RT: Retention Time; MeOH: Methanol; DCM: Dichloromethane; Ace: Acetone; SFE - CO_2 Supercritical Fluid Extraction; GC- FID: Gas Chromatography with Flame Ionization Detection; HD: Hydrodistillation; HD RO AD P: Hydrodistillation of Romanian Air-dried Pelargonium graveolens; HD RO L P: Hydrodistillation of Romanian Lyophilized Pelargonium graveolens; SFE-CO_2 - TR AD *P. graveolens*: Supercritical fluid extraction carbon dioxide of Turkish Air-dried *Pelargonium graveolens*; SFE-CO_2 - TR L *P. graveolens*: Supercritical fluid extraction carbon dioxide of Turkish Lyophilized *Pelargonium graveolens*; SFE-CO_2 - RO AD *P. graveolens*: Supercritical fluid extraction carbon dioxide of Romanian Air-dried *Pelargonium graveolens*

Introduction

Pelargonium graveolens (*P. graveolens*), commonly known as geranium, is a fragrant medicinal plant used in the treatment of various diseases [1-4], in essential oil (EO) production, in aromatherapy, cosmetic products, and at the same time, is used as an ornamental flower. Saraswathi et al. [3] reviewed the phytopharmacological importance of the most important species of Pelargonium. The genus Pelargonium is recognized for its medicinal benefits and as a rich source of monoterpenes, tannins, phenolic acids, cinnamic acids, flavones, flavonoids, coumarins, and flavanols derivatives [3].

The main chemical categories that are found in *P. graveolens* are aliphatic hydrocarbons, aromatic hydrocarbons, terpene hydrocarbons, sesquiterpene hydrocarbons, aliphatic alcohols, terpene alcohols, aromatic alcohols, sesquiterpene alcohols, aliphatic esters, aromatic esters, terpene esters, aliphatic ketones, terpene ketones, sesquiterpene ketones, aliphatic aldehydes, terpene oxides, sesquiterpene oxides, aliphatic acids, terpene acids, and miscellaneous [5]. Also, Blerot et al. [6] reviewed the full Pelargonium EO composition, presenting the fatty acid, the cyclic monoterpenes, the acyclic monoterpenes, the sesquiterpenes, the phenylpropanoid, and their derivatives. These contribute to the flavour and aroma of plants, and, at the same time, they support the respiratory system, being responsible for many of the antibacterial, antiseptic, and antiviral properties [6].

The chemical composition of rose geranium can be influenced by environmental factors such as weather, climate, temperature fluctuations, duration of sunshine, rainfalls, and different harvesting phenological stages. Thus, these environmental factors can significantly impact the EO quality [7]. The general composition of *P. graveolens* fresh leaves or air-dried material, in terms of major components, of the researched articles can be summarized in Table 1. Citronellol, geraniol, and linalool are the most identified compounds [8].

Table 1: Major components in different *P. graveolens* extracts.

Extraction method	Characterization method	Main compounds	Ref.
SFE - CO_2	GC-MS	Geraniol (47.6%), Citronellol (25.7%)	[2]
HD	GC-MS	Citronellol (32.8%), 10-epi-γ-eudesmol (10.6%), Citronellyl formate (10.0%), Isomenthone (6.3%)	[9]
SFE - CO_2	GC-MS and GC-FID	Citronellol (14.44%), Citronellyl formate (7.74%), Geraniol (7.73%), 6,9-Guaiadiene (5.07%), Linalool (0.09%)	[10]
HD	GC-FID	Citronellol (26.18%), Citronellyl formate (12.05%), Geraniol (11.96%), 6,9-Guaiadiene (6.47%), Linalool (4.58%)	[10]
HD	GC-MS	Citronellol (26.9%), Citronellyl formate (13.2%), Geraniol (8.1%), 6,9-Guaiadiene (5.9%), Geranyl formate (5.5%)	[11]
SFE - CO_2	GC-MS	Citronellol (24.8%), Citronellyl formate (10.2%), Geraniol (8.5%), 6,9-Guaiadiene (8.8%), Geranyl formate (7.9%)	[11]
HD	GC-MS and GC-FID	Nerol (45.6%), Linalool (21.2%), isomenthone (9.5%), Geranyl tiglate (6.0%)	[12]
HD	GC-MS	Citronellol (41%), Geraniol (11%), Linalool (3.45%)	[13]
SFE - CO_2	GC-MS	Citronellol (43.2%), Geraniol (13.9%), Linalool (3.94%)	[13]
HD	GC-MS	Citronellol (27.53%), Geraniol (25.85%)	[14]

Abbreviations: SFE - CO_2: Supercritical Fluid Extraction; GC-MS: Gas Chromatography - Mass Spectrometry; GC- FID: Gas Chromatography with Flame Ionization Detection; HD: Hydrodistillation.

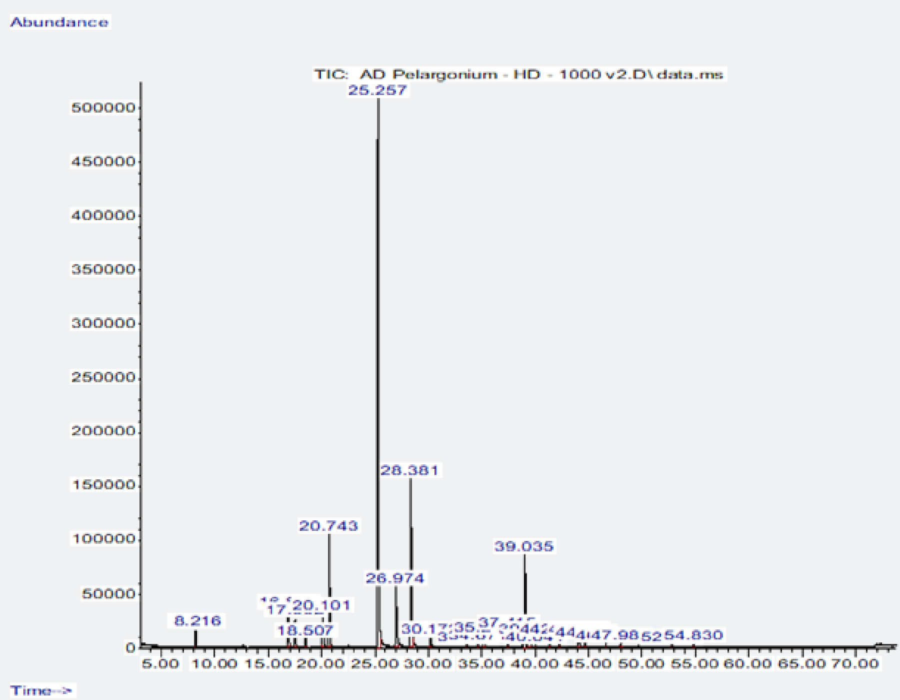

Figure 1: Total ion chromatography (TIC) of GC-MS analysis using Air Dried P. graveolens EO.

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Materials and Methods

Materials

The harvest and preparation of plant material consisted of green leaves of *P. graveolens* plant the plants were collected in January 2024 from cultivation sides in the South of Romania and the South of Turkey. These plants were propagated by stem cuttings. The plant material from Romania was divided into two portions to obtain lyophilized and air-dried material. For the lyophilized material, the plant leaves were kept overnight at a temperature of 25°C, for approximately 24 h under a vacuum of 0.270 mbar. For the air-dried material, the other plant leaves were placed in an incubator at a temperature of 36°C for 72 h. The obtained plant materials were then ground into a powder using a laboratory grinder (IKA MF 10 Basic, Staufen, Germany), to increase the surface area and homogenize the material for extraction.

The plant material from Turkey was also divided in two, in order to obtain lyophilized material and air-dried material. For the lyophilized one, the plant leaves were kept overnight in freeze dry at -35°C for approximately 22 h under a vacuum of -1010 mbar. For the air-dried material, the other plant leaves were placed in an incubator at a temperature of 36°C for 72 h. The obtained plant material was trans-formed into powder using a laboratory grinder, to increase the surface area for extraction.

Hydrodistillation (HD)

HD was the method used for extracting EO s from air-dried and lyophilized leaves using water as a solvent to determine the content of EO. This method was used only for the *Pelargonium* plant from Romania. For the ground *P. graveolens* material (lyophilized and air-dried leaves) 50 g was distilled with 500 mL of water (as the solvent that extracts the EO from the plant material during the distillation process) using a Clevenger-type apparatus. The distillation was carried out for 3 h, a sufficient time to complete the isolation of EO.

Firstly, the apparatus was set at 100°C, and after boiling started, the temperature was reduced to 60 °C. The vaporized water and EO passed through the *P. graveolens* plant material, carrying the volatile compounds with them. Then the vapor was moved into the condenser, where it was cooled and then condensed back into liquid form. The condensed liquid, which was a mixture of water and EO, was collected in a receiving vessel. Since essential oils are less dense than water, they float on the surface. The EO was separated from the water by decantation. The collected *P. graveolens* EO was then stored at 4°C in dark airtight containers to protect it from light and oxidation, which could degrade the quality of the oil, until future analysis. The obtained EO was analyzed using the GC-MS method, with dilutions of 10^{-1}, 10^{-2}, and 10^{-3} made with hexane (HX).

Extraction assisted by ultrasounds using different solvents (UAE)

For this method, the air-dried sample from Romania, and air-dried and lyophilized samples from Turkey were used. From the resulting powder 0.25 g of each sample was extracted with 10 mL of solvents (40:1 (v/w) solvent-to-solid ratio) with in-creasing polarity (HX, methanol (MeOH), dichloromethane (DCM), acetonitrile (MeCN), and acetone (Ace)), using the water bath ultrasonic extractor (ISOLAB, Eschau, Germany) for 120 minutes at room temperature. The mixture was then filtered through filter paper and after through a Hydrophobic PTFE Filter 0.22 µm. The extracts were stored at 4°C in the dark, until future analysis. The obtained filtrated ex-tracts were analyzed using the GC-MS method without making any dilution.

Supercritical fluid extraction carbon dioxide (SFE - CO_2)

For this method, the air-dried sample from Romania, and air-dried and lyophilized samples from Turkey were used. SFE - CO_2 extraction was performed using the extraction system (model SUPEREX, F500 CO_2 EKSTRAKTÖR, Konya, Türkiye), which consists of a 500 mL volume extractor, an HA220-50-06 controller, a pump, and a 50 L of CO_2 cylinder. Then the extract-laden liquid was pumped into a separation chamber where the extract was separated from the gas. The extracted substances were collected at the bottom of the separators, in 50 mL Falcon tubes. The extracts were solubilized in 20 ml of HX and centrifuged for 4 minutes at 4000 rpm. After that, the supernatant was collected and diluted with HX taking into consideration the dilution ratio of 100.3 w/w for GC-MS analysis.

Gas Chromatography-Mass Spectrometry (GC-MS) analysis

The analysis of both the EO and SFE - CO_2 extract was performed using a GC-MS system consisting of an Agilent Technologies GC HP model 7890A inert MSD, equipped with an Agilent Technologies capillary HP-5MS column (30 m length, 0.25 mm inner diameter, 0.25 mm film thickness), and coupled to a mass selective detector (MSD5975C) with an ionization voltage of 70 eV, all from Agilent, Santa Clara, CA, USA. Helium (He) was used as the carrier gas at a flow rate of 1 mL/min. The oven temperature program was as follows: initial hold at 40°C for 2 minutes, ramped to 60°C at 10°C/min, then to 190°C at 2°C/min, and finally to 230°C at 50°C/min. The injection volume was 1 µL, and the injection temperature was set to 250°C.The chromatograph was equipped with a split/splitless injector operated in the splitless mode, with a split ratio of 1:40. Component identification was assigned by comparing their mass spectra with data from Wiley 7n and NIST98 libraries.

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Results

Hydrodistillation (HD)

The identification of the various compounds within this EO was accomplished using GC-MS, and the results were organized based on their Retention Time (RT) and comparison with the commercial databases (NIST 27 and WILEY 7). Among the numerous compounds identified, the primary constituents were β-Citronellol, which ranged from 46.21% to 52.05%, Geraniol, which was present in amounts ranging from 5.84% to 5.89%, and Menthone, with a presence ranging from 2.69% to 11.78%. In the EO derived from air-dried *P. graveolens*, notable compounds included Citronellyl formate, which constituted 14.02% of the oil, and Epizonaren, which made up 8.06%. On the other hand, the EO obtained from lyophilized *P. graveolens* contained significant amounts of 3,7-Guaiadiene at 9.31%, 1-Linalool at 2.69%, and trans-Rose oxide at 2.39%.

These variations in chemical composition highlight the influence of the drying method on the EO 's profile. Further examination of the existing literature reveals that multiple studies have consistently shown that the chemical composition of *P. graveolens* EO includes several key compounds. Specifically, Citronellol is found in concentrations ranging from 26.18% to 32.8%, Geraniol from 7.73% to 11.96%, and Citronellyl formate from 10% to 13.2%. These findings demonstrate a strong similarity to the results presented in Table 1 of this study. However, the literature also identifies other significant compounds such as 6,9-Guaiadiene, which appears in concentrations ranging from 5.07% to 6.47%, Geranyl formate at 5.5%, Geranyl tiglate at 6.0%, and Nerol, which is present in substantial amounts, specifically 45.6%. Interestingly, the compounds 6,9-Guaiadiene, Geranyl formate, Geranyl tiglate, and Nerol were not detected in the essential oils analyzed using the GC-MS method in this study. This discrepancy could be attributed to several factors, including differences in the plant material used, geographical and environmental conditions, and variations in the extraction and analysis methods.

The absence of these compounds in the GC-MS results underscores the complexity of EO composition and the potential variability that can occur due to methodological and environmental differences (Table 2) (Figures 1 & 2).

Table 2: Identified compounds in *P. graveolens* EO.

Identified Compound	HD RO AD P %	HD RO L P %
3,7-Guaiadiene	NA	9.31
Caryophyllene	1.16	1.18
cis-Rose oxide	2.1	NA
Citronellyl formate	14.02	NA
Citronellyl propionate	NA	16.35
Epizonaren	8.06	NA
Geraniol	5.84	5.89
Geraniol formate	0.8	NA
l-Linalool	NA	2.69
Menthone	11.78	2.69
Naphtalene	0.89	1.01
trans-Rose oxide	NA	2.38
β-Citronellol	46.21	52.05
Δ-3-Carene	2.5	NA
Total	80.69	93.55
Unidentified compounds	19.31	6.45

Abbreviations: HD RO AD P: Hydrodistillation of Romanian Air-dried *Pelargonium graveolens*; HD RO L P: Hydrodistillation of Romanian Lyophilized *Pelargonium graveolens*.

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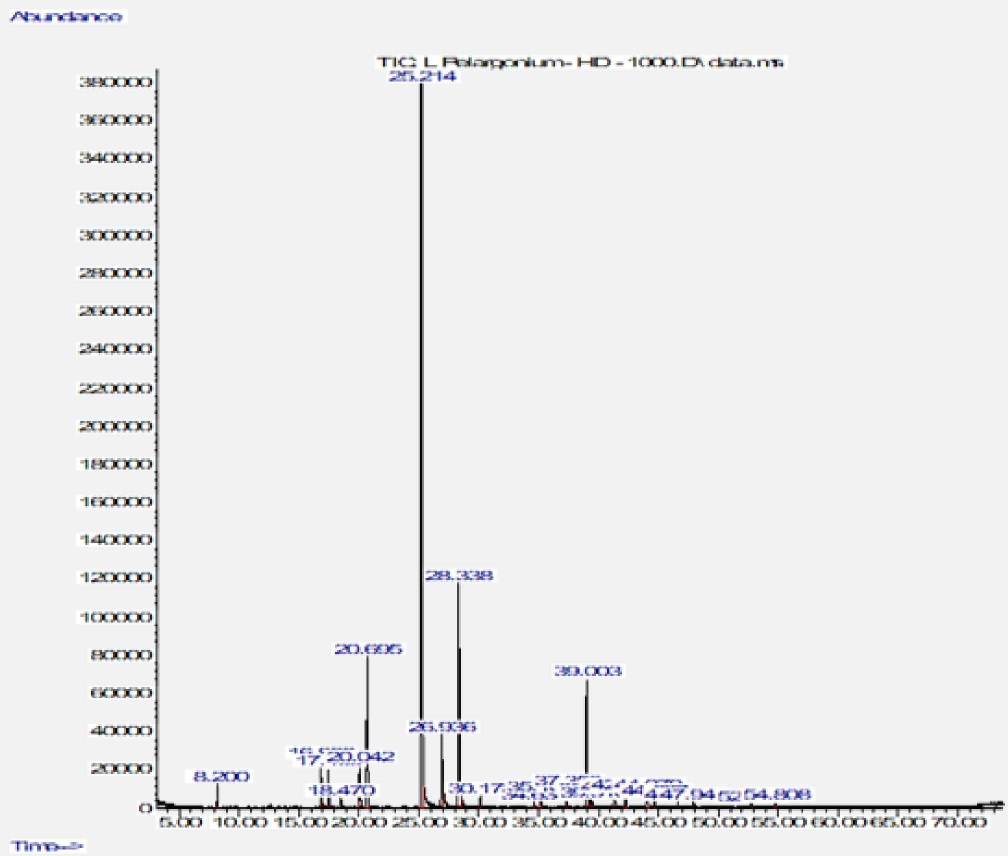

Figure 2: Total ion chromatography (TIC) of GC-MS analysis using Lyophilized P. graveolens EO.

Extraction assisted by ultrasounds using different solvents (UAE)

The data showcases the presence and concentrations of various compounds extracted using ultrasound-assisted extraction (UAE) with different solvents, including hexane (HX), methanol (MeOH), dichloromethane (DCM), acetonitrile (MeCN), and acetone (Ace).

Based on the total presence across various solvents, the most common compounds in your dataset include β-Myrcene, β-Citronellol, Geraniol, Menthone, Citronellyl Formate, and Nerolidol.

i. **β-Myrcene** is one of the most common compounds, appearing with high percentages in solvents such as hexane (HX), di-chloromethane (DCM), and acetonitrile (MeCN). This broad detection across multiple solvents underscores its significance in the samples.

ii. **β-Citronellol** is also prominent, showing high concentrations in solvents like methanol (MeOH) and DCM. Its consistent presence in these solvents suggests that it is a frequently encountered compound in the dataset.

iii. **Geraniol** is another compound that stands out, with high percentages recorded in MeOH and MeCN. The significant presence of Geraniol across these solvents highlights its common occurrence.

iv. **Menthone** is detected in several solvents, including hexane (HX) and MeCN, with substantial percentages. This indicates that Menthone is a regularly observed compound in the analyzed samples.

v. **Citronellyl Formate** appears frequently, particularly in MeOH and MeCN. The repeated detection of this compound in these solvents' points to its importance.

vi. **Nerolidol** is prominently present in MeOH, showing its notable occurrence in this solvent.

Some compounds were only present in specific extraction methods, indicating selectivity in the extraction process. For instance, "1-Butene, 3,3-dimethyl-" was found solely in UAE with hexane at room temperature, while "2-Amino-3-ethoxyquinoxaline" was unique to acetonitrile extraction at ambient temperature. Certain compounds, such as "Ibudilast," "Tocopherol," and "Nerolidol," were found in notable concentrations, highlighting the effectiveness of specific solvents in extracting these components. Overall, the compounds β-Myrcene, β-Citronellol, Geraniol, Menthone, Citronellyl Formate, and Nerolidol are identified as the most common. Their significant and consistent presence across various solvents, including hexane, underscores their relevance and prominence in the dataset (Table 3).

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Table 3: Identified compounds in obtained extracts assisted by ultrasounds.

Identified Compound	UAE HX TR AD P. %	UAE HX TR L P. %	UAE HX RO AD P. %	UAE MeOH TR AD P. %	UAE MeOH TR L P. %	UAE MeOH RO AD P. %	UAE DCM TR AD P. %	UAE DCM TR L P. %	UAE DCM RO AD P. %	UAE MeCN TR AD P. %	UAE MeCN TR L P. %	UAE MeCN RO AD P. %	UAE Ace TR AD P. %	UAE Ace TR L P. %	UAE Ace RO AD P. %
1-Butene, 3,3-dimethyl-	-	-	10.17	-	-	-	-	-	-	-	-	-	-	-	-
2-Amino-3-ethoxy-quinoxaline	-	-	-	-	-	-	-	-	-	8.79	-	-	-	-	-
1-Tetradecyne	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12.87
-(-)Sinularene	-	-	-	-	-	-	-	-	-	-	-	-	-	7.83	-
Methallenestril	-	21.98	-	-	-	-	-	-	-	-	-	-	-	-	-
Ibudilast	-	-	-	-	-	-	-	37.18	-	-	-	-	-	-	-
2-Quinoxalinamine	-	5.72	-	4.8	4.93	-	-	-	-	-	-	-	-	-	-
2-Methyl-pyrroline	-	-	6.96	-	-	-	-	-	-	-	-	7.53	-	-	-
2Z,6E-Farnesol	-	-	-	8.17	-	-	-	-	-	-	-	-	-	-	-
Estragole	-	-	-	-	-	-	6.62	-	-	-	-	-	-	-	-
Nerolidol	-	-	-	-	-	-	-	-	-	-	-	30.62	-	-	-
Tocopherol	-	-	-	-	-	-	-	3.77	-	-	-	-	-	-	-
Zanamivir	-	-	-	-	-	-	-	3.79	-	-	7.46	-	-	-	-
Nerol	1.3	-	18.97	-	-	-	-	-	-	-	-	-	-	-	-
Aristolene	11.4	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sorafenib	-	-	-	-	-	-	-	7.68	-	-	-	-	-	-	-
Mesitylene	-	-	-	-	-	-	-	-	-	-	-	-	10	-	-
Citronellyl formate	-	-	-	25.5	10.19	-	-	10.57	-	-	-	-	8.68	8.78	-
Citronellyl acetate	-	-	-	-	-	15.57	-	-	-	-	-	-	-	-	-
Citronellyl propanoate	-	21.41	-	-	-	-	28.11	15.87	-	17.94	25.82	-	-	-	-
Norbornene	33.32	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elemenal	-	-	-	-	-	-	-	-	-	6.59	-	-	-	-	-
Furfurylamine	-	-	-	-	-	-	-	-	-	-	-	-	17.12	-	-
Diacetone alcohol	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33.21
Chloromethylfuran	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.65
Imidazole-1-D	7.01	-	-	11.11	-	-	-	-	-	-	-	-	-	6.45	-
Isoxazole	-	8.51	4.2	-	-	-	-	-	-	6.88	-	-	3.04	-	-
Lavandulyl acetate	-	-	-	-	-	-	-	-	-	15.65	-	-	-	10.08	-
Geraniol	-	-	-	-	36.31	-	-	-	17.39	-	-	-	-	-	34.69

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Germacrene-D	-	2.2	44.7	-	-	34.58	-	-	-	-	8.12	-	-	-	-
Menthone	23.22	9.12	3.89	8.527	11.75	4	-	-	17.91	19.35	21.12	-	5.6	-	2.99
Naphtalene	-	-	-	-	-	-	-	4.07	-	-	-	-	-	-	-
Oxazole	-	-	-	8.26	-	-	-	-	-	-	-	-	-	-	-
Phenol, 2-(3-isoxazolyl)-	-	-	-	4.64	5.92	-	-	-	-	-	-	-	-	-	-
Phytol	-	-	-	7.13	-	22.45	-	-	-	-	-	27.52	-	-	8.74
Geranyl propionate	-	-	-	-	-	-	-	7.24	-	-	-	-	-	-	-
Methyl p-tert-butylphenylacetate	-	-	11.09	-	-	-	-	-	-	-	-	-	-	-	-
Furfuryl alcohol.	-	-	-	-	-	-	-	-	-	-	14.67	-	-	-	-
Tyranton	-	-	-	-	-	-	-	-	-	-	-	-	44.7	25.04	-
α-Copaene	-	-	-	-	-	-	-	-	14.97	-	-	26.64	-	-	-
β-Citronellol	13.83	-	-	7.36	21.22	-	5.83	4.91	27.01	-	-	-	-	27.4	-
β-Myrcene	3.67	19.84	-	4.4	-	11.92	43.57		14.45	19.44	17.03	-	-	-	-
Total	93.75	83.06	93.02	64.02	79.47	88.52	77.51	80.64	91.73	79.26	86.76	84.78	89.14	77.35	92.5
Unidentified compounds	6.25	16.94	6.98	35.97	20.53	11.48	22.49	19.36	8.27	20.74	13.24	15.22	10.86	22.65	7.5

Supercritical fluid extraction carbon dioxide (SFE - CO_2)

The chemical profile of *P. graveolens* extracts obtained via SFE-CO_2 exhibits both similarities and distinctions across different samples, reflecting variations influenced by geographical origin and preparation methods. A key observation from the data is the presence of high-yield compounds. β-Citronellol, for example, appears in high percentages across all three extractions, particularly in "SFE-CO_2 - TR AD P %" (37.31%), indicating it is a major component of the extracts. Another high-yield compound is Naphthalene, which is present in significant amounts in both "SFE-CO_2 - TR AD P %" (11.56%) and "SFE-CO_2 - RO AD P. %" (13.91%).

Certain compounds are unique to specific extractions. For instance, 1-Methyladamantane, 1-Pentyne, cis, cis-4,6-Octadienol, and Cyclopentane, 1,2-Dimethyl-3-Methylene-, Trans are unique to "SFE-CO_2 - TR AD P %". Similarly, Citronellyl acetate, cis-Ocimene, Phenylethyl Tiglate 2, and several other compounds appear exclusively in "SFE-CO_2 - TR L P. %". Compounds like 2-Phenylethyl propionate, Retinol, Camphene, and Cyclohexene, 3-(2-methylpropyl)- are found only in "SFE-CO_2 - RO AD P. %".

There are also compounds consistently present across different extractions. β-Citronellol appears in all three extractions with high percentages, while Geraniol is another consistent compound. β-Citronellol and β-Myrcene are significant components across multiple extractions, suggesting they are highly extractable with CO_2 under various conditions. Different extraction conditions selectively extract different compounds, as seen with the high percentage of Geraniol in "SFE-CO_2 - TR L P. %" and the substantial amount of Naphthalene in "SFE-CO_2 - RO AD P. %". Some compounds are present in minor amounts (<1%), indicating that while they are extractable, they are not as abundant in the original material or not as soluble under the conditions used. The data also suggests potential for optimizing extraction conditions to selectively isolate certain compounds, such as using the conditions in "SFE-CO_2 - TR AD P %" to maximize β-Citronellol. Overall, the data reflects the diverse nature of compounds that can be extracted using SFE-CO_2 and highlights the importance of extraction parameters in determining the yield and composition of the extract (Table 4) (Figure 3).

Discussion

The chemical profile of *P. graveolens* EO from Romania, as identified by GC-MS, primarily includes β-Citronellol, Geraniol, and Menthone. β-Citronellol emerges as the predominant compound, constituting 46.21% in HD RO AD P and 52.05% in HD RO L P. This suggests it plays a central role in both samples, with significant variations depending on the drying method of the plant material. In the EO derived from air-dried *P. graveolens*, notable compounds included Citronellyl formate (14.02%) and Epizonaren (8.06%). Conversely, the EO obtained from lyophilized *P. graveolens* contained significant amounts of 3,7-Guaiadiene

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(9.31%), 1-Linalool (2.69%), and trans-Rose oxide (2.39%). These variations in chemical composition highlight the influence of the drying method on the EO ‘s profile. Overall, these findings highlight the com-position variability between HD RO AD P and HD RO L P, with β-Citronellol and Citronellyl propionate being particularly significant in defining their respective profiles. However, notable compounds identified in other studies, such as 6,9-Guaiadiene, Geranyl formate, and Nerol, were not detected in this analysis, highlighting the variability in EO composition and the impact of different analytical techniques.

Table 4: Identified compounds in SFE - CO_2.

Identified compound	SFE-CO2 - TR AD P %	SFE-CO2 - TR L P. %	SFE-CO2 - RO AD P. %
1-Methyladamantane	5.67	-	-
1-Pentyne	2.71	-	-
2-Phenylethyl propionate	-	-	2.23
Retinol	-	-	1.06
Camphene	-	-	6.34
Caryophyllene	-	0.24	0.72
cis, cis-4,6-Octadienol	3.93	-	-
cis-Ocimene	-	2.81	-
Citronellyl acetate	-	4.5	-
Cyclohexene, 3-(2-methylpropyl)-	-	-	0.57
Cyclopentane, 1,2-Dimethyl-3-Methylene-, Trans	3.78	-	-
Geraniol	-	25.3	25.4
Germacrene-D	-	1.1	-
Menthone	-	0.99	0.87
Naphthalene	11.56	-	13.91
Neryl propionate	-	-	5.69
Phenol, 2-ethyl-4,5-dimethyl-	-	9.38	-
Phenylethyl Tiglate 2	-	2.15	-
Phytol	-	-	2.93
Thymol	-	-	4.98
α-Amorphene	-	2.76	-
α-Gurjunene	-	-	3.27
β-Citronellol	37.31	22.63	27.97
β-Cubebene	-	8.34	-
β-Myrcene	33.73	1.57	1.14
γ-Muurolene	-	1.81	-
Δ-Selinene	-	14.05	-
Total	98.69	97.63	97.08
Unidentified compounds	1.31	2.37	2.92

Abbreviations: SFE-CO_2 - TR AD *P. graveolens*: Supercritical fluid extraction carbon dioxide of Turkish Air-dried *Pelargonium graveolens*; SFE-CO_2 - TR L *P. graveolens*: Supercritical fluid extraction carbon dioxide of Turkish Lyophilized *Pelargonium graveolens*; SFE-CO_2 - RO AD *P. graveolens*: Supercritical fluid extraction carbon dioxide of Romanian Air-dried *Pelargonium graveolens*.

Regarding the Ultrasonic Extractions, these three extracts provide detailed comparisons of solvent extraction efficiencies for various compounds from different types of *P. graveolens* extracts. In all extracts, the same solvents (HX, MeOH, DCM, MeCN, and Ace) are used for extraction, enabling direct comparison of extraction efficiencies across different compounds. Each extract discusses the extraction efficiency of various compounds, highlighting which solvents are particularly effective for specific types of chemicals such as terpenes, alcohols, esters, and pharmaceuticals. The extraction efficiency variations show that the percentage of

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compounds extracted varies among solvents. For example, HX in the Turkish Air-Dried extract includes Norbornene (33.33%), while in the Turkish Lyophilized extract, it includes Methallenestril (21.98%). Regarding the MeOH, the Romanian Air-Dried extract contains Germacrene-D (34.58%), which is not highlighted in the other extracts. The extracts are derived from different geographical sources (Turkish and Romanian) and processing methods (Air-Dried, Lyophilized), leading to variations in chemical composition and therefore solvent extraction efficiencies.

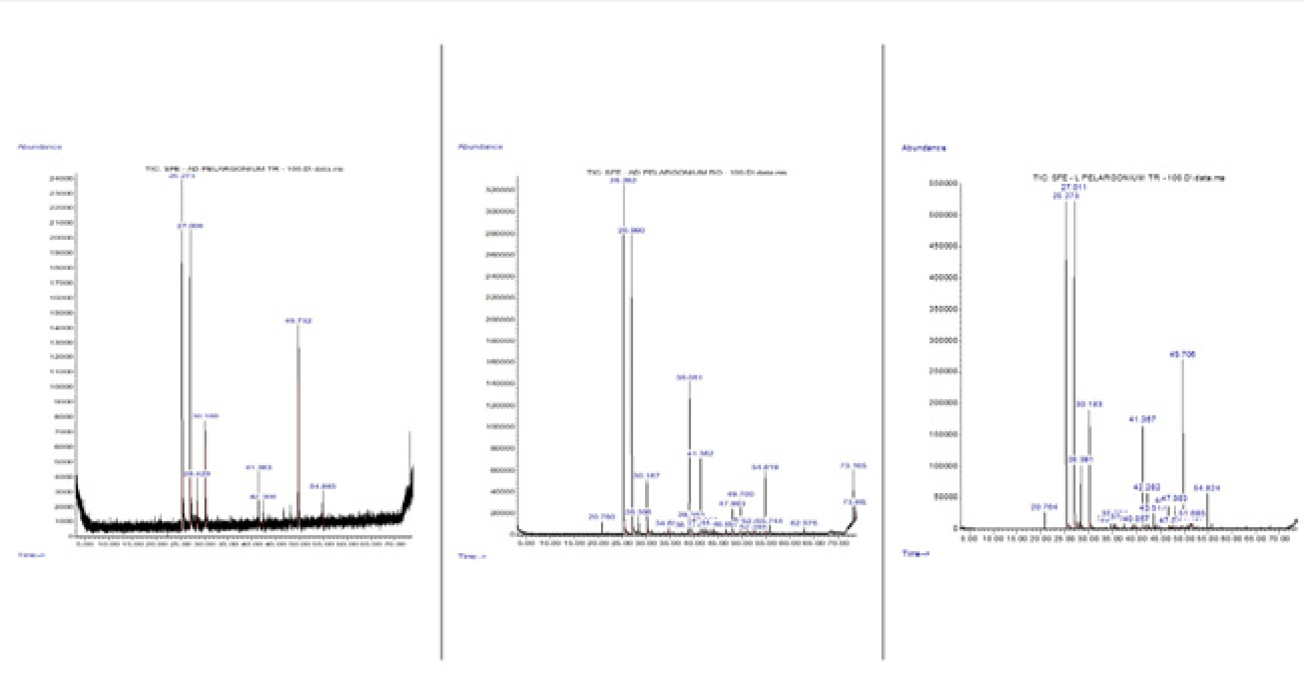

Figure 3: Total ion chromatography (TIC) of GC-MS analysis using SFE - CO_2.

P. graveolens SFE-CO_2 extracts vary in chemical profiles due to drying methods and geographical origins. Turkish air-dried extracts feature pharmaceutical compounds like Naphthalene and 1-Methyladamantane. Turkish lyophilized extracts contain fragrance compounds like 3,7-Guaiadiene and Linalool. Romanian air-dried ex-tracts are rich in Geranyl formate and suited for fragrance applications. These differences highlight the versatility of *P. graveolens* extracts across industries, warranting tailored applications and further research for optimized use.

Conclusion

In conclusion, the choice of drying method, extraction method, and solvent is critical in optimizing the extraction of specific compounds from *P. graveolens* extracts. These insights can guide researchers and manufacturers in tailoring extraction processes based on their desired outcomes, whether focusing on maximizing yields of specific compounds or broad-spectrum extraction for various applications.

Conflict of Interest

The authors declare no conflicts of interest.

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