American Journal of Biomedical Science & Research

www.biomedgrid.com
ISSN: 2642-1747

Research Article

GC-MS Analysis of Essential Oils of Species of the Genus Achillea L.

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To Cite This Article: *Istamkulova Moxigul Murodkulovna, Mukhamadiev Abduqodir Nuralievich, Mukhamadiev Nurali Kurbonalievich*, Keldiyarov Hudoyar Otamuradovich and Istamkulov Murodkul Sultonovich. GC-MS Analysis of Essential Oils of Species of the Genus Achillea L. Am J Biomed Sci & Res. 2024 24(1) AJBSR.MS.ID.003160,* DOI: 10.34297/AJBSR.2024.24.003160

Received: September 09, 2024; **Published:** September 16, 2024

Abstract

This article presents a comprehensive analysis of the chemical composition of essential oils from various species of the genus Achillea L., including Achillea millefolium L., Achillea filipendulina Lam., Achillea arabica Kotschy, and Achillea santolinoides Lag. The analysis was conducted using gas chromatography-mass spectrometry. The study aims to identify the key components and their concentrations in the essential oils, which is crucial for the development of effective and safe phytopreparations. The material used for the study comprised fresh plant flowers collected from different geographical regions. The essential oils were extracted using steam distillation, followed by analysis through GC-MS. The results of this study demonstrate that the composition of yarrow essential oils can vary significantly depending on the species, growing location, and environmental conditions. This highlights the necessity for standardization and meticulous quality control of phytopreparations based on Achillea essential oils. Thus, the study of the chemical composition and the GC-MS analysis of essential oils from different species of the genus Achillea L. enhances our knowledge of the phytochemistry of these plants, aids in the identification of new bioactive compounds, and advances our understanding of their mechanisms of action. This opens new opportunities for their application in medicine, pharmaceuticals, cosmetology and aromatherapy.

Keywords: Medicinal plants, Achillea L., essential oils, GC-MS, chemical composition

Introduction

Essential oils isolated from essential oil plants are known to possess properties such as antiseptic, anti-inflammatory, analgesic (pain relieving), soothing and relaxing, immunomodulatory, refreshing and tonic, digestive, antioxidant, antidepressant, antibacterial, antifungal, antiviral, expectorant, antispasmodic, detoxifying, emotional and mental, antiemetic and other properties that make them useful in various fields of medicine, cosmetology and aromatherapy [1-9]. Such essential oil plants include yarrow. Achillea (latin-Yarrow) is a large genus of perennial plants of the Asteraceae family, or Compositae, widely distributed in Europe, Asia, and North America [1-4]. Yarrow is a perennial plant that has anti-inflammatory, antispasmodic, antimicrobial, antiallergic, styptic and wound-healing properties [1-5,8-24]. In folk medicine, it is used in pulmonary, nasal, gastrointestinal and external bleeding [1,5]. And it is also used in veterinary medicine, manufacturing, perfumery and cosmetics [4,5,7,25-28]. Essential oils from plants of the genus Achillea L. (Yarrow) are widely known for their medicinal properties and are used in traditional medicine and modern phytotherapy [5,6,25-27,29-31].

The essential oils of these plants contain a wide range of bioactive components, including terpenes, phenolic compounds, and flavonoids. GC-MS analysis enables a detailed study of the composition of these oils, identifying key components and their concentrations. This is crucial for the development of effective yarrow-based medicines [32-37,14]. To ensure the safety and efficacy of phytopreparations, standardization of their composition is necessary. GC-MS analysis allows for the accurate determination of the qualitative and quantitative composition of essential oils, contributing to the standardization of medicinal and cosmetic products. This is particularly important in the growing natural products market, where quality control is a key factor [38,39]. Achillea L. (Yarrow) is a widely distributed plant that can be easily cultivated in various climatic conditions [9,11,18,22,24,40-45]. This makes it an accessible and economical source of essential oils. GC-MS analysis helps optimize the extraction and refining processes, ensuring high production efficiency at minimal cost. The study of the chemical composition of essential oils from different species of the genus Achillea L. enhances our understanding of the phytochemistry of these plants [4,20,32,33,46]. This is important for basic science as it allows for the identification of new bioactive compounds and the study of their mechanisms of action. Data from GC-MS analysis can serve as a foundation for further biomedical research and clinical trials [12,14,22,29,30,33,36].

Essential oils of Achillea L. (Yarrow) are widely used in aromatherapy and cosmetology due to their soothing and rejuvenating properties. GC-MS analysis helps identify the components responsible for these effects, facilitating the development of new cosmetic products with predictable and stable properties. The relevance of GC-MS analysis of essential oils from species of the genus Achillea L. stems from their wide range of applications in medicine, pharmaceuticals, cosmetology, and aromatherapy [1,6,7,14,19,27-31]. GC-MS analysis is a crucial tool for standardization, quality control, and further research, making it indispensable in the study and utilization of yarrow essential oils. With the increasing interest in natural sources of bioactive substances, the study of the chemical composition of essential oils from plant species of the genus Achillea L. is particularly relevant [2,4,7,14,17,19,28,32-35,40-64].

Aim

The aim of this work is to run a comprehensive analysis of essential oils from different species of Achillea L. using gas chromatography-mass spectrometry (GC-MS) to identify their chemical composition.

Material and Methods

Four different species of the genus Achillea L. (yarrow) were used for the study: Achillea millefolium L., Achillea filipendulina Lam., Achillea arabica Kotschy, and Achillea santolinoides Lag. Plant material was collected from different geographical regions to examine the variation in composition according to species, location, and time of growth. Essential oils were extracted from fresh flowers of the plants using the hydrodistillation method. The plant flowers were placed in a distillation apparatus where steam distillation was performed. The vapor passing through the plant material captured the volatile components of the essential oils, which were then condensed and collected. Gas chromatography-mass spectrometry (GC-MS) was chosen as the method of study. Sample preparation for analysis involved diluting the essential oil with hexane.

Chromatography Conditions

Column thermostat temperature-initial-60°C 3min (isothermal mode); heating at a rate of 15°C/min (temperature programming mode) up to 250°C and at 250°C (isothermal mode) 3min. Injector temperature-250°C, helium gas flow-1ml/min, SplitRatio-1/100. Detector mass parameters-Solvent delay-3min, Emission-50mA, Scanning range-30-350a.u.m., Scanning speed-1600a.u.m./sec, Ion source temperature-230°C, Transfer temperature-280°C. Time of analysis-21min. Identification of components was carried out by comparing the obtained mass spectra with the NIST mass spectra library and retention times [38]. The internal normalization method was used for quantitative analysis [39]. The chromatograms of essential oils obtained under optimal conditions are shown in Figures 1-4. The composition and content of the identified components are presented in Tables 1-4. (Figure 1, Table 1) (Figure 2, Table 2) (Figure 3, Table 3) (Figure 4, Table 4).

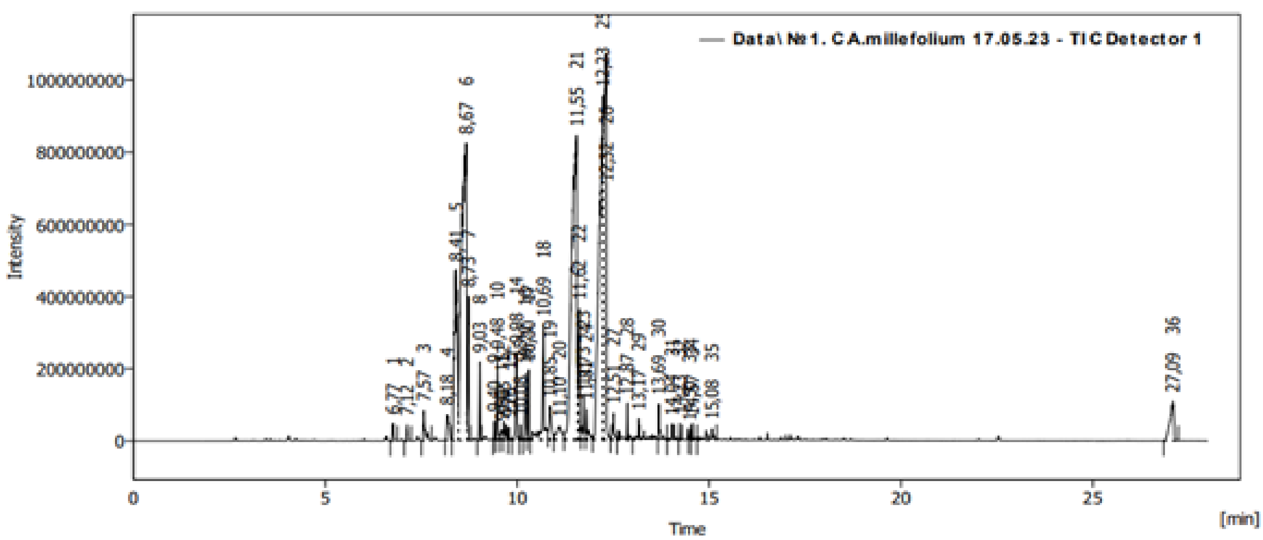

Figure 1: Chromatogram of essential oil of Achillea millefolium L.

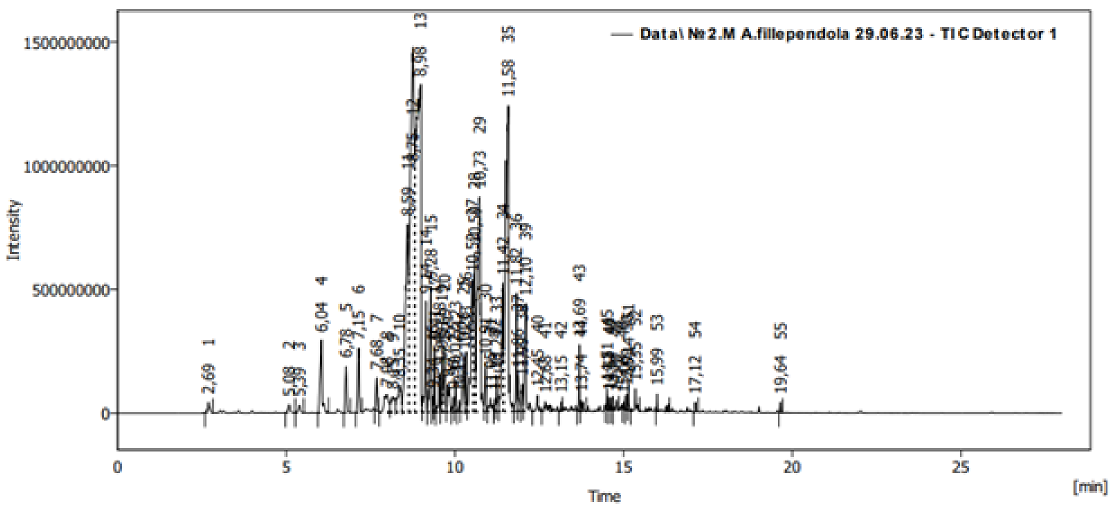

Figure 2: Chromatogram of the essential oil of Achillea filipendulina Lam.

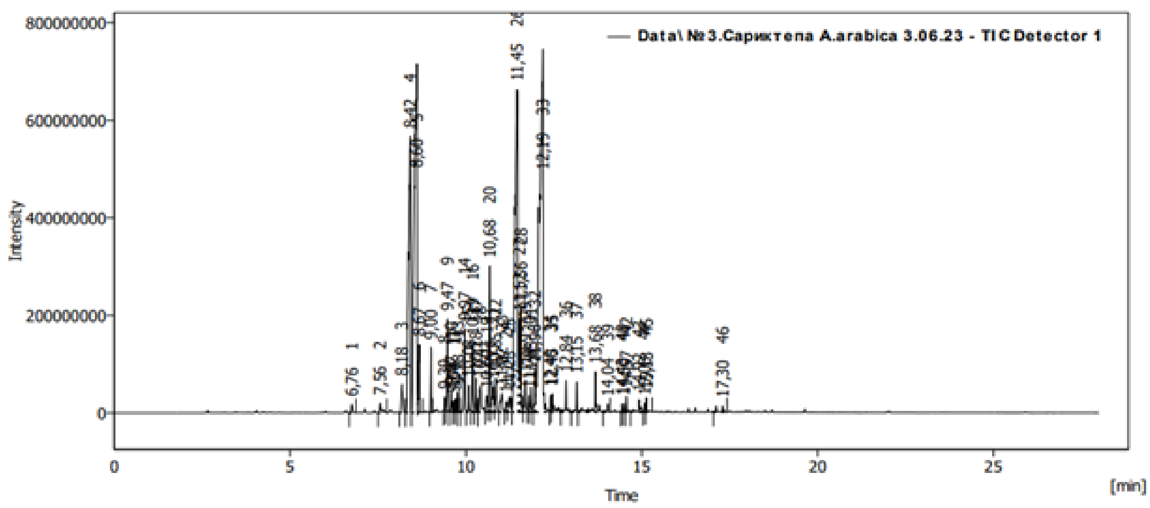

Figure 3: Chromatogram of the essential oil of Achillea arabica Kotschy.

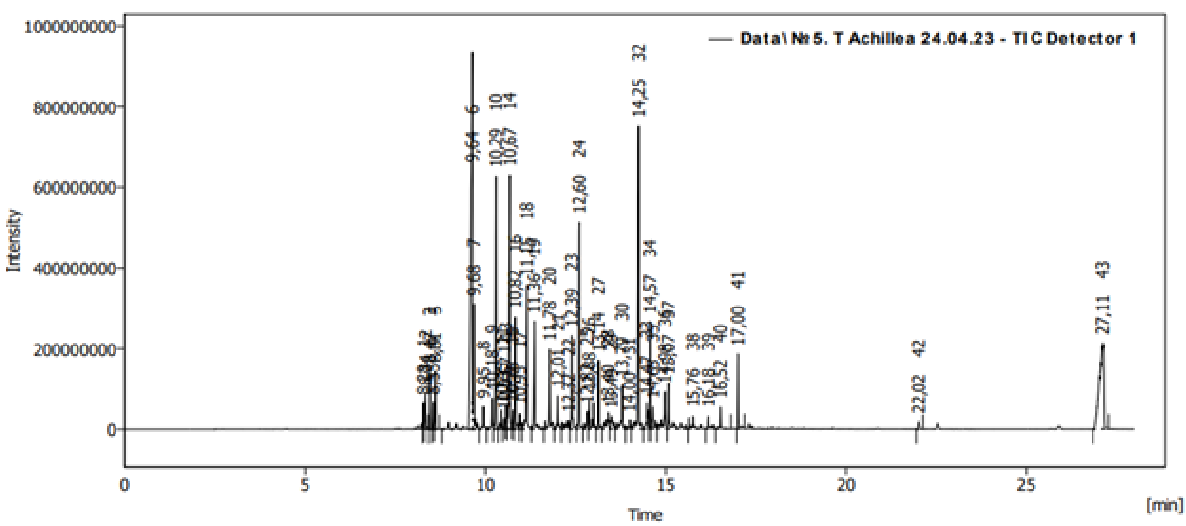

Figure 4: Chromatogram of the essential oil of Achillea santolinoides Lag.

Table 1: Results of GC-MS analysis of chemical composition and content of components of essential oil of Achillea millefolium L.

№	Name of components	Retention time, min	Content, %
1	(+)-α-Pinene	6.765	0.28
2	Camphene	7.124	0.25
3	β-Phellandrene	7.568	0.69
4	α-Thujene	8.177	0.8
5	Terpinolene	8.406	6.78
6	m-Cymene	8.672	18.82
7	Eucalyptol	8.733	1.94
8	γ -Terpinene	9.026	0.84
9	Terpinolene	9.403	0.19
10	1-Methyl-4-(prop-1-en-2-yl) benzene	9.482	0.89
11	Linalool	9.6	0.28
12	Nonanal	9.646	0.47
13	1,3,8-p-Menthatriene	9.783	0.15
14	2-p-Menthen-1-ol	9.983	1.33
15	1,3,8-p-Menthatriene	10.084	0.19
16	2-p-Menthen-1-ol	10.216	0.98
17	Camphor	10.299	1.06
18	(-)-Terpinen-4-ol	10.689	2.96
19	cis-Piperitol	10.85	1.02
20	trans-Piperitol	11.101	0.92
21	Ascaridole	11.549	20.43
22	Ascaridole	11.624	1.94
23	Ascaridole	11.728	0.71
24	Bornyl acetate	11.807	0.62
25	Ascaridole	12.233	16.78
26	Ascaridole	12.323	13.65
27	Eugenol	12.506	0.54
28	Jasmone	12.871	0.71
29	Caryophyllene	13.165	0.28
30	Germacrene D	13.688	0.51
31	Terpinyl propionate	14.04	0.17
32	Nerolidol	14.233	0.14
33	Espatulenol	14.502	0.11
34	Caryophyllene oxide	14.57	0.17
35	Oxacyclopentadecan-2-one	15.075	0.49
36	Bis(2-ethylhexyl)	27.086	1.93
		Total	100

Table 2: Results of GC-MS analysis of chemical composition and content of components of essential oil of Achillea filipendulina Lam.

№	Name of components	Retention time, min	Content, %
1	X1	2.695	0.22
2	Dicyclopropyl ketone	5.085	0.19
3	3-Octyne	5.386	0.18
4	Santolina triene	6.042	1.67
5	α-Pinene	6.776	0.81
6	Camphene	7.145	1.06

7	β- Pinene	7.683	0.52
8	X2	7.984	0.9
9	Yomogi alcohol	8.152	0.71
10	4-Terpinenyl acetate	8.349	1.08
11	m-Cymene	8.593	6.4
12	Cyclohexane methanol, 4-hydroxy-α, α,4-trimethyl-	8.751	16.42
13	Neomenthoglycol	8.983	18.81
14	γ -Terpinene	9.141	1.47
15	Hotrienol	9.284	2.07
16	Terpinolene	9.342	0.16
17	Artemisia alcohol	9.406	0.71
18	Perillaldehyde	9.539	0.47
19	X3	9.614	0.53
20	1,2-epoxyhexadecane	9.693	1.54
21	Citral	9.768	0.71
22	1,3,8-p-Menthatriene	9.954	0.19
23	2,6-Dimethyl-8-(tetrahydropyran-2-yloxy)-octa-2,6-di-en-1-ol	10.015	0.58
24	1,3,8-p-Menthatriene	10.13	0.15
25	Camphor	10.256	1.02
26	(-)-trans-Pinocarveol	10.334	1.91
27	Camphol	10.517	3.3
28	(-)-Terpinen-4-ol	10.589	3.01
29	(+)-Borneol	10.729	8.17
30	trans-Piperitol	10.911	0.68
31	Myrtenol	11.051	0.38
32	Ascaridole	11.18	0.14
33	Verbenol	11.245	0.6
34	Ascaridole	11.42	2.56
35	(+)-trans-Chrysanthenyl acetate	11.581	10.9
36	Bornyl acetate	11.821	1.83
37	Carvacrol	11.864	0.56
38	X4	11.993	0.44
39	Indole	12.101	2.54
40	Eugenol	12.448	0.33
41	λ- Elemene	12.681	0.45
42	Caryophyllene	13.147	0.1
43	Germacrene D	13.688	1.04
44	Terpinyl propionate	13.742	0.2
45	Espatulenol	14.509	0.27
46	Caryophyllene oxide	14.57	0.1
47	X5	14.642	0.1
48	Epicubebol	14.778	0.23
49	tau-Cadinol	15	0.27
50	Oxacyclopentadecan-2-one	15.093	0.15
51	β-Eudesmol	15.14	0.44
52	Oxacyclopentadecan-2-one	15.347	0.3
53	Caryophyllene oxide	15.989	0.26

54	Palmitic acid	17.125	0.09
55	Heptacosane	19.644	0.09
		Total	100

Table 3: Results of GC-MS analysis of chemical composition and content of components of essential oil of Achillea arabica Kotschy.

№	Name of components	Retention time, min	Content, %
1	(+)- α-Pinene	6.758	0.18
2	Sabinen	7.564	0.31
3	α-Phellandrene	8.181	0.82
4	Terpinolene	8.417	11.52
5	m-Cymene	8.604	19.51
6	Eucalyptol	8.672	1.33
7	γ - Terpinene	9.005	0.92
8	Terpinolene	9.392	0.18
9	4-Isopropenyltoluene	9.474	1.4
10	Linalool	9.575	0.36
11	Nonanal	9.639	0.18
12	m-Cymene	9.7	0.2
13	1,3,8-p-Menthatriene	9.775	0.25
14	2-p-Menthen-1-ol	9.965	1.45
15	1,3,8-p-Menthatriene	10.076	0.42
16	2-Menthen-1-ol	10.191	1.27
17	Camphor	10.281	0.52
18	Lavandulol	10.41	0.9
19	Camphol	10.596	0.46
20	(-)-Terpinen-4-ol	10.678	2.9
21	Benzene methanol, α, α,4-trimethyl-	10.772	0.89
22	trans-Piperitol	10.847	0.8
23	trans-Piperitol	11.019	0.74
24	Ascaridole	11.144	0.27
25	Ascaridole	11.234	0.64
26	Ascaridole	11.452	16.85
27	Ascaridole	11.517	1.73
28	Ascaridole	11.563	1.74
29	Ascaridole	11.689	0.69
30	Bornyl acetate	11.782	0.31
31	Carvacrol	11.854	0.48
32	Thymol	11.961	0.76
33	Ascaridole	12.191	24.16
34	p-Cymen-7-ol	12.402	0.21
35	Eugenol	12.452	0.62
36	Jasmone	12.843	0.66
37	Caryophyllene	13.151	0.47
38	Germacrene D	13.685	1.27
39	Terpinyl propionate	14.036	0.15
40	2,6-Dimethyl-8-(tetrahydropyran-2-yloxy)-octa-2,6-dien-1-ol	14.434	0.09
41	Espatulenol	14.498	0.13
42	Caryophyllene oxide	14.566	0.22

43	γ -Eudesmol	14.921	0.43
44	Oxacyclopentadecan-2-one	15.075	0.14
45	β-Eudesmol	15.132	0.23
46	α –Methylionol	17.304	0.23
		Total	100

Table 4: Results of GC-MS analysis of chemical composition and content of components of essential oil of Achillea santolinoides Lag.

№	Name of components	Retention time, min	Content, %
1	X1	8.281	0.51
2	Isopentyl isobutyrate	8.338	0.82
3	m-Cymene	8.471	1.23
4	X2	8.553	0.5
5	(+)-Santolina alcohol	8.607	1.3
6	Linalool	9.636	18.27
7	2-Methylbutyl isovalerate	9.682	3.04
8	2-Menthen-1-ol	9.947	0.62
9	2-p-Menthen-1-ol	10.184	0.79
10	Acetaldehyde, (3,3-dimethylcyclohexylidene)-, (Z)-	10.288	5.72
11	Pinocarvone	10.449	0.57
12	Camphol	10.528	0.35
13	Cyclohexane methanol, α, α-dimethyl-4-methylene	10.574	0.53
14	Terpinen-4-ol	10.675	7.66
15	(-)-Terpinen-4-ol	10.761	0.55
16	p-Mentha-1,5-dien-7-ol	10.822	2.95
17	trans-Piperitol	10.954	0.5
18	Isogeraniol	11.148	3.85
19	Geraniol	11.356	2.97
20	Carvacrol	11.778	2.17
21	Isoascaridol	12.008	0.91
22	Eugenol	12.316	0.67
23	1-Bromo-3,7-dimethyl-2,6-octadiene	12.391	2.01
24	Geranyl acetate	12.603	4.77
25	X3	12.825	0.58
26	3-Methyl-2-pent-2-enyl-cyclopent-2-enone	12.879	1.31
27	Caryophyllene	13.137	1.39
28	6-Epishyobunone	13.402	0.99
29	Germacrene D	13.491	0.82
30	(+)-Bicyclogermacrene	13.792	1.4
31	Terpinyl propionate	14	0.27
32	Nerolidol	14.251	8.5
33	Espatulenol	14.47	0.99
34	Longipinocarvone	14.566	2.08
35	Pentyl 3-phenylpropanoate	14.645	0.86
36	α-Caryophylladienol	14.978	1.54
37	13-tetradecanolide	15.072	1.78
38	γ -costol	15.759	0.76
39	X4	16.179	0.54
40	Palmitoleic acid	16.516	0.51

41	Bergamotol, Z-α-trans-	17.003	1.4
42	Octylpalmitate	22.02	0.3
43	Bis(2-ethylhexyl) terephthalate	27.11	10.73
		Total	100

To conduct a comparative analysis of essential oils from plants of the genus Achillea L., we will consider the main components and their content in each species. Tables 1-4 present data on the content of components for the following species: Achillea millefolium L., Achillea filipendulina Lam., Achillea arabica Kotschy, and Achillea santolinoides Lag. Comparative analyses of the components revealed: m-Cymene which is present in all species, the highest content in Achillea arabica (19.51%) and Achillea millefolium (18.82%); high content of Terpinolene was observed in the essential oil of Achillea arabica (11.52%) and in Achillea millefolium (6.78%); (-)-Terpinen-4-ol is present in all species and highest content in Achillea santolinoides (7.66%) and Achillea filipendulina (3.01%); significant Ascaridol content in Achillea arabica (24.16%) and Achillea millefolium (20.43%); high Linalool content in Achillea santolinoides (18.27%). In addition, unique components such as Cyclohexane methanol 4-hydroxy-αα4-trimethyl (16.42%) and Neomenthoglycol (18.81%) in Achillea filipendulina, and Linalool (18.27%) and Nerolidol (8.50%) in Achillea santolinoides were also detected

Thus, Achillea millefolium and Achillea arabica have significant content of Ascaridole and m-Cymene, making them promising for use in antimicrobial and antifungal preparations. Achillea filipendulina contains unique components such as Neomenthoglycol and Cyclohexane methanol, which may be useful in pharmaceuticals. Achillea santolinoides contains significant amounts of Linalool and Nerolidol, making it valuable for cosmetology and aromatherapy.

To analyze the optical isomers in essential oils from plants of the genus Achillea L., we will identify components that have optical isomers. These isomers share the same molecular formula but differ in the spatial arrangement of atoms, resulting in different physicochemical properties. As a result of analysing the composition of essential oils, we identified such optical isomers as: in Achillea millefolium L. (+)-α-Pinene (0.28%) and (-)-Terpinen-4-ol (2.96%); in Achillea filipendulina Lam. α-Pinene (0.81%) and (-)-Terpinen-4-ol (3.01%) and, (+)-Borneol (8.17%); in Achillea arabica Kotschy (+)-α-Pinene (0.18%) and (-)-Terpinen-4-ol (2.90%); in Achillea santolinoides Lag. (-)-Terpinen-4-ol (0.55%) and (+)-Santolina alcohol (1.30%). Thus, (-)-Terpinen-4-ol is present in all essential oils of the genus Achillea L. with the highest content in Achillea filipendulina (3.01%) and Achillea arabica (2.90%). (+)-α-Pinene is found in Achillea millefolium and Achillea arabica, although its content is negligible. (+)-Borneol is a unique component for Achillea filipendulina where it constitutes a significant proportion (8.17%). (+)-Santolina alcohol is found only in Achillea santolinoides.

Based on the above, it can be stated that GC-MS analysis of essential oils from different Achillea species highlights the diversity of their chemical composition and potential applications. The presence of significant compounds and optical isomers emphasizes their therapeutic, cosmetic, and aromatic value [25,7]. Achillea millefolium and Achillea arabica are characterized by high contents of Ascaridole and m-Cymene, making them potent antimicrobial agents. Achillea filipendulina, containing unique components like Neomenthoglycol and Cyclohexane methanol 4-hydroxy-αα4-trimethyl, is promising for pharmaceutical applications. Achillea santolinoides plays an important role in the cosmetic industry due to its high content of Linalool and Nerolidol. This analysis not only provides insight into the chemical diversity of Achillea essential oils but also paves the way for their targeted use in various industries. Comparative analysis of the data obtained with literature data [32] revealed both similarities and differences in the chemical composition of essential oils from different Achillea species. Detailed GC-MS and initial analyses demonstrate the diversity of essential oil components within this genus, which is influenced by species-specific factors and possibly environmental conditions. This detailed comparison highlights the potential for diverse applications of these oils in medicinal, cosmetic, and aromatic purposes. Each species has unique chemical profiles that can be exploited for specific benefits. Comparison of the data obtained with literature data on major, common, and unique components revealed the following:

The major components in Achillea millefolium L. are m-Cymene (18.82%), Eucalyptol (19.4%), Terpinolene (6.78%), (-)-Terpinen-4-ol (2.96%), Ascaridole (20.43%); in Achillea filipendulina Lam. m-Cymene (6.40%), Cyclohexane methanol 4-hydroxy-αα4-trimethyl (16.42%), Neomenthoglycol (18.81%), (-)-Terpinen-4-ol (3.01%), (+)-Borneol (8.17%); In Achillea arabica Kotschy m-Cymene (19.51%), Terpinolene (11.52%), Ascaridole (24.16%), (-)-Terpinen-4-ol (2.90%), Benzene methanol αα4-trimethyl (0.89%); in Achillea santolinoides Lag. Linalool (18.27%), 2-Methylbutyl isovalerate (3.04%), Terpinen-4-ol (7.66%), Geranyl acetate (4.77%), Nerolidol (8.50%); in A. Biebersteinii Piperitone (19.79%), p-Cymene (16.53%), 2-Carene (16.22%); in A. Wilhelmsii components Camphor (77.19%), Endo-borneol (5.03%), Eucalyptol (3.04%); in A. aleppicasubsp. Zederbaveri components as α-Terpinen (22.28%), Eucalyptol (12.07%), tau-Cadinol (6.89%); in A. Vermicularis, Eucalyptol (28.28%), Piperitone (19.62%), Camphor (9.04%) [32]. Eucalyptol is present in A. millefolium (19.4%) and various other species such as A. wilhelmsii (3.04%) and A. aleppica (12.07%), while high content of p-Cymene in A. biebersteinii (16.53%) and m-Cymene in A. millefolium (18.82%) and in A. arabica (19.51%), and Terpinen-4-ol was found in all analysed species, significant content in A. santolinoides (7.66%), which are considered as common components.

Cyclohexane methanol 4-hydroxy-αα4-trimethyl and Neomenthoglycol are considered unique components in Achillea filipendulina, as they are not detected in the other species analyzed. In

Achillea aleppica, α-Terpinen is found in a high amount (22.28%), whereas in other species this component is not a major constituent. Camphor content is high in Achillea wilhelmsii subsp. wilhelmsii (77.19%) and significant in Achillea vermicularis (9.04%), which is not observed in the four originally analyzed species. As a result of the comparative analysis, it can be noted that our data Achillea millefolium L. contain m-Cymene (18.82%), Eucalyptol (19.4%), Terpinolene (6.78%), (-)-Terpinen-4-ol (2.96%), Ascaridole (20.43%) and according to literature data A. millefolium subsp. millefolium contain Camphor (16.55%), α-Bisabolol (13.55%), Eucalyptol (12.60%). Including the main differences in our data A. millefolium has significant content of Ascaridole and m-Cymene whereas in literature data the main components are Camphor and α-Bisabolol. Eucalyptol is present in both sources, but in different concentrations (19.4% in our data and 12.60% in the literature). It can also be noted that according to our data Achillea filipendulina Lam. contains m-Cymene (6.40%), Cyclohexane methanol 4-hydroxy-αα4-trimethyl (16.42%), Neomenthoglycol (18.81%), (-)-Terpinen-4-ol (3.01%), (+)-Borneol (8.17%), while according to the literature data of A. filipendulina these components are absent [32, 65-70].

According to our data Achillea arabica Kotschy contains m-Cymene (19.51%), Terpinolene (11.52%), Ascaridole (24.16%), (-)-Terpinen-4-ol (2.90%), Benzene methanol αα4-trimethyl (0.89%). Data for A. arabica are not available in the literature. Also, Achillea santolinoides Lag. contain Linalool (18.27%), 2-Methylbutyl isovalerate (3.04%), Terpinen-4-ol (7.66%), Geranyl acetate (4.77%), Nerolidol (8.50%), and there is no data for A. santolinoides in the literature, so it does not allow a direct comparison. Based on the comparative analysis, it is revealed that common components in different species include Eucalyptol, which is present in our data for A. millefolium and in literature data for several species, including A. wilhelmsii subsp. wilhelmsii and A. aleppica subsp. zederbaveri. p-Cymene (or m-Cymene) is a significant component in our data for A. millefolium and A. arabica, and in literature data for A. biebersteinii. According to literature data, other species such as Achillea biebersteinii (arabica) show a high content of Piperitone and p-Cymene; Achillea wilhelmsii subsp. wilhelmsii has a very high content of Camphor (77.19%); Achillea aleppica subsp. zederbaveri contains components such as α-Terpinen and tau-Cadinol; and Achillea vermicularis shows a high content of Eucalyptol and Piperitone.

Thus, the main differences between our data and literature data lie in the composition and concentration of the major components of the essential oils from different Achillea species. Our data include unique components for some species that are not mentioned in the literature, emphasizing the importance of further research and analysis. Some components, such as Eucalyptol and p-Cymene, are present in both sources but in different concentrations and combinations with other components. This comparative analysis highlights the diversity of the chemical composition of Achillea essential oils and underscores the importance of continued research to fully understand their potential and applications.

Conclusions

I. The study revealed a significant variation in the chemical composition of essential oils from different species of Achillea, including Achillea millefolium, Achillea filipendulina, Achillea arabica, and Achillea santolinoides. This diversity is crucial for understanding the therapeutic potential of each species.

II. The essential oils were found to contain major bioactive compounds such as m-Cymene, Terpinolene, Ascaridole, Linalool, and Neomenthoglycol. These components are known for their antimicrobial, antifungal, and medicinal properties, highlighting the potential for pharmaceutical applications.

III. Each species demonstrated unique chemical profiles, which suggests tailored applications:

a) Achillea millefolium and Achillea arabica with high Ascaridole and m-Cymene content, making them promising for antimicrobial and antifungal use.

b) Achillea filipendulina showed the presence of unique compounds like Neomenthoglycol and Cyclohexane methanol, indicating potential pharmaceutical uses.

c) Achillea santolinoides is rich in Linalool and Nerolidol, which are valuable for cosmetic and aromatherapy applications.

d) Achillea millefolium and Achillea arabica with high Ascaridole and m-Cymene content, making them promising for antimicrobial and antifungal use.

e) Achillea filipendulina showed the presence of unique compounds like Neomenthoglycol and Cyclohexane methanol, indicating potential pharmaceutical uses.

f) Achillea santolinoides is rich in Linalool and Nerolidol, which are valuable for cosmetic and aromatherapy applications.

g) The presence of optical isomers such as (+)-α-Pinene and (-)-Terpinen-4-ol, particularly in Achillea filipendulina and Achillea arabica, underscores the complexity of these oils and their varying biological effects based on stereochemistry.

h) The study also highlighted differences between the current results and literature data, showing the presence of some components unique to this analysis and further emphasizing the impact of geographic and environmental factors on essential oil composition.

i) The findings from this GC-MS analysis contribute to the broader field of phytochemistry by identifying new bioactive compounds and laying the groundwork for future studies in medicine, pharmaceuticals, cosmetology, and aromatherapy.

Acknowledgments

None.

Conflict of Interest

None.

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