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STUDY OF THE COMPONENT COMPOSITION OF ESSENTIAL OILS OF *PENTAPHYLLOIDES FRUTICOSA* (L.) O. SCHWARZ (*DASIPHORA FRUTICOSA* (L.) RYBD.) RAW MATERIALS

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Pentaphylloides fruticosa (L.) O. Schwarz (Dasiphora fruticosa (L.) Rybd.) is one of the most common species in Eurasia. There are about 150 known varieties of Pentaphylloides fruticosa, which are used as an ornamental plant. The content of tannins, polyphenols, flavonoids, and macro- and microelements was detected and determined in the above-ground part of some varieties of Pentaphylloides fruticosa. Studies on the content and composition of essential oils have not been conducted.

The aim. *The aim of the work was to study the quantitative composition and identification of components of essential oil from raw materials Pentaphylloides fruticosa.*

Materials and methods. *Hydrodistillates obtained from dried raw materials of Pentaphylloides fruticosa, collected from different growing sites in Ivano-Frankivsk and Vinnytsia regions (Ukraine), were analyzed by gas chromatography-mass spectrometry.*

Research results. *Up to 91 essential oil components were identified and quantified in the studied raw materials. The content of essential oils was from 0.52 to 3.11 mL/kg, depending on the type of raw material. The predominant essential oil compounds in the raw material of Pentaphylloides fruticosa were linalool, geraniol, (E)-β-damascenone, (E)-geranylacetone, (E)-β-ionone, L-β-elemene, germacrene D, hexahydrofarnesyl acetone, phytol, benzyl benzoate. The largest amount of essential oil components was found in shoots with yellow flowers of Pentaphylloides fruticosa. The results of the study revealed strong positive correlation links (>0.9) between such pairs of compounds as L-carvone and hexahydrofarnesyl acetone, benzyl benzoate and 1,2-diphenoxyethane; L-β-pinene and α-muurolene, L-β-pinene and hexahydrofarnesyl acetone; L-bornyl acetate and L-β-elemene, L-bornyl acetate and benzyl benzoate, L-bornyl and 1,2-diphenoxyethane, D-limonene and eucalyptol, L-β-pinene and L-carvone.*

Conclusions. *In connection with the obtained research results and the identification of such compounds as linalool, geraniol, (E)-β-damascenone, (E)-geranylacetone, (E)-β-ionone, germacrene D, phytol, benzyl benzoate, it is advisable to further study the species Pentaphylloides fruticosa, its pharmacological activity and possibilities for further application in medicine.*

Keywords: *Pentaphylloides fruticosa (L.) O. Schwarz, Dasiphora fruticosa (L.) Rybd., essential oil, medicinal plant raw materials, shoots, gas chromatography-mass spectrometry*

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1. Introduction

The genus *Dasiphora* Raf. (*Pentaphylloides* Duhamel) belongs to the Rosaceae family [1, 2]. Species of the genus *Pentaphylloides* Duhamel belong to Holarctic species with a wide, discontinuous range, the main part of which covers the Far East, the mountains of Central Asia, Mongolia, China and Japan [3, 4].

Five types of *Pentaphylloides* DUHAM grow in Eurasia, namely *Pentaphylloides fruticosa* (L.) O. Schwarz, *Pentaphylloides phyllocalyx* Juz., *Pentaphylloides parvifolia* (Fisch) Juz., *Pentaphylloides dryadanthoides* Juz. and *Pentaphylloides davurica* (Nestl.) Kom., which are used as decorative [3].

Among the species represented, the most common is *Pentaphylloides fruticosa* (L.) O. Schwarz (*Dasiphora fruticosa* (L.) Rybd.) which is found in the Arctic, Central and Atlantic Europe, Scandinavia, the Caucasus, Western and Eastern Siberia, Central Asia, Japan, China, and North America [3]. It grows on rocky, dry slopes, river banks, and meadows among shrubs [5]. The plant is drought-resistant and frost-resistant, undemanding to soils, can grow on sandy and rocky soils, prefers moderately moist soils, and is light-loving, although it tolerates a little partial shade [3, 6].

Pentaphylloides fruticosa is used as an ornamental plant for gardens, parks, rockeries, and alpine slides in the form of single and group plantings. About 150 varieties of *Pentaphylloides fruticosa* for decorative purposes are known, which differ in the size and colour of flowers. Varieties with white, pale yellow, yellow and golden yellow flowers are more winter-hardy [7–9]. Rejuvenating pruning should be carried out every 5–6 years to maintain decorativeness.

In Ukraine, *Pentaphylloides fruticosa* is not an official species. In folk medicine, it is used to make vitamin tea, as the plant contains a large amount of vitamin C [3]. The content of tannins, polyphenols, flavonoids, and macro- and microelements was detected and determined in the above-ground part of some varieties of *Pentaphylloides fruticosa* [10, 11]. Studies on the content and composition of essential oils have not been conducted. Therefore, it is relevant to study the species *Pentaphylloides fruticosa* to create new medicines and introduce them into pharmaceutical and medical practice.

The purpose of our work was to study the quantitative content and identify components of essential oil from the raw material *Pentaphylloides fruticosa*.

2. Planning (methodology) of research

The stages describing the investigation of raw material samples of *Pentaphylloides fruticosa* (L.) O. Schwarz (*Dasiphora fruticosa* (L.) Rybd.) in this study are shown in Fig. 1.

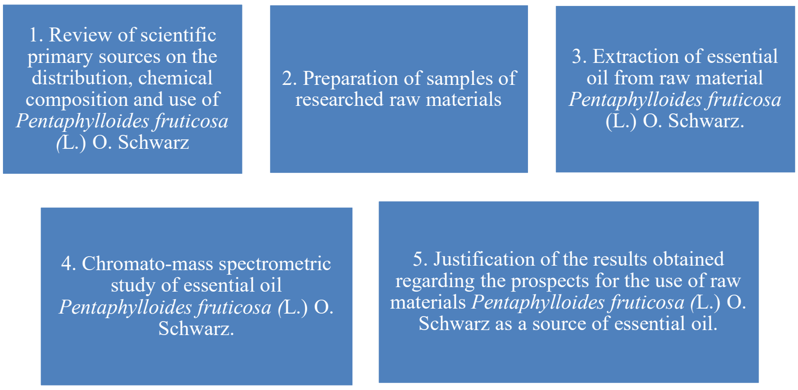

Fig. 1. Planning of research

3. Materials and methods

3. 1. Plant samples

Raw material samples of *Pentaphylloides* were prepared:

– sample 1: shoots of *Pentaphylloides fruticosa* (Shrubby Cinquefoil shoots with flowers of white color) – research plots of medicinal plants of Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine, 2022. Geographical coordinates: 48°56'45.4"N 24°41'50.2"E;

– sample 2: shoots of *Pentaphylloides fruticosa* (Shrubby Cinquefoil shoots with flowers of yellow colour) – research plots of medicinal plants of Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine, 2023. Geographical coordinates: 48°56'45.4"N, 24°41'50.2"E;

– sample 3: leaves of *Pentaphylloides fruticosa* (Shrubby Cinquefoil leaves with flowers of yellow color) – research plots of medicinal plants of Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine, 2024. Geographical coordinates: 48°56'45.4"N, 24°41'50.2"E;

– sample 4: shoots of *Pentaphylloides fruticosa* (Shrubby Cinquefoil shoots with flowers of yellow colour) – Z. Yu. Pavlyk Dendrological Park "Druzhba" Precarpathian National University named after V. Stefanyk, Ivano-Frankivsk, Ukraine, 2024. Geographical coordinates: 48°57'22.0"N, 24°38'55.1"E;

– sample 5: shoots of *Pentaphylloides fruticosa* (Shrubby Cinquefoil shoots with flowers of yellow colour) – Vinnytsia, "Garden Center Krona", Ukraine, 2023. Geographical coordinates: 49°13'30.6"N, 28°27'03.0"E;

– sample 6: shoots of *Pentaphylloides fruticosa* (Shrubby Cinquefoil shoots with flowers of yellow colour) – vicinity of the village of Viktoriv, Ivano-Frankivsk region, Ukraine, 2024. Geographical coordinates: 49°02'59.9"N, 24°37'46.3"E;

– sample 7: shoots of *Pentaphylloides fruticosa* (Shrubby Cinquefoil shoots with flowers of white colour) – Z. Yu. Pavlyk Dendrological Park "Druzhba" Precarpathian National University named after V. Stefanyk, Ivano-Frankivsk, Ukraine, 2024. Geographical coordinates: 48°57'22.0"N, 24°38'55.1"E;

– sample 8: flowers of *Pentaphylloides fruticosa* (Shrubby Cinquefoil flowers of yellow color) – research plots of medicinal plants of Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine, 2024. Geographical coordinates: 48°56'45.4"N, 24°41'50.2"E.

3. 2. Isolation of essential oil

Samples of volatile compounds were hydrodistilled from dry raw materials of *Pentaphylloides fruticosa* using the essential oil distillation method described in the European Pharmacopoeia [12]. 30.0 g of dried raw materials were distilled with 300 mL of distilled water within 2 hours.

3. 3. GC-MS analysis of volatile compounds

The study was carried out using gas chromatography-mass spectrometry with mass detection (GC/MS). The component composition of volatile compounds was analyzed on an Agilent 6890/5973 GCMS chromatograph controlled by mass spectrometry detectors (MSD) Chemstation [12, 13].

1 μL of the sample was injected at an injector temperature of 280 °C in split mode (20:1), using He as the carrier gas onto Agilent HP-5MSI column (30 m length, 0.25 mm inner diameter, 0.25 μm film thickness). The carrier gas was held at the constant flow rate of 1 mL/min. The oven was held at 50 °C for 2 min, followed by a ramp of 4 °C/min to a final temperature of 280 °C and held at 280 °C for 5 minutes [14, 15].

The MSD was operated in EI mode at 70 eV. Mass spectra were recorded in the range of 29–400 m/z with a delay time of 4 min and a scan speed of 3.8 scans per second. The data were analyzed by the deconvolution algorithm of the Agilent Masshunter Software package using different window size factors. Obtained compounds were identified by using NIST23 library with Match Factor ≥90 and by retention indexes (relative to *n*-alkanes C7–C30). The area percentages of each peak were calculated from the total areas in the chromatograms without using correction factors [15, 16].

The percentage of area of each peak was calculated from the total areas on the chromatograms without using correction factors [17, 18].

4. Results

As a result of the studies (Table 1), up to 91 essential oil components were identified in the raw material *Pentaphylloides fruticosa*. The content of essential oils was from 0.52 to 3.11 mL/kg, depending on the type of raw material. Table 2 presents the predominant components of the essential oil of *Pentaphylloides fruticosa,* which were identified during the study.

The correlation between the content of groups and individual compounds in the essential oil of *Pentaphylloides fruticosa* is shown in Table 3.

Table 1

Component composition of essential oil of raw materials *Pentaphylloides fruticosa*

Compound	RI	NIST23	Formula	Average of 1–8	Content (%) in EO samples							
					1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8	9	10	11	12	13
Monoterpene hydrocarbons												
Camphene	946	952	$C_{10}H_{16}$	0.14	0.34	0.15	0.33	0.11	0.09	0.05	0.06	0.21
L-β-Pinene	975	978	$C_{10}H_{16}$	0.06	0.04	0.02	0.05	0.02	0.24	0.02	0.02	0.03
D-Limonene	1028	1031	$C_{10}H_{16}$	0.35	0.20	0.10	0.81	0.11	0.78	0.26	0.38	0.16
α-Terpinolene	1088	1088	$C_{10}H_{16}$	0.09	0.05	0.02	0.30	0.04	0.03	0.10	0.16	0.05
Total:					0.63	0.29	1.49	0.28	1.14	0.43	0.62	0.45
Oxygenated monoterpenes												
Eucalyptol	1030	1032	$C_{10}H_{18}O$	0.06	0.02	0.03	0.14	0.04	0.16	0.03	0.08	0.01
Linalool	1100	1099	$C_{10}H_{18}O$	1.56	2.31	0.30	3.39	0.30	0.44	1.52	2.37	1.86
Camphor	1144	1145	$C_{10}H_{16}O$	0.08	0.22	0.02	0.08	0.03	0.14	0.05	0.02	0.11
α-Terpineol	1190	1189	$C_{10}H_{18}O$	0.62	0.62	0.10	1.56	0.19	0.28	0.57	1.15	0.46
Safranal	1200	1201	$C_{10}H_{14}O$	0.17	0.03	0.06	0.17	0.10	0.37	0.22	0.10	0.30
β-Cyclocitral	1221	1220	$C_{10}H_{16}O$	0.31	0.14	0.14	0.53	0.45	0.16	0.60	0.40	0.05
Nerol	1228	1228	$C_{10}H_{18}O$	0.27	0.51	0.10	0.48	0.08	0.07	0.25	0.38	0.26
L-Carvone	1244	1245	$C_{10}H_{14}O$	0.29	0.05	0.05	0.06	0.32	1.58	0.04	0.16	0.04
Geraniol	1255	1255	$C_{10}H_{18}O$	2.97	9.11	0.41	3.50	0.27	0.32	0.78	5.03	4.31
L-Bornyl acetate	1286	1285	$C_{12}H_{20}O_2$	0.59	1.06	0.55	0.51	0.62	0.46	0.37	0.37	0.76
Eugenol	1358	1357	$C_{10}H_{12}O_2$	0.13	0.14	0.04	0.05	0.04	0.19	0.44	0.08	0.05
Total:					14.21	1.80	10.47	2.44	4.17	4.87	10.14	8.21
Nor-sesquiterpenoids												
(*E*)-β-Damascenone	1386	1386	$C_{13}H_{20}O$	1.28	0.87	0.63	2.47	1.51	0.86	1.05	1.96	0.93
(*E*)-Geranylacetone	1454	1453	$C_{13}H_{22}O$	1.40	1.24	0.99	1.67	0.77	1.77	2.56	1.50	0.67
(*E*)-β-Ionone	1488	1486	$C_{13}H_{20}O$	3.83	3.90	1.88	4.73	4.01	2.21	8.20	4.31	1.37
Total:					6.01	3.50	8.87	6.29	4.84	11.81	7.77	2.97
Sesquiterpene hydrocarbons												
L-β-Elemene	1394	1391	$C_{15}H_{24}$	0.74	1.43	0.76	0.49	0.76	0.41	0.46	0.47	1.17
β-Copaene	1421	1421	$C_{15}H_{24}$	0.32	0.49	0.29	0.17	0.41	0.18	0.21	0.38	0.41
Caryophyllene	1422	1419	$C_{15}H_{24}$	0.27	0.23	0.23	0.23	0.36	0.16	0.18	0.51	0.22
Germacrene D	1484	1481	$C_{15}H_{24}$	2.70	3.72	2.68	1.71	4.62	1.71	2.06	2.09	3.02
α-Muurolene	1502	1499	$C_{15}H_{24}$	0.45	0.54	0.19	0.07	0.27	2.02	0.11	0.12	0.32
D-δ-Cadinene	1525	1524	$C_{15}H_{24}$	0.16	0.05	0.16	0.19	0.26	0.28	0.07	0.17	0.11
Total:					6.46	4.31	2.86	6.68	4.76	3.09	3.74	5.25
Oxygenated sesquiterpenes												
Caryophyllene oxide	1586	1581	$C_{15}H_{24}O$	0.25	0.20	0.22	0.25	0.22	0.15	0.20	0.60	0.18
τ-Cadinol	1644	1640	$C_{15}H_{26}O$	0.24	0.06	0.08	1.43	0.05	0.17	0.05	0.03	0.05
β-Eudesmol	1653	1649	$C_{15}H_{26}O$	0.40	0.06	0.38	0.19	0.83	1.52	0.07	0.08	0.11
Germacra-4(15).5.10(14)-trien-1β-ol	1689	1690	$C_{15}H_{22}O$	0.23	0.20	0.26	0.15	0.26	0.16	0.12	0.45	0.21
Hexahydrofarnesyl acetone	1846	1844	$C_{18}H_{36}O$	3.25	0.03	1.37	1.90	1.84	16.30	1.43	2.19	0.91
Farnesyl acetone	1919	1918	$C_{18}H_{32}O$	1.40	0.84	1.31	0.94	0.64	1.77	3.22	0.85	1.09
Total:					1.39	3.62	4.86	3.84	20.07	5.09	4.2	2.55
Diterpenoids												
Isophytol	1948	1948	$C_{20}H_{40}O$	0.50	0.09	0.28	0.60	0.51	1.26	0.25	0.47	0.13
Kaurene	2040	2034	$C_{20}H_{32}$	0.09	0.02	0.00	0.18	0.02	0.03	0.08	0.38	0.00
Phytol	2109	2114	$C_{20}H_{40}O$	14.18	3.55	16.55	25.26	31.87	8.85	6.18	18.73	2.47
Total:					3.66	16.83	26.04	32.4	10.14	6.51	19.58	2.60

Continuation of Table 1

1	2	3	4	5	6	7	8	9	10	11	12	13
Aromatic compounds												
Benzaldehyde	958	962	C_7H_6O	0.23	0.13	0.09	0.17	0.25	0.55	0.32	0.20	0.11
o-Cymene	1024	1022	$C_{10}H_{14}$	0.37	0.09	0.10	1.12	0.52	0.29	0.25	0.45	0.11
Benzeneacetaldehyde	1043	1045	C_8H_8O	0.38	0.47	0.18	0.25	0.30	0.55	0.54	0.28	0.51
Methyl salicylate	1194	1192	$C_8H_8O_3$	0.24	0.26	0.03	0.25	0.05	0.89	0.09	0.29	0.09
Dehydro-ar-ionene	1354	1354	$C_{13}H_{16}$	1.58	0.28	0.85	4.40	1.83	1.41	0.39	3.12	0.35
(*Z*)-3-Hexenyl benzoate	1572	1570	$C_{13}H_{16}O_2$	0.13	0.04	0.06	0.04	0.24	0.42	0.19	0.05	0.02
Benzophenone	1628	1635	$C_{13}H_{10}O$	0.20	0.22	0.14	0.15	0.16	0.31	0.19	0.17	0.27
Benzyl benzoate	1766	1763	$C_{14}H_{12}O_2$	8.81	21.03	7.87	6.81	6.23	5.56	4.75	5.57	12.64
1.2-Diphenoxyethane	1805	1811	$C_{14}H_{14}O_2$	0.27	0.74	0.21	0.20	0.21	0.10	0.12	0.18	0.43
2-Ethylhexyl salicylate	1807	1807	$C_{15}H_{22}O_3$	0.55	0.71	0.51	0.59	0.44	0.36	0.37	0.55	0.85
Phthalic acid	1870	1869	$C_8H_6O_4$	2.82	3.75	3.06	2.31	2.29	1.42	1.76	2.42	5.58
Dibutyl phthalate	1963	1965	$C_{16}H_{22}O_4$	4.64	8.34	5.52	2.53	2.67	1.30	2.21	3.71	14.56
Total:					36.06	18.62	18.82	15.19	13.16	11.18	16.99	35.52
Aliphatic compounds												
Hexanal	800	801	$C_6H_{12}O$	2.26	1.15	1.83	1.42	4.23	1.27	3.62	3.47	1.06
1-Hexanol	864	868	$C_6H_{14}O$	0.10	0.03	0.08	0.03	0.16	0.05	0.12	0.20	0.03
2-Hexenal	848	851	$C_6H_{10}O$	1.27	0.49	0.45	1.51	2.48	0.52	2.75	1.63	0.34
Heptanal	901	901	$C_7H_{14}O$	0.41	0.21	0.45	0.26	0.74	0.31	0.54	0.42	0.20
(*E*)-2-Heptenal	954	958	$C_7H_{12}O$	0.08	0.08	0.06	0.10	0.13	0.04	0.10	0.10	0.05
2.3-Octanedione	983	984	$C_8H_{12}O_2$	0.40	0.25	0.27	0.63	0.54	0.31	0.54	0.54	0.12
6-Methyl-5-hepten-2-one	986	986	$C_8H_{14}O$	0.15	0.12	0.08	0.20	0.11	0.23	0.24	0.17	0.04
Decane	999	1000	$C_{10}H_{22}$	0.18	0.12	0.14	0.16	0.04	0.07	0.55	0.18	0.18
Octanal	1002	1003	$C_8H_{16}O$	0.45	0.29	0.31	0.92	0.64	0.17	0.23	0.85	0.22
(*E*,*E*)-2.4-Heptadienal	1010	1012	$C_7H_{10}O$	0.79	0.47	0.28	1.36	1.03	0.29	1.29	1.33	0.24
(*E*)-2-Octenal	1057	1060	C_8H1_4O	0.12	0.08	0.10	0.07	0.17	0.10	0.15	0.20	0.09
1-Octanol	1070	1070	$C_8H_{18}O$	0.11	0.09	0.07	0.10	0.12	0.16	0.16	0.15	0.07
Nonanal	1104	1104	$C_9H_{18}O$	4.47	3.38	4.24	5.36	4.86	1.76	8.53	5.35	2.25
(*E*,*E*)-2.6-Nonadienal	1153	1153	$C_9H_{14}O$	0.11	0.09	0.06	0.08	0.09	0.27	0.13	0.08	0.05
(*E*)-2-Nonenal	1159	1162	$C_9H_{16}O$	0.16	0.11	0.14	0.12	0.17	0.18	0.19	0.19	0.14
1-Nonanol	1171	1173	$C_9H_{20}O$	0.14	0.16	0.07	0.12	0.08	0.24	0.13	0.19	0.11
(*Z*)-Butyric acid	1186	1187	$C_4H_8O_2$	0.16	0.16	0.31	0.05	0.27	0.04	0.05	0.24	0.13
Dodecane	1199	1200	$C_{12}H_{26}$	0.37	0.20	0.81	0.15	0.36	0.56	0.34	0.17	0.38
Decanal	1205	1206	$C_{10}H_{20}O$	0.74	0.69	0.75	0.72	1.04	0.45	0.83	0.85	0.56
(*E*)-2-Decenal	1262	1263	$C_{10}H_{18}O$	0.15	0.11	0.13	0.16	0.16	0.05	0.33	0.19	0.08
Pelargonic acid	1270	1273	$C_9H_{18}O_2$	1.02	0.17	0.58	0.37	0.10	4.34	1.18	0.83	0.62
(*E*,*Z*)-2.4-Decadienal	1293	1295	$C_{10}H_{16}O$	0.54	0.60	0.59	0.28	0.49	0.12	0.71	0.75	0.74
Undecanal	1307	1307	$C_{11}H_{22}O$	0.79	0.92	0.64	0.49	0.26	0.18	1.82	0.96	1.03
(*E*,*E*)-2.4-Decadienal	1316	1317	$C_{10}H_{16}O$	1.73	1.74	1.86	1.07	1.99	0.38	2.49	2.46	1.83
Capric acid	1367	1373	$C_{10}H_{20}O_2$	1.03	0.07	2.26	0.21	0.05	2.47	1.86	0.23	1.06
Tetradecane	1399	1400	$C_{14}H_{30}$	0.98	1.25	1.32	0.55	0.55	0.68	1.43	0.92	1.11
1-Dodecanol	1474	1474	$C_{12}H_{26}O$	0.18	0.14	0.20	0.19	0.21	0.15	0.13	0.16	0.22
Tridecanal	1511	1512	$C_{13}H_{26}O$	1.32	0.72	3.01	0.61	1.57	1.33	1.17	0.74	1.42
Lauric acid	1566	1567	$C_{12}H_{24}O_2$	1.82	0.13	1.96	1.17	0.01	6.45	1.02	1.66	2.14
1-Tridecene	1591	1292	$C_{13}H_{26}$	0.10	0.22	0.18	0.02	0.02	0.01	0.02	0.02	0.31
Tetradecanal	1612	1613	$C_{14}H_{28}O$	0.33	0.32	0.31	0.28	0.19	0.22	0.32	0.59	0.43
Pentadecanal	1715	1715	$C_{15}H_{30}O$	2.73	2.81	4.15	1.77	2.08	1.65	4.02	2.51	2.87
Hexadecanal	1816	1817	$C_{16}H_{32}O$	0.49	0.19	0.23	0.34	0.13	2.03	0.26	0.39	0.38
n-Heptadecanol-1	1879	1984	$C_{17}H_{36}O$	0.62	0.13	0.27	0.21	0.26	3.08	0.42	0.13	0.47
Nonadecane	1899	1900	$C_{19}H_{40}$	0.33	0.49	0.20	0.50	0.09	0.13	0.28	0.58	0.35
Methyl palmitate	1926	1926	$C_{17}H_{34}O_2$	0.44	0.82	1.75	0.17	0.07	0.56	0.15	0.12	0.26
Palmitic acid	1962	1968	$C_{16}H_{32}O_2$	1.92	0.18	6.75	0.02	0.00	2.94	0.05	0.02	3.66
Octadecanal	2020	2021	$C_{18}H_{36}O$	0.61	0.73	0.34	1.23	0.11	0.07	0.62	1.22	0.51
1-Octadecanol	2079	2082	$C_{18}H_{38}O$	0.58	0.18	1.03	0.29	1.13	0.38	0.93	0.22	0.46
Heneicosane	2095	2100	$C_{21}H_{44}$	4.10	2.50	5.10	0.72	1.03	4.18	12.94	1.10	5.24

Continuation of Table 1

1	2	3	4	5	6	7	8	9	10	11	12	13
Linolenic acid	2096	2099	$C_{18}H_{30}O_2$	0.54	0.52	1.85	0.15	1.32	0.12	0.09	0.07	0.22
Hexacosane	2594	2600	$C_{26}H_{54}$	3.20	7.73	3.48	0.97	0.61	0.92	0.88	1.46	9.51
Total:					30.84	48.69	25.13	29.69	39.46	53.61	33.64	41.18
Others												
Furfural	830	833	$C_5H_4O_2$	0.04	0.02	0.02	0.02	0.02	0.08	0.04	0.02	0.12
2-n-Butyl furan	891	893	$C_8H_{12}O$	0.07	0.07	0.06	0.04	0.09	0.08	0.08	0.10	0.03
2-Pentenyl-furan	991	993	$C_9H_{12}O$	2.03	0.59	2.18	1.25	2.94	1.90	3.06	3.11	1.06
(*Z*)-2-(2-Pentenyl)furan	1001	1002	$C_9H_{12}O$	0.10	0.05	0.07	0.10	0.10	0.18	0.21	0.08	0.03
Total:					0.73	2.33	1.41	3.15	2.24	3.39	3.31	1.24
Content of EO, mL/kg					0.52	0.54	1.31	3.11	0.96	1.94	2.63	0.46

Table 2

The predominant components of the essential oil of *Pentaphylloides fruticosa* were analyzed by GC-MS

Groups of compounds	Content (%) in EO samples							
	1	2	3	4	5	6	7	8
Monoterpene hydrocarbons	0.63	0.29	1.49	0.28	1.14	0.43	0.62	0.45
Oxygenated monoterpenes	14.21	1.80	10.47	2.44	4.17	4.87	10.14	8.21
Nor-Sesquiterpenoids	6.01	3.50	8.87	6.29	4.84	11.81	7.77	2.97
Sesquiterpene hydrocarbons	6.46	4.31	2.86	6.68	4.76	3.09	3.74	5.25
Oxygenated sesquiterpenes	1.39	3.62	4.86	3.84	20.07	5.09	4.20	2.55
Diterpenoids	3.66	16.83	26.04	32.4	10.14	6.51	19.58	2.60
Aromatic compounds	36.06	18.62	18.82	15.19	13.16	11.18	16.99	35.52
Aliphatic compounds	30.84	48.69	25.13	29.69	39.46	53.61	33.64	41.18
Others	0.73	2.33	1.41	3.15	2.24	3.39	3.31	1.24
Total:	99.99	99.99	99.95	99.96	99.98	99.98	99.99	99.97

Table 3

Correlation between the content of groups and individual compounds in the essential oil of *Pentaphylloides fruticosa*

Couples		Correlation coefficient
1	2	3
L-β-Pinene	L-Carvone	0.96
	α-Muurolene	0.97
	Hexahydrofarnesyl acetone	0.97
	Methyl salicylate	0.95
α-Terpinolene	α-Terpineol	0.95
	(*E*)-β-Damascenone	0.90
D-Limonene	Eucalyptol	0.96
Linalool	α-Terpineol	0.92
	Nerol	0.94
L-Bornyl acetate	L-β-Elemene	0.96
	Benzyl benzoate	0.96
	1.2-Diphenoxyethane	0.96
Eugenol	Farnesyl acetone	0.93
(*E*)-β-Damascenone	o-Cymene	0.92
L-β-Elemene	Benzyl benzoate	0.94
	1.2-Diphenoxyethane	0.95
L-Carvone	α-Muurolene	0.95
	β-Eudesmol	0.92
	Hexahydrofarnesyl acetone	0.99
	Isophytol	0.91
	Methyl salicylate	0.90
Caryophyllene	Germacra-4(15).5.10(14)-trien-1β-ol	0.92
α-Muurolene	Hexahydrofarnesyl acetone	0.94
	Methyl salicylate	0.91
Caryophyllene oxide	Kaurene	0.92
o-Cymene	Dehydro-ar-ionene	0.92
β-Eudesmol	(*Z*)-3-Hexenyl benzoate	0.90

Continuation of Table 3

1	2	3
Hexahydrofarnesyl acetone	Isophytol	0.92
	Methyl salicylate	0.92
Benzyl benzoate	1.2-Diphenoxyethane	0.99
Phthalic acid	Dibutyl phthalate	0.99
2-Ethylhexyl salicylate	Phthalic acid	0.93
	Dibutyl phthalate	0.90

5. Discussion

The essential oil of the shoots, leaves, and flowers of *Pentaphylloides fruticosa* was analyzed for the first time. It was found that almost all samples of *Pentaphylloides fruticosa* raw material were characterized by a high content of essential oils. The highest content of essential oil is characterized by shoots with yellow flowers of *Pentaphylloides fruticosa* (3.11 ml/kg), harvested in the Z. Yu. Pavlyk Dendrological Park «Druzhba» of the V. Stefanyk Precarpathian National University in 2024. The least amount of essential oil is contained in sample 8 (yellow flowers) of *Pentaphylloides fruticosa* (0.46 mL/kg), collected in the experimental plots of medicinal plants of Ivano-Frankivsk National Medical University in 2024.

The studied raw material samples contain chemical compounds of the following classes: monoterpene hydrocarbons (0.28–1.49 %), oxygenated monoterpenes (1.80–14.21 %), nor-sesquiterpenoids (2.97–11.81 %), sesquiterpene hydrocarbons (2.86–6.68 %), oxygenated sesquiterpenes (2.55–20.07 %), diterpenoids (2.60–26.04 %), aromatic compounds (11.18–36.06 %), aliphatic compounds (25.13–53.61 %), others (0.73–3.39 %).

The quantitative content and chemical composition of the essential oil in *Pentaphylloides fruticosa* varies depending on the type of soil, conditions, and place of growth. The research found that the highest content of essential oil is found in shoots with yellow and white flowers harvested in the Z. Yu. Pavlyk Dendrological Park «Druzhba» of the V. Stefanyk Precarpathian National University in 2024, 3.11 mL/kg and 2.63 mL/kg, respectively. The level of essential oil in the shoots of *Pentaphylloides fruticosa* with yellow flowers, harvested on the outskirts of the village of Viktoriv, Ivano-Frankivsk region in 2024 – 2.63 ml/kg.

In samples of raw materials *Pentaphylloides fruticosa* shoots with white flowers, harvested in the experimental areas of medicinal plants of Ivano-Frankivsk National Medical University in 2022, 0.52 mL/kg of essential oils were found, and in shoots with yellow flowers, collected in 2023, 0.54 ml/kg, while in leaves with yellow flowers, collected in this area, but in 2024, 1.31 mL/kg.

The highest content of monoterpene hydrocarbons (0.63 %), in particular camphene (0.33 %), D-limonene (0.81 %), α-terpinolene (0.30 %), was found in sample No. 3. Oxygenated monoterpenes (linalool (3.39 %), α-terpineol (1.56 %) were also found there. However, sample No. 1 contains more oxygenated monoterpenes: camphor (0.22 %), nerol (0.51 %), geraniol (9.11 %), L-bornyl acetate (0.59 %). Sample 6 contains nor-sesquiterpenoids (11.81 %): (*E*)-geranylacetone (2.56 %), (*E*)-β-ionone (8.20 %), aliphatic compounds (53.61 %): 2-hexenal (2.75 %), decane (0.55 %), nonanal (8.53 %), (*E*)-2-nonenal (0.19 %), (*E*)-2-decenal (0.33 %), capric acid (1.86 %), heneicosane (12.94 %). Oxygenated sesquiterpenes were found in the largest amount (20.07 %) in sample No. 5: β-eudesmol (1.52 %), hexahydrofarnesyl acetone (16.30 %). Diterpenoids were found in the largest amount (32.4%) in Sample №4 and were represented by phytol (31.87 %). Sample No. 8 (Shrubby Cinquefoil flowers of yellow colour collected and harvested from research plots of medicinal plants of Ivano-Frankivsk National Medical University, Ivano-Frankivsk, Ukraine, 2024) contains a high content of aromatic compounds (35.52 %), namely benzyl benzoate (12.64 %), 2-ethylhexyl salicylate (0.85 %), phthalic acid (5.58 %) and dibutyl phthalate (14.56 %).

The quantitative content and chemical composition of the essential oil in *Pentaphylloides fruticosa* varies depending on the type of soil, conditions, and place of growth. The obtained results of the studies prove that almost all samples of raw materials of *Pentaphylloides fruticosa*, which were collected and harvested at different times and from different places, contain a fairly high content of essential oil components, 99.96–99.99 %.

The main components of the essential oil in *Pentaphylloides fruticosa* samples are: D-limonene (0.10–0.81 %), linalool (1.86–3.39 %), geraniol (0.27–9.11 %), (*E*)-β-damascenone (0.63–1.96 %), (*E*)-geranylacetone (0.67–2.56 %), (*E*)-β-ionone (1.37– 8.20 %), germacrene D (1.71–4.62 %), hexahydrofarnesyl acetone (0.03–16.30 %), phytol (2.47–31.87 %), dehydro-arionene (0.28–4.40 %), benzyl benzoate (4.75–21.03 %), phthalic acid (1.42–5.58 %), dibutyl phthalate (1.30–14.56 %), hexanal (1.06–4.23 %), nonanal (1.76–8.53 %), nauric acid (0.01–6.45 %), heneicosane (0.72–12.94 %), and hexacosane (0.61–7.73 %).

The results of the analysis (Table 3) revealed strong positive correlation links (>0.9) between such pairs of compounds as: L-carvone and hexahydrofarnesyl acetone, benzyl benzoate and 1,2-diphenoxyethane (r=0.99); L-β-pinene and α-muurolene, L-β-pinene and hexahydrofarnesyl acetone (r=0.97); L-Bornyl acetate and L-β-elemene, L-bornyl acetate and benzyl benzoate, L-bornyl and 1,2-diphenoxyethane, D-limonene and eucalyptol, L-β-pinene and L-carvone (r=0.96).

The mutual influence of some components on others allows the essential oil to exhibit its biological activity. For example, linalool has biological properties that include antimicrobial, anti-inflammatory, anticancer, and antioxidant effects. Multiple *in vivo* studies have demonstrated its influence on the central nervous system. Linalool serves an essential function in nature by participating in the intricate pollination mechanisms of various plant species, aiding in their reproduction and survival. Additionally, linalool is a crucial component in the industrial synthesis of fragrance compounds such as geraniol, nerol, citral, and their derivatives, as well as a key precursor in producing vitamins A and E. Furthermore, its well-documented insect-repelling properties highlight its potential in environmentally friendly pest control strategies [19, 20]. Phytol is a naturally occurring herbal phytochemical and phytoconstituent that is widely distributed in nature. It is a branched-chain unsaturated alcohol found in all plants as a component of chlorophyll. This acyclic diterpene alcohol exhibits a broad spectrum of biological activities, including cytotoxic, anti-inflammatory, anti-diabetic, anti-hyperalgesic, antimicrobial, antifungal, anti-tumor, anti-mutagenic, anticonvulsant, antispasmodic, anxiolytic, and antidepressant properties. Additionally, phytol and its derivatives have been linked to antibiotic chemotherapy, lipid regulation, immune modulation, hair growth stimulation, and anti-scratching behavioural effects [21, 22]. The role of phytol in human health is significant, and it is also being explored as a potential drug candidate for various conditions, including chronic polyneuropathy (CP), Refsum's disease (RD), Zellweger's disease with hyperpipecolic acidemia (ZDHA). Moreover, phytol serves as an essential biomarker for these and related disorders [23, 24].

During the research, such biologically active substances as linalool, geraniol, (*E*)-β-damascenone, (*E*)-geranylacetone, (*E*)-β-ionone, germacrene D, phytol, benzyl benzoate were identified, which indicates the feasibility of conducting further pharmacological studies of the raw material of *Pentaphylloides fruticosa* will study its antioxidant, wound-healing, antibacterial, anti-inflammatory, and antitumor properties.

As a result of studying the component composition of essential oils of flowers, shoots, and leaves of *Pentaphylloides fruticosa*, 2-pentylfuran was discovered, which belongs to the class of furans, in which hydrogen in position 2 is replaced by a pentyl group. It plays the role of an *Aspergillus* metabolite, an essential oil component, an insect repellent, a flavouring agent, a plant growth promoter, and a bacterial metabolite.

Practical Relevance. New data on the chemical composition of volatile fractions in the raw materials of *Pentaphylloides fruticosa have been obtained.* Most of these compounds were identified in these raw materials for the first time. This provides a basis for further study of these raw materials for developing new plant-based medicinal products.

Research limitations. In the GC/MS method, the obtained mass spectra of the compounds were compared with the spectra from the database library; therefore, it is likely that not all compounds were identified. Only raw materials of Ukrainian origin were studied.

Prospects for further research. Considering the obtained research results and the identification of such compounds as linalool, geraniol, (*E*)-β-damascenone, (*E*)-geranylacetone, (*E*)-β-ionone, germacrene D, phytol, benzyl benzoate, it is advisable to further study the species *Pentaphylloides fruticosa*, its pharmacological activity and possibilities for further application in medicine. It's advisable to study the raw materials from other countries.

6. Conclusions

The component composition and essential oil content of raw materials (shoots, leaves, flowers) of *Pentaphylloides fruticosa* (L.) O. Schwarz, collected from different growing locations in Ivano-Frankivsk and Vinnytsia regions (Ukraine), were studied by gas chromatography-mass spectrometry with mass detection. Up to 91 essential oil components were identified and quantified in the studied raw materials. The content of essential oils was from 0.52 to 3.11 mL/kg, depending on the type of raw material.

The largest amount of essential oil components was found in shoots with yellow flowers of *Pentaphylloides fruticosa*. Strong positive correlation links (>0.9) were found between such pairs of compounds as: L-carvone and hexahydrofarnesyl acetone, benzyl benzoate, 2-diphenoxyethane; L-β-pinene and α-murolene, L-β-pinene and hexahydrofarnesyl acetone; L-bornyl acetate and L-β-elemen, L-bornyl acetate and benzyl benzoate, L-bornyl and 1,2-diphenoxyethane, D-limonene and eucalyptol, L-β-pinene and L-carvone.

Conflicts of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this article.

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Data availability

Data will be made available at a reasonable request.

Use of artificial intelligence

The authors confirm they did not use artificial intelligence technologies when creating the current work.

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