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Chemical Composition of Essential Oils of *Dahlia imperialis* (Asteraceae) Growing Wild in Costa Rica

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Abstract. *Dahlia* is a genus of flowering plants of about 35 to 40 species, distributed mainly in Mesoamerica. The aim of this work was to study the chemical composition of the leaflet and capitulum essential oils of *D. imperialis* growing wild in Costa Rica. The essential oils were obtained by hydrodistillation in a modified Clevenger apparatus. The chemical composition of the oils was performed by capillary gas chromatography with a flame detector (GC-FID) and gas chromatography-mass spectrometry (GC-MS) using the retention indices on a DB-5 type capillary column in addition to mass spectral fragmentation patterns. A total of 131 compounds were identified, accounting for 96.5-99.3 % of the total amount of the oils. The major constituents in the leaflet oil were β-pinene (35.2 %), α-phellandrene (21.9 %), α-pinene (18.0 %), *p*-cymene (8.3 %), limonene (4.3 %) and γ-muurolene (3.9 %). The major constituents in the capitulum (flower head) oil were β-pinene (27.7 %), α-phellandrene (26.2 %), α-pinene (12.4 %), β-phellandrene (6.6 %), limonene (5.6 %), (*E*)-β-ocimene (2.9 %), and germacrene D (2.2 %). This is the first report about the chemical composition of essential oils from *D. imperialis.*
Keywords: *Dahlia imperialis*; essential oils; β-pinene; α-phellandrene; α-pinene; GC-MS.

Resumen. *Dahlia* es un género de plantas floríferas que consta de 35 a 40 especies, distribuidas principalmente en Mesoamérica. El objetivo de este trabajo fue determinar la composición química de los aceites esenciales de hojuelas e inflorescencias de *D. imperialis* creciendo silvestre en Costa Rica. La extracción del aceite se efectuó por hidrodestilación con un equipo Clevenger modificado. La composición química del aceite se analizó mediante las técnicas de cromatografía gaseoso-líquida con detector de ionización de llama (GC-FID) y de cromatografía gaseoso-líquida acoplada a un detector selectivo de masas (GC-MS). Se utilizaron índices de retención obtenidos en una columna capilar tipo DB-5 y se compararon con los patrones de fragmentación de masas. Se identificaron en total 131 compuestos, correspondientes a 96.5-99.3 % de los constituyentes totales. Los componentes mayoritarios del aceite de los foliolos fueron β-pineno (35.2 %), α-felandreno (21.9 %), α-pineno (18.0 %), *p*-cimeno (8.3 %), limoneno (4.3 %) y γ-muuroleno (3.9 %). Los componentes mayoritarios del aceite de los capítulos florales fueron β-pineno (27.7 %), α-felandreno (26.2 %), α-pineno (12.4 %), β-felandreno (6.6 %), limoneno (5.6 %), (*E*)-β-ocimeno (2.9 %) y germacreno D (2.2 %). Este es el primer informe acerca de la composición química de aceites esenciales de *D. imperialis.*
Palabras clave: *Dahlia imperialis*; aceites esenciales; β-pineno; α-felandreno; α-pineno; GC-MS.

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Introduction

Asteraceae –the 'daisy' family– is one of the largest flowering plant families on Earth. It has a cosmopolitan distribution, more than 1600 genera, and ca. 24000 accepted species which are mostly herbaceous and shrubby plants, with few tree species [1,2]. This family is particularly well-represented in Mexico and Central America. The typical Asteraceous plant is characterized by composite flower heads (the capitula) and one-seeded achene fruits. Some species of diverse genera of Asteraceae are economically and ecologically important. Many plants are utilized in horticulture as ornamentals and as a source of insecticide substances, while others are of great significance as herbal medicines. Around the world, several species are used as a source of food, for example, *Cynara cardunculus* L., artichoke, *Helianthus annuus* L., sunflower, *Lactuca sativa* L., lettuce, *Smallanthus sonchifolius* (Poepp.) H. Rob., 'yacón' [3], and some are used as spices, like *Artemisia dracunculus* L., tarragon, and *Tagetes lucida* Cav., 'pericón' or 'Mexican tarragon' (in Mesoamerica, this plant can be a substitute for tarragon) [4,5].

Dahlia Cav. is a genus included in the tribe Coreopsideae, composed of about 35-40 species, native to the higher elevations of Mexico, Central America, and Colombia. *Dahlia imperialis* Roezl ex Ortgies is a large perennial herbaceous shrub about 2 to 6 m tall. The Aztecs named it 'xicamiti' and 'acocoxóchitl', the latter meaning water cane because its hollow stems are filled with water. Some regional hunters take advantage of this situation and use it as a source of water [6]. This plant has a distributional range from southern Mexico to northern South America [7]. In 1963, dahlia (*Dahlia* spp.) was declared the national flower of Mexico by presidential decree [8,9]. This wonder that nature gives us, according to Castro-Castro et al. [10] corresponds to the species *D. coccinea* Cav. which appears beautifully illustrated on *folium 34r* of the *Libellus de medicinalibus Indorum herbis* ('Little Book about Indians medicinal herbs'), known as 'Códice de la Cruz - Badiano', a manuscript dating from 1552, which compiles remedies for the treatment of various diseases, considered the oldest American herbalist [11-13]. In Costa Rica, *D. imperialis* is found in the uplands and wet mountains, occurring at elevations between 1300 and 2700 meters. It is common in roadsides and open areas and it is known vernacularly as 'dalia' and 'catalina' [14]. Leaves are 50-90 cm long, opposite bipinnate or tripinnate divided. Robust plants bear many suberect flower heads, usually on long peduncles. The ray flowers have pubescent tubes, pale pink or lavender to bright purple-colored and the disc flowers are yellow [7,15,16] (see Fig.1).

In the Kekchí area of Guatemala, the young leaves of *D. imperialis* are cooked as greens and once boiled are drained before being consumed. They can be fried with lard or oil [17] and can be seasoned with pepita (*Cucurbita* spp. seeds) and chili. The leaflets can be eaten after being cooked with beans and eggs [18]. In Honduras, the water accumulated in the stems is taken as a remedy against urinary tract infections, kidney troubles, and for cleansing the eyes [19].

Fig. 1. *Dahlia imperialis* blooming in Costa Rica. (Photography by J. F. Cicció).

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Scarce phytochemical investigations have been performed on *D. imperialis*. Acetylenic substances have been isolated and identified from roots and tubers [20]; several flavonoids were determined by Giannasi [21]. From leaves, Booth et al. [22] and more recently Castro-Osorio [23] reported a nutritional characterization of samples from Guatemala (proximate composition, mineral content, and total carotenoid amount). One of the most distinctive features in the biochemistry of the Asteraceae is the production of important storage polysaccharides of D-fructose instead of D-glucose. These unusual polysaccharides are known as fructans. They are found in nature as oligosaccharides with up to 10 units and as polysaccharides with up to 50 units. The best-known fructan is inulin (used pharmaceutically as a dietary fiber with prebiotic benefits, and for patients with metabolic disorders) isolated for the first time from the tubers of *Inula helenium* L. in the 19^{th} century [24-26]. In Colombia, Bernal et al. [27] extracted and isolated inulin from the tubers of *D. imperialis*, with a yield of 13.8% on a dry basis. For a recent review of its physiological functions and applications in the pharmaceutical industry, see Wan et al. [28].

To the best of our knowledge, no previous reports on the chemical composition of essential oils of *D. imperialis* have been published. This prompted us to carry out analyses of the chemical composition of leaflet and capitulum oils of this species, mainly because it has been used as a traditional food source in some Mesoamerican regions.

Experimental

Plant material

The aerial parts of *Dahlia imperialis* were collected during the flowering stage in December 2017 and January 2018, in the locality of San Rafael de Montes de Oca, province of San José (9º56'38"N, 84º01'19"W), Costa Rica, at an elevation of 1310 m. The plant was identified by Carlos O. Morales, School of Biology, University of Costa Rica (UCR). A voucher specimen (CCC20-2711) was deposited in the Herbarium of the UCR.

Isolation of the essential oils

The oils were isolated from fresh plant material by hydrodistillation at atmospheric pressure, for 3 h using a circulatory Clevenger-type apparatus. The distilled oils were collected and dried over anhydrous sodium sulfate, filtered, and stored between 0 °C and 10 °C in the dark, until further analysis. The essential oil yields (v/w) were 0.14 % (leaflet), and 0.08 % (capitulum).

Gas chromatography (GC-FID)

The collected essential oils were analyzed by gas chromatography with a flame ionization detector (GC-FID) using a Shimadzu GC-2014 gas chromatograph. The data were obtained on a 5 % phenyl 95 % dimethylpolysiloxane type fused silica capillary column (30 m x 0.25 mm; film thickness 0.25 µm; MDN-5S, Supelco). The GC integrations were performed with a LabSolutions®, Shimadzu GC Solution Chromatography Data System software version 2.3. The operating conditions used were carrier gas N_2, flow 1.0 mL/min; oven temperature program: (60 to 280 °C) at 3 °C/min, 280 °C (2 min); sample injection port temperature 250 °C; detector temperature 280 °C; split 1:60.

Gas chromatography-mass spectrometry (GC-MS)

The analysis by gas chromatography coupled to the mass selective detector (GC-MS) was carried out using a Shimadzu GCMS-QP2010 SE apparatus and GCMSsolution® software version 4.20, with Wiley 139, NIST computerized databases. The data were obtained on a 5% phenyl 95% dimethylpolysiloxane equivalent fused silica capillary column (30 m x 0.25 mm; film thickness 0.25 µm; SH-Rxi-5Sil MS, low polarity crossbond® silarylene phase). The operating conditions used were carrier gas He, flow 1.4 mL/min; oven temperature program: (60 to 280 °C) at 3 °C/min; sample injection port temperature 250 °C; detector temperature 260 °C; ionization voltage: 70 eV; ionization current 60 µA; scanning speed 0.5 s over 35 to 400 Da range; split 1:70.

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Compound identification

Identification of individual oil components was based on a comparison of their linear retention indices which were calculated in relation to a homologous series of *n*-alkanes, on a 5 % phenyl 95 % dimethylpolysiloxane type column [29], and by comparison of their mass spectral fragmentation patterns with those published in the literature [30-32], or those of our own database or comparing their mass spectra with those available in the computerized databases (NIST 107 and Wiley 139) or in a web source [33]. To obtain the retention indices for each peak, 0.1μL of the *n*-alkane mixture (Sigma, C_8-C_{32} standard mixture) was injected under the same experimental conditions reported above. Integration of the total chromatogram (GC-FID), expressed as area percent, without correction factors, has been used to obtain quantitative compositional data.

Results and discussion

The chemical composition of leaflet and capitulum oils of *Dahlia imperialis* from Costa Rica is summarized in Table 1. Eighty-six compounds were identified in the essential oil from leaflets. This oil consisted largely of monoterpene hydrocarbons (91.4 %) with a lesser amount of sesquiterpene hydrocarbons (5.5 %) and a minute amount (1.9 %) of oxygenated derivatives (Fig. 2). The major constituents of leaflet oil were β-pinene (35.2 %), α-phellandrene (21.9 %), α-pinene (18.0 %), *p*-cymene (8.3 %), limonene (4.3 %), and γ-muurolene (3.9 %).

Table 1. Chemical composition of essential oils isolated from leaflets and capitula of *Dahlia imperialis* from Costa Rica.

Compound[a]	RT[b] (min)	RI[c]	Lit. RI[d]	Class	Leaflet (%)	Capitulum (%)	I. M.[e]
(*E*)-Hex-2-enal	4.24	849	846	A	0.2		1,2
(*Z*)-Hex-2-en-1-ol	4.29	858	859	A	0.1		1,2
Hexanol	4.46	861	863	A	t[f]		1,2
Tricyclene	5.89	923	921	M	t		1,2
α-Thujene	6.02	927	924	M	0.1		1,2
α-Pinene	6.19	934	932	M	**18.0**	**12.4**	1,2,3
α-Fenchene	6.47	942	945	M	t		1,2
Camphene	6.62	947	946	M	0.2	0.2	1,2,3
Sabinene	7.53	973	969	M	1.0	1.9	1,2
β-Pinene	7.78	975	974	M	**35.2**	**27.7**	1,2,3
Myrcene	7.91	989	988	M	0.9	1.0	1,2
Mesitylene	8.20	994	994	B	t		1,2
α-Phellandrene	8.43	1007	1002	M	**21.9**	**26.2**	1,2
δ-2-Carene	8.49	1008	1000	M		t	1,2
α-Terpinene	8.86	1016	1014	M	0.2		1,2
***p*-Cymene**	8.95	1024	1020	M	**8.3**	**0.2**	1,2
Limonene	9.22	1025	1024	M	**4.3**	**5.6**	1,2,3
β-Phellandrene	9.36	1029	1025	M	**t**	**6.6**	1,2
(*Z*)-β-Ocimene	9.58	1036	1032	M	t	t	1,2
Benzene acetaldehyde	9.85	1043	1036	B	t		1,2
(*E*)-β-Ocimene	9.96	1046	1044	M	0.8	2.9	1,2
γ-Terpinene	10.37	1057	1054	M	0.3	0.4	1,2
cis-Sabinene hydrate	10.75	1067	1065	M	t	t	1,2
Terpinolene	11.62	1089	1086	M	0.2	0.3	1,2
p-Cymenene	11.65	1090	1089	M	t	t	1,2,3
Linalool	11.62	1092	1095	OM	t		1,2,3

trans-Sabinene hydrate	11.79	1095	1098	OM	t		1,2
α-Fenchocamphorone	12.26	1105	1104	OM	t		1,2
α-Pinene oxide	12.23	1107	1099	OM		t	1,2
endo-Fenchol	12.57	1116	1114	OM		t	1,2
exo-Fenchol	12.70	1117	1118	OM	t		1,2
cis-p-Menth-2-en-1-ol	12.95	1123	1118	OM	0.1	0.1	1,2
5,8-Menthatriene	13.10	1131	1135	M		t	1,2
trans-Pinocarveol	13.20	1131	1135	OM	t	t	1,2
trans-p-Menth-2-en-1-ol	13.65	1139	1136	OM	0.1	t	1,2
trans-Verbenol	13.73	1141	1140	OM		0.1	1,2
Camphene hydrate	14.02	1147	1145	OM	t	t	1,2
β-Pinene oxide	14.10	1150	154	OM		t	1,2
(*E*)-Non-2-enal	14.17	1151	1157	A		0.1	1,2
1-(1,4-Dimethyl-3-cyclohexen-1-yl)-ethanone	14.44	1156	1152	OM	t		1,2
Terpinen-4-ol	15.36	1179	1174	OM	0.5	0.5	1,2,3
Dill ether	15.66	1186	1184	OM	t		1,2
trans-p-Menth-1(7),8-dien-2-ol	15.66	1186	1187	OM		0.1	1,2
α-Terpineol	15.96	1193	1186	OM	0.1	0.2	1,2,3
cis-Piperitol	16.20	1194	1195	OM	t	t	1,2
α-Phellandrene epoxide	16.60	1204	1202[g]	OM	t	0.2	1,2
Decanal	16.72	1208	1201	A		t	1,2,3
trans-Piperitol	16.79	1210	1207	OM	t	t	1,2
β-Cyclocitral	17.19	1223	1217	OM	t	t	1,2
Nerol	17.68	1230	1227	OM	t		1,2
Thymol methyl ether	17.80	1231	1232	OM	t	t	1,2
Carvacrol methyl ether	18.11	1240	1241	OM	t	t	1,2
Piperitone	18.55	1248	1249	OM	t		1,2
trans-Linalool oxide acetate (pyranoid)	20.39	1288	1287	OM		t	1,2
Bornyl acetate	20.48	1288	1287	OM	t	0.1	1,2
trans-Pinocarvyl acetate	20.75	1296	1297	OM	t	t	1,2
Carvacrol	20.80	1297	1298	OM	t		1,2
6-Hydroxy-carvotanacetone	21.24	1309	1309	OM		0.1	1,2
(2*E*,4*E*)-Deca-2,4-dienal	21.60	1314	1315	A		t	1,2
cis-2,3-Pinanediol	21.69	1319	1318	OM	0.4	0.2	1,2
(*Z*)-Hex-3-enyl tiglate	21.65	1321	1319	A	t		1,2
iso-Dihydro carveol acetate	22.15	1329	1326	OM		t	1,2
δ-Elemene	22.50	1337	1335	S		0.3	1,2
α-Cubebene	22.87	1346	1345	S		t	1,2
Neryl acetate	23.50	1362	1359	OM		t	1,2
α-Copaene	23.52	1371	1371	S		t	1,2
Geranyl acetate	23.74	1374	1379	OM	t		1,2
β-Bourbonene	24.23	1386	1387	S	t		1,2
β-Cubebene	24.58	1388	1387	S	t	0.1	1,2
β-Elemene	25.02	1399	1389	S	0.1	0.3	1,2
(*E*)-Caryophyllene	26.13	1421	1417	S	0.9	1.5	1,2,3
γ-Elemene	26.50	1427	1435	S		0.1	1,2
β-Copaene	26.52	1433	1430	S	t		1,2

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β-Gurjunene	26.70	1429	1431	S		0.1	1,2
α-Humulene	27.55	1453	1452	S	0.2	t	1,2,3
(*E*)-β-Farnesene	27.27	1459	1454	S	0.1	1.0	1,2
epi-Bicyclosesquigermacrene	28.09	1464	1467	S	t		1,2
γ-Muurolene	28.64	1478	1478	S	3.9	t	1,2
Germacrene D	28.69	1486	1484	S		2.2	1,2
γ-Amorphene	29.35	1494	1495	S		t	1,2
Bicyclogermacrene	29.45	1496	1500	S	0.2	0.3	1,2
α-Muurolene	29.75	1501	1500	S	t	t	1,2
(*E*,*E*)-α-Farnesene	29.94	1509	1505	S	t		1,2
Germacrene A	30.29	1509	1508	S		0.1	1,2
γ-Cadinene	30.33	1515	1513	S	t	t	1,2
δ-Cadinene	30.60	1522	1522	S	0.1	0.1	1,2,3
10-*epi*-*cis*-Dracunculifoliol	31.46	1539	1540	OS	t		1,2
Elemol	31.73	1547	1548	OS	t		1,2
Germacrene B	31.95	1561	1559	S		0.1	1,2
(*E*)-Nerolidol	32.21	1561	1561	OS	t		1,2,3
(*Z*)-Hex-3-enyl benzoate	32.49	1568	1565	B	t		1,2
Spathulenol	32.82	1578	1577	OS		0.4	1,2
Caryophyllene oxide	33.13	1583	1582	OS		0.2	1,2
Globulol	33.26	1590	1590	OS	0.1	0.1	1,2
Viridiflorol	33.58	1593	1592	OS	t	t	1,2
Cubeban-11-ol	33.69	1596	1595	OS		t	1,2
Ethyl dodecanoate	33.83	1596	1594	A		t	1,2
Widdrol	33.87	1599	1599	OS	t		1,2
Humulene epoxide II	34.22	1610	1608	OS		t	1,2
Junenol	34.56	1622	1627	OS		t	1,2
1-*epi*-Cubenol	34.79	1625	1627	OS		t	1,2
epi-α-Cadinol (T-cadinol)	35.08	1638	1638	OS	0.1	t	1,2
epi-α-Muurolol (T-muurolol)	35.31	1643	1640	OS	0.2		1,2
β-Eudesmol	35.84	1654	1649	OS	0.1		1,2
α-Cadinol	35.99	1658	1652	OS	0.2		1,2
α-Bisabolol	36.90	1683	1685	OS	t		1,2
Pentadecanal	38.09	1712	1710	A	0.1		1,2
Hexadecanoic acid	47.61	1967	1973	A	0.1	0.1	1,2
Ethyl hexadecanoate	48.17	1994	1993	A	t	t	1,2
(*E*,*E*)-Geranyl linalool	49.16	2031	2026	OS		t	1,2
Octadecanol	50.76	2081	2077	A		t	1,2
Methyl linoleate	50.94	2087	2095	A		t	1,2
Methyl linolenate	51.40	2093	2095	A		t	1,2
Heneicosane	51.48	2100	2100	A	t	0.3	1,2,3
(*E*)-Phytol	51.83	2116	2111[h]	D		t	1,2
Linoleic acid	52.35	2134	2132	A		0.1	1,2
Linolenic acid	52.73	2142	2143	A		0.1	1,2
Ethyl linoleate	53.37	2163	2159	A	t	0.2	1,2
Ethyl linolenate	53.66	2171	2169	A	t	0.1	1,2
Ethyl octadecanoate	54.34	2193	2196	A		t	1,2
Docosane	54.53	2200	2200	A	t	t	1,2,3
(*Z*)-Tricos-9-ene	56.58	2271	2272	A		t	1,2
Eicosanol	57.00	2280	2281	A		t	1,2

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Tricosane	57.50	2300	2300	A	t	1.0	1,2,3
Tetracosane	60.36	2400	2400	A	t	0.1	1,2,3
Docosanol (Behenic alcohol)	62.67	2486	2498	A		0.1	1,2
Pentacosane	63.14	2500	2500	A	t	0.4	1,2,3
Hexacosane	65.80	2600	2600	A		t	1,2,3
Docosyl acetate	66.12	2612	2611	A		t	1,2
Heptacosane	68.17	2700	2700	A		0.1	1,2,3
Class components							
Monoterpene hydrocarbons (M)					91.4	85.4	
Oxygenated monoterpenes (OM)					1.2	1.6	
Sesquiterpene hydrocarbons (S)					5.5	6.2	
Oxygenated sesquiterpenes (OS)					0.7	0.7	
Aliphatics (A)					0.5	2.6	
Bencenoids (B)					t		
Diterpenes (D)					t	t	
Identified components (%)					99.3	96.5	

[a]Compounds listed in order of elution from 5 % phenyl 95 % dimethylpolysiloxane type column. [b]RT = Retention time (min). [c]RI = Retention index relative to C_8-C_{32} *n*-alkanes on the 5 % phenyl 95 % dimethylpolysiloxane type column. [d]Lit. RI = DB-5 [32,33]. [e]I.M. = Identification method: 1 = Experimental retention index; 2 = MS spectra; 3 = Standard. [f]t = Traces (<0.05 %). [g][34]; [h][35]. Major compounds are in boldface.

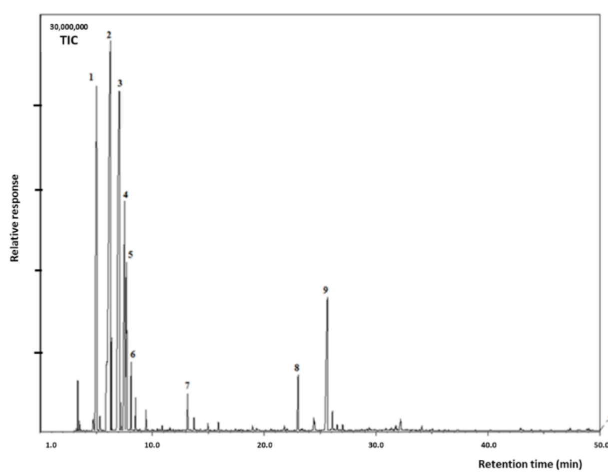

Fig. 2. GC-MS chromatogram (TIC) of *Dahlia imperialis* leaflet oil: **1.** α-pinene; **2.** β-pinene; **3**. α-phellandrene; **4.** *p*-cymene **5.** limonene; **6.** (*E*)-β-ocimene; **7.** terpinen-4-ol; **8.** (*E*)-caryophyllene; **9.** γ-muurolene.

Ninety-six constituents were identified in the essential oil from capitula. As can be seen, also monoterpene hydrocarbons (85.4 %) with a lesser amount of sesquiterpene hydrocarbons (6.2 %) were the most represented classes of compounds. The major constituents of the capitulum oil were β-pinene (27.7 %), α-phellandrene (26.2 %), α-pinene (12.4 %), β-phellandrene (6.6 %), limonene (5.6 %), (*E*)-β-ocimene (2.9 %), and germacrene D (2.2 %) (Fig. 3).

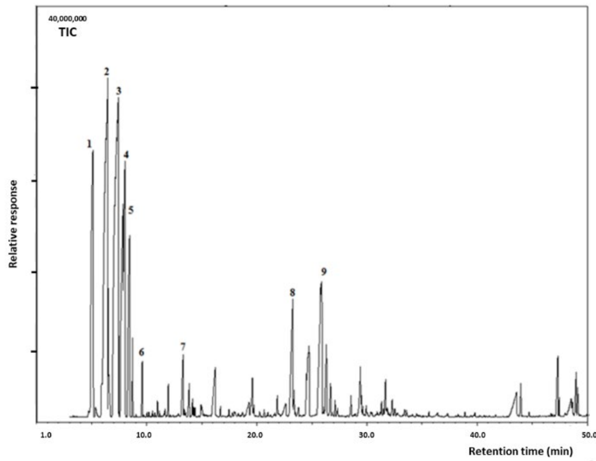

Fig. 3. GC-MS chromatogram (TIC) of *Dahlia imperialis* capitulum oil: **1**. α-pinene; **2**. β-pinene; **3**. α-phellandrene; **4**. limonene; **5**. β-phellandrene; **6**. (*E*)-β-ocimene; **7**. terpinen-4-ol; **8**. (*E*)-caryophyllene; **9**. germacrene D.

The pinane class of monoterpenes accounts for more than 50 % of the total leaflet oil composition, and more than 40 % of the capitulum oil composition with α-pinene and β-pinene occurring as major components. The principal source of these two compounds is turpentine (an oil obtained from pine trees) purified as a by-product in the Kraft paper-making process. These compounds are widespread in essential oils of conifers, as well as in essential oils of diverse genera of plants growing in Costa Rica like *Schinus molle* L., 'pirul', Anacardiaceae [36], *Smallanthus maculatus* (Cav.) H. Rob., 'tora', and *S. quichensis* (J.M. Coult.) H. Rob., 'cacamuca', Asteraceae [37,38]; *Ocotea austinii* C.K. Allen, *O. morae* Gómez-Laur. and *Povedadaphne quadriporata* W.C. Burger, 'ira rosa', Lauraceae [39-41]; and *Manekia naranjoana* (C.DC.) Callejas ex N. Zamora, Hammel & Grayum, Piperaceae [42], where these two compounds occur in large amounts. α-Pinene has a sharp and fresh pine odor and industrially it is converted to synthetic pine oil used as a solvent and as a constituent of several disinfectants. α-Pinene is used as a building block for the synthesis of various compounds used in the flavor and fragrance industry and for the synthesis of sustainable biopolymers [43]. The therapeutic potential and biological activity of α- and β-pinenes have been extensively studied and summaries are found in the recent reviews of Salehi et al. [44] and Allenspach & Steuer [45]. α-Phellandrene has a mint-citrusy and herbaceous flavor whereas its isomer β-phellandrene has a peppery-minty and slightly citrusy. Both are useful components of fragrances for soap and bath formulations. *p*-Cymene is an aromatic monoterpene naturally occurring in essential oils of plants used as condiments such as *Cuminum cyminum* L., cumin, Apiaceae [46], *Thymus vulgaris* L., thyme, Lamiaceae [47], and *Origanum* spp., oregano, Lamiaceae [48]. This compound is used as an industrial intermediate in fine chemical synthesis. The biological benefits and pharmacological properties of *p*-cymene have been reviewed recently by Balahbib et al. [49].

The major constituents of the essential oils of *Dahlia imperialis* [α- and β-pinene, α-phellandrene, *p*-cymene, limonene, and (*E*)-caryophyllene] are ingredients that contribute to the aroma and flavor of several spices used in the food industry. These compounds were approved by the United States Food and Drug Administration (FDA) as food additives, and they are generally granted the safe (GRAS) status by FDA classification] [50].

The leaf, flower, stem, and root essential oil compositions of *Dahlia pinnata* from China have been reported [51]. The major volatile compounds of the leaf essential oil were butyric acid (44.2 %) and methallyl cyanide (7.0 %) whereas the main constituents of the flower essential oil were 4-terpineol (25.7 %), methallyl

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cyanide (14.0 %) and limonene (10.5 %). Maman et al. [52] reported the chemical composition of the flower oil of *Dahlia* 'Eveline', a member of decorative Dahlias. They found that the major constituents were the phenylpropanoids anethole (82.8 %) and estragole (4.1 %).

The leaflet and capitulum essential oil compositions of *Dahlia imperialis* from Costa Rica presented considerable differences and they cannot be compared with studied oils because, among others, they do not contain nitriles or phenylpropanoids. To have a better understanding of the chemical and biological capacities of plants of this genus, it is desirable to conduct much more research, especially on wild plant populations.

The leaflets and flower heads (capitula) of *Dahlia imperialis* from Costa Rica produce monoterpenoid-rich essential oils whose compositions are dominated by β-pinene (27.7-35.2 %), α-phellandrene (12.4-21.9 %), α-pinene (12.4-18.0 %), *p*-cymene (0.2-8.3 %), limonene (4.3-5.6 %) and β-phellandrene (t-6.6 %). A total of 124 constituents were identified in the oils. Considering the chemical nature of principal compounds that constitutes the volatile fraction of this plant, its consumption as a leafy green vegetable seems to be safe.

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