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Chemical Diversity of Essential Oils from Cyperus articulatus, Cyperus esculentus and Cyperus papyrus

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Chemical Diversity of Essential Oils from *Cyperus articulatus, Cyperus esculentus* and *Cyperus papyrus*

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Abstract: Gas chromatography mass spectrometry was used to analyze the essential oil of three common *Cyperus* species grown in Egypt. The essential oils were obtained from the tubers and aerial parts of the plants using either hydrodistillation or head space analysis. The results revealed similarity between the tubers and aerial parts contents among the same species but showed variations between different species. Both *C. articulatus* and *C. esculentus* were much higher in their contents of sesquiterpenes relative to monoterpens, compared to *C. papyrus*. Major chemical constituents were identified to be pinene, eucalyptol, myrtenol, copaene, cyperene, caryophyllene, patchoulene and caryophyllene oxide. Essential oils of tubers and stems (aerial parts) from *C. articulatus* were characterized by much larger amount of sesquiterpenes (73 % and 71 % respectively) than monoterpenes (27 % and 24 % respectively), while the *C. esculantus* essential oil showed similar percentage of sesquiterpenes (74 % and 71 % for tubers and stem respectively) but had much lower percentage of monoterpenes (8 % and 12 % for tubers and stems respectively. *C. esculantus* essential oil also was characterized by higher contents of none terpenoid compounds (18 % and 17 % for tubers and stems respectively. On the other hand essential oil of *C. papyrus* was rich in monoterpens (67 % and 61 % for tubers and stems respectively) and only 33 % and 39 % sesquiterpenes in tubers and stems respectively, it also showed the absence of none terpenoid compounds.

Key words: Chemical ecology, biodiversity, terpenoids, herbal medicine, phytochemistry, Cyperaceae, sesquiterpenes, Habb El Aziz.

Introduction

The family Cyperaceae is monocotyledons having 90 genera and 4000 species, the genus *Cyperus* consists of about 550 species. They are usually found in marshy or aquatic habitats [1]. Although it is a very large family, few species of the Cyperaceae have an economic importance. There are 19 species of *Cyperus* species grow wild in Egypt at different habitats ranging from extremely arid desert, sand dunes to river Nile banks, rice fields, edges of water springs and wetlands as described by Boulos [2]. Three of the 19 species (*Cyperus articulatus* L, *Cyperus esculentus* L, and *Cyperus papyrus* L.) were found to have some commercial values as nutritional supplemental foods, herbal medicine and as starting materials in perfume industry. Images of the three selected species are shown in Figure 1. Rhizomes of *C. articulatus* are used in the treatment of migraine [3], reducing the risk of colon cancer [4] and as an effective antibiotic against *Pseudomonas aeruginosa* and *Staphylo-*

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cocus aureus [5]. *C. esculentus* is known in Egypt as "Habb el Aziz" and in many other countries as tiger nut or chufa plant [6]. The tubers are daily ingredients of the diet of many people in North Africa and Spain. The plant is native to the Mediterranean region but it is now widely cultivated in many other warm countries [7]. Salem *et.al*.[8] found that feeding the tubers to ApoE-mice significantly inhibited the atherosclerotic lesions in these mice. The tubers are said to be aphrodisiac, carminative, diuretic, emmenagogue, stimulant, and tonic [9]. *C. papyrus* is a giant herb, known in Egypt as Bardi; the plant isdistributed in northern Africa (Egypt, Sudan) and central

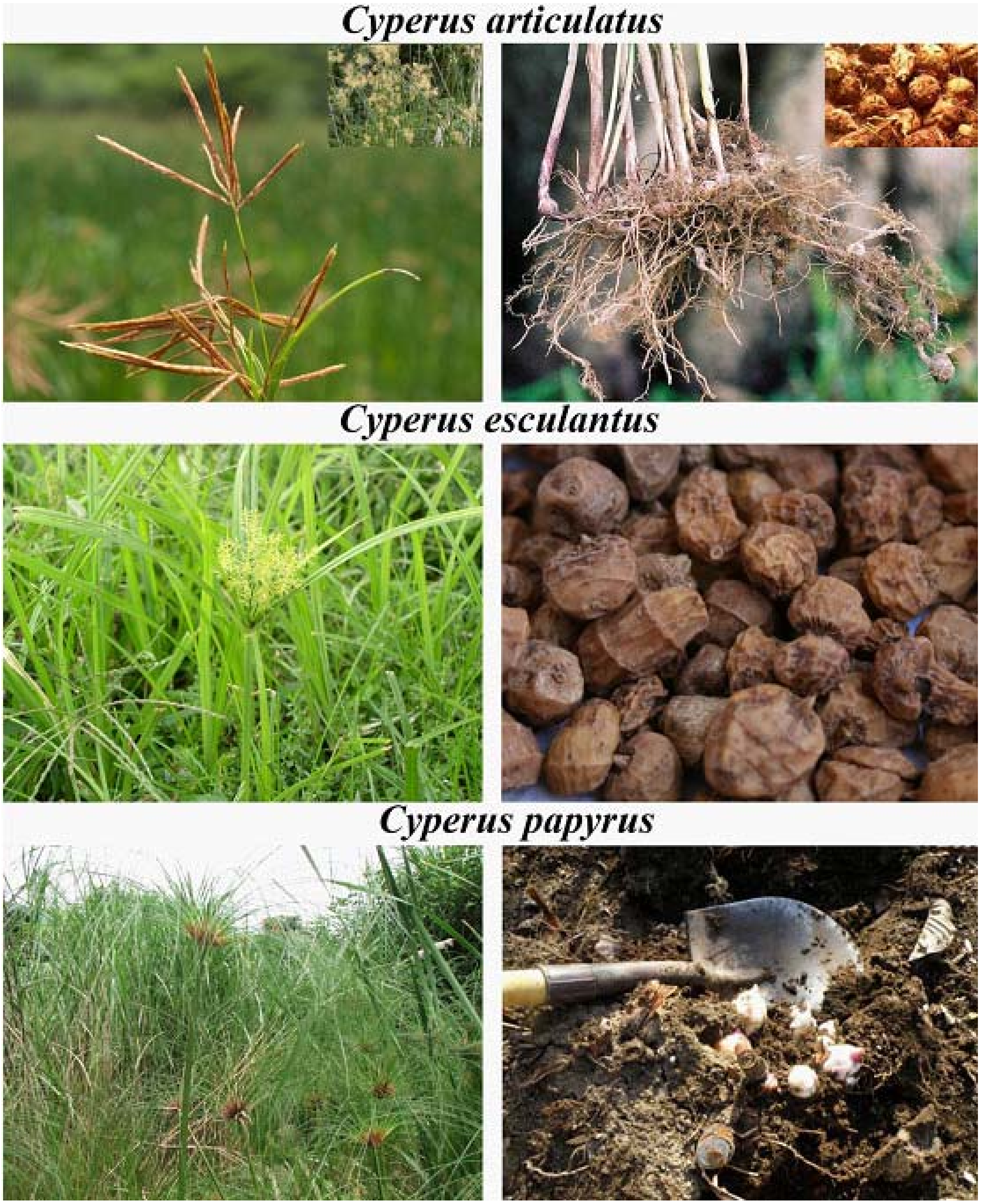


Figure 1. Images of the three investigated Cyperus species with their tubers shown on the right side.

Africa (Cameroon, Guinea, Nigeria). The essential oils of *Cyperus* plants are reported to possess analgesic, anti-inflammatory, antipyretic and antifungal activity [10]. Several sesquiterpenes including cyperone, cyperene and patchoulenone are thought to be the biological active ingredients in the essential oil [6]. In this paper we present the results of performing a comparative evaluation of the volatile chemical constituents both in the tubers and leaves of three of commonly distributed *Cyperus* species in Egypt.

Experimental

Plant material

Plant materials (aerial and underground parts) were collected in September 2008 from wild-growing population sites in Egypt. *Cyperus articulatus* L. was collected from Fayoum governorate, *Cyperus esculentus* L. was collected from Borg Rashid, Rashid governorate and *Cyperus papyrus* L. was collected from El-Karamos village, Sharqia governorate. The plants were dried at room temperature for two weeks. 200 g of air dried aerial parts and tubers of each plant sample were subjected to hydrodistillation with 1.5 L of distilled water for 2.5 hours using the original Clevenger-type apparatus [11]. The obtained oils were separated by extraction with diethyl ether, dried over anhydrous sodium sulfate and immediately analyzed.

Analysis of the essential oils

GC-MS analyses of the oils were performed on a Hewlett Packard 5890 Series II gas chromatograph coupled with a HP 5985 mass spectrometer system equipped with a DB-5 capillary column (30 m x 0.25 mm id, film thickness 0.25 μm). The oven temperature was programmed from 70 to 240°C at the rate of 5°C/min. The ion source was set at 240°C and electron ionization at 70 eV. Helium was used as the carrier gas at a flow rate of 1 mL/min. Scanning range was 50 to 425 amu. 1.0 μL oil in hexane was injected into the GC-MS. Head Space analysis was carried on 5 grams of dry powdered samples mixed with 20 ml of distilled water and subjected to head space analysis for the essential oil using an HP 7694 head space sampler connected to a Hewlett Packard 5890 Series II gas chromatograph coupled with a HP 5985 mass spectrometer system. Essential oil analysis of the head space samples were carried out under the same conditions described above.

The identification of the chemical constituents of the oil was determined based on GC retention times, retention indices and interpretation of their mass spectra and confirmed by mass spectral library search using the National Institute of Standards and Technology (NIST) database [12, 13]. The retention indices were calculated for all of the volatile constituents using a homologous series of n-alkanes C_8-C_{20}.

Results and discussion

GC-MS analysis of the essential oil of the three *Cyperus* species revealed at least 71 terpenoides and 8 none terpenoides volatile chemicals as shown in Table 1. All tested samples showed that sesquiterpenoids were the predominate constituents of both stems (aerial parts) and tubers except in the case of *C. papyrus*, monoterpens were the major constituents. 13 monoterpene hydrocarbons, 24 oxygenated monoterpenoids, 21 sesquiterpene hydrocarbons, 16 oxygenated sesquiterpenoids and 8 none terpenoids were identified, their chemical structures are shown in Figures 2-5. Percentage composition of each group of the identified compounds is shown in Table 2 for each individual oil sample.

Essential oils of tubers and stems from *C. articulatus* were characterized by much larger amounts of sesquiterpenes (73 % and 71 % respectively) than monoterpenes (27 % and 24 % respectively), while the *C. esculantus* essential oils showed similar percentage of sesquiterpenes (74 % and 71 % for tubers and stem respectively) but had much lower percentage of monoterpenes (8 % and 12 % respectively). *C. esculantus* essential oil was also found to have higher contents of none terpenoid compounds (18 % and 17 % for tubers and stems respectively). On the other hand essential oil of *C. papyrus* was richer in monoterpens (67 % and 61 % for tubers and stems respectively) and only 33 % and 39 % sesquiterpenes in tubers and stems respectively, and none terpenoid compounds were not found. Essential oil of *C. articulatus* is dominated by α-pinene, β-pinene, *trans*-pinocarveol, verbeol,

Table 1. Names, Molecular Formula, Molecular Weight (MW), Chemical Abstract Registry Number (CAS#), GC Retention Time (t_R), Kovats Retention Index (KI), Identification Number (ID#) and Percentage Composition of the Essential Oils from the three Cyperus Species

Name	Formula	MW	CAS #	t_R	KI	ID #	Percentage (%) Composition of the Essential oils					
							Cyperus articulatus		*Cyperus esculentus*		*Cyperus spapyrus*	
							Tubers	Stem	Tubers	Stem	Tubers	Stem
1,3,5-Trioxepane	$C_4H_8O_3$	104	5981-06-6	9.54	658	i	BDL*	1.04	1.40	BDL	BDL	BDL
3-Furaldehyde	$C_5H_4O_2$	96	498-60-2	10.34	689	ii	BDL	1.30	1.99	2.00	BDL	BDL
5-Methyl-2-furancarbo-xaldehyde	$C_6H_6O_2$	110	620-02-0	11.32	728	iii	BDL	1.59	2.30	1.21	BDL	BDL
Bicyclo(2.2.1)hepta-2,5-dien-7ol	C_7H_8O	108	822-80-0	12.36	742	iv	0.01	0.74	BDL	3.77	BDL	BDL
2-Ethylfuran	C_6H_8O	96	3208-16-0	13.88	894	v	BDL	0.69	BDL	BDL	BDL	BDL
α-Thujene	$C_{10}H_{16}$	136	2867-05-2	14.20	923	1	0.06	0.29	0.05	0.57	BDL	BDL
α-Pinene	$C_{10}H_{16}$	136	80-56-8	14.53	937	2	0.62	0.63	0.07	0.31	0.73	1.31
Camphene	$C_{10}H_{16}$	136	79-92-5	15.42	953	3	0.18	0.33	0.07	BDL	BDL	BDL
Sabinene	$C_{10}H_{16}$	136	3387-41-5	15.92	973	4	0.23	BDL	1.82	0.24	BDL	BDL
β-Pinene	$C_{10}H_{16}$	136	127-91-3	16.35	981	5	0.60	0.64	0.12	BDL	BDL	1.50
Myrcene	$C_{10}H_{16}$	136	123-35-3	16.82	991	6	BDL	BDL	0.10	BDL	BDL	BDL
o-Cymene	$C_{10}H_{14}$	134	527-84-4	16.88	1020	12	BDL	BDL	0.10	BDL	BDL	BDL
p-Cymene	$C_{10}H_{14}$	134	99-87-6	17.01	1025	10	0.04	2.60	0.30	BDL	BDL	BDL
Limonene	$C_{10}H_{16}$	136	138-86-3	18.17	1034	7	0.04	0.42	0.03	BDL	BDL	BDL
m-Cymene	$C_{10}H_{14}$	134	535-77-3	18.33	1029	11	0.14	0.19	0.24	2.62	BDL	BDL
Eucalyptol	$C_{10}H_{18}O$	154	470-82-6	18.46	1039	14	0.33	0.28	0.30	0.92	2.76	3.28
γ-Terpinene	$C_{10}H_{16}$	136	99-85-4	20.49	1059	8	0.07	0.41	0.89	1.78	BDL	BDL
5-Ethylidene-1-methyl-cycloheptene	$C_{10}H_{16}$	136	15402-94-5	20.50	1060	9	BDL	0.63	BDL	BDL	BDL	BDL
cis-Limonene oxide	$C_{10}H_{16}O$	152	4680-24-4	20.58	1074	15	0.06	2.73	0.27	BDL	BDL	3.34
trans-Linalool oxide	$C_{10}H_{18}O_2$	170	23007-29-6	21.25	1088	16	0.04	BDL	0.20	BDL	BDL	BDL
α-Linalool	$C_{10}H_{18}O$	154	598-07-2	21.32	1099	17	0.14	BDL	0.10	BDL	BDL	BDL

table 1. (continued).

Name	Formula	MW	CAS #	t_R	KI	ID #	Percentage (%) Composition of the Essential oils: *Cyperus articulatus* Tubers	*Cyperus articulatus* Stem	*Cyperus esculentus* Tubers	*Cyperus esculentus* Stem	*Cyperus spapyrus* Tubers	*Cyperus spapyrus* Stem
α-Thujone	$C_{10}H_{16}O$	152	546-80-5	21.67	1102	18	0.27	0.20	0.10	BDL	BDL	BDL
α-Campholenal	$C_{10}H_{16}O$	152	4501-58-0	21.88	1106	19	0.23	0.23	0.12	BDL	BDL	BDL
p-Cymenene	$C_{10}H_{12}$	132	1195-32-0	22.38	1118	13	0.84	BDL	0.1	BDL	BDL	BDL
trans-Pinocarveol	$C_{10}H_{16}O$	152	547-64-5	22.46	1141	20	4.96	3.77	0.10	BDL	1.92	2.34
cis-Verbenol	$C_{10}H_{16}O$	152	18881-04-4	22.55	1142	21	2.78	1.10	0.10	BDL	BDL	BDL
Camphor	$C_{10}H_{16}O$	152	76-22-2	22.73	1143	22	0.48	BDL	0.10	BDL	BDL	BDL
iso-Borneol	$C_{10}H_{18}O$	154	124-76-5	22.82	1156	23	0.30	0.33	0.10	BDL	BDL	BDL
Borneol	$C_{10}H_{18}O$	154	507-70-0	22.99	1165	24	0.32	0.11	0.18	BDL	BDL	BDL
Pinocarvone	$C_{10}H_{14}O$	150	30460-92-5	23.16	1168	25	0.88	1.04	0.28	BDL	BDL	BDL
Terpinen-4-ol	$C_{10}H_{18}O$	154	562-74-3	23.44	1178	26	0.58	0.48	0.28	BDL	BDL	BDL
α-Terpineol	$C_{10}H_{18}O$	154	98-55-5	23.58	1185	27	0.13	BDL	0.08	0.98	BDL	BDL
β-Cyclocitral	$C_{10}H_{16}O$	152	432-25-7	23.75	1218	28	0.71	0.57	0.14	BDL	BDL	BDL
Dihydrocarveol	$C_{10}H_{18}O$	154	619-01-2	24.01	1192	29	0.55	0.25	0.30	BDL	BDL	BDL
Myrtenol	$C_{10}H_{16}O$	152	515-00-4	24.27	1229	30	4.75	3.81	0.26	0.91	51.55	48.75
Neral	$C_{10}H_{16}O$	152	106-26-3	24.54	1235	31	0.20	0.16	0.12	BDL	BDL	BDL
cis-Carveol	$C_{10}H_{16}O$	152	1197-06-4	24.67	1242	32	4.58	1.61	0.05	0.28	5.46	0.78
Geraniol	$C_{10}H_{18}O$	154	106-24-1	24.84	1255	33	BDL	BDL	BDL	BDL	1.71	BDL
Piperitone	$C_{10}H_{16}O$	152	89-81-6	25.04	1282	34	0.82	0.26	0.12	BDL	1.32	BDL
Perillaldehyde	$C_{10}H_{14}O$	150	18031-40-8	25.52	1291	35	0.15	0.43	0.03	1.63	BDL	BDL
Carvone	$C_{10}H_{14}O$	150	2244-16-8	25.86	1299	36	0.61	0.31	0.03	0.74	BDL	BDL
Geraniol formate	$C_{11}H_{18}O_2$	182	105-86-2	26.04	1300	37	0.05	0.33	0.09	0.86	BDL	BDL
4-Hydroxy-2-methyl-benzaldehyde	$C_8H_8O_2$	136	41438-18-0	26.81	1352	38	0.25	BDL	0.60	BDL	1.25	BDL
Neryl acetate	$C_{12}H_{20}O_2$	196	141-12-8	26.90	1376	39	0.06	BDL	0.07	BDL	BDL	BDL
Copaene	$C_{15}H_{24}$	204	3856-25-5	29.67	1391	40	1.82	6.47	1.08	15.56	8.83	1.14
β-Elemen	$C_{15}H_{24}$	204	515-13-9	29.95	1393	41	0.05	1.29	0.10	BDL	BDL	2.81

table 1. (continued).

Name	Formula	MW	CAS #	t_R	KI	ID #	Percentage (%) Composition of the Essential oils *Cyperus articulatus* Tubers	*Cyperus articulatus* Stem	*Cyperus esculentus* Tubers	*Cyperus esculentus* Stem	*Cyperus spapyrus* Tubers	*Cyperus spapyrus* Stem
Cyperene	$C_{15}H_{24}$	204	2387-78-2	30.43	1398	42	0.46	3.41	0.38	23.06	4.42	18.32
β-Caryophyllene	$C_{15}H_{24}$	204	87-44-5	30.76	1428	43	1.27	3.88	0.10	7.14	3.36	2.80
β-Gurjunene	$C_{15}H_{24}$	204	17334-55-3	31.15	1432	44	0.91	0.48	0.12	BDL	0.59	BDL
Aromadendrene	$C_{15}H_{24}$	204	109119-91-7	31.30	1439	45	0.91	0.53	2.22	8.38	BDL	BDL
α-Cubebene	$C_{15}H_{24}$	204	17699-14-8	31.52	1351	46	0.43	0.16	0.41	BDL	1.33	0.33
α-Carophyllene	$C_{15}H_{24}$	204	6753-98-6	31.63	1454	47	0.12	BDL	0.44	BDL	2.46	1.99
Rotundene	$C_{15}H_{24}$	204	65128-08-7	31.69	1468	48	0.28	0.30	0.30	BDL	3.60	2.45
γ-Muurolene	$C_{15}H_{24}$	204	30021-74-0	31.82	1477	49	0.58	0.85	0.86	BDL	1.89	0.99
α-Muurolene	$C_{15}H_{24}$	204	31983-22-9	32.26	1499	50	0.30	0.43	0.45	0.92	BDL	BDL
Germacrene D	$C_{15}H_{24}$	204	23986-74-5	32.63	1499	51	0.18	0.17	0.63	BDL	2.33	2.45
trans-Calamenene	$C_{15}H_{22}$	202	483-77-2	32.72	1503	52	0.73	0.62	0.08	BDL	2.16	1.98
γ-Cadinene	$C_{15}H_{24}$	204	39029-41-9	33.12	1512	53	0.20	0.27	0.53	BDL	BDL	BDL
cis-Calamenane	$C_{15}H_{22}$	202	483-77-2	33.37	1519	54	1.28	1.16	1.72	4.37	BDL	BDL
δ-Cadinene	$C_{15}H_{24}$	204	483-76-1	33.68	1530	55	0.10	0.12	0.28	BDL	BDL	BDL
Ledene oxide	$C_{15}H_{24}O$	222	JJJ45-N	33.81	1536	61	0.91	0.54	1.53	6.60	BDL	BDL
γ-Patchoulene	$C_{15}H_{24}$	204	508-55-4	33.94	1549	56	12.79	12.07	13.11	BDL	BDL	BDL
Amorphene	$C_{15}H_{24}$	204	483-75-0	34.19	1550	57	0.92	0.76	1.24	BDL	BDL	BDL
Caryophyllene oxide	$C_{15}H_{24}O$	220	1139-30-6	34.40	1573	62	16.63	18.22	19.41	BDL	BDL	BDL
Longipinocarvone	$C_{15}H_{22}O$	218	NA	34.62	1576	63	0.96	1.18	1.27	BDL	BDL	BDL
Ledol	$C_{15}H_{26}O$	222	577-27-5	34.79	1589	64	2.14	2.07	3.01	BDL	BDL	BDL
β-Selinene	$C_{15}H_{24}$	204	17066-67-0	34.80	1591	58	BDL	BDL	1.26	BDL	BDL	BDL
α-Selinene	$C_{15}H_{24}$	204	473-13-2	34.84	1597	59	BDL	BDL	1.10	BDL	BDL	BDL
Cedra-8-en-15-ol	$C_{15}H_{24}O$	220	21441-72-5	35.08	1601	65	2.21	BDL	1.80	BDL	BDL	BDL
Globulol	$C_{15}H_{26}O$	222	51371-47-2	35.23	1610	66	2.34	BDL	2.89	BDL	BDL	BDL
Cedrol	$C_{15}H_{26}O$	222	77-53-2	35.38	1612	67	5.29	3.06	5.04	2.96	BDL	BDL
1-epi-Cubenol	$C_{15}H_{26}O$	222	19912-67-5	35.52	1616	68	2.68	0.65	2.64	BDL	BDL	BDL

table 1. (continued).

Name	**Formula**	**MW**	**CAS #**	t_R	**KI**	**ID #**	**Percentage (%) Composition of the Essential oils**					
							Cyperus articulatus		***Cyperus esculentus***		***Cyperus spapyrus***	
							Tubers	**Stem**	**Tubers**	**Stem**	**Tubers**	**Stem**
α-Bulnesene	$C_{15}H_{24}$	204	3691-11-0	35.77	1635	60	0.84	BDL	0.93	BDL	BDL	BDL
Dillapiol	$C_{12}H_{14}O_4$	222	484-31-1	35.86	1641	69	1.08	BDL	0.77	BDL	BDL	BDL
α-Cadinol	$C_{15}H_{26}O$	222	481-34-5	36.14	1652	70	6.59	5.21	2.73	BDL	BDL	BDL
Germacrone	$C_{15}H_{22}O$	218	6902-91-6	36.39	1693	71	2.67	1.85	1.37	BDL	BDL	BDL
β-Bisabolol	$C_{15}H_{26}O$	222	15352-77-9	36.50	1701	72	0.56	0.46	0.50	BDL	BDL	BDL
Cyperotundone	$C_{15}H_{22}O$	218	3466-15-7	36.65	1720	73	0.59	0.61	0.56	BDL	BDL	BDL
α-Cyperone	$C_{15}H_{22}O$	218	473-08-5	36.81	1727	74	2.33	2.11	1.35	1.15	1.32	1.88
Cyclocolorenone	$C_{15}H_{22}O$	218	489-45-2	37.02	1745	75	1.24	1.15	0.71	BDL	1.01	1.56
Aristolone	$C_{15}H_{22}O$	218	6831-17-0	37.19	1756	76	0.55	0.42	0.70	0.81	BDL	BDL
Ethylpalmitate	$C_{18}H_{36}O_2$	284	628-97-7	40.54	1993	vi	BDL	BDL	4.76	3.58	BDL	BDL
Ethyl-(E)-9-Octadecenoate	$C_{20}H_{38}O_2$	310	6114-18-7	41.27	2179	vii	BDL	BDL	7.70	6.65	BDL	BDL
Ethyleicosanoate	$C_{22}H_{44}O_2$	340	18281-05-5	41.51	2185	viii	BDL	BDL	0.22	BDL	BDL	BDL

* Below Detection Limit (BDL)

carveol copaene, caryophyllene, γ-patchoulene, caryophyllene oxide, cedrol and cadinol. Essential oil of *C. esculantus* is dominated by sabinene, cyperene, caryophyllene, ledene oxide, aromadendrene, β-patchoulene, caryophyllene oxide and several non terpenoids. Essential oil of *C. papyrus* is dominated by α-pinene, β-pinene, eucalyptol, myrtenol, copaene, caryophyllene, rotundene, germacrene D, *trans*-calamenene, cyperene and cyperone. Total ion chromatogram of *C. articulatus* essential oil is presented in Figure 6 as an example of the separation resolution and the pattern of elution of each chemical class of compounds. Figure 7 presents the total ion chromatograms of the tubers essential oil of both *C. articulatus* and *C. esculantus* to illustrate the differences and similarity between the two species. It is evident that there are some similarities between the two species; however, they were greatly different from *C. papyrus* oil. The chemical pattern of the three oils is somewhat different from those previously reported in the literature on the essential oils of *Cyperus* species from different countries [14,15], which further suggests the existence of more chemical diversity within the *Cyperus*species [16]. This could be due to climactic and environmental conditions, chemo types, nutritional status of the plants, and other factors, which can influence essential oil composition.

Table 2. Chemical classes composition of the tested essential oils

Groups	***Cyperus articulates***		***Cyperus esculentus***		***Cyperus papyrus***	
	Tubers	**Stem**	**Tubers**	**Stem**	**Tubers**	**Stem**
Monoterpenes						
Hydrocarbons	3.07	6.14	4.49	5.52	1.98	2.81
Oxygenated	23.98	18.00	3.52	6.32	64.72	58.49
subtotal	27.05	24.14	8.01	11.84	66.70	61.30
Sesquiterpenes						
Hydrocarbons	24.17	32.97	27.34	59.43	30.97	35.26
Oxygenated	48.77	37.53	46.28	11.52	2.33	3.44
subtotal	72.94	70.50	73.62	70.95	33.30	38.70
None terpenoids	0.01	5.36	18.37	17.21	00.00	00.00

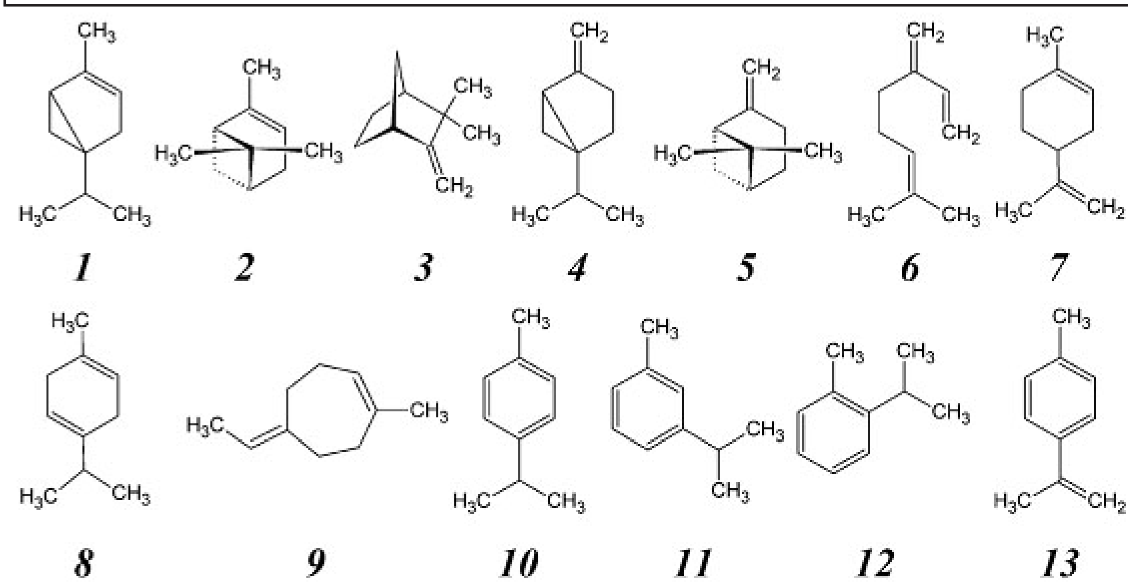


Figure 2. Chemical structure of the identified monoterpene hydrocarbon compounds with their ID # as presented in Table 1.

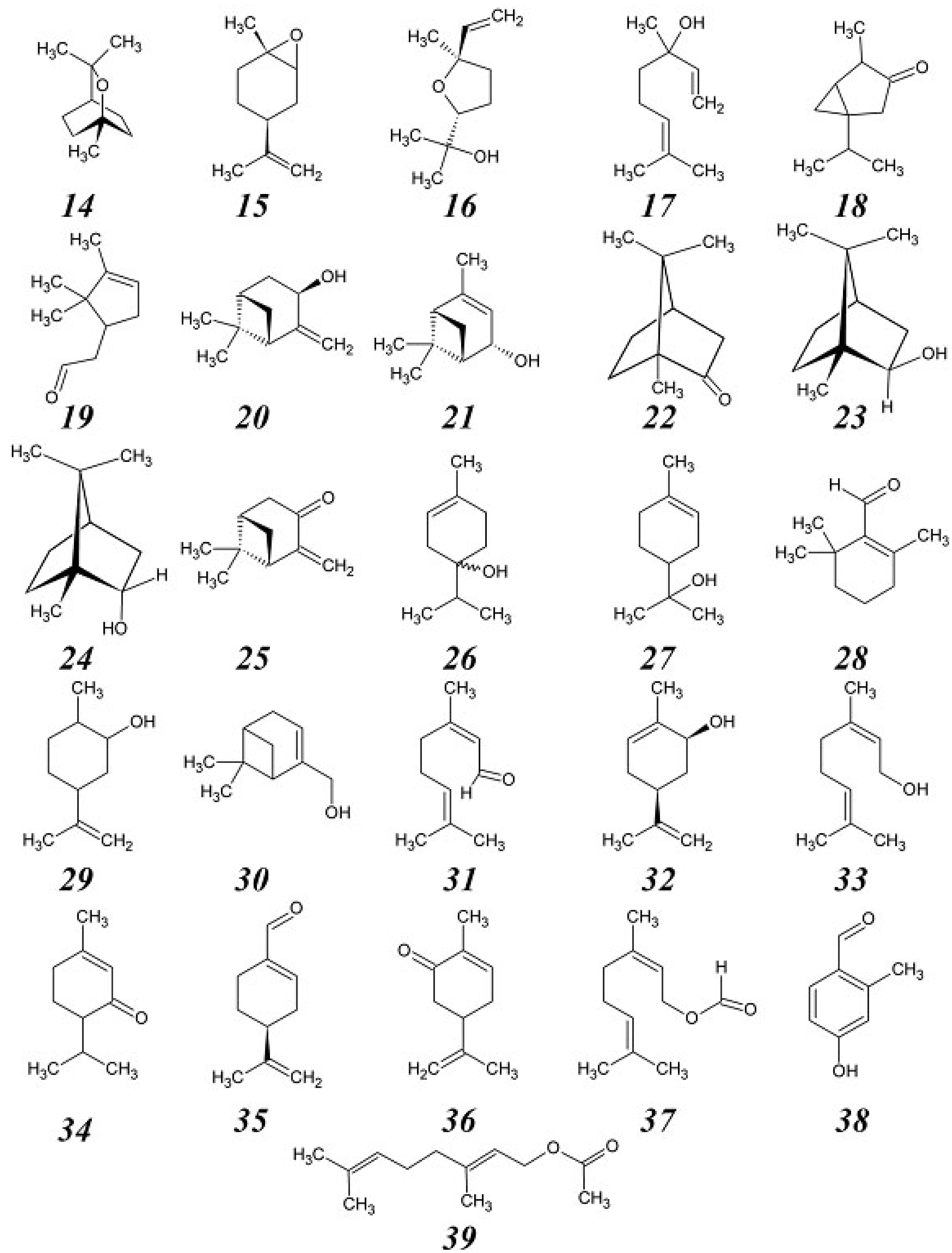


Figure 3. Chemical structure of the identified oxygenated monoterpene compounds with their ID # as presented in Table 1.

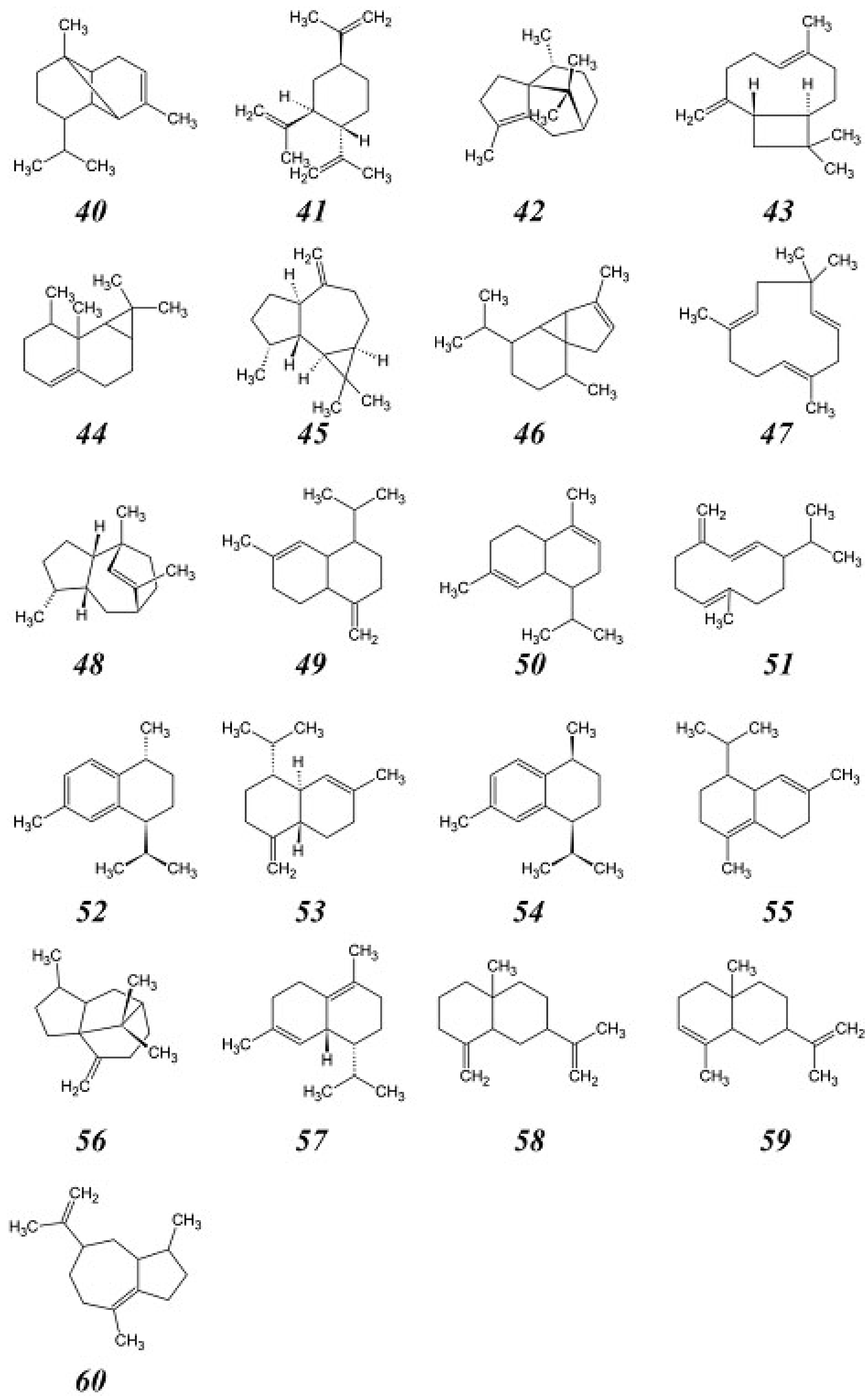
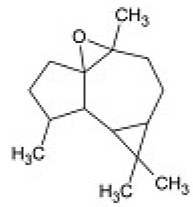


Figure 4. Chemical structure of the identified sesquiterpene hydrocarbon compounds with their ID # as presented in Table 1.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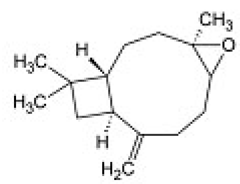
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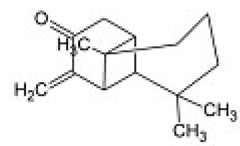
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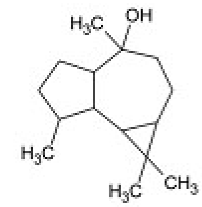
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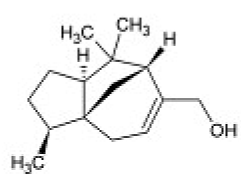
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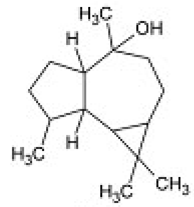
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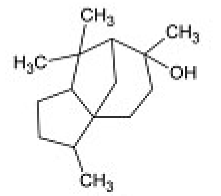
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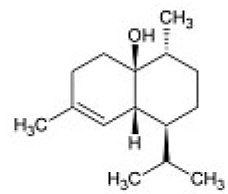
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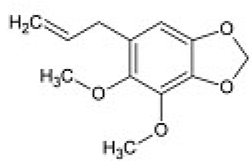
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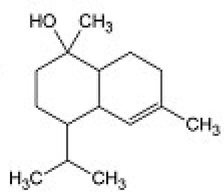
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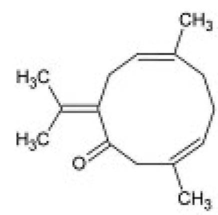
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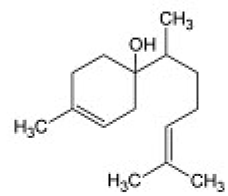
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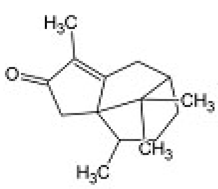
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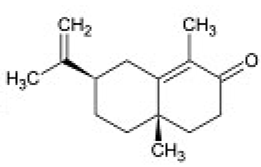
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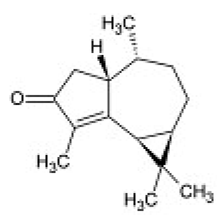
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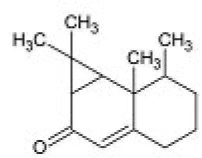
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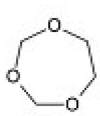
Figure 5. Chemical structure of the identified oxygenated sesquiterpene compounds with their ID # as presented in Table 1.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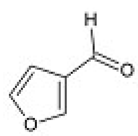
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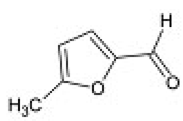
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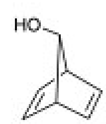
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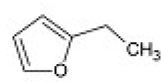
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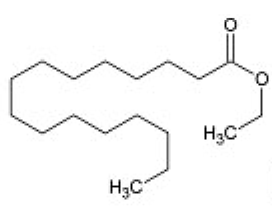
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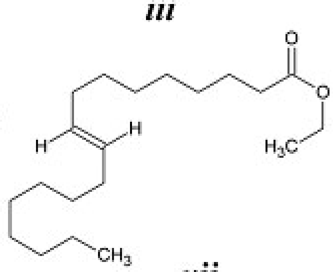
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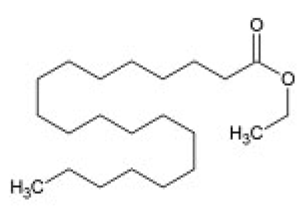
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Figure 6. Chemical structure of the identified none terpenoid compounds with their ID # as presented in Table 1.

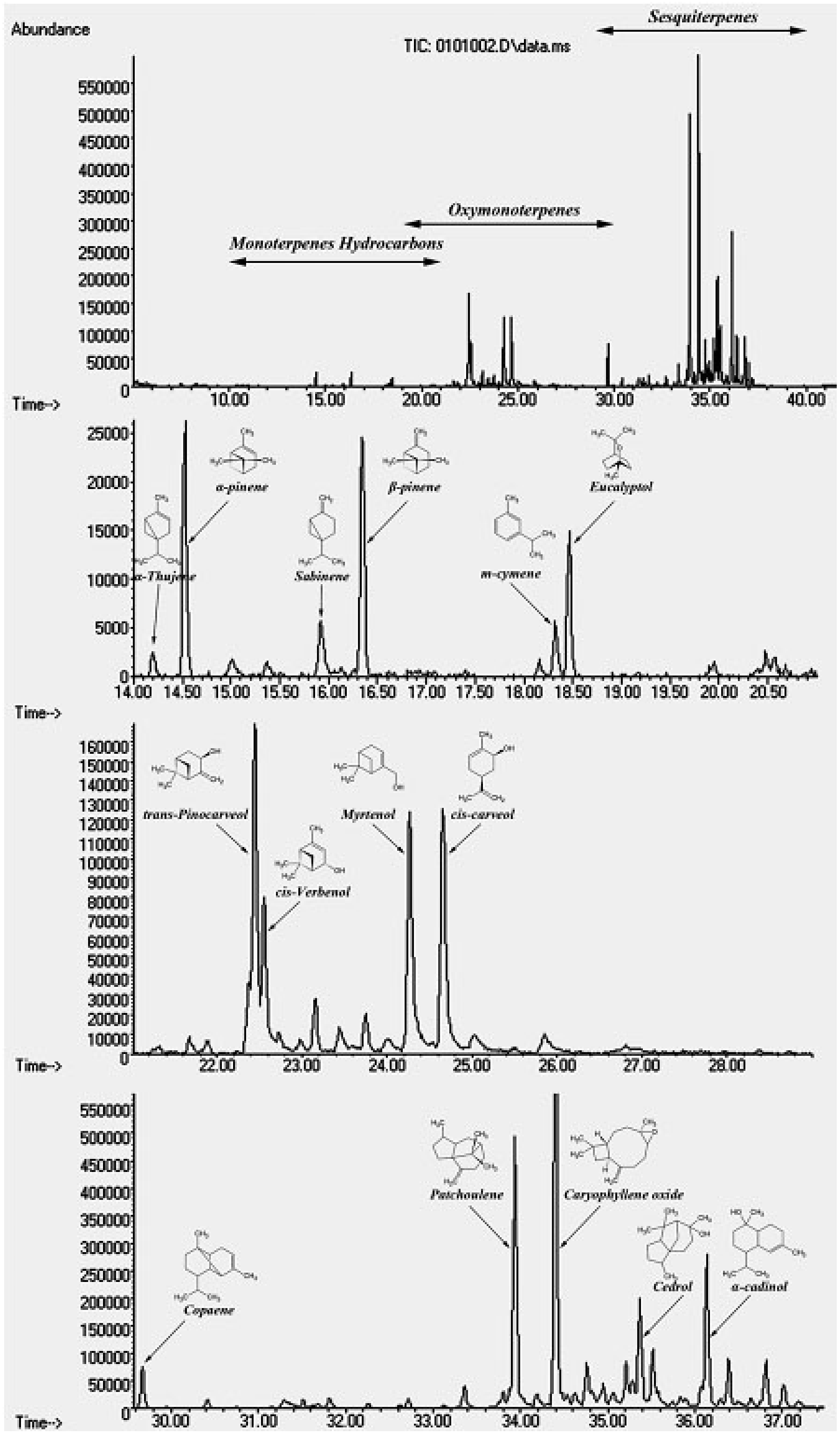

Figure 7. Total ion chromatogram of the essential oil of *Cyperus articulatus* tubers with designated regions of terpene classes and selected chemical structures.

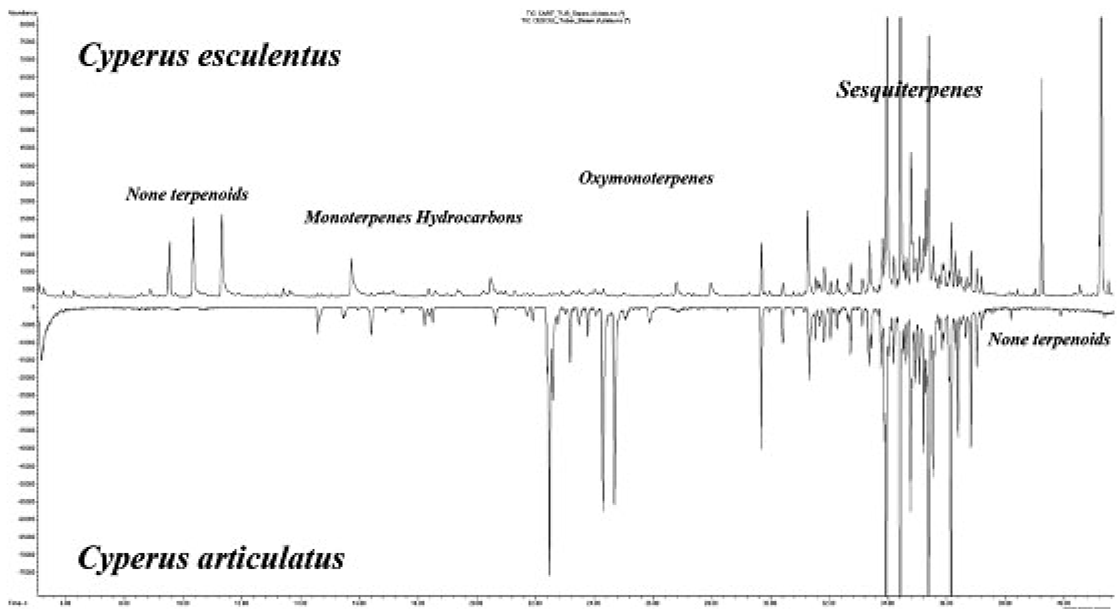

Figure 8. Comparison between total ion chromatograms of the essential oils from *Cyperus articulatus* and *Cyperus esculantus*.

Acknowledgements

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