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Volatile compositions of two cactus species growing in the Sonoran Desert of southern Arizona

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ABSTRACT

The essential oils of *Opuntia acanthocarpa* var. *major* and *Opuntia phaeacantha* var. *discata* (Cactaceae) growing wild in the Organ Pipe Cactus National Monument, Ajo, Arizona, and the Arizona-Sonora Desert Museum, Tucson, Arizona, were obtained by hydrodistillation and analyzed by gas chromatography – mass spectrometry. The volatile oil yields and compositions of each cactus species growing in the two locations were significantly different. The differences may be attributed to rainfall differences as well as differences in soil composition between the two sites. Organ Pipe Cactus National Monument is a drier habitat than the Arizona-Sonora Desert museum. The soil of the Organ Pipe Cactus National Monument is rich with lime while soil at the Arizona-Sonoran Desert Museum is dominated by caliche. *O. acanthocarpa* var. *major* and *O. acanthocarpa* var. *discata* growing in the drier, limey soil of the Organ Pipe Cactus National Monument had essential oils dominated by alkane hydrocarbons, while *O. acanthocarpa* var. *major* from the Arizona-Sonora Desert Museum was rich in chromenes, and *p*-vinylguaiacol dominated the composition of *O. acanthocarpa* var. *discata* growing in the caliche-rich soil of the Arizona-Sonora Desert Museum.

Keywords: *Opuntia acanthocarpa* var. major, *Opuntia phaeacantha* var. *discata,* lime, caliche, eupatoriochromene, homosalate, p-vinylguaiacol**.**

1. Introduction

The Sonoran Desert, which is considered to be a subtropical desert, is located in southeastern California, southwestern Arizona, and northern Mexico. Although the Sonoran Desert is one of the hottest and driest deserts in North America, it has a large diversity of species, and is home to at least 60 species of mammals, more than 350 bird species, 20 amphibians, 100 reptiles, approximately 30 species of native fish, and more than 2,000 species of plants [1]. The portion of the Sonoran Desert lying within the United States is topographically divided into a lower, western section that includes the Organ Pipe Cactus National Monument, and a higher, wetter eastern section that includes Tucson and the Arizona-Sonora Desert Museum [2]. The scarcity and uncertain distribution of rainfall within the Sonoran Desert is the single most important climatic factor influencing the survival and distribution of plant species [3]. The average rainfall for Tucson, Arizona and Ajo, Arizona is 318 and 213 mm per year, respectively [4].

The Sonoran Desert lies in the Basin and Range geologic area wherein desert and grassland valleys are rimmed by parallel mountains extending north from Mexico [5]. These mountains are believed to be formed by active volcanoes 20-40 million years ago. The Sonoran Desert has differing soils that affect vegetation. Soil composition in the desert basins may be gravelly, sandy, or made up of clays, which may be humus poor and gray in color or rich in lime and reddish in color [6]. Soil of the Organ Pipe Cactus National Monument is rich in lime [7]. Soil at the Arizona-Sonora Desert Museum is rich with a unique mineral deposit called caliche that forms within granite rocks and soils [6]. Caliche is a reddish-brown layer of deposit formed when mineral-rich water flows through soil [6]. The water leaves behind a calcium carbonate precipitate that hardens as it forms layers within the soil [6]. Atmospheric calcium contained in dust and precipitation has been shown to contribute to the formation of caliche soil [8].

This study investigates whether there are differences in the essential oil composition of two cactus species commonly found in the Sonoran Desert, *Opuntia acanthocarpa* var. major (Engelm. & J.M. Bigelow) L.D. Benson and *Opuntia phaeacantha* var. *discata* (Griffiths) L.D. Benson & Walk., growing in the lime-based soil of the Organ Pipe Cactus National Monument and the caliche soil found at the Arizona-Sonora Desert Museum. *O. acanthocarpa* is a cylindro-opuntia native to the sandy soils of flats and washes in the desert at 300 to 1,000 m elevation from Sonora, Mexico, Riverside County, California, and the Southern Counties of Arizona [9], including both the Organ Pipe Cactus National Monument and the Arizona-Sonora Desert Museum. *O. acanthocarpa* var. *major* (commonly known as buckhorn cholla) is a shrub, arborescent plant, or a small tree with a trunk of 10 to 15 cm in diameter and a height of 1 to 2 m [9]. The 2- to 5-cm tubercles are presented on joints of 15 to 30 cm long (Benson, 1969). The Pima Indians of Southern Arizona steamed the flower buds in pits and utilized them for food [9]. *O. acanthocarpa* var. *discata* (syn. *Opuntia engelmannii* var. *engelmannii*) is a prickly pear cactus distributed in sandy soils of plains and grasslands at 500 up to 1500 m elevation [9]. The range of *O. acanthocarpa* var. *discata* extends from Sonora and Chihuahua, Mexico, through the California mountains bordering the deserts eastward to Utah and Texas [9]. The flat, jointed pads of *O. acanthocarpa* var. *discata* are orbiculate to elliptic with a length of 20 to 40 cm long and 18 to 23 cm wide [9]. In Mexico, cattle, deer, and other animals consume *O. acanthocarpa* as forage [10]. In fact, opuntias such as *O. acanthocarpa* can be the principal component of a desert animal's diet [10]. White-tail deer have been found to have a diet composed of 21% opuntia fodder [10]. The native O'odham people utilized prickly pear cactus pads as a food source [6]. Additionally, the O'odham split and heated the cactus pads and applied to joints of the body to treat arthritis and rheumatism [6].

Samples for this study collected from the Organ Pipe Cactus National Monument were obtained from very gravelly, limy soil [7]. The surface layer is light brown, very gravelly loam about 5 cm thick [7]. The subsoil is pink, very gravelly loam about 20 cm thick and the substratum is white and pinkish gray, very gravelly loam and weakly cemented with lime to 1.5 m and more [7]. This soil is composed of younger intermediate alluvial fan and terrace deposits of poorly sorted cobbles, pebbles, and sand, with lesser amounts of silt, clay and boulders [11]. The Arizona-Sonora Desert Museum is located in the Tuscon Mountain range located in Tucson, Arizona. Soil in the Tucson Mountain range lacks argillic horizons and has weak structural development characterized by moderately to highly cemented calcic horizons at depths in excess of 20-25 cm [12]. Petrocalcic horizons have been found throughout the upper 10 m of alluvium comprising the land surface within the Tucson Mountain range [12].

2. Materials and Methods

2.1 Plant Material

Cactus specimens were identified and collected from the Organ Pipe Cactus National Monument by Tim Tibbits of the National Park Service, U.S. Department of the Interior. Specimens of cactus were also collected by Julie Wiens of the Arizona-Sonora Desert Museum. Samples were chopped and frozen at -20 °C until studied. The plant samples were hydrodistilled using a Likens-Nickerson apparatus with continuous extraction with chloroform for a four-hour period. The chloroform was evaporated from the distillates to give the essential oils (Table 1). The distillates were stored at 4 °C until analysis.

Table 1: Essential oil yields of Arizona *Opuntia* species.

Sample	Collection site	Mass of plant material	Oil yield and description
O. acanthocarpa var. *major*	Organ Pipe Cactus National Monument	134.88 g	40.0 mg colorless oil
O. acanthocarpa var. *major*	Arizona-Sonora Desert Museum	58.3 g	42.3 mg yellow oil
O. acanthocarpa var. *discata*	Organ Pipe Cactus National Monument	149.77 g	34.0 mg colorless oil
O. acanthocarpa var. *discata*	Arizona-Sonora Desert Museum	135.07	110 mg colorless oil

2.2 Gas Chromatography – Mass Spectrometry

The cactus essential oils of *O. acanthocarpa* var. *major* and *O. acanthocarpa* var. *discata* were subjected to gas chromatographic – mass spectral analysis on an Agilent system consisting of a Model 6890 gas chromatograph, a Model 5973 mass selective detector [MSD, operated in EI mode (electron energy = 70ev), scan range = 40-400amu, and scan rate = 3.99 scans/sec], and an HP-5ms fused silica capillary with a (5% phenyl)-poly-methylsiloxane stationary phase, film thickness of 0.25 μm, a length of 30 m, and an internal diameter of 0.25 mm. The carrier gas was helium with a column head pressure of 48.7 kPa and a flow rate of 1.0 mL/min. inlet temperature was 200 ºC and interface temperature was 280 ºC. The GC oven temperature program was used as follows: 60 ºC initial temperature, hold for 5 mins; increased at 3ºC/min to 280 ºC; increased at 3ºC/min. A 1% w/v solution of the sample in CH_2Cl_2 was prepared and injected using a 10:1 split ratio.

Identification of the oil components was based on their retention indices determined by reference to a homologous series of *n*-alkanes, and by comparison of their mass spectral fragmentation patterns with those reported in the literature [13] and stored on the MS library [NIST database (G1036A, revision D.01.00)/Chem Station data system (G1701CA, version C.00.01.080)]. The percentages of each component are reported as raw percentages based on total ion current without standardization. The essential oil compositions of *O. acanthocarpa* var. *major* are summarized in Tables 2 and 3. Tables 4 and 5 list the essential oil components of *O. acanthocarpa* var. *discata*.

Table 2: Chemical composition of the essential oil of *Opuntia acanthocarpa* var. *major* from Organ Pipe Cactus National Monument.

RI[a]	Compound	%[b]		RI[a]	Compound	%[b]
801	Hexanal	tr[c]		1566	2-Methylpentadecane	0.4
810	2-Hexanol	8.6		1578	Dodecanoic acid	1.7
836	Furfural	1.7		1600	Hexadecane	2.1
838	3-Methyl-2-hexanone	tr		1615	Tetradecanal	0.5
871	*n*-Hexanol	1.0		1652	2,6,10-Trimethylpentadecane (= Norpristane)	0.5
893	2-Heptanone	1.6		1700	Heptadecane	0.7
900	2-Heptanol	tr		1708	2,6,10,14-Tetramethylpentadecane (= Pristane)	0.6
903	Heptanal	0.9		1812	2,6,10,14-Tetramethylhexadecane (= Phytane)	0.6
908	Butyl propanoate	0.2		1884	1-Nonadecene	0.7
918	Prenyl acetate	0.3		2000	Eicosane	0.3
965	Benzaldehyde	0.5		2030	Isopropyl palmitate	1.1
973	Dimethyl trisulfide	0.5		2089	1-Heneicosene	0.9
994	2-Pentylfuran	0.5		2100	Heneicosane	3.5
1034	Unidentified[d]	1.0		2199	1-Docosene	0.9
1044	Benzeneacetaldehyde	0.9		2200	Docosane	2.0
1073	*cis*-Linalool oxide (furanoid)	1.5		2300	Tricosane	10.8
1088	*trans*-Linalool oxide (furanoid)	0.8		2398	1-Tetracosene	2.1
1106	Decanal	1.0		2400	Tetracosane	4.1
1127	α-Campholenal	0.7		2459	Unidentified[e]	1.3
1166	Camphenone	1.0		2464	Unidentified[f]	0.9
1179	Octanoic acid	12.3		2495	1-Pentacosene	0.8
1274	Vitispirane	0.5		2500	Pentacosane	4.9
1280	Nonanoic acid	0.6		2599	1-Hexacosene	0.9
1300	Tridecane	0.8		2600	Hexacosane	0.7
1377	Decanoic acid	10.0		2700	Heptacosane	3.5
1400	Tetradecane	1.0		2800	1-Octacosene	0.2
1411	Dodecanal	0.3		2800	Octacosane	0.3
1464	2,6,10-Trimethyltridecane	1.4		2833	Squalene	0.3
1500	Pentadecane	2.0		2900	Nonacosane	0.7
1552	Nonylcyclohexane	0.7			Total Identified (56)	96.9

[a] RI = "Retention Index" determined in reference to a homologous series of *n*-alkanes on an HP-5ms column.
[b] The percentages of each component are reported as raw percentages based on total ion current without standardization.
[c] tr = "trace" (< 0.05%).
[d] MS, m/z(%): 139(9), 137(14), 119(21), 117(64), 112(70), 110(100), 77(27), 75(38), 71(61), 65(13), 63(13), 55(16), 43(93).
[e] MS, m/z(%): 280(14), 279(54), 163(18), 137(14), 123(21), 111(20), 109(29), 105(23), 97(27), 95(50), 85(25), 83(27), 81(54), 71(27), 69(100), 67(57), 57(39), 55(48), 43(30), 41(45).
[f] MS, m/z(%): 280(7), 263(15), 245(7), 179(8), 165(10), 163(11), 151(11), 137(11), 125(18), 111(30), 109(18), 105(18), 97(46), 95(23), 85(26), 83(46), 81(22), 71(33), 69(100), 67(25), 57(50), 55(46), 43(36), 41(39).

Table 3: Chemical composition of the essential oil of *Opuntia acanthocarpa* var. *major* from Arizona-Sonora Desert Museum.

RI[a]	Compound	%[b]		RI[a]	Compound	%[b]
1190	α-Terpineol	tr[c]		1715	Pentadecanal	0.2
1206	Decanal	tr		1766	Eupatoriochromene	66.2
1300	Tridecane	0.1		1800	Octadecane	0.7
1375	α-Copaene	tr		1803	2-Ethylhexyl salicylate	0.6
1392	β-Elemene	0.2		1812	Unidentified[e]	0.8
1410	Dodecanal	0.1		1839	6,10,14-Trimethylpentadecan-2-one	0.4
1418	(*E*)-Caryophyllene	0.1		1870	Encecalin	1.6
1438	Aromadendrene	0.3		1885	Homosalate	0.7

1478	γ-Muuolene	0.2		1888	Unidentified[f]	1.1
1484	*ar*-Curcumene	0.1		1900	Nonadecane	0.2
1495	Valencene	0.2		1923	Unidentified[g]	2.4
1500	Pentadecane	0.5		1937	Unidentified[h]	1.7
1510	β-Bisabolene	0.3		2000	Eicosane	0.1
1514	γ-Cadinene	0.1		2029	Isopropyl hexadecanoate	0.7
1524	δ-Cadinene	0.2		2076	Octadecanol	0.1
1550	Elemol	0.2		2100	Heneicosane	0.8
1566	(*E*)-Nerolidol	1.2		2117	(*E*)-Phytol	1.1
1570	(3*Z*)-Hexenyl benzoate	0.1		2200	Docosane	0.2
1578	Spathulenol	2.5		2277	(9*Z*)-Tricosene (= Muscalure)	0.2
1583	Caryophyllene oxide	1.1		2300	Tricosane	1.2
1600	Hexadecane	0.3		2400	Tetracosane	0.4
1619	Unidentified[d]	1.8		2457	2-Methyltetracosane	0.2
1631	γ-Eudesmol	0.2		2500	Pentacosane	0.4
1651	Demethoxyencecalin	3.0		2600	Hexacosane	0.1
1655	Selin-11-en-4α-ol	1.1		2700	Heptacosane	1.2
1678	Androencecalinol	0.3		2900	Nonacosane	0.5
1700	Heptadecane	1.4			Total Identified (48)	91.5

[a] RI = "Retention Index" determined in reference to a homologous series of *n*-alkanes on an HP-5ms column.
[b] The percentages of each component are reported as raw percentages based on total ion current without standardization.
[c] tr = "trace" (< 0.05%).
[d] MS, m/z(%): 206(19), 162(100), 147(59), 134(20), 133(21), 121(24), 120(41), 119(27), 108(31), 107(50), 106(56), 105(52), 95(30), 93(58), 91(68), 81(56), 79(56), 77(33), 67(41), 55(34), 53(21), 43(13).
[e] MS, m/z(%): 234(14), 220(14), 219(100), 203(20), 201(40), 187(21), 159(9), 115(9), 91(12), 79(9), 77(9), 69(11), 55(12), 43(25), 41(13).
[f] MS, m/z(%): 216(81), 201(100), 173(21), 138(6), 121(7), 115(21), 109(13), 97(17), 95(13), 91(16), 83(23), 69(38), 57(21), 55(31), 43(44).
[g] MS, m/z(%): 218(54), 203(100), 185(5), 147(8), 133(6), 105(6), 77(7), 69(10), 55(10), 43(31), 41(8).
[h] MS, m/z(%): 219(3), 187(5), 159(4), 147(5), 135(16), 134(29), 121(12), 119(18), 107(38), 93(53), 91(12), 81(21), 79(20), 71(36), 67(31), 55(26), 43(100), 41(18).

Table 4: Chemical composition of the essential oil of *Opuntia phaeacantha* var. *discata* from Organ Pipe Cactus National Monument.

RI[a]	Compound	%[b]		RI[a]	Compound	%[b]
758	4-Methyl-2-pentanol	tr[c]		1900	Nonadecane	1.0
836	Furfural	tr		1932	Methyl palmitate	0.3
1044	Phenylacetaldehyde	tr		1953	1-Heptadecanol	0.5
1067	Acetophenone	1.3		1972	Palmitic acid	7.0
1072	*cis*-Linalool oxide (furanoid)	5.1		2000	Eicosane	0.3
1088	*trans*-Linalool oxide (furanoid)	4.8		2031	Isopropyl palmitate	3.5
1102	Linalool	0.6		2068	2-Methyleicosane	0.6
1186	*p*-Cymen-8-ol	1.0		2101	Methyl linoleate	0.4
1190	Octanoic acid	tr		2100	Heneicosane	3.6
1191	α-Terpineol	0.7		2142	Linoleic acid	1.1
1307	*p*-Vinylguaiacol	0.5		2148	Oleic acid	1.4
1309	(2*E*,4*E*)-Decadienal	0.4		2199	1-Docosene	0.5
1345	Benzalacetone	0.8		2200	Docosane	2.4
1368	Decanoic acid	3.0		2227	(2*Z*)-Docosene	0.4

1429	(*E*)-β-Famesene	0.1		2280	(9*Z*)-Tricosene (= Muscalure)	1.1
1431	6-Amyl-α-pyrone	0.4		2300	Tricosane	15.5
1446	Massoilactone	0.6		2397	1-Tetracosene	1.9
1488	Maltyl isobutyrate	3.1		2400	Tetracosane	4.0
1499	α-Zingiberene	1.9		2494	1-Pentacosene	0.6
1500	Pentadecane	0.7		2500	Pentacosane	6.3
1509	(*E*,*E*)-α-Farnesene	1.1		2531	13-Methylpentacosane	0.8
1569	Lauric acid	4.5		2598	1-Hexacosene	0.8
1600	Hexadecane	0.7		2600	Hexacosane	0.9
1666	2-Methylhexadecane	tr		2636	13-Methylhexacosane	0.8
1700	Heptadecane	0.9		2700	Heptacosane	4.1
1772	Myristic acid	1.3		2739	Methyl lignocerate	1.1
1800	Octadecane	0.5		2800	Octacosane	0.3
1836	Butyl salicylate butyl ether	0.4		2841	Hexacosanal	1.0
1861	Tributyrin	0.6		2900	Nonacosane	0.8
1888	Homosolate	2.1		2910	3,7-Dimethyloctacosane	1.4
					Total Identified (60)	100.0

[a] RI = "Retention Index" determined in reference to a homologous series of *n*-alkanes on an HP-5ms column.
[b] The percentages of each component are reported as raw percentages based on total ion current without standardization.
[c] tr = "trace" (< 0.05%).

Table 5: Chemical composition of the essential oil of *Opuntia phaeacantha* var. *discata* from Arizona-Sonora Desert Museum.

RI[a]	Compound	%[b]		RI[a]	Compound	%[b]
1072	*cis*-Linalool oxide (furanoid)	3.4		2072	2-Methyleicosane	0.3
1091	*trans*-Linalool oxide (furanoid)	3.5		2087	1-Octadecanol	6.8
1104	Linalool	0.9		2100	Heneicosane	2.0
1194	α-Terpineol	1.3		2117	(*E*)-Phytol	5.2
1196	Octanoic acid	tr[c]		2274	2-Methyldocosane	0.5
1256	Geraniol	0.6		2284	(9*Z*)-Tricosene (= Muscalure)	3.1
1287	Nonanoic acid	0.9		2296	1-Tricosene	1.0
1310	Undecanal	0.4		2300	Tricosane	2.8
1316	*p*-Vinylguaiacol	16.2		2500	Pentacosane	1.7
1380	Decanoic acid	5.7		2584	Hexadecyl octanoate	0.9
1413	Dodecanal	0.2		2595	Unidentified[d]	3.9
1500	Pentadecane	0.3		2600	Hexacosane	0.6
1516	Tridecanal	0.5		2700	Heptacosane	1.1
1584	Lauric acid	5.9		2800	Octacosane	tr
1677	Tridecanoic acid	0.5		2900	Nonacosane	0.8
1773	Myristic acid	1.7		2994	1-Triacontene	0.6
1861	Tributyrin	7.8		3000	Triacontane	0.8
1887	1-Hexadecanol	6.6		3100	Untriacontane	1.6
1900	Nonadecane	0.8		3200	Dotriacontane	1.6
1934	(2*Z*)-Nonadecene	0.3		3351	5-Methyltriacontane	1.4
1971	Palmitic acid	3.0		3600	Hexatriacontane	1.7
2035	Isopropyl palmitate	1.1			Total Identified (42)	96.1

[a] RI = "Retention Index" determined in reference to a homologous series of *n*-alkanes on an HP-5ms column.
[b] The percentages of each component are reported as raw percentages based on total ion current without standardization.
[c] tr = "trace" (< 0.05%).
[d] MS, m/z(%): 299(20), 298(100), 283(3), 251(3), 233(4), 223(5), 195(3), 165(5), 151(4), 137(3), 115(3), 89(3), 77(3), 51(1).

3. Results and Discussion

Fifty-six compounds were identified in *O. acanthocarpa* var. major growing wild in the Organ Pipe Cactus National Monument. The primary components of the *O. acanthocarpa* oil from the Organ Pipe Cactus National Monument included octanoic acid (12.3%), tricosane (10.8%), decanoic acid (10.0%), and 2-hexanol (8.6%). Alkanes made up 37.7% of the total oil composition, fatty acids and fatty-acid derivatives comprised 28.4%, with only 8.2% terpenoids. Interestingly, the oil also contained 0.5% dimethyl trisulfide. Although dimethyl trisulfide can be harmful if consumed or inhaled by humans, it has been identified in several foods, including garlic [14, 15], cruciferous vegetables [16,17], and white truffle [18], as well as brewed coffee [19], aged beers [20], and sake [21].

A total of 48 compounds were identified in the essential oil of *O. acanthocarpa* var. major growing wild in the Arizona-Sonora Desert Museum. Chromene compounds composed 71.5% of the total essential oil composition. Eupatoriochromene (66.6%) dominated the oil composition of the cactus growing in the caliche-rich soil. Eupatoriochromene is an abundant phytochemical constituent of Eupatorium species [22], as well as *Hemizonia fitchii* [23], an annual herb native to California, *Centaurea solstitialis*, the yellow starthistle [24], and the brittlebush, *Encelia farinosa* [25]. Additional chromenes also identified in *O. acanthocarpa* from the Arizona-Sonora Desert Museum include demethoxyencecelin (3.0%), encecalin (1.6%), and androencecalinol (0.3%).

O. acanthocarpa var. *discata* growing wild at the Organ Pipe Cactus National Monument contained 60 identifiable compounds. The major components of the oil included tricosane (15.5%), palmitic acid (7.0%), pentacosane (6.3%), cis-linalool oxide (5.1%), trans-linalool oxide (4.8%), and lauric acid (4.5%). Alkane hydrocarbons made up 45.8% of the total oil, with 25.7% fatty acids and derivatives, and only 12.8% terpenoids. *O. acanthocarpa* from the Organ Pipe Cactus National Monument also contained 2.1% homosalate (3,3,5-trimethylcyclohexyl salicylate). Homosalate, a naturally occurring sunscreen that may protect DNA from ultraviolet radiation, has been identified as an emission of both the saguaro cactus (*Carnegiea gigantea*) and yucca (*Yucca baccata*) growing in the Las Vegas, Nevada desert area [26]. Homosalate and 2-ethylhexyl salicylate were also detected in *O. acanthocarpa* from the Arizona-Sonora Desert Museum (Table 3).

Forty-two compounds were identified in the oil of *O. acanthocarpa* var. *discata* growing wild at the Arizona-Sonora Desert Museum. The major components identified in the oil include p-vinylguaiacol (16.2%), tributyrin (7.8%), 1-octadecanol (6.8%), and 1-hexadecanol (6.6%). The essential oil contained 33.2% fatty acids and fatty-acid derivatives and 17.8% alkanes. The major component, p-vinylguaiacol, is a phenolic compound that has been found in several tropical fruits, including in papaya [27], star apple [28], and mango [29].

The essential oil composition of *O. acanthocarpa* growing in the drier, lime soil of the Organ Pipe Cactus National Monument differed significantly from that growing in the wetter, caliche soil of the Arizona-Sonora Desert Museum. *O. acanthocarpa* from the Arizona-Sonora Desert Museum contained 66.2% eupatoriochromene and consisted of a total chromene concentration of 71.1%, while *O. acanthocarpa* from the Organ Pipe Cactus National Monument was devoid of any chromenes. There were 12 n-alkanes common to *O. acanthocarpa* from both soil types as well as two fatty aldehydes (decanal and dodecanal), and isopropyl palmitate.

Similarly, *O. acanthocarpa* growing in the limey, drier soil of the Organ Pipe Cactus National Monument differed significantly from that growing in the caliche-rich, wetter soil of the Arizona-Sonora Desert Museum. Notable differences were the relatively abundant concentrations of p-vinylquaiacol, tributyrin, hexadecanol, and phytol in the sample from the Arizona-Sonora Desert Museum site that were either absent or in small concentrations in the Organ Pipe Cactus National Monument sample. Additionally, high-molecular-weight alkanes (≥ C30) were present in the Arizona-Sonora Desert Museum sample, but absent from the Organ Pipe Cactus National Monument sample. Conversely, homosalate and isopropyl palmitate were relatively concentrated in the Organ Pipe Cactus National Monument sample, while the Arizona-Sonora Desert Museum sample had only a trace amount of isopropyl palmitate and no homosalate. On the other hand, there were several compounds common to the two samples, including the monoterpenoids, cis- and trans-linalool oxide, linalool, and α-terpineol, the fatty acids decanoic acid, lauric acid, myristic acid, and palmitic acid, and a number of n-alkanes.

The volatile oil yields for both *O. acanthocarpa* and *O. acanthocarpa* were lower for the samples collected from the Organ Pipe Cactus National Monument (0.030% and 0.023%, respectively), than those collected from the Arizona-Sonora Desert Museum (0.073% and 0.081%, respectively). Additionally, both O. acanthocarpa and *O. acanthocarpa* oils from Organ Pipe Cactus National Monument had greater concentrations of alkanes than those from the Arizona-Sonora Desert Museum, and fatty acids were more abundant in O. acanthocarpa from Organ Pipe Cactus National Monument. For *O. acanthocarpa*, fatty acid and terpenoid concentrations were similar for the two collection sites.

4. Conclusions

Two cactus species, *Opuntia acanthocarpa* var. *major* and *O. acanthocarpa* var. *discata*, were collected from two different sites in southern Arizona, the Organ Pipe Cactus National Monument and the Arizona-Sonora Desert Museum. The essential oils from each of the cactus species were significantly different in oil yields and chemical compositions. The differences can be attributed to the different habitats of the two sites; the limey, drier soil of the Organ Pipe Cactus National Monument, compared to the caliche-rich, wetter soil of the Arizona-Sonora Desert Museum.

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