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Volatile components of organ pipe cactus, *Stenocereus thurberi* Engelm., growing in the Organ Pipe Cactus National Monument and the Arizona-Sonora Desert Museum

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Abstract

The essential oils of *Stenocereus thurberi* Engelm. (Cactaceae) growing wild in the Organ Pipe Cactus National Monument and cultivated at the Arizona-Sonora Desert Museum were obtained by hydrodistillation and analyzed by gas chromatography – mass spectrometry. The oil compositions were markedly different. The oil composition of *S. thurberi* from Organ Pipe Cactus National Monument was dominated by alkenes and alkanes along with 2.8% lapachol. *S. thurberi* cultivated at the Arizona-Sonora Desert Museum, on the other hand, was dominated by carboxylic acids. Octanoic acid comprised 41.7% of the total Arizona-Sonora Desert Museum specimen volatile oil and was devoid of lapachol. These differences may be attributed to differences in rainfall, temperature, and the soil content of the two Sonoran Desert locations.

Keywords: *Stenocereus thurberi*, Cactaceae, essential oil composition, alkenes, alkanes, carboxylic acids.

1. Introduction

Stenocereus thurberi Engelm., also known as organ pipe cactus, is a Mexican columnar cactus native to the Sonoran Desert. The native range of *S. thurberi* includes the Sonora Desert of Northern Mexico, southern Baja California and western Sonora Mexico [1]. The native range extends no more than 500 kilometers beyond the Mexican border into Arizona and includes Pinal and Pima counties [2]. *S. thurberi* is found growing on slopes up to 910 meters in elevation [1]. It is sensitive to frost and must be protected if cultivated at elevations above 910 meters. *S. thurberi* has numerous columnar branches stemming from ground level that resemble the pipes of an organ. The organ pipes of *S. thurberi* are commonly 2.7 to 6.1 meters in height with the outside perimeter of the columns reaching a width of 3.7 meters [3]. The cactus blooms white or lavender from late spring to early summer and produces an edible fruit in late summer [3]. Each column contains a porous wooden skeleton approximately 60 mm in diameter that runs the length of each column.

The Seri Indians of Northwestern Mexico and the Tohono O'odham Indians, formerly known as the Papago Indians, of southern Arizona are known to have utilized both the columns and fruits of *S. thurberi* [1, 3]. The Seri called *S. thurberi* "ool" and the fruit was called "ool imám" [4]. The Seri consumed the tennis-ball sized fresh fruits of *S. thurberi* [1], used the fruits for winemaking [4], and dried the fruits for later consumption [1]. The seeds, which are high in oil and protein, were dried and stored by the Seri [5]. The Seri utilized *S. thurberi* medicinally. Cactus stems with the spines removed were heated in coals, wrapped in cloth and placed on the body to relieve aches and pains [4]. The wooden skeleton, which was called "ool ittaaxk", was used to build the traditional Seri hut, reinforce baskets used to carry heavy loads, bundled to make torches for night hunting, used to make smoke signals, and burned for a lantern [4]. The Papago called *S. thurberi* "pitahaya dulce" [6]. The fruit of *S. thurberi* was so important to their diet and so plentiful that the Papago name for the Milky Way was "the second harvest of pitahaya" [7]. The Papago consumed the fruit, fermented the fruit and consumed the fermented beverage in special ceremonies [7].

Although *S. thurberi* grows wild at the Organ Pipe Cactus National Monument, it is cultivated at the Arizona-Sonora Desert Museum. The elevation of Organ Pipe Cactus National Monument, which is located on the American-Mexican border, ranges from 305 meters to 1,463 meters [4], and *S. thurberi* is found growing wild at the lower elevations of the National Monument. The elevation at the Arizona-Sonora Desert Museum, which is located near Tucson, Arizona, is approximately 866 meters [5], and *S. thurberi* does not grow wild at the Arizona-Sonora Desert Museum and must be protected from frost due to the elevation of the park. Additionally, the Arizona-Sonora Desert Museum typically receives snow once or twice a year [5]. This difference in elevation affects the amount of precipitation that the cultivated plant receives at the Arizona-Sonora Desert Museum. The Arizona-Sonora Desert Museum receives 372.9 mm (14.68 inches) [8] of annual precipitation while the Organ Pipe Cactus National Monument receives just 196.1 mm (7.72 inches) [9] of annual precipitation. The soil of the Arizona-Sonora Desert Museum is rich with caliche (calcium carbonate) while the soil of the Organ Pipe Cactus National Monument is rich with lime [10]. Previous phytochemical investigations of this cactus species have revealed lupane and oleanane triterpenoids [11] and steroids [12]. The seed oil of *S. thurberi* was found to be rich in unsaturated fatty acids, predominantly linoleic and oleic acids [13]. This study investigates whether *S. thurberi* grown in differing environments within the Sonora Desert will have different essential oil compositions. To our knowledge, the volatile compositions of this cactus species have not been previously reported.

2. Materials and Methods

2.1 Plant Material

S. thurberi was identified and collected from the Organ Pipe Cactus National Monument in southwestern Arizona by Luciano Matzkin. Samples were chopped and frozen at -20 °C until studied. The green cactus exuded a faint, pleasant odor. The 120.51 grams of cactus was hydrodistilled using a Likens-Nickerson apparatus. Continuous extraction of the distillates with chloroform for four hours gave clear, slightly yellow essential oil (1.3 mg), which was stored at 4 °C until analysis. *S. thurberi* was identified and collected from the Arizona-Sonora Desert Museum by Julie Wiens. Hydrodistillation of 104.74 grams of cactus, as above, gave 144.2 mg of slightly yellow essential oil, which was stored at 4 °C until analysis.

2.2 Gas Chromatography – Mass Spectrometry

The cactus essential oils of *S. thurberi* growing wild at Organ Pipe Cactus National Monument and cultivated at Arizona-Sonora Desert Museum 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, and an HP-5 ms fused silica capillary column as described previously [10]. Identification of the oil components was based on their retention indices determined by reference to a homologous series of *n*-alkanes (the calibration mixture of alkanes was injected separately rather than co-injected), and by comparison of their mass spectral fragmentation patterns with those reported in the literature [14, 15] and stored on the MS library [NIST database (G1036A, revision D.01.00)/ChemStation 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.

3. Results and Discussion

A total of 50 compounds (Table 1), accounting for 93.4% of the composition, were identified in the volatiles of *S. thurberi* growing wild at the Organ Pipe Cactus National Monument. The volatile extract was composed of 30.9% alkene hydrocarbons, 29.2% alkane hydrocarbons, 10.1% fatty acid esters, 7.6% carboxylic acids, 6.5% aldehydes, and 4.6% alcohols. The two compounds in *S. thurberi* oil with the greatest percentage were 1-eicosene (6.2%) and isopropyl hexadecanoate (6.2%). The other major components of the oil sample were tetracosane (5.0%), 1-nonadecene (4.9%), decanoic acid (4.6%), 1-octadecanol (3.8%), and lapachol (2.8%). Thirty compounds were identified in the essential oil of *S. thurberi* cultivated at the Arizona-Sonora Desert Museum (Table 2). The three primary components of the cactus extract were octanoic acid (41.7%), leaf alcohol (13.3%), and decanoic acid (13.1%). The volatile fraction was composed of 61.9% carboxylic acids, 24.1% alcohol-derived compounds, and 4.2% alkane hydrocarbons. Additionally, 3-methylene-4-methylpentan-1-ol (Figure 1) was identified in this sample. To our knowledge, this is the first report of a natural source of this compound.

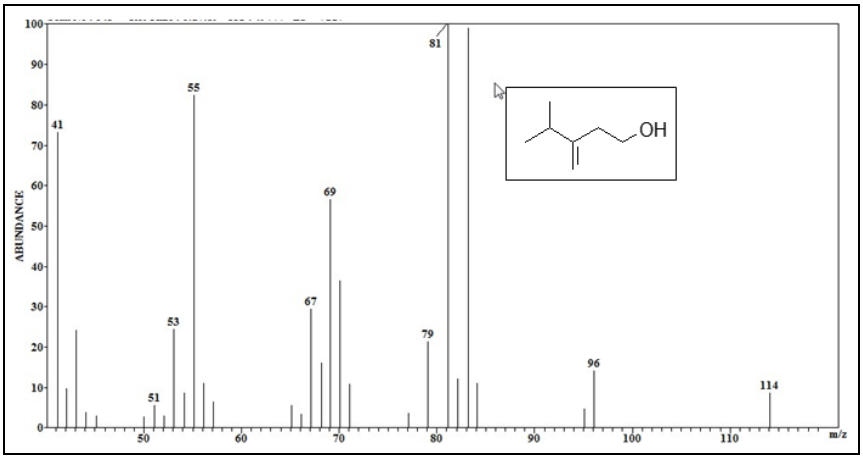

Fig 1: Mass spectrum and structure of 3-methylene-4-methylpentan-1-ol.

Table 1: Chemical composition of essential oil of *Stenocereus thurberi* Engelm. growing at Organ Pipe Cactus National Monument.

RI[a]	Compound	% [b]		RI[a]	Compound	% [b]
1106	Nonanal	1.2		1921	Methyl palmitate	1.8
1206	Decanal	1.0		1929	*cis*-2-Nonadecene	0.9
1285	Bornyl acetate	0.8		1996	1-Eicosene	6.2
1323	Methyl decanoate	0.9		2000	Eicosane	1.9
1371	Decanoic acid	4.6		2013	*cis*-2-Eicosene[c]	0.8
1388	Unidentified	2.5		2029	Isopropyl hexadecanoate	6.2
1410	Dodecanal	0.4		2090	Octadecanol	3.8
1506	Unidentified	0.9		2100	Heneicosane	2.6
1511	Tridecanal	0.3		2116	Lapachol	2.8
1527	Methyl laurate	1.0		2173	Unidentified	1.0
1566	Lauric acid	2.0		2195	1-Docosene	3.4
1588	Hexadecene	1.3		2200	Docosane	2.1
1613	Tetradecanal	2.1		2294	1-Tricosene	2.3
1634	1-*epi*-Cubenol	0.8		2300	Tricosane	0.2
1696	Heptadecene	2.6		2396	1-Tetracosene	2.2
1700	Heptadecane	1.1		2400	Tetracosane	5.0
1715	Pentadecanal	0.4		2496	1-Pentacosene	1.0
1722	*cis*-2-Heptadecene	0.6		2500	Pentacosane	1.6
1729	Methyl myristate	0.4		2596	1-Hexacosene	0.3
1795	1-Octadecene	3.6		2600	Hexacosane	1.2
1800	Octadecane	2.1		2696	1-Heptacosene	0.3
1809	*trans*-2-Octadecene	0.2		2700	Heptacosane	1.6
1815	Hexadecanal	1.1		2796	1-Octacosene	0.3
1839	6,10,14-Trimethyl-2-pentadecanone	1.7		2800	Octacosane	0.8
1880	Unidentified	0.6		2900	Nonacosane	3.3
1896	1-Nonadecene	4.9		3000	Triacontane	1.0
1900	Nonadecane	3.4		3100	Hentriacontane	1.3
					% Identified	93.4

[a] RI = "Retention Index" calculated 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] May be the *trans*-isomer.

Table 2: Chemical composition of *Stenocereus thurberi* Engelm. cultivated at the Arizona-Sonora Desert Museum.

RI[a]	Compound	% [b]		RI[a]	Compound	% [b]
801	3-Hexenal[c]	0.4		1093	2-Nonanone	0.2
810	2-Hexanol	4.2		1105	Nonanal	0.2
835	Furfural	0.6		1183	Octanoic acid	41.7
860	*cis*-3-Hexen-1-ol (leaf alcohol)	13.3		1191	α-Terpineol	3.9
871	1-Hexanol	1.8		1379	Decanoic acid	13.1
891	2-Heptanone	0.5		1400	Tetradecane	0.3
904	Heptanal	0.2		1500	Pentadecane	0.4
906	3-Methylene-4-methylpentan-1-ol	2.1		1571	Dodecanoic acid	4.3
940	3,4-Dimethyl-1-pentanol	1.2		1600	Hexadecane	0.5
960	6-Methyl-2-heptanone	0.4		1888	Hexadecanol	0.6
974	1-Heptanol	0.3		1967	Palmitic acid	0.5
973	Hexanoic acid	2.3		2400	Tetracosane	0.2
1005	*cis*-3-Hexenyl acetate	0.3		2700	Heptacosane	0.5
1035	Unidentified	1.2		2896	1-Nonacosene	1.1
1044	Benzene acetaldehyde	0.3		2900	Nonacosane	2.3
1073	Octanol	0.5			% Identified	98.3

[a] RI = "Retention Index" calculated 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] Correct isomer (*cis/trans*) not determined.

4. Conclusions

The essential oil composition of *S. thurberi* growing wild at the Organ Pipe Cactus National Monument varied quantitatively and qualitatively from the specimen cultivated at the Arizona-Sonora Desert Museum. Although alkenes and alkanes dominated essential oil of the Organ Pipe Cactus National Monument specimen (60.1%), alkenes were absent from the Arizona-Sonora Desert Museum specimen and alkanes constituted just 4.2% of the total essential oil. Carboxylic acids dominated the cultivated specimen growing at the Arizona-Sonora Desert Museum but constituted just 7.6% of the Organ Pipe Cactus National Monument specimen. The alcohol content was significantly greater in the cultivated Arizona-Sonora Desert Museum specimen (24.1%) than in the Organ Pipe Cactus National Monument specimen (4.6%). Although lapachol was identified in the essential oil of the Organ Pipe Cactus National Monument specimen, it was notably absent from the Arizona-Sonora Desert Museum specimen. These substantial differences in essential oil composition may be due to environmental conditions. Organ Pipe Cactus National Monument is a drier, hotter climate than the Arizona-Sonora Desert Museum climate. Additionally, the soil content of the Organ Pipe Cactus National Monument is rich with lime while the soil at the Arizona-Sonora Desert Museum is composed primarily of caliche.

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