

The Leaf Essential Oils of *Juniperus communis* L. Varieties in North America and the NMR and MS Data for Isoabienol

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Abstract

This is first report on the composition of the leaf essential oils of *J. communis* L. varieties from the Western Hemisphere. The oil of *Juniperus communis* var. *jackii* had the most distinct oil and contained moderate amounts of α -pinene (16.1–18.9%), δ -3-carene (17.9–28.4%) and β -phellandrene (9.2–13.4%) along with several diterpenes including isoabienol. *Juniperus communis* var. *charlottensis* oil had a very high concentration of α -pinene (59.3%), with moderate amounts of β -pinene (5.9%), δ -3-carene (3.6%) and β -phellandrene (2.9%). The oil of *J. communis* var. *depressa* was dominated by α -pinene (53.9%), δ -3-carene (9.3%) and β -pinene (5.5%) and was a little unusual in also containing citronellol, citronellyl acetate, neryl acetate and geranyl acetate with no diterpenes. The oil of *J. communis* var. *megistocarpa* possessed large amounts of α -pinene (58.5%), limonene (20.4%) and β -pinene (5.0%) and, like *J. communis* var. *depressa*, its oil also contained citronellol, citronellyl acetate, neryl acetate and geranyl acetate. Putative *J. communis* var. *saxatilis* from Idaho, USA, had a high concentration of α -pinene (56.5%) with moderate amounts of δ -3-carene (11.5%), β -pinene (5.4%), myrcene (4.5%) and β -phellandrene (3.1%).

The oils of these North American varieties were compared to *J. communis* var. *communis* (Sweden) and *J. communis* var. *saxatilis* (Switzerland). A survey of approximately 65 species of *Juniperus* revealed that isoabienol was present in eight species. X-ray, MS and ^{13}C -NMR were used to determine the structure of isoabienol (**I**) and KI and a mass spectrum is presented to aid future identification.

Key Word Index

Juniperus communis var. *charlottensis*, *Juniperus communis* var. *depressa*, *Juniperus communis* var. *jackii*, *Juniperus communis* var. *megistocarpa*, *Juniperus communis* var. *saxatilis*, Cupressaceae, essential oil composition, α -pinene, δ -3-carene, β -phellandrene, isoabienol.

Introduction

Juniperus communis L. is a pan-arctic species growing in the Northern Hemisphere and is the only *Juniperus* species that grows in both the Eastern and Western Hemispheres (1). In the monograph of *Juniperus* (1), three varieties were recognized from the Eastern Hemisphere: *J. communis* var. *communis*, *J. communis* var. *nipponica* (Maxim.) E. H. Wilson and *J. communis* var. *saxatilis* Pall.; and two varieties from the Western Hemisphere: *J. communis* var. *depressa* Pursh. and *J. communis* var. *megistocarpa* Fernald & H. St. John. The taxonomic status of the Western Hemisphere *J. communis* taxa has been

revised (2) based on both morphology and DNA fingerprinting data. In a more recent study, Adams (3) utilized nrDNA SNPs as well as morphology and DNA fingerprinting. Five varieties were recognized (3) from North America: *J. communis* var. *charlottensis* R. P. Adams, *J. communis* var. *depressa*, *J. communis* var. *jackii* Rehr., *J. communis* var. *megistocarpa*, and *J. communis* var. *saxatilis*.

The essential oils of *J. communis* and its varieties from the Eastern Hemisphere have been reported on in 163 papers (CAS on-line, 11/2007). However, there are no reports on the oils of *J. communis* varieties from the Western Hemisphere. The single report on the oil citing *J. communis* var. *depressa* from

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Caucasus region (4) is incorrect as the plant was misidentified and should be referred to *J. communis* var. *saxatilis* in that report.

During the course of the investigation of the leaf oils of *J. communis* in North America, a major unknown compound was encountered and preparative work along with NMR analysis was performed to elucidate its structure. The purpose of this paper is to present analyses of the leaf oils of *J. communis* varieties from the Western Hemisphere.

Experimental

Plant material: Specimens used in this study: *J. communis* var. *charlottensis*, 61 m, muskeg bog, Queen Charlotte Island, British Columbia, Canada, Adams 10304-10308; *J. communis* var. *communis*, 30 m, Stockholm, Sweden, Adams 7846-7848; *J. communis* var. *depressa*, 2512 m, 19 km N of Guadalupita, NM, USA, Adams 10936-10940; *J. communis* var. *jackii*, 2095 m, 8 km E of US 101 on Rowdy Ck. Rd., CA, USA, Adams 10287-10291, 1792 m, Mt. Hood, OR, USA, Adams 10300-10303; *J. communis* var. *megistocarpa*, 3 m, sand dunes, Magdalen Islands, Quebec, Canada, Adams 8585-8577; *J. communis* var. *saxatilis*, 1500 m, 1 km W of Gletsch, Switzerland, Adams 7618-7621, and 1997 m, Redfish Lake, ID, USA, Adams 10890-10894. Voucher specimens have been deposited at the Herbarium, Baylor University (BAYLU).

Isolation of oils: Fresh leaves (200 g) were water distilled for 2 h using a circulatory Clevenger-type apparatus (5). The oil samples were concentrated (diethyl ether trap removed) with N_2 and the samples stored at -20°C until analyzed. The exhausted leaves were oven-dried (48 h, 100°C) for determination of oil yields.

Analyses: Oils from 3–5 trees of each of the taxa were analyzed and average values are reported. The oils were analyzed on an HP5971 MSD mass spectrometer, scan time 1/s, directly coupled to an HP5890 gas chromatograph, using a J&W DB-5, 0.26 mm \times 30 m, 0.25 micron coating thickness, fused silica capillary column (see 5 for operating details). Identifications were made by library searches of the authors' volatile oil library (6), using the HP Chemstation library search routines, coupled with retention time data of authentic reference compounds. Quantitation was by FID on an HP5890 gas chromatograph using a J&W DB-5, 0.26 mm \times 30 m, 0.25 micron coating thickness, fused silica capillary column using the HP Chemstation software.

Additional GC/MS data were acquired at 70 eV under EI conditions with an AGILENT 5973 Network Mass Selective Detector interfaced with an AGILENT 6950 GC system fitted with a 30 m \times 0.25 mm (film thickness 0.25 μm) HP-5MS capillary column. The GC was programmed at initial temperature of 50°C for 10 min, followed by $3^\circ\text{C}/\text{min}$ to 230°C , and then isothermal at 230°C for 10 min. NMR spectral data were acquired with a Varian Mercury 300 spectrometer using CDCl_3 as the solvent. Optical rotation was measured with a Perkin-Elmer 241 polarimeter at 589 nm using a 10 mm microcuvet.

Isolation of isoabiienol: A 0.25 g sample of the oil dissolved in 1 mL hexane was subjected to column chromatography using 6 g silica gel (Aldrich, silica gel 200–400 mesh) packed as a slurry in a 25 mL buret using 10 mL each of 100:0, 99:1, 98:2, 96:4, 92:8, 88:12, 84:16, 75:25, 60:40 and 50:50 hexane:ether

mixtures as the mobile phase. The column was further eluted with 20 mL ether. Forty-two fractions about 3 mL each were collected. Based on TLC profile of the column chromatography fractions, fraction numbers 24–30 containing two components with very close R_f values were selected for further isolation work. The selected fractions were further chromatographed with 3 g of reverse phase silica gel taken from PrepSep- C_{18} cartridges using 10 mL each of 70:30, 75:25, 80:20, 85:15, 90:10, 95:5 and 100:0 mixtures of acetonitrile:water as the eluents. Forty fractions, each about 2 mL, were collected. Reverse phase TLC profile indicated the presence of single component in fractions 20–25. Each one of the 20–25 fractions was dried with 50 mg of anhydrous Na_2SO_4 . The GC of the clear solutions indicated better than 96% purity and upon drying under N_2 deposited crystalline residues. The solid recrystallized from aqueous ethanol provided appropriate crystals for X-ray diffraction work; m.p. $64\text{--}65^\circ\text{C}$ (uncorr.), $[\alpha]_D^{20} = +7.6^\circ$. Lit. m.p. $68\text{--}68.5^\circ\text{C}$, $[\alpha]_D^{20} = -6.4^\circ$ ($c = 0.2$, CHCl_3) (8), $[\alpha]_D^{20} = +7.6^\circ$ ($c 5.40$) (9).

Results and Discussion

(1R,2R,4aS,8aS)-decahydro-2,5,5,8a-tetramethyl-1-(3-methylene-4-penten-1-yl)-2-naphthalenol (isoabiienol) **I** - The structure of **I** was derived from the X-ray diffraction data of its crystal (Figure 1). Additionally, its ^{13}C -NMR chemical shifts data agreed completely with the reported data (7). It should be pointed out that earlier workers have assigned the same configuration as **I** for the *levorotatory* isoabiienol (8). However, later authors have assigned the same configuration to the *dextrorotatory* enantiomer (9). Their assignment of absolute configuration as **I** for the *dextrorotatory* enantiomer was based on its co-occurrence with (+)-gomerldehyde in *J. infusca* and whose absolute configuration was established from the X-ray diffraction data of its derivative (9).

The compositions of the leaf oils of *J. communis* varieties are shown in Table I. The leaf oil of *J. communis* var. *jackii* was

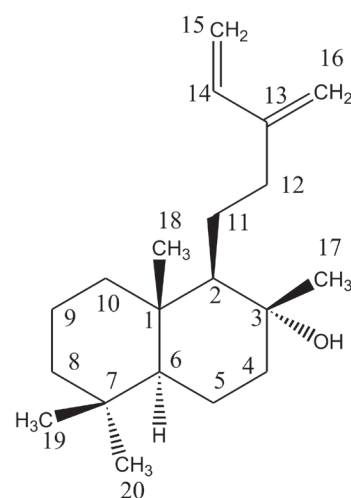


Figure 1. Structure for isoabiienol (**I**). See text for discussion of NMR data.

J. communis

Table I. Composition of the leaf oils of *J. communis* var. *jackii* from northwest California (*jackii*¹) and Mt Hood, Oregon (*jackii*²), var. *charlottensis* (*char*), var. *depressa* (*dep*), var. *megistocarpa* (*meg*) and putative var. *saxatilis*, Idaho (*sax NA*) compared with literature reports (10) for *J. communis* var. *communis*, Sweden (*com Sw*) and *J. communis* var. *saxatilis*, Europe (*sax EU*)

KI	Compound	North America					Europe		
		<i>jackii</i> ¹	<i>jackii</i> ²	<i>char</i>	<i>dep</i>	<i>meg</i>	<i>sax NA</i>	<i>com Sw</i>	<i>sax EU</i>
854	(E)-2-hexenal	0.2	1.0	0.4	0.1	0.1	0.3	0.7	1.2
926	tricyclene	t	t	0.1	0.1	0.1	0.1	0.3	t
931	α -thujene	t	t	t	t	t	t	0.1	4.1
939	α-pinene	16.1	18.9	59.3	53.9	58.5	56.5	56.8	14.1
953	α -fenchene	0.3	0.6	0.1	1.0	t	0.5	0.3	0.1
953	camphene	0.3	0.6	0.6	1.0	0.6	0.5	0.6	0.2
954	thuja-2,4-diene	-	-	0.1	0.1	-	-	-	-
967	verbenene	0.3	0.3	-	-	-	-	-	-
976	sabinene	0.1	0.3	0.3	0.3	0.3	0.3	0.7	32.8
978	1-octen-3-ol	0.1	-	-	t	t	-	-	-
980	β-pinene	1.9	1.9	5.9	5.5	5.0	5.4	4.4	1.9
991	myrcene	3.2	3.2	4.8	4.1	3.9	4.5	5.2	5.0
997	ethyl hexanoate	-	-	0.1	-	-	-	-	-
1001	δ -2-carene	0.2	0.2	0.1	0.2	0.2	0.1	0.2	0.4
1005	α -phellandrene	2.2	2.5	0.1	0.2	0.1	0.1	2.1	0.5
1011	δ-3-carene	17.9	28.4	3.6	9.3	0.7	11.5	4.7	0.5
1018	α -terpinene	-	-	-	t	0.1	-	t	1.9
1026	p-cymene	1.1	0.8	0.2	0.2	0.1	t	0.3	0.3
1031	limonene	6.6	0.5	1.9	2.6	20.4	2.1	5.1	6.7
1031	β-phellandrene	13.4	9.2	2.9	2.5	1.0	3.1	8.9	0.6
1050	(E)- β -ocimene	0.3	t	-	t	t	-	0.1	0.1
1057	amyl isobutyrate	-	-	-	-	-	-	0.2	-
1062	γ-terpinene	0.1	0.1	0.1	0.1	0.1	0.1	t	3.4
1068	cis-sabinene hydrate	-	-	-	-	t	t	t	1.8
1088	terpinolene	3.2	4.4	1.0	1.4	0.5	1.8	1.1	3.0
1095	linalool	-	-	0.1	0.3	0.4	0.2	0.1	-
1097	trans-sabinene hydrate	-	-	-	-	-	-	-	1.3
1100	nonanal	-	-	0.1	-	-	-	-	-
1103	isoamyl-isovalerate	-	-	-	-	-	-	0.1	t
1112	3-methyl-3-butenyl-isovalerate	-	-	t	0.1	t	0.1	t	-
1114	trans-thujone (= β -thujone)	-	-	-	-	-	-	-	0.6
1121	cis-p-menth-2-en-1-ol	0.2	0.1	-	-	t	t	t	-
1125	α -campholenal	0.2	0.2	0.4	0.5	t	0.1	t	-
1132	cis-limonene oxide	0.1	0.4	-	0.2	0.2	-	-	-
1133	cis-p-mentha-2,8-dien-1-ol	-	-	-	-	-	0.1	-	-
1139	trans-pinocarveol	0.2	0.3	0.4	0.5	t	0.1	-	-
1141	camphor	-	-	0.2	-	-	0.2	-	-
1143	trans-verbenol	0.2	0.3	0.2	0.7	t	-	-	-
1147	3-methyl-2-butenyl-isovalerate	-	-	-	0.1	-	0.2	t	-
1148	citronellal	-	-	-	0.2	0.2	0.1	-	-
1158	pinocarvone	-	-	0.1	-	-	-	-	-
1159	p-mentha-1,5-dien-8-ol	0.4	0.3	0.3	0.5	-	0.1	t	-
1165	borneol	-	-	0.3	-	0.2	0.1	0.2	t
1172	pinocamphone	-	-	0.1	-	-	0.1	-	-
1177	terpinen-4-ol	0.7	0.3	0.5	0.5	0.2	0.3	0.2	7.3
1176	m-cymen-8-ol	-	-	0.1	0.2	-	-	-	-
1179	naphthalene	-	-	0.1	-	0.2	-	t	0.3
1183	p-cymen-8-ol	0.3	0.3	0.1	0.2	-	-	t	t
1189	α -terpineol	0.3	0.3	1.0	0.6	1.5	0.5	0.2	0.4
1190	methyl salicylate	-	-	0.1	-	-	0.1	-	-
1194	myrtenol	0.4	0.3	0.3	0.5	0.5	0.3	-	-
1204	verbenone	0.3	0.5	0.3	0.3	-	t	t	-
1217	trans-carveol	0.4	t	0.3	0.2	t	t	-	-
1223	citronellol	-	-	0.1	0.5	0.3	0.2	-	-
1235	methyl thymol	0.2	0.2	-	-	t	0.1	-	0.1
1239	carvone	-	-	0.1	-	-	0.1	-	-
1249	piperitone	-	-	-	0.4	t	0.2	t	-
1257	methyl citronellate	-	-	0.2	0.1	t	0.3	t	-
1285	bornyl acetate	0.5	0.5	1.0	0.6	0.5	0.7	0.9	0.2
1291	trans-verbenyl acetate	-	-	-	-	t	-	-	-

Table I. Continued

KI	Compound	North America					Europe		
		<i>jackii</i> ¹	<i>jackii</i> ²	<i>char</i>	<i>dep</i>	<i>meg</i>	<i>sax</i> NA	<i>com</i> Sw	<i>sax</i> EU
1292	(E,Z)-2,4-decadienal	-	-	t	-	t	t	-	-
1293	methyl myrtenate	0.2	0.5	-	-	-	-	-	-
1302	<i>α</i>-terpinyl formate	1.0	1.5	1.0	0.2	-	0.3	-	-
1312	citronellic acid	-	-	-	t	t	t	-	-
1324	myrtenyl acetate	1.6	2.7	1.2	1.1	1.1	1.0	t	-
1332	<i>cis</i> -piperitol acetate	-	-	-	-	-	0.1	-	-
1365	<i>cis</i> -carvyl acetate	-	-	0.1	-	-	t	-	-
1350	<i>α</i> -terpinyl acetate	0.9	5.8	t	1.7	0.2	0.6	-	0.5
1350	citronellyl acetate	-	-	0.1	0.3	t	0.1	t	-
1359	neryl acetate	-	-	0.1	0.1	t	0.1	-	-
1379	geranyl acetate	-	-	0.1	1.3	0.1	0.3	-	-
1381	<i>trans</i> -myrtanyl acetate	t	t	-	-	-	-	-	t
1391	β-elemene	0.3	0.1	0.2	0.1	t	0.1	0.2	t
1418	β-caryophyllene	0.4	t	t	-	-	0.1	0.7	t
1448	<i>cis</i>-muurola-3,5-diene	-	-	0.1	-	-	-	-	-
1454	<i>α</i> -humulene	0.5	0.2	0.1	t	-	0.1	0.5	t
1465	<i>cis</i> -muurola-4(14),5-diene	t	t	0.1	-	-	-	-	-
1475	<i>trans</i> -cadina-1(6),4-diene	-	-	0.1	-	-	0.1	-	-
1477	γ-muurolole	t	t	0.1	0.1	t	0.1	t	t
1480	germacrene D	4.1	1.1	0.3	0.2	0.1	0.6	0.7	0.4
1493	<i>trans</i> -muurola-4(14),5-diene	-	-	0.1	-	-	0.1	-	-
1493	epi-cubebol	0.3	t	0.2	-	-	-	t	-
1499	<i>α</i> -muurolole	0.6	0.2	0.3	0.1	0.1	0.2	0.2	0.2
1503	germacrene A	t	t	0.1	0.1	t	0.1	0.1	0.2
1505	β-bisabolene	-	-	0.1	-	-	-	-	-
1513	γ-cadinene	1.2	0.4	0.4	0.2	0.1	0.3	0.2	0.4
1524	δ-cadinene	2.2	0.7	1.4	0.5	0.4	0.7	0.5	0.8
1538	<i>α</i> -cadinene	0.2	0.1	0.1	0.1	t	0.1	t	t
1549	elemol	t	-	-	t	-	t	t	-
1556	germacrene B	0.5	0.3	0.3	0.3	-	1.2	0.3	0.3
1561	(E)-nerolidol	-	-	t	t	0.1	t	-	-
1574	germacrene D-4-ol	0.9	0.8	0.8	1.0	0.5	1.2	0.8	1.8
1577	spathulenol	-	-	0.1	-	0.1	0.1	t	-
1607	β-oplopenone	-	-	0.1	-	t	0.1	-	-
1581	caryophyllene oxide	0.2	t	-	-	-	-	t	-
1594	salvial-4(14)-en-1-one	0.1	-	-	-	-	-	-	-
1606	humulene epoxide II	t	t	-	0.1	-	-	t	-
1627	1-epi-cubebol	1.5	t	t	-	-	t	t	t
1640	epi- <i>α</i> -cadinol	0.7	0.3	0.3	0.2	0.1	0.2	t	0.5
1640	epi- <i>α</i> -muurolol	0.8	0.3	0.3	0.2	0.1	0.3	0.4	0.5
1645	<i>α</i> -muurolol	0.4	0.1	0.1	0.1	t	0.1	t	0.1
1653	<i>α</i> -cadinol	2.0	1.1	0.9	0.7	0.3	0.8	0.5	1.3
1685	<i>α</i>-bisabolol	-	-	1.0	0.7	t	0.2	-	-
1685	germacra-4(15),5,10(14)-trien-1-al	0.3	-	-	-	-	-	t	-
1688	shyobunol	t	t	0.2	0.1	-	0.3	0.7	-
1714	(E,Z)-farnesal	-	-	-	-	t	-	-	-
1722	(Z,E)-farnesal	-	-	-	-	0.3	-	-	-
1742	(E,E)-farnesal	-	-	-	-	t	-	-	-
1806	nootkatone	-	-	0.1	-	-	-	-	-
1933	cyclohexadecanolid	0.1	-	0.1	-	-	-	-	-
1968	sandaracopimara-8(14),15-diene	-	t	-	-	-	-	-	-
2022	abieta-8,12-diene	-	t	-	-	-	-	-	-
1989	manoyl oxide	0.2	0.3	-	-	-	-	-	0.1
2055	abietatriene	0.3	0.6	0.1	-	-	-	-	0.2
2056	manool	0.6	0.7	-	-	-	-	-	-
2080	abietadiene	-	1.1	-	-	-	-	-	0.4
2106	isoabienol	0.2	0.9	-	-	-	-	-	0.1
2331	<i>trans</i>-ferruginol	t	0.2	-	-	-	-	-	-

KI = Kovat's Index on DB-5 (= SE54) column. * Tentatively identified. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported. Those compounds that appear to distinguish taxa are in boldface.

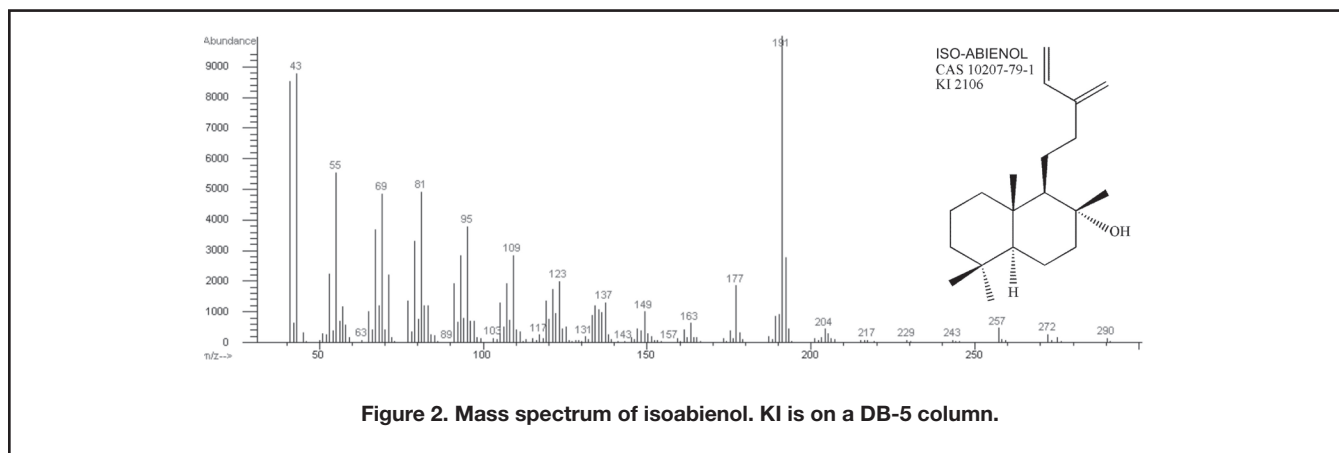


Figure 2. Mass spectrum of isoabiolenol. KI is on a DB-5 column.

similar in both populations sampled. These two populations grow in extreme edaphic sites: the northwest California site is on serpentine soil (having a high concentration of MgO and FeO and low in calcium-magnesium ratio, and lacking essential nutrients such as nitrogen, potassium and phosphorus) and the Mt. Hood site is on the lava slopes of Mt. Hood (high in Fe and Mg, very low in nutrients). The major components of the oil of *J. communis* var. *jackii* were α -pinene (16.1–18.9%), δ -3-carene (17.9–28.4%) and β -phellandrene (9.2–13.4%) (Table I). However, the oil was much lower in α -pinene than var. *depressa*, var. *megistocarpa*, and putative var. *saxatilis* (Idaho) (Table I). The oil of *J. communis* var. *jackii* contained several diterpenes including isoabiolenol (Table I) that are not found in var. *depressa*, var. *megistocarpa*, or var. *communis*. Interestingly, these diterpenes were also found in *J. communis* var. *saxatilis* (Table I) from Switzerland but not in the putative var. *saxatilis* from North America.

The oil of *J. communis* var. *charlottensis* was very high in α -pinene (59.3%), with moderate amounts of β -pinene (5.9%), δ -3-carene (3.6%) and β -phellandrene (2.9%). It was generally quite similar to var. *depressa*, var. *megistocarpa*, and var. *saxatilis* (Idaho). It appears to have a few unique compounds: ethylhexanoate, nonanal, pinocarvone, and *cis*-muurolo-3,5-diene (Table I). The only diterpene found was abietatriene (0.1%).

Juniperus communis var. *depressa* oil was dominated by α -pinene (53.9%), δ -3-carene (9.3%) and β -pinene (5.5%). The oil seemed to be a little unusual in possessing citronellol, citronellyl acetate, neryl acetate and geranyl acetate. In addition, it shared α -bisabolol with other taxa from North America, except var. *jackii* (Table I). The oil was void of diterpenes.

The oil of *J. communis* var. *megistocarpa* contained large amounts of α -pinene (58.5%), limonene (20.4%) and β -pinene (5.0%). Like *J. communis* var. *depressa*, the oil also contained citronellol, citronellyl acetate, neryl acetate and geranyl acetate. The female cones of *J. communis* var. *megistocarpa* are unusually larger (10–13 mm dia.) than other *J. communis* varieties (6–9 mm dia.) (1). It is very restricted in distribution, being found only on sand dunes in Newfoundland, Nova Scotia, and Sable and Magdalen Islands, Quebec. It is thought to be of recent origin, arising from *J. communis* var. *depressa* or a common ancestor (1). The oil of *J. communis*

var. *megistocarpa* did contain three farnesal isomers (Table I) not found in other varieties.

Juniperus communis var. *saxatilis* from Redfish Lake, Idaho had an oil that was very much like the other North American varieties except var. *jackii* (Table I). The oil had a high concentration of α -pinene (56.5%) with moderate amounts of δ -3-carene (11.5%), β -pinene (5.4%), myrcene (4.5%) and β -phellandrene (3.1%). Notice that all the North America varieties shared citronellol, citronellyl acetate, neryl acetate and geranyl acetate, except var. *jackii* (Table I).

Juniperus communis var. *communis*, from Sweden, (10) was included in Table I and shows the typical pattern of very large concentration of α -pinene (56.8%), with considerable amounts of β -phellandrene (8.9%), limonene (5.1%), δ -3-carene (4.7%) and β -pinene (4.4%). Its oil was void of diterpenes (Table I).

The oil of *J. communis* var. *saxatilis*, from Switzerland, (10) has been characterized (Table I) by possessing large amounts of sabinene (32.8%) and α -pinene with moderate amounts of terpinen-4-ol (7.3%), limonene (6.7%), myrcene (5.0%) and α -thujene (4.1%). It was also found to contain several diterpenes that it shared with *J. communis* var. *jackii* (Table I). Both of these varieties have short, curved leaves with the stomatal band being twice or more the width of the green margin (1). The distribution of *J. communis* var. *jackii* ranges from northwest California, along the coastal range, thence into Alaska (3). This is a Pacific Rim distribution suggesting that a corridor for invasion from Asia across the Bering Straits may have been available at some point in the past. The *J. communis* taxon from the Kamchatka peninsula is the nearest extant population (2). The relationship of *J. communis* var. *jackii* to the Kamchatka peninsula population is currently being investigated.

Isoabiolenol has been reported in papers on *Pinus* (13 refs.), *Cupressus* (5 refs.), liverworts (4 refs.), *Abies* (1 ref.), *Picea* (1 ref.) and *J. cedrus* from Madeira Island by Cavaleiro et al. (11). Isoabiolenol ranged from 0.5–1.3% in *J. cedrus* from Madeira (10). But Pino et al. (12) also reported on the leaf oil of *J. cedrus* from Madeira and they found that it did not contain any isoabiolenol. Re-examination of the author's (RPA) oils of *J. cedrus* from Tenerife Island, Canary Islands also revealed that it did not contain any isoabiolenol. However, the oils from Tenerife differed considerably from the oil from Madeira,

and the report by Cavaleiro et al. (10) identified isoabienol by both MS and NMR, so their report of isoabienol seems well documented.

Re-examination of the oils of *Juniperus* sect. *Juniperus* (10) revealed that isoabienol occurred in *J. brevifolia* (Seub.) Ant. (0.6%) and *J. conferta* Parl. (5.1%). In the multi-seeded Eastern Hemisphere *Juniperus* (13), isoabienol occurred in *J. procera* (2.6%). Three *Juniperus* species among the serrate leaf taxa of the Western Hemisphere (14) were found to possess isoabienol: *J. angosturana* (0.9%), *J. comitana* (trace) and *J. saltillensis* (0.5%). Isoabienol was not found among the smooth leaf *Juniperus* of the Western Hemisphere (15) or the one-seeded *Juniperus* of the Eastern Hemisphere (16).

In order to assist colleagues in the identification of isoabienol in essential oils, the mass spectrum of isoabienol is presented in Figure 2 along with KI (Kovat's Index) on a DB-5 column.

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References

1. R.P. Adams, *Junipers of the world: The genus Juniperus*. Trafford Publ., Vancouver, B.C., Canada (2004).
2. R.P. Adams and S. Nguyen, *Post-Pleistocene geographic variation in Juniperus communis in North America*. *Phytologia*, **89**, 43–57 (2007).
3. R.P. Adams, *Taxonomy of Juniperus communis in North America: Insight from variation in nrDNA SNPs*. *Phytologia*, **90**, 176–192 (2008).
4. M.I. Goryaev, L.N. Lishtvanova, V.S. Bazilitskaya and S.B. Teppeev, *Chemical composition of essential oils of Juniperus depressa and J. oblonga*. *Izv. Akad. Nauk Kazak. SSR, Ser. Khim.* No. 2, 103–105 (1962).
5. R.P. Adams, *Cedarwood oil - analysis and properties*. In: *Modern Methods of Plant Analysis: Oils and Waxes*. Edits., H.F. Linskings and J.F. Jackson, pp. 159–173, Springer-Verlag, Berlin, Germany (1991).
6. R.P. Adams, *Identification of Essential Oils Components by Gas Chromatography/Mass Spectrometry*. 4th Ed., Allured Publ. Corp., Carol Stream, IL (2006).
7. M. Toyota, F. Nagashima and Y. Asakawa, *Clerodane, Kaurane and Labdane Diterpenoids from the Liverwort Jungermannia infusca*. *Phytochemistry*, **28**, 3415–3419 (1989).
8. K. Yamazawa, K. Kato, R. Yamauchi and Y. Ueno, *Bitter Principal of Tubers of Sagittaria trifolia (Kuwai)*. *Agric. Biol. Chem.*, **50**, 3179 (1986).
9. F. Nagashima, S. Takaoka, Y. Asakawa, *Diterpenoids from the Japanese Liverwort, Jungermannia infusca*. *Phytochemistry*, **49**, 601–608 (1998).
10. R.P. Adams, *Systematics of Juniperus section Juniperus based on leaf essential oils and RAPD DNA fingerprinting*. *Biochem. Syst. Ecol.*, **28**, 515–528 (2000).
11. C. Cavaleiro, L. Salgueiro, J.G. Barroso, A. Figueiredo, P.L. Cristina, S.S. Fontinha, A. Bighelli, J. Casanova, A. Looman and J.J.C. Scheffer, *Composition of the essential oil of Juniperus cedrus Webb & Berth. grown in Madeira*. *Flav. Fragr. J.*, **17**, 111–114 (2002).
12. J.A. Pino, P. Fernandes, G. Freitas and R. Marbot, *Chemical composition of the leaf oil of Juniperus cedrus Webb et Berth. from Madeira*. *J. Essent. Oil Res.*, **15**, 331–332 (2003).
13. R.P. Adams, *Systematics of multi-seeded eastern hemisphere Juniperus based on leaf essential oils and RAPD DNA fingerprinting*. *Biochem. Syst. Ecol.*, **27**, 709–725 (1999).
14. R.P. Adams, *The serrate leaf margined Juniperus (Section Sabina) of the western hemisphere: Systematics and evolution based on leaf essential oils and Random Amplified Polymorphic DNAs (RAPDs)*. *Biochem. Syst. Ecol.*, **28**, 975–989 (2000).
15. R.P. Adams, *Systematics of smooth leaf margin Juniperus of the western hemisphere based on leaf essential oils and RAPD DNA fingerprinting*. *Biochem. Syst. Ecol.*, **28**, 149–162 (2000).
16. R.P. Adams, *Systematics of the one seeded Juniperus of the eastern hemisphere based on leaf essential oils and random amplified polymorphic DNAs (RAPDs)*. *Biochem. Syst. Ecol.*, **28**, 529–543 (2000).