Geographic Variation in the Leaf Essential Oils of *Juniperus sabina* L. and *J. sabina* var. *arenaria* (E.H. Wilson) Farjon

Robert P. Adams* and Sanko Nguyen
Biology Department, Baylor University, Box 97366, Waco, TX 76798
Jianquan Liu
Northwest Plateau Institute of Biology, CAS, Xiguan St. 59, Xining 810001, Qinghai, China

Abstract

The composition of the leaf oils from seven populations of *J. sabina* L., one population of *Juniperus sabina* var. *arenaria* (E. H. Wilson) Farjon were examined for their geographic variation. In addition, the leaf oils of *J. chinensis* L. and *J. davurica* Pall. were compared to *J. sabina*. *Juniperus sabina* var. *arenaria*, the sand loving juniper, oil was found to be very similar to that of *J. davurica*, Mongolia, and *J. sabina*, on sand dunes in Mongolia. This suggests that *J. sabina* var. *arenaria* might be conspecific with *J. davurica*. Farjon's move (2001) of *J. sabina* var. *arenaria* out of *J. chinensis* is supported. Considerable differentiation was found in populations of *J. sabina* from the Iberian peninsula. Cedrol, citronellol, safrole, *trans*-sabinyl acetate, terpinen-4-ol and β-thujone were found to be polymorphic in several populations.

Key Word Index

Juniperus sabina, var. *arenaria*, *Juniperus chinensis*, *Juniperus davurica*, Cupressaceae, essential oil composition, α-pinene, sabinene, limonene, *trans*-sabinyl acetate, cedrol, geographic variation, systematics.

Introduction

The genus *Juniperus* consists of approximately 67 species (1), all of which grow in the northern hemisphere, although, *J. procera* Hochst. ex Endl. also grows southward along the rift mountains in East Africa into the southern hemisphere (2). The recent monograph of the genus (1) divides *Juniperus* into three sections: *Caryocedrus* (one species, *J. drupacea* Labill.); *Juniperus* (= *Oxycedrus* with 11 species) and *Sabina* (the remaining 55 species).

Section *Sabina* can be further divided into junipers with serrate and those with entire (smooth) leaf margins. The serrate leaf margined junipers are confined to the western hemisphere (except for *J. phoenicea*, which I would call "pseudoserrate" as its DNA clearly points to *J. phoenicea's* affinity with the smooth leaf margined junipers) (3).

The *Juniperus* of section *Sabina*, of the eastern hemisphere can be further divided into two groups based on the number of seeds per female cone (often called berry) and female cone shape. The single seed/cone (single seeded) *Juniperus* of the eastern hemisphere have cones that are ovoid with a noticeable pointed tip, whereas the multi-seeded *Juniperus* are generally round and often have an irregular surface. *Juniperus sabina* L. is a smooth leaf margined, multi-seeded juniper of the eastern hemisphere. It is very widely distributed from Spain through Europe to central Asia (Kazakhstan, Mongolia and western China (Figure 1). It can be seen from this figure that the range is discontinuous from Europe to central Asia. The species is generally a small shrub less than 1 m tall and ranging up to 1-2 m wide. But in the Sierra Nevada of Spain, it forms a horizontal shrub and in Mongolia it occurs as a prostrate plant on sand dunes.

The sole variety, *J. sabina* var. *arenaria* (E.H. Wilson) Farjon occurs on high sand dunes on the shores of Lake Qinghai, China. Wilson (J. Arnold Arbr. 9:20, 1928) described it as *J. chinensis* var. *arenaria*, but Farjon (4) moved it to *J. sabina*.

In this paper, we report on geographic variation in the essential oil of *J. sabina* and *J. sabina* var. *arenaria*. We also include the closely related taxa *J. chinensis* L. (China) and *J. davurica* Pall. (Mongolia) for comparison.

The leaf oils of the species in this study have been reported on and reviewed recently: *J. chinensis* (5); *J. davurica* (6), *J. sabina* (7).

*Address for correspondence

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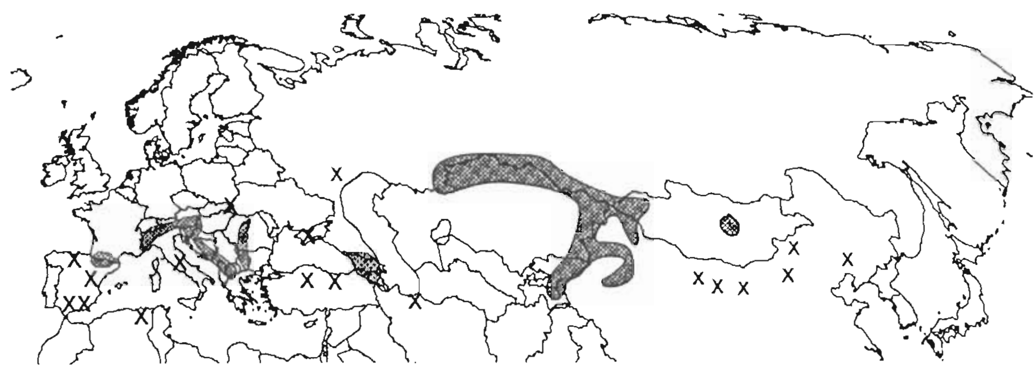

Figure 1. Distribution of *Juniperus sabina*; X represents isolated populations

Experimental

Specimens used in this study (species, popn. id., location, collection numbers): *J. chinensis*, CH, Lanzhou, Gansu, China, Adams 6765-67; *J. davurica*, DV, 15 km se Ulan Bator, Mongolia, Adams 7252, 7253, 7601; *J. sabina*, SN, Sierra Nevada, Spain, Adams 7197, 7199, 7200; PY, Pyrenees Mtns., Spain/ France border, Adams 7573-77; SW, Switzerland, Adams 7611, 7612, 7614, 7615; KZ, 30 km n. of Jarkent, Kazakhstan, Adams 7811-13; AM, Altair Mtns., Mongolia, Adams 7585-88; TS, Tian Shan Mtns., Xinjiang, China, Adams 7836-38; MS, sand dunes, 80 km SW Ulan Bator, Mongolia, Adams 7254-56; AR, sand dunes, Lake Qinghai, Qinghai, China, Adams 10347-52. Voucher specimens for all collections are deposited at Baylor University Herbarium (BAYLU).

Fresh adult leaves (200 g fresh wt.) were steam distilled for 2 h using a circulatory Clevenger apparatus (8). All leaf samples were collected during the summer or early fall, well after the spring new growth season to ensure compatibility among samples. The oil samples were concentrated (ether trap removed) with nitrogen and the samples stored at -20°C until analyzed. The extracted leaves were oven dried (48 h, 100°C) for determination of oil yields.

Table I. Comparisons of the percent total oil for leaf oils for *J. chinensis* (CH), *J. davurica* (DV), *J. sabina* populations

RI	Compound	SN	PY	SW	KZ	TS	AM	MS	AR	DV	CH
931	α-thujene	0.6	1.0	0.9	0.6	0.9	0.7	1.0	0.9	1.1	0.8
939	**α-pinene**	**1.5**	**1.8**	**2.0**	**15.8**	**1.9**	**1.4**	**2.0**	**3.8**	**3.4**	**17.1**
953	α-fenchene	t	-	t	-	t	t	t	t	-	t
953	camphene	t	t	t	0.3	t	t	t	t	-	0.3
976	**sabinene**	**38.1**	**54.9**	**34.8**	**42.6**	**46.5**	**50.0**	**56.7**	**57.1**	**55.8**	**32.5**
980	β-pinene	t	t	t	0.7	t	t	t	t	t	t
991	myrcene	3.0	3.1	4.2	3.8	3.6	3.3	3.1	3.4	2.6	2.8
996	**methyl 4-methylhexanoate***	-	-	-	-	-	-	**0.5**	**0.7**	**0.9**	-
996	**mesitylene**	-	-	-	-	-	-	-	-	-	**t**
1001	δ-2-carene	t	0.1	-	0.1	0.1	0.3	t	0.2	0.3	t
1005	α-phellandrene	t	0.1	t	t	0.1	0.1	t	0.2	t	t
1011	δ-3-carene	0.1	0.1	-	0.2	0.1	0.1	t	0.2	t	-
1018	α-terpinene	1.0	1.5	1.0	0.7	0.9	0.7	1.0	0.9	0.8	0.2
1026	p-cymene	0.3	0.4	0.2	0.1	0.3	0.1	0.7	0.1	0.4	0.6
1031	**limonene**	**2.0**	**2.4**	**3.0**	**2.1**	**1.3**	**1.7**	**0.6**	**1.4**	**0.8**	**14.5**
1031	**β-phellandrene**	**t**	**t**	**t**	**1.4**	**0.9**	**0.4**	**0.6**	**t**	**0.5**	**t**
1032	1,8-cineole	t	t	-	t	-	-	-	-	-	-
1050	(E)-β-ocimene	0.6	0.7	1.1	0.1	0.2	0.3	0.2	0.2	0.3	0.2
1062	γ-terpinene	1.9	2.5	1.1	0.1	1.4	1.2	1.7	1.5	1.4	0.6
1068	*cis*-sabinene hydrate	1.4	1.4	0.7	0.5	0.7	0.7	1.5	1.5	1.6	0.6
1074	*trans*-linalool oxide(furanoid)	t	t	t	-	-	-	t	-	-	-
1088	terpinolene	1.0	1.0	0.8	0.7	0.9	0.9	0.8	0.9	0.6	0.6
1091	**2-nonanone**	-	-	-	**0.4**	-	-	**0.5**	**0.5**	**0.8**	-
1097	*trans*-sabinene hydrate	0.6	1.1	0.3	0.4	0.3	0.3	0.9	0.9	0.5	0.5
1098	linalool	0.9	0.3	1.5	0.2	0.8	1.1	0.5	0.8	0.5	0.6
1102	nonanal	-	-	t	t	t	0.1	-	t	-	-
1102	*cis*-thujone (=α-thujone)	0.4	-	0.1	-	t	t	-	-	-	-
1103	**isoamyl-isovalerate**	-	-	-	-	-	-	**0.4**	**0.2**	**0.2**	-
1108	*cis*-rose oxide	-	0.1	-	-	-	-	-	-	t	-

Table I. continued

RI	Compound	SN	PY	SW	KZ	TS	AM	MS	AR	DV	CH
1114	***trans*-thujone(=β-thujone)**	**2.8**	**0.1**	**0.7**	-	**0.3**	**0.6**	-	-	-	-
1116	3-methyl-3-butenyl-isovalerate	-	-	-	0.2	-	-	0.6	0.5	-	-
1121	***cis*-p-menth-2-en-1-ol**	**0.6**	**0.6**	**0.2**	**0.2**	**0.2**	**0.3**	**0.4**	**0.3**	**0.3**	**0.3**
1127	*trans*-rose oxide	-	-	-	-	-	t	-	-	t	-
1134	*cis*-limonene oxide	-	-	-	-	-	-	-	-	-	0.1
1140	*trans*-sabinol	0.6	0.3	0.7	-	0.2	-	-	-	-	-
1140	*trans*-p-menth-2-en-1-ol	-	-	-	0.2	0.2	0.4	0.2	0.2	0.1	0.2
1148	camphene hydrate	-	-	-	-	-	-	-	-	-	0.1
1153	citronellal	0.1	0.4	0.2	-	t	0.1	0.3	0.3	0.3	-
1156	sabina ketone	-	-	-	-	-	-	t	-	-	0.1
1177	**terpinen-4-ol**	**6.9**	**7.2**	**1.4**	**2.9**	**3.0**	**3.1**	**4.7**	**3.2**	**3.7**	**2.2**
1179	naphthalene	-	-	0.5	-	t	0.1	0.1	-	-	-
1183	p-cymen-8-ol	-	-	-	-	-	-	-	-	-	0.1
1189	α-terpineol	0.3	0.3	0.1	0.2	0.2	0.2	0.1	0.1	t	t
1193	(Z)-4-decenal	0.1	0.1	t	-	t	0.5	0.1	0.1	t	-
1193	*cis*-piperitol	0.2	0.2	t	0.1	0.1	t	0.2	0.2	-	t
1196	methyl chavicol(=estragole)	0.2	t	-	-	-	-	-	-	-	0.1
1205	*trans*-piperitol	0.2	0.2	-	0.1	0.1	0.1	0.1	t	t	-
1228	citronellol	1.4	4.1	0.6	0.4	0.1	0.3	1.3	1.7	2.4	-
1232	(Z)-3-hexenyl isovalerate	-	-	-	0.1	-	-	0.1	-	0.1	t
1252	piperitone	0.1	0.2	-	0.1	0.1	0.2	0.1	0.2	0.1	-
1257	linalyl acetate	-	-	0.2	0.3	0.4	0.3	0.1	0.3	0.2	-
1257	(Z)-4-decen-1-ol	0.1	0.1	-	-	t	0.3	-	-	0.2	-
1261	**methyl citronellate**	**0.5**	**0.8**	**0.7**	**0.1**	**0.2**	**0.7**	**2.8**	**2.0**	**3.6**	**0.1**
1274	pregeijerene B	t	0.1	-	-	-	-	-	-	-	-
1285	bornyl acetate	-	-	t	0.4	0.1	0.2	t	t	t	0.4
1285	**safrole**	**3.2**	**1.8**	-	-	-	-	-	-	-	**3.5**
1286	*trans*-linalool oxide acetate (pyranoid)	-	-	-	-	t	t	-	-	t	-
1290	*trans*-sabinyl acetate	16.2	t	35.0	-	15.9	18.3	-	2.6	-	-
1291	**2-undecanone**	-	-	-	**0.2**	-	-	**2.3**	**1.2**	**2.5**	-
1319	(E,E)-2,4-decadienal	t	-	-	-	-	0.2	-	t	-	-
1323	methyl geranate	0.2	0.1	0.3	0.1	0.5	0.2	1.3	0.7	1.1	-
1350	**α-terpinyl acetate**	-	-	**0.1**	**0.2**	**0.3**	**0.5**	**t**	**t**	-	-
1353	citronellyl acetate	-	-	-	-	-	-	-	0.4	t	-
1362	neryl acetate	-	-	-	-	-	-	-	t	-	-
1381	geranyl acetate	-	-	-	-	-	-	-	0.3	-	-
1376	α-copaene	0.3	-	-	-	-	-	t	-	t	-
1383	β-bourbonene	0.1	-	-	-	-	-	-	-	-	-
1389	β-cubebene	0.1	0.1	-	-	-	-	-	-	-	-
1401	**methyl eugenol**	**4.2**	**1.1**	-	-	-	-	**t**	-	-	**2.2**
1409	**α-cedrene**	-	-	-	**0.2**	**0.3**	-	-	-	-	**0.1**
1412	2-epi-β-funebrene	-	-	-	-	-	-	-	-	0.2	-
1415	β-funebrene	-	-	-	-	-	-	-	-	-	t
1418	(E)-caryophyllene(β-caryophyllene)	0.1	0.1	-	-	-	-	0.1	-	0.3	-
1418	**β-cedrene**	-	-	-	**0.1**	**0.2**	-	-	-	-	**0.1**
1429	***cis*-thujopsene**	-	-	-	**0.4**	**0.2**	-	-	-	-	**0.2**
1432	β-copaene	-	-	-	-	-	-	t	-	-	-
1446	*cis*-muurola-3,5-diene	-	0.2	-	-	-	-	t	-	-	-
1452	*trans*-muurola-3,5-diene	t	-	-	-	-	-	t	-	-	-
1454	α-humulene	t	t	-	-	-	-	t	-	-	-
1461	*cis*-muurola-4(14),5-diene	-	t	-	-	-	-	-	-	-	-
1461	*cis*-cadina-1,4-diene	-	-	-	t	-	-	0.2	-	-	-
1469	ar-curcumene	-	-	-	t	-	-	-	-	-	-
1471	dauca-5,8-diene	-	-	-	-	-	-	t	-	-	-
1473	*trans*-cadina-1(6),4-diene	t	0.2	-	-	-	-	-	-	-	-
1477	γ-muurolene	0.1	t	0.1	0.1	-	0.1	0.2	0.1	0.2	-
1480	germacrene D	0.2	0.1	-	-	-	0.1	0.3	0.1	0.1	0.1
1491	*trans*-murrola-4(14),5-diene	0.1	0.6	-	t	-	0.1	-	-	0.1	-
1493	epi-cubebol	0.1	0.3	0.1	-	-	0.1	0.2	0.1	0.2	0.1
1495	γ-amorphene	-	-	-	0.1	-	-	-	-	-	-
1499	α-muurolene	0.2	0.2	0.1	0.2	0.1	0.3	0.2	0.2	0.3	0.1

Table I. continued

RI	Compound	SN	PY	SW	KZ	TS	AM	MS	AR	DV	CH
1508	α-chamigrene	-	-	-	-	-	-	-	-	-	0.1
1513	γ-cadinene	0.5	0.8	0.3	0.3	0.2	0.7	0.8	0.6	0.9	0.1
1513	cubebol	-	-	-	-	-	-	-	-	-	0.1
1520	**endo-1-bourbonol**	-	-	-	-	-	-	**1.7**	**0.1**	**0.4**	-
1524	δ-cadinene	1.0	1.0	0.5	0.8	0.2	1.3	1.7	0.8	1.4	0.5
1530	zonarene	-	t	-	-	-	-	-	-	-	-
1532	*trans*-cadina-1,4-diene	t	-	-	0.1	t	0.1	t	-	t	-
1535	10-epi-cubebol	-	-	-	-	-	-	t	-	-	t
1538	α-cadinene	0.1	0.1	0.1	0.1	t	0.2	0.2	0.1	0.2	0.1
1549	elemol	1.5	2.1	0.8	0.1	0.1	0.9	-	t	-	0.4
1554	**elemicin**	**0.9**	**0.4**	-	-	-	-	-	-	-	-
1556	germacrene B	t	t	-	t	-	-	t	t	-	-
1561	*cis*-murrola-5-en-4α-ol	-	-	-	-	-	-	t	-	-	-
1561	E-nerolidol	-	-	-	t	t	-	-	-	-	-
1570	(Z)-3-hexenyl benzoate	t	t	-	-	-	-	-	-	-	0.3
1574	germacrene D-4-ol	1.5	0.7	1.4	1.1	0.6	2.8	2.5	3.5	2.5	0.5
1587	**allo-cedrol**	**t**	-	-	**1.1**	**0.6**	-	-	-	**0.1**	**0.8**
1596	**cedrol**	-	-	-	**15.9**	**13.2**	-	-	-	**2.3**	**10.6**
1606	β-oplopenone	0.4	0.3	0.1	-	0.1	0.2	0.4	0.3	0.3	0.2
1611	epi-cedrol	-	-	-	0.1	-	-	-	-	-	-
1618	1,10-di-epi-cubenol	t	-	-	-	-	-	-	-	-	-
1627	1-epi-cubenol	0.1	0.4	t	-	0.1	t	-	t	t	-
1630	**γ-eudesmol**	**0.1**	**0.2**	**t**	-	-	-	-	-	-	-
1632	α-acorenol	-	-	-	0.2	t	-	-	-	-	0.1
1640	epi-α-cadinol	0.3	0.3	0.2	0.3	0.1	0.4	0.6	0.4	0.4	0.4
1640	epi-α-muurolol	0.3	0.2	0.2	0.3	0.1	0.4	0.5	0.4	0.4	0.4
1645	α-muurolol	0.1	0.1	0.1	0.1	t	0.1	0.2	0.1	0.1	0.2
1649	β-eudesmol	0.1	0.2	-	-	-	-	-	-	-	-
1652	α-eudesmol	-	0.3	-	-	-	-	-	-	-	-
1653	α-cadinol	1.0	0.5	0.6	0.9	0.4	1.2	1.4	1.0	1.2	1.4
1666	bulnesol	t	0.1	t	t	t	t	-	-	-	-
1686	germacra-4(15),5,10(14)-trien-1-al	-	-	-	-	-	-	-	-	-	0.1
1689	shyobunol	0.8	-	0.1	0.1	0.1	0.1	t	0.1	-	-
1725	(E,E)-2,6-farnesol	-	-	-	-	-	-	t	t	-	-
1733	**oplopenone**	-	-	-	-	-	-	**t**	-	-	**0.6**
1961	sandaracopimara-8(14),15-diene	-	-	0.1	-	-	-	-	-	t	
2054	abietatriene	t	t	-	-	t	t	t	t	-	t
2057	manool	-	-	-	t	-	-	-	-	-	-
2080	abietadiene	0.1	0.1	-	t	t	t	0.2	0.1	0.2	-
2283	sempervirol	-	-	-	0.1	-	-	-	-	-	-
2288	4-epi-abietal	0.1	0.1	t	t	t	t	0.1	0.4	0.1	t
2302	abieta-7,13-dien-3-one	0.1	0.1	0.1	0.2	0.1	0.1	0.3	1.2	0.3	-
2325	*trans*-ferruginol	-	-	-	t	-	-	-	t	-	
2402	abietol	-	-	-	-	-	-	-	0.1	-	

Juniperus sabina population codes: SN, Sierra Nevada, Spain; PY, Pyrenees Mtns.; SW, Switzerland; KZ, Kazakhstan; TS, Tian Shan, China; AM, Altair Mtns., Mongolia; MS, sand dunes, Mongolia; other species codes: DV, *J. davurica*, Mongolia, AR, *J. sabina* var. *arenaria*, sand dunes, Qinghai, China; components that tend to separate the species are highlighted in boldface; RI = Kovat's retention index on DB-5(=SE54) column using alkanes; *tentatively identified; compositional values less than 0.1% are denoted as traces (t); unidentified components less than 0.5% are not reported

The oils were analyzed on a HP5971 MSD mass spectrometer, directly coupled to a HP 5890 gas chromatograph, using a J & W DB-5, 0.26 mm x 30 m, 0.25 µm coating thickness, fused silica capillary column (see 9 for operating details). Identifications were made by library searches of our volatile oil library (9), using the HP Chemstation library search routines, coupled with retention time data of authentic reference compounds. Quantitation was by FID on an HP 5890 gas chromatograph using the HP Chemstation software.

Fifty-one of the compounds with the largest concentration (Table I) were used to compute similarity measures. Similarity measures were computed using absolute character state differences (Manhattan metric), divided by the maximum observed value for that character over all taxa (= Gower metric, 10-12). Principal coordinate analysis (PCO) of the similarity matrix follows Gower (13).

Results and Discussion

The compositions of the leaf oil are given in Table I. Several trends are apparent from the terpenoid data. The leaf oils of all of the taxa and populations are rich in sabinene (32.5-57.1%).

Table II. Comparison of polymorphic compounds and their range of variation by population and taxon; SN - MS are *J. sabina*; AR = *J. sabina* var. *arenaria*, DV = *J. davurica*, CH = *J. chinensis*

Compound	SN	PY	SW	KZ	AM	TS	MS	AR	DV	CH
β-thujone	0.5-8.73	0.4-0.8	0.10-0.2	0.3-0.2	0.2-0.5	0.2-0.3	0.4-0.6	0.2-0.4	0.3-0.48	0.1-0.3
terpinen-4-ol	3.6-14.4	0.07-0.2	0.01-0.05	0.07-0.1	0.04-0.1	0.04-0.08	0	0	0.01-0.08	0.05-0.1
citronellol	1.0-1.9	2.00-6.4	0.3-0.7	0-0.03	0-0.06	0-0.1	0.4-0.5	0.5-2.1	0.03-4.6	0
safrole	0	0.03-6.6	0	0-0.1	0-0.2	0-0.01	0	0	0.01-0.05	0.02-6.6
trans-sabinyl acetate	6.4-41.3	0-0.04	30.7-54.4	0	0-38.0	0-36.5	0	0-3.2	0	0
methyl eugenol	0.01-12.1	0-3.8	0	0	0	0	0	0	0-0.01	0-4.4
cedrol	0.3-1.0	0.1-0.2	0.1-0.2	4.3-13.3	0-0.2	4.8-9.5	0	0	0.5-5.2	1.0-16.0

The Iberian Peninsula populations of *J. sabina* (SN, PY) are differentiated by the presence of safrole, methyl eugenol, elemicin and γ-eudesmol. Populations of *J. sabina* var. *arenaria* (MS, AR) share compounds with *J. davurica* (DV): methyl 4-methylhexenoate, isoamyl isovalerate, endo-1-bourbonol and 2-undecanone. The populations from central Asia (KZ, TS, AM) tend to have larger concentrations of β-phellandrene, α-terpinyl acetate and bornyl acetate (Table I).

Several compounds were found to be polymorphic within populations. Table II shows that the Sierra Nevada, Spain (SN) population was the most polymorphic with compounds exhibiting the most extreme variation in the SN population for β-thujone (0.5% to 8.7%), terpinen-4-ol (3.6-14.4%), *trans*-sabinyl acetate (6.4-41.3%), methyl eugenol (0.01-12.1%). In the Pyrenees population (PY, Table II), citronellol varied from 2.0-6.4% and safrole varied from 0.03-6.6%. Cedrol, a compound normally associated with cedarwood oil, was found in many populations, being the most variable in the Kazakhstan population (KZ, Table II), 4.3-13.3%. Cedrol was also very variable in the *J. chinensis* samples (1.0-16.0%).

The matrix of oil similarities of the 10 operational taxonomic units (OTUs) (7 *J. sabina* populations, *J. sabina* var. *arenaria*, *J. davurica* and *J. chinensis*) was factored by principal coordinates analysis (PCO) and the nine eigenroots accounted for 28.72, 22.11, 13.18, 7.86, 6.69, 6.18, 5.52, 5.10 and 4.64% of the variance (sum = 100%). Only the first three eigenroots were larger than the average diagonal value and the eigenroots appear to become constant after the first four eigenroots, implying that the first three or four eigenroots are significant.

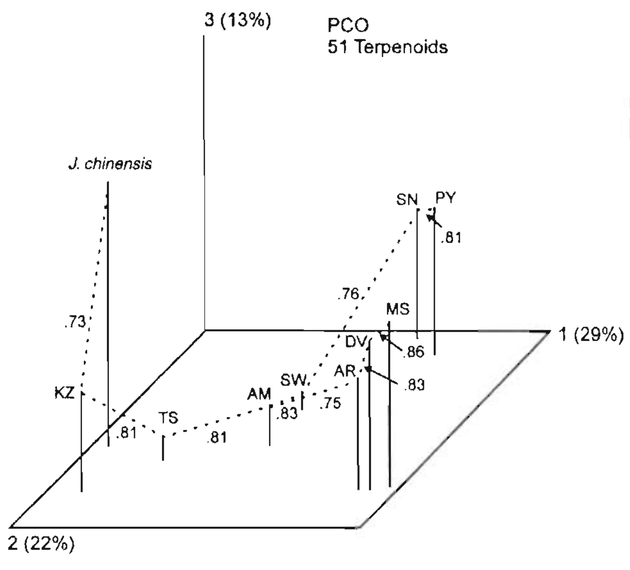

Figure 2. Principal coordinates analysis based on 51 terpenoids; note the clear separation of *J. chinensis* and the close grouping of DV (*J. davurica*), MS (*J. sabina*, sand dunes, Mongolia) and AR (*J. sabina* var. *arenaria*, sand dunes, Qinghai, China); the Iberian populations of *J. sabina* (SN, Sierra Nevada, Spain; PY, Pyrenees, Spain/France) are quite differentiated from the other *J. sabina* populations

The first three principal coordinates show (Figure 2) that *J. chinensis* is well resolved. *Juniperus davurica* (DV) forms a close grouping with *J. sabina* from the sand dunes in Mongolia (MS) and *J. sabina* var. *arenaria*, on sand dunes in Qinghai, China (AR). This ordination clearly supports Farjon (4) transfer of *J. chinensis* var. *arenaria* E.H. Wilson to *J. sabina* var. *arenaria*. Recently, Farjon (4) moved *J. davurica* Pall. under *J. sabina* (*J. sabina* var. *davurica* (E. H. Wilson) Farjon), although, Adams (1) has recognized *J. davurica* in his recent monograph showing that *J. davurica* is distinct from *J. sabina*. However, *J. sabina* var. *arenaria* was not included in Adams' (1) analysis of the terpenoids and RAPDs DNA. It appears from the terpenoids data in this study, that *J. davurica* and *J. sabina* var. *arenaria* may be conspecific.

To better understand the variation within *J. sabina*, *J. chinensis* was excluded from the data set, a matrix of similarities were calculated and the matrix was subjected to a minimum spanning network analysis. Geographic variation was examined by clustering the populations (Figure 3). Three groups are apparent in Figure 3: the Iberian Peninsula (SN, PY), Switzerland, central Asia (SW, KZ, TX, AM) and the *J. davurica*, *J. sabina* var. *arenaria* group (DV, MS, AR). These three groups are joined together at about the same similarity (0.75). It should be noted that most of these populations were glaciated during the last ice age (14,000-70,000 ybp). The plants in the Iberian Peninsula likely survived at lower elevations. The Switzerland population was likely recolonized from seed in populations in Italy. The central Asian populations may have been recolonized from southern refugia.

This study shows a that *J. sabina* from the Iberian Peninsula is differentiated from other populations in their leaf oils. The oil data shows that *J. sabina* var. *arenaria* is much more like *J. sabina* than *J. chinensis* oil, supporting the recognition of *J. sabina* var. *arenaria* rather than placing it within *J. chinensis* (as

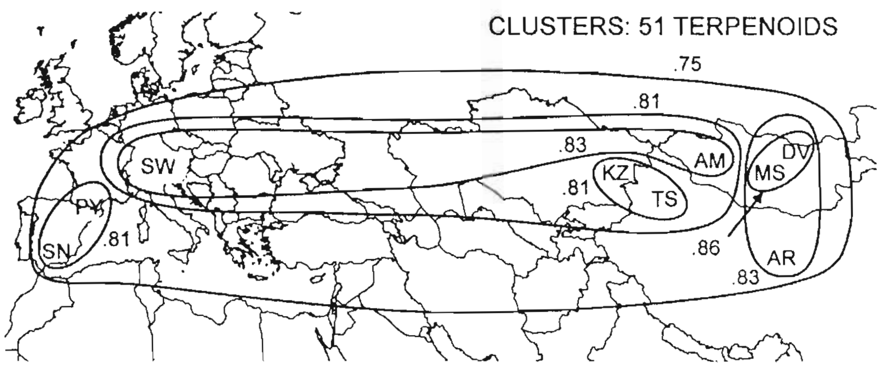

Figure 3. Geographic clustering of populations of *J. sabina* (plus *J. davurica*, DV); three groups are apparent: Central Asia - Switzerland, Iberian Peninsula; and *J. davurica* (DV) - *J. sabina* var. *arenaria* (AR, MS)

originally described, *J. chinensis* var. *arenaria* E. H. Wilson). The leaf oils of *J. sabina* var. *arenaria* and *J. davurica* were very similar, suggesting that these taxa may be conspecific. Additional study using DNA markers and sequencing is in progress to resolve this taxonomic question.

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