PERGAMON Biochemical Systematics and Ecology 26 (1998) 637–645

biochemical systematics and ecology

The leaf essential oils and chemotaxonomy of *Juniperus* sect. *Juniperus*

Robert P. Adams

Plant Biotechnology Center, Baylor University, Box 669, Gruver, TX 79040, USA

Received 7 November 1997; Accepted 22 January 1998

Abstract

The composition of the leaf essential oils of all ten species of *Juniperus* in sect. *Juniperus* (=sect. *Oxycedrus*) are reported and compared (*J. brevifolia, J. cedrus, J. communis, J. conferta, J. formosana,. J. navicularis, J. oblonga, J. oxycedrus, J. rigida, J. sibirica*). The oils of these *Juniperus* are all dominated by monoterpenes (α-pinene, sabinene and limonene). The simplest oil was found in *J. cedrus* (27 components, endemic to the Canary Islands) and the most complex oil was in *J. oblonga* (82 components). Quantitative data is presented for 138 compounds found in these ten taxa. The far eastern junipers, *J. conferta, J. formosana* and *J. rigida*, appear to form a natural group. Systematic and evolutionary relationships are discussed.

Keywords: *Juniperus*; *Cupressaceae*; Essential oils; Terpenes; Chemosystematics

1. Introduction

The genus *Juniperus* consists of approximately sixty species, 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 (Adams and Demeke, 1993). The genus is divided into three sections: *Caryocedrus* (one species, *J. drupacea* Labill.); *Juniperus* (=*Oxycedrus*, 9 or 10 species) and *Sabina* (the remaining, approximately 50 species).

The composition of the leaf essential oil of *J. brevifolia* (Seub.) Ant. endemic to the Azores Islands, has not been reported. *Juniperus cedrus* Webb and Berth. is endemic to the Canary Islands and no reports were found on its leaf essential oil. *Juniperus conferta* Parl. is endemic to sandy seashores of Japan and Sakhalin Island. Although

* Fax: 001 806 733 5605; e-mail: rpadams@JUNO.com.

0305-1978/98/$19.00
PII: S0305-1978(98)00020-9

there are several reports on the essential oil of the wood of *J. conferta*, no reports were found for the leaf essential oil.

Juniperus communis L. is generally recognized to have four varieties (or subspecies, Franco, 1964). The type variety is an upright shrub to small tree that occurs in much of Europe. The other three varieties occur across the northern hemisphere. This is the only *Juniperus* species that occurs in both the eastern and western hemispheres. Needless to say, there is tremendous geographic variation in its morphology and essential oils. Chatzopoulou and Katsiotis (1993) reported that the leaf essential oil of *J. communis* from northern Greece was dominated by α-pinene (41.3%) and sabinene (17.4%), whereas Caramiello et al. (1995) list sabinene as the dominant component (41.4%) with 13.4% α-pinene. An analysis of geographic variation in the leaf oils of *J. communis* and its varieties is beyond the scope of this paper and will be addressed in a separate study. The leaf essential oils of *J. formosana* Hayata and *J. rigida* Mig. in Sieb. from China have recently been reported (Adams et al. 1995a, b) and these results are included in this paper for comparisons.

Juniperus navicularis Grand has been treated as *J. oxycedrus* ssp. *transtagana* Franco in the Flora Europea (Franco, 1964) but Franco subsequently recognized it at the specific level (Franco, 1986). It has a very limited distribution on Pliocene sands in SW Portugal and possibly in southern Spain. No reports were found on its volatile leaf oil.

Juniperus oblonga M.-Bieb. has a limited distribution from Albania to Turkey to the Caucasus Mts. to nw Iran. It has been treated as a variety of *J. communis* [var. *oblonga* (M.-Bieb.) Loud.], but a recent analysis, using DNA fingerprinting data (Adams and Demeke, 1993), supported recognition as a distinct species, *J. oblonga*. Akimov et al. (1976) reported that the leaf oil of *J. oblonga* was dominated by sabinene (26.9%) and α-pinene (16.1%) with moderate amounts of sabinol (7.8%), myrcene (7.3%), γ-terpinene (6.1%) and limonene (5.7%).

There are several reports on the essential oils of the fruits of *J. oxycedrus* L. and (Hernandez et al., 1987; Teresa et al. 1974; Stassi et al., 1995) and some reports on the monoterpenes of the leaves (Banthrope et al., 1973; Horster, 1974). The most complete report on the leaf oil was of *J. oxycedrus* subsp. *macrocarpa* (Stassi et al., 1995) from the island of Elaphonissos (S. Greece). The leaf oil was dominated by α-pinene (26.94%) and cedrol (13.88%) with moderate amounts of dihydro-p-cymen-8-ol (8.49%), α-terpineol (6.6%) and δ-cadinene (4.55%). Akimov et al. (1976) reported that *J. oxycedrus* from the Crimea contained 10.2% limonene, 7.8% α-pinene and minor amounts of other terpenes.

Juniperus sibirica Burgsd. is often included in *J. communis* var. *montana* Ait. (Adams and Demeke, 1993; Franco, 1964). I have noted that the leaves of *J. communis* var. *montana* in the western hemisphere and Europe are longer and straighter than the putative, *J. sibirica* from Kazakstan and Mongolia. So I have included materials from Mongolia under the name *J. sibirica* in this study. Shatar (1984) made a brief report on *J. sibirica* from Mongolia and reported the oil was dominated by α-pinene (32–55%), sabinene (1–14%) with moderate amounts of myrcene and limonene. Recently, Caramiello et al. (1995) reported that the oil of *J. sibirica* (possibly *J. communis* var. *montana*?) from Italy contained 30.5% α-pinene, 12.4% sabinene, 8.3% terpinen-4-ol and 4.1% β-eudesmol as the major components.

The purpose of this paper is to make initial reports on the leaf essential oils for several junipers and compare the oil compositions between species in section *Juniperus*.

2. Materials and methods

Specimens used in this study: *J. brevifolia*, Adams 8152-8154, Serra da Tronqueira, ca. 800 m, San Miguel Island, Azores Islands; *J. cedrus*, Adams 8127, 8146, 8140, S. of La Orotava, Tenerife, Canary Islands; *J. communis* var. *communis*, Adams 7846-48, ca 30 m, Stockholm, Sweden; *J. conferta*, Adams 4925, Kew Gardens (origin = Japan), London; Adams 5413-5414, Strybing Arboretum (origin = Japan), San Francisco, Adams 5625, Royal Botanic Garden (origin = Japan), Edinburgh; *J. formosana*, Adams 6772, 6774, 6792, Gansu, China; *J. navicularis*, Adams 8239-8243, Lisbon, Portugal; *J. oblonga*, Adams 5509-5510, Arnold Arboretum (origin = Stavropol Bot. Gard.), Adams 5640, Berlin Bot. Garden (origin = Starvopol Province, Russia), Adams 6144, Tbilisi Botanic Garden (origin = Caucasus Mts.); *J. oxycedrus* subsp. *oxycedrus*, Adams 7080-7082, El Penon, Spain, 720 m; *J. rigida*, Adams 6797-6799, Beijing Bot. Garden (origin = ne China), *J. sibirica*, Adams 7589-7591, Altai Mts., 2550 m, Mongolia. Voucher specimens are deposited at SRCG herbarium, Baylor University.

Fresh leaves (200 g fresh wt.) were steam distilled for 2 h using a circulatory Cleavenger apparatus (Adams, 1991a). 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. After initial GCMS analyses, composite oil samples were made for each of the ten taxa in this study. These composite (average) oil samples were then subjected to GCMS for compound identification and quantitation by TIC.

The essential oils were analyzed on a Finnigan Ion Trap (ITD) mass spectrometer, model 800, directly coupled to a Varian 6500 gas chromatograph, using a J and W DB-5, 0.26 mm × 30 m, 0.25 μm coating thickness, fused silica capillary column (see Adams, 1995 for operating details). Identifications were made by library searches of our volatile oil library, LIBR(TP) (Adams, 1995), using the Finnigan library search routines based on fit and purity, coupled with retention time data of reference compounds.

3. Results and discussion

Oil yields (calculated as oil wt./wt. of oven dried, extracted leaves) varied from 0.2 to 0.5%. The oils were clear to very light yellow in color. Table 1 shows the tabulated results. *Juniperus brevifolia*, endemic to the small, isolated Azores Islands, has the most distinctively different oil composition. The oil is very low in α-pinene (6.1%) and very high in limonene (43.4%) and sandaracopimara-8(14),15-diene (19.5%, Table 1) as well as having the largest amounts of diterpenes found in this section, *Juniperus*

Table 1
Comparisons of the per cent total oil for leaf essential oils for *J. brevifolia* (BR), *J. cedrus* (CE), *J. communis* (CO), *J. sibirica* (SB), *J. oblonga* (OB), *J. oxycedrus* (OX), *J. navicularis* (NA), *J. formosana* (FR), *J. rigida* (RG) and *J. conferta* (CF). Components that tend to separate the species are highlighted in boldface

KI compound	BR	CE	CO	SB	OB	OX	NA	FR	RG	CF
Number of compounds	49	27	32	53	82	50	42	78	79	51
854 (E)-2-hexenal	0.2	0.2	0.7	0.0	0.8	0.1	0.2	0.2	2.4	0.3
856 Ethyl isovalerate	–	–	–	0.2	–	–	–	–	–	–
926 Tricyclene	t	0.3	0.3	0.2	0.1	0.1	0.1	0.1	0.2	0.1
931 α-Thujene	0.1	0.1	0.1	t	1.9	0.1	2.1	–	t	t
939 α-Pinene	**6.1**	**70.7**	**56.8**	**58.2**	**21.7**	**41.3**	**22.9**	**47.7**	**39.7**	**53.2**
953 α-Fenchene	t	–	0.4	–	0.2	–	–	–	0.6	0.2
953 Camphene	0.1	0.6	0.6	0.6	0.4	0.2	0.2	0.6	1.0	0.8
957 Thuja-2,4(10)-diene	–	–	–	–	0.1	0.1	–	0.1	t	–
967 Verbenene	–	–	–	0.3	0.2	–	–	1.5	0.1	–
976 Sabinene	**2.5**	**1.0**	**0.7**	**1.0**	**13.4**	**0.6**	**8.2**	**0.2**	**t**	**0.4**
978 1-Octen-3-ol	1.4	1.0	–	–	t	–	–	–	–	1.0
980 β-Pinene	**0.2**	**4.1**	**4.4**	**4.7**	**2.2**	**1.7**	**3.5**	**2.9**	**1.9**	**8.0**
991 Myrcene	**6.3**	**6.3**	**5.2**	**4.5**	**3.8**	**4.7**	**8.6**	**7.2**	**11.2**	**10.4**
1001 δ-2-Carene	–	t	0.2	0.2	0.3	0.3	1.2	0.8	0.8	t
1005 α-Phellandrene	–	**0.5**	**2.1**	**0.1**	**0.8**	**8.2**	**8.0**	**1.2**	**1.0**	**0.3**
1011 δ-3-Carene	–	–	**4.7**	–	**2.4**	t	–	–	**t**	**3.2**
1018 α-Terpinene	0.2	t	–	–	1.1	0.2	0.9	t	t	–
1026 p-Cymene	**0.1**	**0.2**	**0.3**	–	**1.2**	**6.2**	**2.6**	**0.9**	**0.6**	**0.2**
1031 Limonene	**43.4**	**4.5**	**6.9**	**1.3**	**2.0**	**4.5**	**14.3**	**4.0**	**4.2**	**1.9**
1031 β-Phellandrene	–	**4.6**	**6.9**	**1.2**	**1.9**	**5.0**	**3.5**	**1.4**	**2.1**	**4.0**
1040 (Z)-β-Ocimene	t	–	0.2	–	t	–	–	–	t	–
1050 (E)-δ-Ocimene	**3.8**	–	–	–	**0.5**	–	**0.4**	–	**t**	–
1057 Pentyl isobutyrate	–	–	0.2	–	0.4	–	0.1	0.2	0.6	0.2
1062 γ-terpinene	0.3	0.1	t	–	2.0	0.4	1.6	0.1	0.2	0.1
1065 3-Methyl-2-buten-1-yl, acetate[a]	–	–	–	–	–	–	–	0.6	–	–
1068 *cis*-Sabinene hydrate	t	–	–	–	2.3	–	0.1	–	t	–
1087 Fenchone	–	–	–	–	–	–	–	–	1.6	–
1088 Terpinolene	4.4	0.6	1.1	0.7	2.2	2.9	2.9	1.0	0.8	0.5
1091 2-nonanone	–	–	–	–	–	–	–	0.1	t	–
1095 α-Pinene oxide	–	–	–	–	–	–	–	1.4	–	–
1097 Ipsenol	–	–	–	–	–	–	–	0.7	–	–
1098 Linalool	0.9	–	–	–	–	t	0.2	–	0.6	–
1102 *n*-Nonanal	t	–	–	–	–	–	–	–	–	–
1103 Isopentyl-isovalerate	–	–	0.1	0.1	0.3	–	–	–	–	–
1110 1-Octen-3-yl acetate	–	0.2	–	–	–	–	–	–	–	–
1112 Endo-fenchol	–	–	–	–	–	–	–	**0.5**	**0.8**	**0.5**
1114 *trans*-Thujone	–	–	–	–	0.5	–	–	–	–	–
1116 3-Methyl butanoate, 3-methyl-3-butenyl-	–	–	0.1	0.1	–	–	–	–	–	–
1121 *cis*-p-Menth-2-en-1-ol	–	–	–	–	0.6	0.1	0.1	0.2	–	–
1125 α-Campholenal	–	–	–	t	0.3	0.5	–	0.3	0.2	–
1139 *trans*-Pinocarveol	–	–	–	–	–	**0.5**	–	**0.3**	**0.2**	**t**
1140 *trans*-*p*-Menth-2-en-1-ol	–	–	–	–	0.5	–	t	–	–	–
1140 *trans*-Sabinol	–	–	–	–	0.1	–	–	–	–	–
1140 *cis*-Verbenol	–	–	–	–	–	t	–	0.1	t	–

—*continued*

Table 1—*continued*

KI compound	BR	CE	CO	SB	OB	OX	NA	FR	RG	CF
1143 Camphor	–	–	–	–	–	–	–	–	0.6	t
1143 *cis*-Sabinol[a]	–	–	–	0.1	0.8	–	–	–	–	t
1143 *trans*-Verbenol	–	–	–	–	–	0.5	–	0.5	t	–
1148 Camphene hydrate	–	–	–	–	–	–	–	**0.3**	**0.2**	**0.2**
1153 Citronellal	–	–	–	–	0.3	–	–	–	–	–
1159 p-Mentha-1,5-dien-8-ol	–	–	–	–	0.1	0.3	–	–	–	–
1160 *trans*-Pinocamphone	–	–	–	–	–	–	–	t	–	–
1162 Pinocarvone	–	–	–	–	–	–	–	t	–	–
1165 Borneol	0.1	0.1	0.2	t	0.3	–	–	0.4	0.5	0.4
1173 *cis*-Pinocamphone	–	–	–	–	–	–	–	t	t	t
1177 Terpinen-4-ol	**0.8**	**t**	**0.2**	**0.2**	**6.4**	**1.5**	**2.8**	**0.5**	**0.6**	**0.2**
1179 Naphthalene	0.2	0.1	t	–	–	–	0.1	–	t	–
1183 *p*-Cymen-8-ol	t	–	t	–	0.3	0.4	t	0.1	t	t
1189 α-Terpineol	**0.3**	**0.3**	**0.2**	**0.3**	**2.3**	**5.0**	**1.1**	**0.6**	**1.1**	**0.5**
1194 Myrtenol	–	–	–	t	0.2	–	–	0.2	t	–
1204 Verbenone	–	–	–	–	0.3	t	–	0.1	t	t
1217 *trans*-Carveol	–	–	–	–	0.1	0.2	–	0.1	t	–
1220 endo-fenchyl acetate	–	–	–	–	–	–	–	**0.2**	**0.6**	**0.6**
1228 Citronellol	–	–	t	–	0.6	–	–	0.4	0.2	0.2
1235 *trans*-Chrysanthenyl acetate	–	–	–	0.2	0.2	–	–	0.3	–	–
1242 Carvone	–	–	–	t	–	–	–	–	–	–
1244 Methyl carvacrol	0.2	–	–	–	–	–	–	–	–	–
1252 Piperitone	–	–	–	0.2	–	t	–	0.6	t	–
1255 Geraniol	–	–	–	–	–	–	–	0.2	–	–
1261 Methyl citronellate	–	–	–	0.4	1.9	–	–	–	–	0.1
1262 (see Adams et al., 1995a)	–	–	–	–	–	–	–	1.2	0.8	–
1283 (E)-Anethole	0.1	–	–	–	–	–	–	–	t	–
1285 Bornyl acetate	–	0.7	0.9	1.1	1.6	–	t	1.6	1.3	2.0
1291 2-Undecanone	–	–	–	–	1.7	–	–	–	4.8	t
1292 (see Adams et al., 1995a)	–	–	–	–	–	–	–	1.4	–	–
1297 *trans*-Pinocarvyl acetate	–	–	–	–	t	–	–	–	–	–
1298 Carvacrol	0.1	–	–	–	–	t	–	–	–	–
1324 Terpene alcohol	–	–	–	0.5	0.9	–	–	0.1	–	t
1350 α-Terpinyl acetate	–	1.0	–	0.7	–	–	–	0.2	–	0.6
1351 α-Cubebene	0.1	–	–	–	–	t	–	–	–	–
1354 Citronellyl acetate	–	–	–	–	0.3	–	–	–	–	0.1
1376 α-copaene	–	–	–	t	–	–	t	0.2	–	–
1381 *trans*-Myrtanyl acetate	–	–	–	–	0.2	–	–	–	–	–
1383 Geranyl acetate	–	–	–	–	–	–	–	0.2	–	–
1384 β-Bourbenene	–	–	–	–	t	0.2	–	–	0.2	–
1390 β-Cubebene	0.1	–	–	t	–	–	–	–	–	–
1391 β-Elemene	–	–	0.2	0.2	0.2	–	–	–	–	–
1418 (E)-Caryophyllene	0.3	0.4	0.7	t	0.2	0.2	0.7	1.0	1.6	0.5
1454 α-Humulene	0.4	t	0.5	t	0.1	t	0.3	0.6	1.3	0.4
1458 (E)-β-Farnesene	–	–	–	–	–	–	t	0.2	0.4	t
1471 (see Adams et al., 1995b)	–	–	–	–	–	–	–	–	1.3	–
1477 γ-muurolene	–	–	–	0.3	–	–	0.1	t	t	–
1480 Germacrene D	0.2	–	0.7	0.3	1.2	1.0	0.2	2.3	2.3	–
1493 epi-Cubebol	–	–	–	–	t	–	–	t	–	–

—*continued*

Table 1—*continued*

KI compound	BR	CE	CO	SB	OB	OX	NA	FR	RG	CF
1494 Bicyclogermacrene	–	–	–	–	0.1	–	–	–	–	–
1495 (E)-Methyl isoeugenol	–	–	–	–	–	–	–	0.2	0.7	–
1499 α-Muurolene	**t**	–	**0.2**	**1.3**	**t**	–	**0.3**	**0.2**	**t**	–
1503 Germacrene A	–	–	0.1	0.4	0.2	–	–	–	t	–
1507 (see Adams et al., 1995a)	–	–	–	–	–	–	–	0.5	–	–
1508 α-Farnesene	–	–	–	–	–	–	–	–	0.7	–
1513 γ-Cadinene	**0.3**	–	**0.2**	**1.7**	**0.6**	**0.5**	**0.6**	**2.4**	**0.6**	–
1517 (see Adams et al., 1995a)	–	–	–	–	–	–	–	0.5	–	–
1524 δ-Cadinene	**0.3**	–	**0.5**	**2.6**	**0.5**	**t**	**1.9**	**0.9**	**0.1**	**0.1**
1529 Citronellyl butyrate	–	–	–	–	–	–	–	0.1	–	–
1538 α-Cadinene	–	–	–	0.3	–	–	–	0.1	–	–
1549 Elemol	–	–	–	–	0.1	–	–	–	–	–
1556 Germacrene B	0.1	–	0.3	0.2	0.7	–	–	–	0.2	0.1
1562 Geranyl butyrate	–	–	–	–	–	–	–	0.5	0.3	–
1564 (E)-Nerolidol	–	–	–	–	**t**	**3.3**	**4.2**	**0.3**	**1.0**	**0.2**
1574 Germacrene D-4-ol	–	–	**0.8**	**6.8**	**1.3**	–	**0.1**	**0.9**	–	–
1576 Spathulenol	–	–	–	–	0.8	–	–	–	0.3	–
1581 Caryophyllene oxide	–	–	–	–	t	0.2	–	0.3	0.6	t
1596 Cedrol	–	–	–	–	–	–	–	–	0.3	–
1606 Humulene epoxide II	0.1	–	–	–	0.2	–	–	0.2	0.5	–
1616 Sesquiterpene alcohol	–	–	–	–	0.9	–	–	–	–	–
1627 1-epi-Cubenol	0.4	–	–	–	0.2	–	–	t	–	–
1640 epi-α-Cadinol (=T-cadinol)	–	–	t	0.7	0.1	t	1.6	1.6	0.6	–
1640 epi-α-Muurolol	–	–	0.4	0.9	0.1	–	–	–	–	–
1642 Cubenol	t	–	–	–	–	–	–	–	–	–
1645 α-Muurolol (=torreyol)	–	–	–	0.2	t	–	0.3	0.2	–	–
1652 α-Eudesmol	–	–	–	t	–	–	–	t	–	–
1653 α-Cadinol	–	–	**0.5**	**2.3**	**0.6**	**t**	**2.2**	**1.1**	**0.3**	–
1686 epi-α-Bisabolol	–	–	–	–	–	–	–	–	0.7	2.0
1689 Sesquiterpene alcohol	–	–	–	–	0.9	–	–	–	–	–
1713 (Z,Z)-Farnesol	–	–	–	–	0.2	0.3	–	–	t	–
1722 (E,E)-Farnesol	–	–	–	–	**3.3**	**0.9**	–	**0.7**	**1.4**	**0.2**
1773 (E)-α-Atlantone	–	–	0.3	0.4	–	–	–	–	–	–
1742 (E,Z)-Farnesol	–	–	–	–	0.5	0.4	–	–	t	–
1843 (E,E)-Farnesyl acetate	–	–	–	–	0.2	–	–	–	–	–
1941 Pimaradiene	0.2	–	–	–	–	–	–	–	–	–
1961 Sandaracopimara-8(14),15-diene	**19.5**	–	–	**0.2**	–	–	–	–	–	–
1989 Manoyl oxide	**1.2**	–	–	–	**0.2**	**5.3**	**0.1**	**t**	–	**0.2**
2010 epi-13-Manoyl oxide	–	–	–	–	–	t	–	–	–	–
2054 Abietatriene	1.3	0.1	–	0.2	t	t	–	t	0.5	0.3
2080 Abietadiene	0.3	–	–	0.2	0.1	0.7	–	t	t	t
2103 Diterpene	0.6	–	–	–	–	–	–	–	–	5.1
2205 *cis*-Totarol, methyl ether	0.3	–	–	–	–	–	–	–	–	–
2234 *trans*-Totarol, methyl ether	t	–	–	–	–	–	–	–	–	–
2302 *trans*-Totarol	0.4	–	–	–	–	–	–	–	t	–

Note: KI = Kovat's index on DB-5(=SE54) column. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported.

[a] Tentatively identified.

(=*Oxycedrus*). It is not surprising that this island population has been subject to the founder's effect and subsequent genetic drift. Its relationship to the other *Juniperus* species is not clear from the essential oil data.

Juniperus cedrus, another island endemic, has the simplest composition found in the section (27 compounds, Table 1). The oil is dominated by α-pinene (70.7%) with moderate amounts of β-pinene (4.1%), limonene (4.5%) and β-phellandrene (4.6%). Its oil is very similar to *J. communis* and its DNA verified this relationship (Adams and Demeke, 1993).

The oil of *J. communis*, from plant collected in Sweden, is dominated by α-pinene (56.8%), with moderate amounts of β-pinene, myrcene, limonene, 3-carene and β-phellandrene. In contrast to the reports on sabinene and terpinen-4-ol in *J. communis* from Greece (14.7, 8.7%, Chatzopoulou and Katsiotis, 1993) and Italy (41.4, 2.8%, Caramiello et al., 1995), the oil from Sweden was very low in sabinene (0.7%) and terpinen-4-ol (0.2%). It is likely that geographical variation accounts for these differences and this will be the subject of a subsequent paper.

The oil of *J. sibirica* (possibly *J. communis* var. *montana*) from Mongolia was also dominated by α-pinene (58.2%) with moderate amounts of β-pinene and appreciable amounts of sesquiterpenoids (α-muurolene, γ-cadinene, δ-cadinene, germacrene D-4-ol and α-cadinol) that were missing or trace components in *J. communis* (Table 1). The report of 4.1% β-eudesmol in "*J. sibirica*" from Italy (Caramiello et al., 1995) is surprising because β-eudesmol was not found in any of the taxa of this study (Table 1) which surveyed the entire section, *Juniperus*. The oil of *J. sibirica* from Mongolia is quite similar to *J. communis* from Sweden, but one should await geographic studies and DNA data to determine if it is conspecific.

Juniperus oblonga had the most complex oil in the section (82 compounds, Table 1). The oil had a lesser amount of α-pinene (21.7%, Table 1), considerable sabinene (13.4%), terpinen-4-ol (6.4%) and numerous sesquiterpenoids (Table 1). Note particularly the farnesols that are conspicuously absent in the first four taxa in Table 1. DNA data (Adams and Demeke, 1993) showed *J. oblonga* bridging the gap between *J. communis* var. *montana* (from Murmansk, Russia) and *J. oxycedrus* (Greece). Whether *J. oblonga* should be recognized as a distinct species or a variety of the highly variable *J. communis* taxon is not clear at present.

The leaf oil of *J. navicularis* is dominated by α-pinene (22.9%) and limonene (14.4%) with moderate amounts of sabinene, myrcene, β-phellandrene, terpinolene, and (E)-nerolidol. Although the oil places it in the group with *J. communis* and *J. oxycedrus* (as opposed to the far Eastern group of *J. conferta*, *J. formosana* and *J. rigida*), there is little support to submerge *J. navicularis* as a subspecies of *J. oxycedrus*.

Morphologically, *J. oxycedrus* is one of the most distinct taxa in the section *Juniperus*. DNA analysis (Adams and Demeke, 1993) showed *J. oxycedrus* to be quite distinct, with its closest affinity to *J. oblonga*. The essential oil is dominated by α-pinene (41.3%), with moderate amounts of α-phellandrene, p-cymene, β-phellandrene, limonene, myrcene, α-terpineol, (E)-nerolidol and manoyl oxide (Table 1). It also contains the farnesols found in the far-eastern junipers (*J. formosana*, *J. rigida*, and *J. conferta*). There are three varieties (or subspecies) of *J. oxycedrus* and considerable infraspecific variation that needs to be analyzed to better understand this species.

In contrast to the other seven species of section *Juniperus*, the natural distributions of *J. conferta*, *J. rigida* and *J. formosana* are rather limited, as they occur from Japan and Taiwan to Korea to mid- and northeastern China. These three species, as well almost all of the section *Juniperus*, contain large amounts of α-pinene and moderate amounts of myrcene (Table 1). However, these three species share several compounds not found or very rare in the other six species: endo-fenchol, *trans*-pinocarveol, camphene hydrate, endo-fenchyl acetate, and (E,E)-farnesol (Table 1). Based on DNA data (Adams and Demeke, 1993), *J. conferta*, *J. formosana* and *J. rigida* clustered together. This relationship is also seen in their essential oil compositions.

The composition of leaf essential oils of section *Juniperus* are generally much simpler and dominated by simple monoterpenes, in contrast to the essential oils of section *Sabina*, where oxygenated monoterpenes (e.g. camphor) and sesquiterpenes (e.g. cedrol) are major constituents (Adams, 1991b). This may reflect the evolutionary history of the genus as it appears (Adams and Demeke, 1993) that section *Sabina* is the derived (advanced) group relative to section *Juniperus* (=*Oxycedrus*). It may be that the radiation of the approximately fifty species in section *Sabina* around the northern hemisphere has led to increased selection in various habitats and, thus, to the increased diversity found in the leaf essential oils of section *Sabina*.

Mass spectra for unidentified constituents: [ITMS, 240°C, *m/z* (rel. int.): **KI** 1324, M^+196?, terpene alcohol acetate?, 143(1), 134(5), 119(30), 108(11), 91(100), 79(18), 65(9), 53(10), 43(98); **KI** 1616, M^+222?, sesquiterpene alcohol, 204(1), 189(1), 179(5), 161(9), 149(4), 135(3), 123(13), 109(14), 93(10), 81(17), 69(57), 55(17), 41(100), **KI** 1689, M^+222?, sesquiterpene alcohol, 204(4), 189(3), 179(1), 161(20), 149(3), 133(8), 119(15), 105(31), 91(22), 81(32), 67(32), 55(34), 41(100); **KI** 2103, M^+272(1), diterpene; 272(1), 257(8), 229(1), 204(5), 191(11), 149(7), 133(10), 119(15), 109(18), 91(30), 79(36), 67(36), 55(35), 41(100).

Acknowledgements

This research was supported in part with funds from Baylor University.

References

Adams, R. P., 1991a. Cedar wood oil—analysis and properties. In: Linskins, H. F., Jackson, J. F. (Eds.), Modern Methods of Plant Analysis: Oils and Waxes. Springler, Berlin, pp. 159–173.

Adams, R. P., 1991b. Analysis of juniper and other forest tree oils. In: Linskins, H. F., Jackson, J. F. (Eds.), Modern Methods of Plant Analysis: Oils and Waxes. Springler, Berlin, pp. 131–157.

Adams, R. P., 1995. Identification of Essential Oils Components by Gas Chromatography/Mass Spectroscopy. Allured Publ., Carol Stream, IL, 469 pp.

Adams, R. P., Demeke, T., 1993. Systematic relationships in Juniperusbased on random amplified polymorphic DNAs (RAPDs). Taxon 42, 553–571.

Adams, R. P., Zhang, S.-Z., Chu, G.-L., 1995a. Essential oil of *Juniperus formosana* Hayata leaves from China. J. Ess. Oil Res. 7, 687–689.

Adams, R. P., Chu, G.-L., Zhang, S.-Z., 1995b. Comparisons of the volatile leaf oils of *Juniperus rigida* Mig. from northeastern China, Korea and Japan. J. Ess. Oil Res. 7, 49–52.

Akimov, A. P., Kuznetsov, S. I., Nilov, G. I., Chirkina, N. N., Krylova, A. P., Litvinenko, R. M., 1976. Essential oils of Junipers from ancient Mediterranean region. Composition, properties and prospectives of use. Tr. Nikitsk. Botan. Sad. 69, 79–93.

Banthrope, D. V., Davies, H. S., Gatford, C., Williams, S. R., 1973. Monoterpene patterns in *Juniperus* and *Thuja* species. Planta Medica 23, 64–69.

Caramiello, R., Bocco, A., Buffa, G., Maffei, M., 1995. Chemotaxonomy of *Juniperus communis, J. sibirica* and *J. intermedia*. J. Ess. Oil. Res. 7, 133–145.

Chatzopoulou, R. S., Katsiotis, S. T., 1993. Chemical investigation of the leafoil of *Juniperus communis* L. J. Ess. Oil Res. 5, 603–607.

Franco, J. A., 1964. *Juniperus*. In: Tutin, T. G., Heywood, V. H., Burges, N. A., Valentine, D. H., Walters, S. M., Webb, D. A. (Eds.), Flora Europaea, vol. 1. Cambridge Press, UK, pp. 38–39.

Franco, J. A., 1986. *Juniperus*. In: Castroviejo, S., Lainz, M., Lopez Gonzalez, G., Montserrat, P., Munoz Garmendia, F., Paiva, J., Villar, L. (Eds.), Real Jardin Botanico, Madrid, pp. 181–188.

Hernandez, E. G., Martinez, M., Villanova, R. G., 1987. Determination by gaschromatography of terpenes in the berries of the species *Juniperus oxycedrus* L., *J. thurifera* L. and *J. sabina* L. J. Chromatography 396, 416–420.

Horster, V. H., 1974. Vergleigh der monterpenfraktionen von *Juniperus drupacea* und *Juniperus oxycedrus*. Planta Medica 26, 113–118.

Shatar, S., 1984. Mono- und sesquiterpene in atherischen ol mongolischer *Juniperus-Arten*. Pharmazie 39, 66–67.

Stassi, V., Verykokidou, E., Loukis, A., Harvala, A., Philianos, S., 1995. Essential Oil of *Juniperus oxycedrus* L. subsp. *macrocarpa* (Sm.) Ball. J. Essent. Oil Res. 7, 675–676.

Teresa, J., San Feliciano, A., del Corral, M. J., 1974. Components of the fruits of *Juniperus oxycedrus* III. Anales de Quimica 70, 1015–1019.