

Geographic variation in the volatile leaf oils of *Juniperus excelsa* and *J. polycarpos***Robert P. Adams**

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ABSTRACT

Analyses of *J. excelsa* revealed the volatile leaf oils from Bulgaria and Greece were higher in α -pinene, limonene and β -phellandrene than populations from Turkey, Cyprus and Lebanon. Otherwise, there was little variation in the oils between these populations. Cedrol was a major component in each of the populations, ranging from 22.6 to 29.3%. Analyses of *J. polycarpos* var. *polycarpos* from Azerbaijan revealed the presence of high cedrol and zero cedrol chemotypes. The high cedrol chemotype was similar to the oil from Armenia. The Azerbaijan zero cedrol chemotype was similar to the oil from El Njass, Lebanon. The compositions of oils of *J. polycarpos* var. *turcomanica* and *J. seravschanica* were compared with the oils of *J. excelsa* and *J. polycarpos* var. *polycarpos*. Published on-line: www.phytologia.org Phytologia 96(2): 96-106 (April 1, 2014). ISSN 030319430

KEY WORDS: *Juniperus excelsa*, *J. polycarpos* var. *polycarpos*, *J. polycarpos* var. *turcomanica*, *J. seravschanica*, geographic variation, leaf oils, terpenes, cedrol, α -pinene, limonene.

Adams et al. (2013) recently examined geographic variation in *J. excelsa* and reviewed the leaf essential oil literature. They found *J. excelsa* oils from Bulgaria and Greece to have lower α -pinene (24.3, 21.6%) than oils from Turkey and Cyprus (41.7, 41.8%) plus many other quantitative differences. Cedrol was present at 25.4 to 29.3% in each population and ranged from 11.3% to 35.8% in all 12 trees examined.

The oils of *J. polycarpos* var. *polycarpos*, *J. p.* var. *turcomanica* and *J. p.* var. *seravschanica* (now *J. seravschanica*) have been the subject of several studies by Adams et al. (2008). Initial reports on *J. polycarpos* (Adams 2001; Adams et al. 2008) oils from Armenia (Lake Sevan) were high in α -pinene and cedrol. Recently, Adams and Hojjati (2013) analyzed the leaf essential oils of *J. polycarpos* var. *turcomanica* and *J. seravschanica* from central and southern Iran and included analyses of *J. polycarpos*, (Armenia) and *J. excelsa* (Eskisehir, Turkey).

The distributions of *J. excelsa* and *J. polycarpos* (*stricto sensu*) are shown in Figure 1. It is difficult to distinguish these taxa and they have been treated as conspecific (Farjon, 2005, 2010; Douaihy et al., 2011). Douaihy et al. (Fig. 4, 2011), using 3 microsatellites, found the *J. excelsa* ordinated into 3

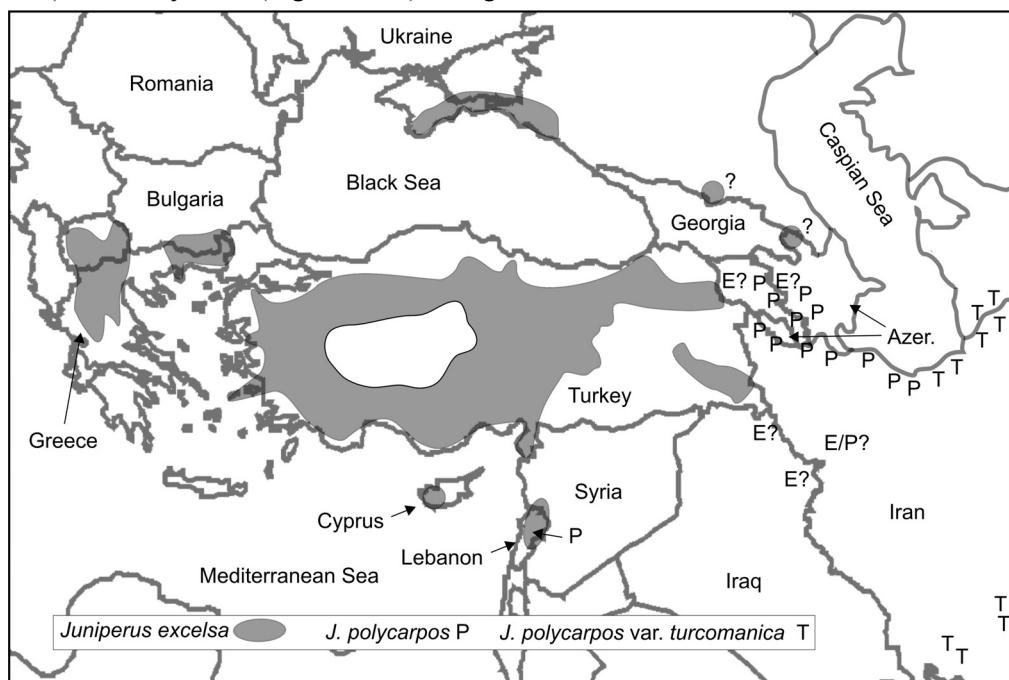


Figure 1. Distribution of *J. excelsa*, *J. polycarpos* var. *polycarpos* and *J. p.* var. *turcomanica* (modified from Adams (2014)). Questionable populations of *J. excelsa* and *J. polycarpos* are indicated by E? and P?.

groups: Greece, Ukraine (Crimea), Turkey, Crete; Lebanon (moderate elevations: Qammouaa, Danniyyeh, Barqa, Afqa) and Lebanon (two very high elevations, Aarsal 2180 m; El Njass 2287 m). Recently, Adams et al. (2014), using 4430 bp of DNA sequence data, have shown that the trees at Afqa, 1307 m, are *J. excelsa* and the trees at El Njass, 2287 m, are *J. polycarpos*, but appearing intermediate to *J. p.* var. *turcomanica*.

Recently, leaf materials suitable for distillation were obtained of *J. excelsa* and *J. polycarpos* from Lebanon and *J. polycarpos* from Azerbaijan. This afforded the opportunity to further examine geographic variation in the volatile leaf oils of both *J. excelsa* and *J. polycarpos*.

MATERIALS AND METHODS

Plant material -

J. excelsa: Eskisehir, Turkey, 820m, Adams 13193 (9433-9435), Bulgaria, 356 m, Adams 14056 (13720-13724), Alex Tashev, 2012-1-JE -5-JE, 42° 01' 22.0" N; 24° 28' 03.1" E, Central Rhodopes, above the town of Kritchim, Reserve "Izgorialoto Gune"; Lemos, Greece, 1100m, Adams 6031 (5983-5985,

5987), Cyprus, Adams 13487, A. K. Christou s.n., bulk 5 trees; Afqa, Lebanon, 1306 m, Adams 14155-14157, Bouchra Douaihy 1-3, 34° 04' 58.12"N, 35° 53' 08.52"E, 4 Nov 2013,
J. polycarpos: Armenia, Lake Sevan, 1900 m, Adams 13194 (8761-8763); Azerbaijan, 177-231m, Adams 14162-14171, Vahid Farzaliyev 1-10, 40° 74' 47.6" N; 40° 58' 55" E, Dec 2013; Lebanon, Danniye-Wadi El Njass, 2287 m, Adams 14158-14161, Bouchra Douaihy 4-7, 34° 20' 47.79"N, 36° 05' 45.54"E, 14 Nov 2013.
J. polycarpos var. *turcomanica*: Adams 13197 (8758-90), Kopet Mtns., Turkmenistan;
J. seravschanica: Adams 13195 (8483-85), Pakistan.
Voucher specimens deposited in the Herbarium, Baylor University (BAYLU).

Fresh or air dried (100 g) leaves were steam distilled for 2 h using a circulatory Clevenger-type apparatus (Adams, 1991). The oil samples were concentrated (diethyl ether trap removed) with nitrogen and the samples stored at -20° C until analyzed. The extracted leaves were oven dried (48h, 100° C) for the determination of oil yields. The oils were analyzed on a HP5971 MSD mass spectrometer, scan time 1/ sec., directly coupled to a HP 5890 gas chromatograph, using a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column (see Adams, 2007 for operating details). Identifications were made by library searches of our volatile oil library (Adams, 2007), 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 a J & W DB-5, 0.26 mm x 30 m, 0.25 micron coating thickness, fused silica capillary column using the HP Chemstation software.

RESULTS AND DISCUSSION

The compositions of the leaf oils for the five populations of *J. excelsa* are given in Table 1. The major components of the oils are cedrol (22.6 - 29.3%), α-pinene (21.6 - 41.8%, limonene (0.5 - 13.3%) and β-phellandrene (0.4 - 9.2%). The oils from Bulgaria and Greece are higher in α-pinene, limonene and β-phellandrene than populations from Turkey, Cyprus and Lebanon. Otherwise, there was little variation in the oils between these populations of *J. excelsa*. Variation in cedrol among *J. excelsa* trees, ranges from 11.3% (Eshisehir, Table 2) to 35.8% (Greece, Table 2). In contrast to *J. polycarpos* (see below) where all trees contained considerable amounts of cedrol (and associated cedarwood oil components).

The leaf oil of *J. polycarpos* (El Njass, Lebanon) is included in Table 1 and it's oil differs from *J. excelsa* by lacking the typical cedarwood compounds α-cedrene β-cedrene, thujopsene, cuparene, cedrol, widdrol, etc. (Adams, 2014). In addition, *J. polycarpos* has a larger concentration of α-pinene (55.6%), plus (4Z)-decen-1-ol, (E)-caryphylene, α-murolene, γ-cadinene, elemol, germacrene B, germacrene D-4-ol, junenol, epi-α-cadinol, epi-α-murolol, α-murroolol, α- and β-eudesmols and shyobunol.

Analyses of *J. polycarpos* var. *polycarpos* from Azerbaijan revealed the presence of high cedrol and low (trace amounts) cedrol (and cedarwood components) chemotypes. Most *Juniperus* species produce two kinds of essential oils: leaf oils and heartwood oils and these oils have few components in common (Adams, 1991). *Juniperus excelsa*, along with *J. foetidissima*, *J. polycarpos*, and *J. seravschanica* have leaf oils that contain significant amounts of the heartwood oil components (cf. α-cedrene β-cedrene, thujopsene, cuparene, cedrol, widdrol, etc., see Adams, 2014). For example, Adams (1990) reported 4.4, 0.2, trace and 8.3% cedrol in the leaf oils from four trees of *J. foetidissima* from Greece. Whereas, Tunalier et al. (2004) reported 13.0 and 12.2% of cedrol and widdrol in the stem heartwood of *J. foetidissima* from Turkey. Ucar and Balaban (2002) analyzed the sapwood (white wood) of *J. excelsa*, Turkey, and reported the oil to contain 22.5% widdrol and 9.0% cedrol (these components are difficult to separate on non-polar columns and the mass spectra are nearly identical, so their identification is often problematic).

When *Juniperus* species contain heartwood components in the leaf oils, it is common to find chemical polymorphisms in cedrol (and associated heartwood terpenes) between trees. That is the case for *J. polycarpos* from Azerbaijan with cedrol in five trees ranging from 24.8 to 34.4% (hi cedrol chemotype, Table 3) and the cedrol of five other trees ranging from 0.00 to 0.03% (low cedrol chemotype, Table 3). The samples from Armenia ranged from 26.0 to 34.3% in cedrol. In the trees from El Njass, Lebanon, cedrol ranged from 0.00 to 0.01%. Trace amounts of cedrol may be due to free radical interactions rather than enzyme based reactions (or even cross-contamination during distillation, and GC analysis). It is interesting that in trees of *J. p.* var. *turcomanica* from Turkmenistan, only trace amounts of cedrol were found (Table 4), but in a population from Fasa, Iran, two chemotypes were found (0.00 to 0.1%, and 10.1, 13.8%, Table 4). Adams and Hojjati (2013) found *Juniperus* in the Fasa area to be quite variable and it seems likely that some of the samples are hybrids or introgressants with *J. p.* var. *polycarpos* in that population (see Adams, Hojjati and Schwarzbach, 2014 for DNA analyses).

Geographic variation in the leaf terpenoids of *J. polycarpos* is difficult to assess due to the high and low cedrol chemotypes in populations. The compositions of the leaf oils for the four populations of *J. polycarpos* are given in Table 4. The Azerbaijan high cedrol chemotype oil was similar to the high cedrol oil from Armenia (Table 4). The Azerbaijan low cedrol chemotype was similar in composition to the low cedrol oil from El Njass, Lebanon. The higher concentrations of several major compounds in El Njass and Azerbaijan, low cedrol) oils seems to be explained by the presence of cedrol (and other cedarwood compounds) in the high cedrol oils of Azerbaijan and Armenia. For example, removing the cedrol and other cedarwood components from Azerbaijan and Armenia, high cedrol oils, shows the revised concentrations of α -pinene, germacrene B and shyobunol to be quite similar (Table 5) to that found in El Njass and Azerbaijan (low cedrol). However, the correction for cedarwood oil components was not sufficient to produce uniform levels for δ -cadinene, germacre-4-ol, and α -eudesmol (Table 5). It appears the terpene synthase genes for production of cedrol (and related compounds) interferes with the production of some other compounds (cf. δ -cadinene, germacre-4-ol, and α -eudesmol) between Azer lo ced and Azer hi ced, Table 5).

The low-cedrol leaf oils of *J. polycarpos* var. *polycarpos* (Njass, Azerbaijan) and *J. p.* var. *turcomanica* are nearly identical in compositions. (Table 4). DNA sequence data (Adams et al., 2014) showed the El Njass trees to be somewhat intermediate between *J. polycarpos* var. *polycarpos* and *J. p.* var. *turcomanica*. This is shown in α -pinene as it is intermediate in concentration. The oil of El Njass does show complementary amounts for some terpenes (var. *turcomanica*, El Njass, var. *polycarpos*): δ -3-carene (t, 2.1, 2.3); terpinolene (0.8, 0.8, 1.2); trans-verbenol (0, 0.4, 0.8); 4Z-decen-1-ol (0, 0.2, 0.2); β -elemene (0.2, 0.2, 0); epi-cubebol (0.5, 0.5, 0); germacrene D-4-ol (8.9, 4.0, 3.7); junenol (0, 0.5, 0.2); α -cadinol (3.6, 1.1, 0.8); manoyl oxide (0, 0.6, 0.2) and 4-epi-abietal (1.9, 0.7, 0.9). Additional research on the relationship of the El Njass trees to *J. polycarpos* var. *polycarpos* and *J. p.* var. *turcomanica* should prove interesting.

In spite of the presence or absence of cedarwood components in the leaf oils in some populations of *J. polycarpos* var. *polycarpos*, there appear to be only minor geographical differences in the leaf oils. The leaf oil of *J. p.* var. *turcomanica* is most similar to the low cedrol oils found in El Njass and Azerbaijan (Table 4).

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Table 1. Leaf essential oils from populations of *J. excelsa*. Afqa, Lebanon, Adams 14155-14157; Bulgaria: Adams 13720-13724; Lemos, Greece: Adams 5983-5985, 5987, Eskisehir, Turkey; Adams 9433-9435 and Cyprus, Adams 13487 (bulk, 5 trees) and *J. polycarpos*, El Njass, Lebanon, Adams 14158-14161. Components that are typical of heartwood oil are highlighted in italics.

| KI | Compound | <i>J. excelsa</i> | | | | | <i>polycarpos</i> |
|-------------|--|----------------------|-----------------|---------------------|-------------|------------------|-------------------|
| | | Kritchim Bulgaria | Lemos Greece | Eskisehir Turkey | Cyprus | Afqa, Lebanon | |
| 921 | tricyclene | t | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 |
| 932 | α-pinene | 24.3 | 21.6 | 41.7 | 41.8 | 37.9 | 55.6 |
| 945 | α -fenchene | 0.1 | 0.1 | 0.3 | t | 0.5 | 0.2 |
| 946 | camphene | 0.2 | 0.3 | 0.2 | 0.1 | 0.2 | 0.3 |
| 953 | thuja-2,4(10)-diene | t | t | 0.1 | t | t | 0.1 |
| 961 | verbenene | t | t | t | t | - | - |
| 969 | sabinene | t | 0.2 | 0.1 | 0.1 | t | t |
| 974 | β -pinene | 0.5 | 0.5 | 0.7 | 0.4 | 0.6 | 0.8 |
| 988 | myrcene | 1.4 | 1.2 | 1.2 | 0.5 | 1.4 | 1.5 |
| 1002 | α -phellandrene | t | t | 0.1 | t | t | t |
| 1008 | δ -3-carene | 0.8 | 1.7 | 5.3 | t | 10.8 | 2.1 |
| 1014 | α -terpinene | t | t | 0.1 | t | 0.1 | t |
| 1020 | p-cymene | 0.5 | 0.4 | 0.6 | 0.1 | 0.2 | 0.2 |
| 1024 | sylvestrene | - | - | - | - | t | - |
| 1024 | limonene | 11.3 | 13.2 | 1.2 | 0.5 | 0.8 | 1.0 |
| 1025 | β-phellandrene | 7.5 | 9.2 | 0.9 | 0.4 | 0.8 | 0.7 |
| 1044 | (E)- β -ocimene | t | t | t | t | t | t |
| 1054 | γ -terpinene | 0.5 | 0.4 | 0.5 | 0.3 | 0.4 | 0.3 |
| 1065 | cis-sabinene hydrate | t | t | t | t | - | - |
| 1086 | terpinolene | 0.8 | 0.7 | 1.1 | 0.3 | 1.9 | 0.8 |
| 1095 | linalool | - | - | - | - | t | 0.4 |
| 1097 | trans-sabinene hydrate | t | t | t | t | - | - |
| 1112 | 3-me-3-butenyl-methyl butanoate | 0.4 | 0.1 | t | t | 0.1 | 0.1 |
| 1114 | endo-fenchol | 0.2 | 0.2 | t | t | t | - |
| 1118 | cis-p-menth-2-en-1-ol | - | - | 0.1 | t | - | - |
| 1122 | α -campholenal | 0.2 | 0.1 | 0.5 | 0.1 | 0.2 | 0.2 |
| 1135 | trans-pinocarveol | 0.4 | 0.2 | 0.8 | 0.1 | 0.2 | 0.2 |
| 1137 | trans-verbenol | - | - | 0.2 | - | - | 0.3 |
| 1141 | camphor | 0.7 | 0.5 | 1.2 | 0.2 | 0.8 | 0.4 |
| 1145 | camphene hydrate | t | t | 0.1 | t | t | 0.1 |
| 1158 | trans-pinocamphone | - | - | - | - | 0.1 | - |
| 1165 | borneol | - | - | - | - | - | 0.2 |
| 1166 | p-mentha-1,5-dien-8-ol | t | t | - | t | t | - |
| 1172 | cis-pinocamphone | t | t | 0.2 | t | t | - |
| 1174 | terpinen-4-ol | t | 0.2 | 0.1 | 0.1 | - | t |
| 1178 | naphthalene | t | t | 0.1 | t | - | - |
| 1179 | p-cymen-8-ol | t | t | 0.1 | t | - | - |
| 1186 | α -terpineol | t | t | t | t | - | t |
| 1193 | (4Z)decenal | - | - | - | - | - | 0.2 |
| 1195 | myrtenol | - | - | - | - | - | 0.1 |
| 1204 | verbenone | t | t | 0.2 | t | 0.1 | 0.2 |
| 1215 | trans-carveol | 0.2 | 0.1 | 0.2 | t | 0.1 | 0.1 |
| 1218 | endo-fenchyl acetate | t | 0.2 | 0.1 | t | - | - |
| 1241 | hexyl isovalerate | - | - | - | - | - | 0.1 |

| KI | Compound | Kritchim Bulgaria | Lemos Greece | Eskisehir Turkey | <i>J. excelsa</i> | Afqa, Lebanon | <i>polycarpos</i> El Njass Lebanon |
|------|-----------------------------|-------------------|--------------|------------------|-------------------|---------------|---------------------------------------|
| 1249 | piperitone | t | t | 0.1 | t | 0.1 | - |
| 1255 | (4Z)-decen-1-ol | - | - | - | - | - | 0.2 |
| 1260 | 3-me-3-butenol hexanoate | 0.2 | 0.1 | - | - | t | - |
| 1274 | pregeijerene B | - | - | - | - | - | - |
| 1284 | bornyl acetate | t | 0.6 | 0.4 | 0.1 | 0.1 | 0.3 |
| 1292 | (2E,4Z)-decadienal | t | 0.3 | 0.1 | t | - | - |
| 1319 | (2E,4E)-decadienol | 3.9 | 3.6 | 2.4 | 2.3 | 3.5 | - |
| 1335 | δ -elemene | - | - | - | - | - | 0.2 |
| 1374 | α -copaene | - | - | - | - | - | 0.1 |
| 1387 | β -bourbonene | t | 0.1 | 0.1 | t | t | 0.1 |
| 1389 | β -elemene | - | - | - | - | - | 0.2 |
| 1390 | 7-epi-sesquithujene | 0.2 | 0.1 | 0.1 | 0.3 | - | - |
| 1410 | α -cedrene | 1.0 | 1.1 | 0.8 | 1.7 | 1.2 | - |
| 1413 | β -funebrene | 1.0 | 0.9 | 0.7 | 1.8 | 0.6 | - |
| 1417 | (E)-caryophyllene | - | - | - | - | - | 0.7 |
| 1419 | β -cedrene | 1.1 | 1.0 | 0.5 | 1.0 | 0.7 | - |
| 1429 | cis-thujopsene | 0.3 | 0.4 | 0.3 | 0.8 | 0.3 | - |
| 1434 | γ -elemene | - | - | - | - | - | 0.2 |
| 1449 | trans-sibirene | - | - | - | - | - | 0.2 |
| 1451 | trans-muurola-3,5-diene | 0.2 | 0.1 | 0.1 | 0.7 | t | - |
| 1452 | α -humulene | 0.1 | 0.2 | 0.1 | 0.2 | t | 0.1 |
| 1454 | (E)- β -farnesene | 0.1 | 0.2 | 0.2 | 0.3 | 0.1 | - |
| 1469 | β -acoradiene | 0.1 | 0.1 | 0.2 | 0.4 | 0.1 | - |
| 1475 | trans-cadina-1(6),4-diene | 0.4 | 0.3 | 0.2 | 0.7 | 0.1 | t |
| 1478 | γ -muurolene | - | - | - | - | - | 0.2 |
| 1480 | germacrene D | 0.8 | 0.8 | 0.6 | 1.2 | 1.2 | 1.1 |
| 1489 | β -selinene | - | - | - | - | - | 0.2 |
| 1493 | trans-muurola-4(14),5-diene | 0.6 | 0.4 | 0.2 | 1.5 | 0.1 | - |
| 1493 | epi-cubebol | - | - | 0.3 | - | 0.3 | 0.5 |
| 1496 | valencene | 0.6 | 0.5 | 0.3 | t | - | - |
| 1500 | α -muurolene | - | - | - | - | - | 0.4 |
| 1500 | β -himachalene | - | t | 0.1 | - | 0.1 | - |
| 1504 | cuparene | - | t | 0.1 | t | - | - |
| 1508 | germacrene A | - | - | - | - | - | 0.2 |
| 1506 | (Z)- α -bisabolene | - | - | 0.1 | t | - | - |
| 1512 | α -alaskene | 0.4 | 0.3 | 0.2 | 0.2 | 0.4 | - |
| 1513 | γ -cadinene | - | - | - | - | - | 1.4 |
| 1514 | cubebol | 0.8 | 0.7 | 0.4 | 1.2 | 0.3 | - |
| 1521 | trans-calamenene | 0.5 | 0.2 | 0.2 | 0.5 | 0.2 | - |
| 1522 | δ -cadinene | 0.5 | 0.3 | 0.3 | 0.6 | 0.2 | 1.6 |
| 1532 | γ -cuparene | 0.3 | 0.2 | 0.2 | 0.5 | - | - |
| 1537 | α -cadinene | - | - | - | - | - | 0.3 |
| 1548 | elemol | - | - | - | - | - | 1.2 |
| 1559 | germacrene B | - | - | - | - | - | 3.6 |
| 1561 | (E)-nerolidol | - | - | - | - | - | 0.1 |
| 1574 | germacrene D-4-ol | - | - | - | - | - | 4.0 |
| 1582 | caryophyllene oxide | - | - | - | - | - | 0.3 |
| 1589 | allo-cedrol | 1.7 | 2.0 | 1.9 | 2.4 | 1.4 | - |
| 1594 | ethyl decanoate | - | - | - | - | - | 0.3 |
| 1600 | cedrol | 25.5 | 29.3 | 25.4 | 27.5 | 22.6 | - |

| KI | Compound | Kritchim Bulgaria | Lemos Greece | Eskisehir Turkey | Cyprus | Afqa, Lebanon | <i>polycarpos</i> |
|------|----------------------------|-------------------|--------------|------------------|--------|---------------|-------------------|
| 1608 | humulene epoxide II | t | t | t | t | t | - |
| 1608 | β -oploopenone | t | t | t | t | t | 0.4 |
| 1618 | junenol | - | - | - | - | - | 0.5 |
| 1622 | sesquiterp. 67,134,174,202 | - | - | - | - | - | 1.0 |
| 1627 | 1-epi-cubenol | 0.8 | 0.7 | 0.5 | 0.7 | t | - |
| 1630 | γ -eudesmol | - | - | - | - | - | 03 |
| 1632 | β -acorenol | t | 0.1 | 0.1 | 0.2 | - | - |
| 1638 | epi- α -cadinol | t | t | t | t | - | 0.9 |
| 1640 | epi- α -muurolol | t | t | t | t | - | 0.8 |
| 1644 | α -muurolol | - | - | - | - | - | 0.3 |
| 1645 | cubenol | t | t | 0.1 | t | - | - |
| 1649 | β -eudesmol | - | - | - | - | - | 1.1 |
| 1652 | α -eudesmol | - | - | - | - | - | 1.0 |
| 1653 | α -cadinol | t | t | t | t | - | - |
| 1661 | sesquiterpene 85,57,41,238 | 1.1 | 0.9 | 1.0 | 1.2 | 1.3 | - |
| 1668 | β -atlantone | 0.7 | 0.5 | 0.6 | 0.7 | 0.8 | - |
| 1688 | shyobunol | - | - | - | - | - | 3.7 |
| 1700 | eudesm-7(11)-en-4-ol | - | - | - | - | - | 0.3 |
| 1713 | cedroxyde | - | - | 0.1 | t | - | - |
| 1792 | β -eudesmol acetate | - | - | - | - | - | 0.2 |
| 1987 | manoyl oxide | t | 0.2 | 0.1 | t | - | 0.6 |
| 2055 | abietatriene | t | 0.4 | t | t | t | t |
| 2087 | abietadiene | - | - | - | - | 0.2 | 0.1 |
| 2181 | sandaracopimarinal | - | - | - | - | - | 0.1 |
| 2298 | 4-epi-abietal | 0.2 | 0.2 | 0.2 | t | t | 0.7 |
| 2401 | abietol | - | - | - | - | - | 0.1 |

KI = linear Kovats Index on DB-5 column. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported.

Table 2. Variation in cedrol (% total oil) among individual trees in populations of *J. excelsa*. Note that the Cyprus value for cedrol is from bulked leaves from 5 trees.

| | | | | | |
|---------------|------|------|------|------|------|
| Bulgaria | 22.1 | 24.4 | 24.4 | 26.0 | 28.2 |
| Greece | 18.8 | 23.0 | 28.0 | 35.8 | |
| Eskisehir | 11.3 | 22.1 | 27.6 | | |
| Afqa, Lebanon | 14.7 | 18.2 | 25.1 | | |
| Cyprus | 27.5 | | | | |

Table 3. Variation in cedrol (% total oil) among individual trees in populations of *J. polycarpos* and *J. p. var. turcomanica*.

| <i>J. polycarpos</i> var. <i>polycarpos</i> | | | | | |
|--|------|------|------|-------|-------|
| Armenia | 26.0 | 30.2 | 34.3 | | |
| Azerbaijan, hi cedrol | 24.8 | 29.1 | 30.0 | 33.1 | 34.4 |
| Azerbaijan, low cedrol | 0.0 | 0.01 | 0.01 | 0.02 | 0.03 |
| El Njass, Lebanon | 0.0 | 0.01 | 0.01 | 0.01 | |
| <i>J. polycarpos</i> var. <i>turcomanica</i> | | | | | |
| Kopet Mtns., Turkmenistan | 0.1 | 0.1 | 0.2 | | |
| Fasa, Iran (introgressed) | 0.0 | 0.1 | 1.1 | 10.1* | 13.8* |

*hybrid or introgressed from *J. seravschanica*?

Table 4. Leaf essential oils from populations of *J. polycarpos*, (El) Njass, Lebanon, Adams 14158-14161; Armenia, Adams 8761-8763, Azerbaijan, high cedrol, Adams 14162, 14165, 14167, 14168, 14171, low cedrol, Adams 14163, 14164, 14166, 14169, 14170; *turco* - *J. p.* var. *turcomanica* Adams 8758-90, Turkmenistan; serav - *J. seravschanica*, Adams 8483-85, Pakistan; excel - *J. excelsa*, Adams 9433-35, Eskisehir, Turkey. Components from cedarwood oils are highlighted in italics.

| KI | Compound | <i>turco.</i> | <i>J. polycarpos</i> var. <i>polycarpos</i> | | | | <i>excelsa</i> | <i>serav.</i> |
|-------------|---|-----------------|---|----------------|----------------|-------------------|------------------|------------------|
| | | Turkm lo ced | Njass lo ced | Azer lo ced | Azer hi ced | Armenia hi ced | Turkey hi ced | Pakist hi ced |
| 926 | tricyclene | 0.1 | 0.1 | 0.2 | 0.1 | 0.1 | 0.2 | 0.1 |
| 931 | α -thujene | t | t | - | t | t | - | 0.4 |
| 939 | α-pinene | 45.0 | 55.6 | 62.4 | 45.5 | 39.9 | 41.7 | 19.9 |
| 953 | α -fenchene | 0.1 | 0.2 | 0.1 | 0.1 | t | 0.3 | 0.1 |
| 953 | camphene | 0.2 | 0.3 | 0.4 | 0.3 | 0.2 | 0.2 | 0.2 |
| 957 | thuja-2,4(10)-diene | t | 0.1 | 0.1 | t | t | 0.1 | - |
| 961 | verbenene | t | - | - | - | t | t | t |
| 976 | sabinene | 0.3 | t | 0.2 | 0.2 | 0.4 | 0.1 | 0.5 |
| 980 | β -pinene | 0.8 | 0.8 | 0.9 | 0.7 | 0.5 | 0.7 | 0.9 |
| 991 | myrcene | 1.9 | 1.5 | 2.5 | 2.0 | 1.3 | 1.2 | 27.4 |
| 1005 | α -phellandrene | - | t | t | t | - | 0.1 | 0.1 |
| 1011 | δ-3-carene | t | 2.1 | 2.3 | 0.4 | t | 5.3 | 0.8 |
| 1018 | α -terpinene | t | t | 0.1 | t | t | 0.1 | 0.1 |
| 1026 | p-cymene | 0.2 | 0.2 | 0.2 | 0.1 | 0.2 | 0.6 | 0.6 |
| 1031 | limonene | 1.0 | 1.0 | 1.1 | 1.4 | 1.0 | 1.2 | 1.4 |
| 1031 | β -phellandrene | 0.8 | 1.0 | 1.0 | 0.9 | 0.4 | 0.9 | 1.3 |
| 1050 | (E)- β -ocimene | - | - | t | t | - | t | t |
| 1062 | γ -terpinene | 0.4 | 0.3 | 0.5 | 0.4 | 0.3 | 0.5 | 1.0 |
| 1068 | cis-sabinene hydrate | t | t | t | t | t | t | 0.2 |
| 1088 | terpinolene | 0.8 | 0.8 | 1.2 | 0.8 | 0.6 | 1.1 | 0.8 |
| 1098 | linalool* | t | 0.4 | 0.5 | 0.5 | 0.1 | - | 0.8 |
| 1116 | 3-methyl butanoate, 3-methyl-3-butenyl- | 0.1 | t | 0.1 | 0.2 | - | t | - |
| 1121 | cis-p-menth-2-en-1-ol | - | - | - | - | - | 0.1 | - |
| 1125 | α -campholenal | 0.2 | 0.2 | 0.4 | 0.3 | 0.3 | 0.5 | 0.1 |
| 1139 | trans-pinocarveol | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.8 | t |
| 1140 | cis-verbенол | t | 0.1 | 0.1 | 0.1 | t | 0.2 | - |
| 1143 | camphor | 1.0 | 0.3 | 0.9 | 0.4 | - | 1.2 | - |
| 1143 | trans-verbенол | - | 0.4 | 0.8 | 0.5 | 1.1 | - | 0.3 |
| 1148 | camphene hydrate | t | t | t | t | - | 0.1 | - |
| 1159 | p-mentha-1,5-dien-8-ol | 0.1 | t | 0.2 | 0.1 | t | 0.1 | t |
| 1160 | pinocarvone | - | t | 0.1 | 0.1 | - | - | - |
| 1165 | borneol | - | 0.2 | - | - | - | - | - |
| 1172 | cis-pinocamphone | - | - | - | - | t | 0.2 | - |
| 1177 | terpinen-4-ol | t | t | 0.1 | t | t | 0.1 | 0.4 |
| 1179 | naphthalene | 0.6 | - | - | - | 0.2 | 0.1 | - |
| 1183 | p-cymen-8-ol | t | t | t | t | t | 0.1 | - |
| 1189 | α -terpineol | t | t | 0.1 | t | t | t | t |
| 1193 | 4Z-decenal | - | 0.1 | 0.2 | 0.1 | - | - | - |
| 1195 | myrtenol | - | 0.1 | 0.2 | t | - | - | - |
| 1204 | verbenone | 0.1 | 0.1 | 0.2 | 0.1 | 0.2 | 0.2 | t |
| 1217 | trans-carveol | t | 0.1 | 0.2 | 0.1 | t | 0.2 | - |
| 1243 | hexyl 3-methyl butanoate | 0.4 | t | 0.2 | t | 0.2 | - | t |
| 1252 | piperitone | - | - | - | - | - | 0.1 | - |
| 1257 | 4Z-decen-1-ol | - | 0.2 | 0.2 | 0.1 | - | - | 0.1 |
| 1285 | bornyl acetate | 0.3 | 0.3 | 0.5 | 0.3 | 0.4 | 0.4 | 0.4 |
| 1290 | trans-sabinyacetate | - | - | - | - | - | - | 0.2 |
| 1315 | (2E,4E)-decadienal | t | - | 0.1 | - | - | 2.4 | 0.3 |
| 1319 | (2E,4E)-decadienol | - | - | 0.1 | - | - | - | - |

| KI | Compound | <i>turco.</i> | <i>J. polycarpos</i> var. <i>polycarpos</i> | | | | <i>excelsa</i> | <i>serav.</i> |
|-------------|-----------------------------|-----------------|---|----------------|----------------|-------------------|------------------|------------------|
| | | Turkm lo ced | Njass lo ced | Azer lo ced | Azer hi ced | Armenia hi ced | Turkey hi ced | Pakist hi ced |
| 1320 | phenolic 149,91,77,164 | - | - | 0.1 | - | - | - | - |
| 1339 | δ-elemene | 0.1 | 0.2 | 0.1 | t | t | - | t |
| 1376 | α-copaene | 0.1 | 0.1 | t | t | - | - | t |
| 1382 | hexyl n-hexanoate | 0.1 | - | 0.2 | 0.1 | 0.2 | - | 0.2 |
| 1383 | β-bourbonene | - | 0.1 | t | t | - | 0.1 | - |
| 1389 | β-elemene | 0.2 | 0.2 | - | t | - | - | t |
| 1389 | β-cubebene | t | - | - | - | 0.1 | 0.1 | - |
| 1409 | α-cedrene | 0.1 | - | - | 0.7 | 1.0 | 0.8 | 0.6 |
| 1413 | β-funebrene | - | - | - | 0.7 | 1.5 | 0.7 | 0.7 |
| 1418 | (E)-caryophyllene | 0.6 | 0.7 | 0.4 | - | 0.8 | - | 0.3 |
| 1418 | β-cedrene | t | - | - | 0.6 | 0.2 | 0.5 | 0.2 |
| 1429 | cis-thujopsene | - | - | - | 0.4 | 0.4 | 0.3 | 0.2 |
| 1434 | γ-elemene | t | 0.2 | - | - | - | - | - |
| 1446 | cis-muurola-3,5-diene | t | - | - | 0.1 | - | 0.2 | - |
| 1449 | trans-sibirene | - | - | t | - | - | - | - |
| 1454 | α-humulene | 0.2 | 0.1 | t | - | - | 0.1 | t |
| 1458 | (E)-β-farnesene | - | - | - | 0.2 | 0.3 | 0.2 | 0.2 |
| 1461 | cis-muurola-1(6),4-diene | 0.2 | - | t | 0.1 | 0.1 | - | t |
| 1466 | β-acoradiene | - | - | - | 0.1 | 0.2 | 0.1 | t |
| 1473 | trans-cadina-1(6),4-diene | - | t | t | 0.1 | - | 0.2 | - |
| 1477 | γ-muurolene | 0.3 | 0.2 | 0.1 | - | - | - | t |
| 1480 | germacrene D | 1.3 | 1.1 | 0.8 | 0.3 | 0.6 | 0.6 | 0.3 |
| 1489 | β-selinene | - | 0.2 | - | - | - | - | - |
| 1491 | trans-murrola-4(14),5-diene | 0.2 | - | 0.3 | 0.3 | - | 0.2 | 0.2 |
| 1493 | epi-cubebol | 0.5 | 0.5 | - | 0.1 | - | 0.3 | - |
| 1498 | β-alaskene | - | - | - | 0.1 | - | - | - |
| 1494 | bicyclogermacrene | - | - | - | - | 0.3 | - | t |
| 1499 | α-muurolene | 0.7 | 0.4 | 0.3 | - | - | 0.1 | 0.2 |
| 1502 | cuparene | - | - | - | - | - | 0.1 | t |
| 1503 | germacrene A | 0.2 | 0.1 | - | - | - | - | - |
| 1505 | α-cuprenene | - | - | - | 0.1 | - | - | - |
| 1509 | β-bisabolene | - | - | - | t | t | 0.1 | t |
| 1513 | α-alaskene | - | - | - | 0.5 | 0.1 | 0.2 | 0.3 |
| 1513 | γ-cadinene | 1.7 | 1.4 | 1.2 | - | 1.0 | - | 0.7 |
| 1513 | cubebol | - | - | - | 0.6 | - | 0.4 | - |
| 1524 | δ-cadinene | 2.8 | 1.6 | 1.4 | 0.4 | 0.8 | 0.5 | 0.8 |
| 1532 | (E)-γ-bisabolene | - | - | - | - | 0.3 | 0.2 | - |
| 1532 | γ-cuprenene | - | - | - | 0.2 | - | 0.2 | t |
| 1537 | α-cadinene | 0.4 | 0.3 | 0.2 | - | - | - | 0.1 |
| 1549 | elemol | 0.7 | 1.2 | 1.3 | 0.4 | 0.4 | - | 0.9 |
| 1556 | germacrene B | 2.8 | 3.6 | 1.9 | 0.8 | 1.6 | - | 0.7 |
| 1561 | (E)-nerolidol | - | 0.1 | 0.1 | - | - | - | - |
| 1574 | germacrene D-4-ol | 8.9 | 4.0 | 3.7 | 1.0 | 1.5 | - | 2.9 |
| 1582 | caryophyllene oxide | - | 0.3 | t | - | - | - | - |
| 1587 | allo-cedrol | - | - | - | 1.9 | 2.3 | 1.9 | 1.2 |
| 1594 | ethyl dodecanoate | - | 0.3 | - | - | - | - | - |
| 1596 | cedrol | 0.2 | - | - | 27.2 | 30.3 | 25.4 | 22.7 |
| 1606 | β-oplopenone | 0.4 | 0.4 | 0.2 | - | - | t | - |
| 1618 | junenol | - | 0.5 | 0.2 | - | - | - | - |
| 1622 | sesquiterp.67,134,174,202 | - | 1.0 | - | - | - | - | - |
| 1627 | 1-epi-cubenol | - | - | - | - | - | 0.5 | - |
| 1628 | sesquiterp.43,119,161,204 | - | - | 0.3 | 0.6 | - | - | - |
| 1630 | γ-eudesmol | - | 0.3 | t | - | 0.4 | - | - |
| 1638 | epi-α-cadinol | 1.4 | 0.8 | 0.8 | 0.2 | 0.2 | t | 0.4 |
| 1640 | epi-α-muurolol | 1.4 | 0.9 | 0.7 | 0.1 | 0.3 | t | 0.4 |

| KI | Compound | <i>turco.</i> | <i>J. polycarpos</i> var. <i>polycarpos</i> | | | | <i>excelsa</i> | <i>serav.</i> |
|-------------|-------------------------------|-----------------|---|----------------|----------------|-------------------|------------------|------------------|
| | | Turkm lo ced | Njass lo ced | Azer lo ced | Azer hi ced | Armenia hi ced | Turkey hi ced | Pakist hi ced |
| 1645 | α-muurolol | 0.5 | 0.3 | 0.2 | t | t | t | 0.1 |
| 1649 | β-eudesmol | 0.2 | 0.8 | 0.4 | 0.1 | t | - | 0.2 |
| 1652 | α-eudesmol | t | 1.0 | 0.9 | 0.2 | 0.2 | - | 0.2 |
| 1653 | α-cadinol | 3.6 | 1.1 | 0.8 | 0.2 | 0.5 | t | 1.0 |
| 1661 | sesquiterpene 85,57,41,238 | t | - | - | - | - | 1.0 | - |
| 1663 | β-atlantone | - | - | - | - | - | 0.6 | - |
| 1666 | bulnesol | 0.2 | - | - | - | 0.3 | - | 0.2 |
| 1666 | (2E,4E)-decadienol | - | - | - | - | - | 0.6 | - |
| 1688 | shybunol | 2.1 | 3.7 | 2.9 | 1.0 | 1.2 | - | 1.6 |
| 1700 | eudesm-7(11)-en-4-ol | - | 0.3 | 0.1 | t | - | - | - |
| 1789 | 8-α-acetoxyelemol | 0.1 | - | - | - | - | - | t |
| 1792 | β-eudesmol acetate | | 0.2 | 0.1 | t | | | |
| 1989 | manoyl oxide | - | 0.6 | 0.2 | 0.3 | 0.4 | 0.1 | 0.2 |
| 2054 | abietatriene | t | t | 0.2 | 0.2 | t | 0.1 | t |
| 2080 | abietadiene | 0.7 | 0.1 | 1.5 | 1.0 | 0.8 | 0.5 | 0.3 |
| 2147 | abieta-8(14),13(15)-diene | t | - | - | - | - | - | - |
| 2184 | sandaracopimarinal | 0.1 | 0.1 | t | t | - | - | - |
| 2288 | 4-epi-abietal | 1.9 | 0.7 | 0.9 | 0.9 | 1.5 | 0.2 | 1.2 |
| 2312 | abieta-7,13-dien-3-one | | - | 0.2 | 0.1 | | | |
| 2331 | trans-ferruginol | | - | 0.1 | 0.1 | | | |
| 2401 | abietol | | 0.1 | 0.1 | 0.1 | | | |

KI = linear Kovats Index on DB-5 column. Compositional values less than 0.1% are denoted as traces (t). Unidentified components less than 0.5% are not reported.

Table 5. Comparison of major components by total oil vs. oil minus cedarwood oil components for *J. polycarpos*, hi-cedrol populations. Total concentration (%) of cedarwood oil components:
Azer hi ced: 31.5%, correction factor = 1.315; Armenia hi ced: 35.7%; correction factor = 1.357.

| KI | Compound | <i>turco.</i> | <i>J. polycarpos</i> var. <i>polycarpos</i> | | | |
|-------------|---------------------------------------|-----------------|---|----------------|----------------|-------------------|
| | | Turkm lo ced | Njass lo ced | Azer lo ced | Azer hi ced | Armenia hi ced |
| | concentration as % total oil | | | | | |
| 939 | α-pinene | 45.0 | 55.6 | 62.4 | 45.5 | 39.9 |
| 1524 | δ-cadinene) | 2.8 | 1.6 | 1.4 | 0.4 | 0.8 |
| 1556 | germacrene B | 2.8 | 3.6 | 1.9 | 0.8 | 1.6 |
| 1574 | germacrene D-4-ol | 8.9 | 4.0 | 3.7 | 1.0 | 1.5 |
| 1652 | α-eudesmol | t | 1.0 | 0.9 | 0.2 | 0.2 |
| 1688 | shybunol | 2.1 | 3.7 | 2.9 | 1.0 | 1.2 |
| | concentration without cedrol, etc. | | | | | |
| 939 | α-pinene | 45.0 | 55.6 | 62.4 | 59.8 | 54.1 |
| 1524 | δ-cadinene | 2.8 | 1.6 | 1.4 | 0.5 | 1.1 |
| 1556 | germacrene B | 2.8 | 3.6 | 1.9 | 1.1 | 2.2 |
| 1574 | germacrene D-4-ol | 8.9 | 4.0 | 3.7 | 1.3 | 2.0 |
| 1652 | α-eudesmol | t | 1.0 | 0.9 | 0.3 | 0.3 |
| 1688 | shybunol | 2.1 | 3.7 | 2.9 | 1.3 | 1.6 |