JOHNSON, C. K. (1976). *ORTEPII*. Report ORNL-5138. Oak Ridge National Laboratory, Tennessee, USA.

MAIN, P., FISKE, S. J., HULL, S. E., LESSINGER, L., GERMAIN, G., DECLERCQ, J.-P. & WOOLFSON, M. M. (1982). *MULTAN*11/82. *A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data*. Univs. of York, England, and Louvain, Belgium.

PURANIK, D. B. & FINK, M. J. (1989). *J. Am. Chem. Soc.* **111**, 5951–5952.

PURANIK, D. B., JOHNSON, M. P. & FINK, M. J. (1989). *Organometallics*, **8**, 770–777.

WEIDENBRUCH, M., BLINTJER, B., PETERS, K. & VON SCHNERING, H. G. (1986). *Angew. Chem. Int. Ed. Engl.* **25**, 1129–1131.

Structure of the Naturally Occurring Sesquiterpene Lactone 8-Epiisolipidiol

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Abstract. Decahydro-4,8-dihydroxy-3,9-dimethyl-6-methyleneazuleno[4,5-*b*]furan-2(3*H*)-one, $C_{15}H_{21}O_4$, $M_r = 265.3$, orthorhombic, $P2_12_12_1$, $a = 5.755$ (1), $b = 13.891$ (2), $c = 17.511$ (2) Å, $V = 1399.9$ (4) Å^3, $Z = 4$, $D_x = 1.25$ Mg m^{-3}, $\lambda(\text{Cu }K\alpha) = 1.54178$ Å, $\mu = 0.65$ mm^{-1}, $F(000) = 572$, $T = 295$ K, $R = 0.055$, $wR = 0.070$ for 1685 observed reflections. The three-ring guaianolide system contains an *exo*-methylene-cycloheptane moiety *cis*-fused with the cyclopentane [at C(1)—C(5)] and *trans*-annelated with the α-methyl-γ-lactone [at C(6)—C(7)]. The two five-membered rings are in envelope conformations while the seven-membered ring is about midway between chair and twist-chair forms. The secondary hydroxyl groups are at C(3) and C(8), and are both β-orientated; they participate in intermolecular hydrogen bonds, O(8) both as a donor and an acceptor, and O(3) as a donor only.

Introduction. Chemotaxonomic studies are becoming increasingly important in the classification of plants. So far from the plants of the tribe *Lactuceae* (*Compositae* family) predominantly guaiane-type sesquiterpene lactones related to lactucin (I) have been isolated. Recently a series of structurally related 8β-hydroxyguaian-6,12-olides with additional oxygen functions at C(3) have been isolated from *Crepis* species (Barbetti, Casinovi, Santurbano & Longo, 1979; Kisiel, 1983a, b, 1984), *Andryala* (Bohlmann & Gupta, 1982; Massanet, Collado, Macias, Luis & Vergara, 1984), *Ixeris* (Nishimura, Miyse, Ueno, Noro, Kuroyanagi & Fukushima, 1985) and

Prenanthes (Miyase, Yamada & Fukushima, 1987). The presence of these guaianolides in plants of the tribe *Lactuceae* might be of chemotaxonomical importance, since their C(8) epimers appear mostly in plants of the tribes *Cynareae, Vernonieae* and *Mutisieae*. 8-Epiisolipidiol (II) was obtained for the first time from *Crepis capillaris* (L.) Wallr. (Kisiel, 1983a), and its 8α-hydroxy analogue was isolated from *Amberboa lippii* D. C. (*Cynareae*) (Gonzalez, Garcia Marrero & Breton, 1970). An initial molecular structure, (II), was proposed for 8-epiisolipidiol based on chemical and spectroscopic methods (Kisiel, 1983a). Confirmation of the structure was sought through crystallographic analysis.

(I)   (II)
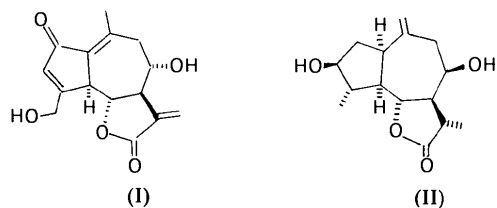
Experimental. 8-Epiisolipidiol (II) was extracted from the aerial parts of *Crepis capillaris* (L.) Wallr. with ethanol and isolated by silica-gel column chromatography.

A crystal approximately $0.2 \times 0.3 \times 0.3$ mm, obtained from methanol solution, was used for X-ray analysis. Syntex $P2_1$ diffractometer, θ–2θ scan, variable scan rate, graphite-monochromated Cu $K\alpha$ radiation, cell parameters by least-squares refinement

Table 1. Final fractional coordinates and equivalent isotropic thermal parameters (Å²)

$$U_{eq} = (U_{11} + U_{22} + U_{33})/3.$$

	x	y	z	U_{eq}
C(1)	-0.3359 (8)	0.0464 (3)	-0.4939 (2)	0.068 (1)
C(2)	-0.404 (1)	0.0780 (5)	-0.5743 (3)	0.122 (3)
C(3)	-0.5675 (9)	0.0043 (3)	-0.6056 (2)	0.080 (2)
C(4)	-0.6812 (7)	-0.0393 (2)	-0.5352 (2)	0.060 (1)
C(5)	-0.4810 (7)	-0.0469 (2)	-0.4793 (2)	0.053 (1)
C(6)	-0.5418 (7)	-0.0610 (2)	-0.3964 (2)	0.049 (1)
C(7)	-0.3319 (7)	-0.0696 (2)	-0.3431 (2)	0.055 (1)
C(8)	-0.2659 (8)	0.0252 (3)	-0.3054 (2)	0.064 (1)
C(9)	-0.1782 (8)	0.1006 (3)	-0.3632 (2)	0.066 (1)
C(10)	-0.3414 (8)	0.1206 (3)	-0.4299 (2)	0.067 (1)
C(11)	-0.4025 (7)	-0.1489 (3)	-0.2864 (2)	0.055 (1)
C(12)	-0.5883 (7)	-0.2025 (3)	-0.3277 (2)	0.057 (1)
C(13)	-0.2065 (8)	-0.2126 (3)	-0.2588 (2)	0.071 (2)
C(14)	-0.467 (1)	0.1994 (4)	-0.4310 (3)	0.107 (3)
C(15)	-0.820 (1)	-0.1293 (4)	-0.5513 (3)	0.106 (2)
O(3)	-0.7215 (7)	0.0463 (2)	-0.6594 (2)	0.096 (1)
O(6)	-0.6676 (5)	-0.1517 (2)	-0.3881 (1)	0.0621 (8)
O(8)	-0.4639 (6)	0.0584 (2)	-0.2639 (1)	0.071 (1)
O(12)	-0.6735 (6)	-0.2801 (2)	-0.3131 (2)	0.075 (1)

of setting angles of 15 reflections, $20.7 < 2\theta < 31.8°$. Two standard reflections remeasured every 100 reflections showed no change in intensity greater than $2.6\sigma(I)$. 2273 reflections measured, $2\theta \le 115°$, 1690 with $I > 1.96\sigma(I)$ considered significant, index range h 0/6, k 0/15, l −18/18. Measurements made for hkl and $hk\bar{l}$ octants to allow later anomalous-dispersion refinements. Profile analysis according to Lehmann & Larsen (1974) using the *PRARA* program (Jaskólski, 1982). Lorentz and polarization corrections, no absorption correction. Structure solved by direct methods using *MULTAN*80 (Main, Fiske, Hull, Lessinger, Germain, Declercq & Woolfson, 1980); non-H atoms refined anisotropically. Positions of H atoms calculated, allowed to ride on parent C atoms with the exception of the hydroxyl- and methylene-H atoms which were located from a difference Fourier map and were allowed to vary; methyl group was refined as a rigid group. The H atoms were given a common isotropic temperature factor which refined to a value $U = 0.101$ (3) Å². An attempt to establish the absolute configuration by the use of anomalous scattering of oxygen was not successful. Therefore the usual assumption that the C(7) equatorial substituent is β (Fisher, Olivier & Fisher, 1979) was made and, accordingly, the signs of all atomic coordinates were changed. An empirical isotropic extinction parameter x was introduced ($F_c = 1 - xF_o^2/\sin\theta$) and refined to 1.6 (3) $\times 10^{-6}$. Five reflections (068, 310, 201, 002, 029) with small intensity and large $\Delta F/\sigma$ excluded from final refinement. Refinement on F by full-matrix least squares (*SHELX*76, Sheldrick, 1976); $R = 0.055$; $wR = 0.070$ for 1685 reflections and 192 refined parameters $[w^{-1} = \sigma^2(F) + 0.0001F^2]$. Mean and maximum Δ/σ 0.09 and 0.40 for non-H atoms; residual electron density

Table 2. Bond lengths (Å), bond angles (°) and selected torsional angles (°) with e.s.d.'s in parentheses

C(1)—C(2)	1.526 (7)	C(6)—O(6)	1.460 (4)
C(1)—C(5)	1.562 (6)	C(7)—C(11)	1.538 (5)
C(1)—C(10)	1.523 (6)	C(8)—C(9)	1.542 (5)
C(2)—C(3)	1.494 (8)	C(8)—O(8)	1.428 (6)
C(3)—C(4)	1.521 (6)	C(9)—C(10)	1.524 (6)
C(3)—O(3)	1.419 (6)	C(10)—C(14)	1.314 (7)
C(4)—C(5)	1.515 (5)	C(11)—C(12)	1.490 (5)
C(4)—C(15)	1.512 (7)	C(11)—C(13)	1.513 (6)
C(5)—C(6)	1.506 (5)	C(12)—O(12)	1.212 (5)
C(6)—C(7)	1.532 (5)	C(12)—O(6)	1.350 (4)
C(7)—C(8)	1.521 (5)		

C(2)—C(1)—C(5)	104.6 (3)	C(6)—C(7)—C(11)	103.9 (3)
C(2)—C(1)—C(10)	118.5 (3)	C(8)—C(7)—C(11)	114.0 (3)
C(5)—C(1)—C(10)	115.5 (3)	C(7)—C(8)—C(9)	112.6 (3)
C(1)—C(2)—C(3)	107.6 (4)	C(7)—C(8)—O(8)	107.5 (3)
C(2)—C(3)—C(4)	104.2 (4)	C(9)—C(8)—O(8)	112.1 (3)
C(2)—C(3)—O(3)	110.8 (4)	C(8)—C(9)—C(10)	115.2 (3)
C(4)—C(3)—O(3)	115.7 (3)	C(1)—C(10)—C(9)	115.3 (3)
C(3)—C(4)—C(5)	102.9 (3)	C(1)—C(10)—C(14)	124.4 (4)
C(3)—C(4)—C(15)	113.9 (3)	C(9)—C(10)—C(14)	120.2 (4)
C(5)—C(4)—C(15)	117.8 (3)	C(7)—C(11)—C(12)	103.5 (3)
C(1)—C(5)—C(4)	104.1 (3)	C(7)—C(11)—C(13)	115.3 (3)
C(1)—C(5)—C(6)	112.9 (3)	C(12)—C(11)—C(13)	113.5 (3)
C(4)—C(5)—C(6)	117.0 (3)	C(11)—C(12)—O(6)	111.2 (3)
C(5)—C(6)—C(7)	114.5 (3)	C(11)—C(12)—O(12)	129.1 (3)
C(5)—C(6)—O(6)	108.9 (2)	O(6)—C(12)—O(12)	119.6 (3)
C(7)—C(6)—O(6)	105.2 (3)	C(6)—O(6)—C(12)	111.2 (3)
C(6)—C(7)—C(8)	113.2 (3)		

5-membered ring

C(5)—C(1)—C(2)—C(3)	-3.1 (5)	C(2)—C(3)—C(4)—C(5)	-40.1 (4)
C(2)—C(1)—C(5)—C(4)	-21.6 (4)	C(3)—C(4)—C(5)—C(1)	37.8 (3)
C(1)—C(2)—C(3)—C(4)	26.6 (4)		

7-membered ring

C(10)—C(1)—C(5)—C(6)	-17.4 (4)	C(6)—C(7)—C(8)—C(9)	-65.9 (4)
C(5)—C(1)—C(10)—C(9)	80.8 (4)	C(7)—C(8)—C(9)—C(10)	53.9 (4)
C(1)—C(5)—C(6)—C(7)	-60.0 (3)	C(8)—C(9)—C(10)—C(1)	-79.3 (4)
C(5)—C(6)—C(7)—C(8)	95.8 (3)		

γ-lactone ring

O(6)—C(6)—C(7)—C(11)	-20.5 (3)	C(7)—C(11)—C(12)—O(6)	-15.1 (3)
C(7)—C(6)—O(6)—C(12)	12.1 (3)	C(11)—C(12)—O(6)—C(6)	2.1 (3)
C(6)—C(7)—C(11)—C(12)	21.2 (3)		

in difference map showed two maxima 0.68 and 0.51 e Å⁻³ near to atoms C(2), C(3), O(3) whose temperature factors refined to rather large values. Scattering factors for C, H and O as in *SHELX*76. *ORTEP* (Johnson, 1965) and *PLUTO* (Motherwell & Clegg, 1978) were used for diagrams.

Discussion. Final atomic coordinates are given in Table 1.* Bond lengths, bond angles and torsion angles are listed in Table 2. Fig. 1 shows a perspective view of the molecule (*ORTEP*, Johnson, 1965). The X-ray analysis confirms that 8-epiisolipidiol has the stereochemistry shown in (I). The ring junctions in this tricyclic molecule are *cis* at C(1)—C(5) and *trans* at C(6)—C(7). The cycloheptane ring adopts a

conformation which is almost exactly intermediate between symmetrical chair and twist-chair forms. An approximate twofold axis passes through C(5) and the midpoint of the C(8)—C(9) bond while an approximate mirror plane passes through C(8) and the midpoint of the C(1)—C(5) bond. The half-chair conformation, with the approximate twofold axis passing through C(5), seems particularly favourable for guaian-6,12-olides having one five-membered ring cis-fused and the other trans-fused to a cyclo-heptane ring (Hendrickson, 1963), and is observed in several such species e.g. 3-oxograndolide (Rych-lewska, 1985), solstitialin (Thiessen & Hope, 1970), bromodihydroisophotosantonic lactone acetate (Asher & Sim, 1965) and grosshemin (U. Rychlewska, unpublished observations). Partial con-tribution of the C_s form in the cycloheptane ring of 8-epiisolipidiol is a result of cis-fusion of the five-membered ring at a dihedral angle of 21·6 (4)°, which is significantly smaller than the calculated preferred value of 41° (Hendrickson, 1963).

The cyclopentane ring exhibits a C(4) β-envelope conformation, with some signs of disorder in the C(2), C(3), O(3) region. The average magnitude of the five endocyclic torsion angles is 25·8 (13·3)°.

The γ-lactone is less puckered. The average torsion-angle magnitude is 14·2 (6·9)° and the ring

approximates a 7α-envelope conformation, a confor-mation common among saturated γ-lactones.

Most of the bond lengths and angles are within normal ranges. The longest C—C bond appears at the carbocyclic ring junction, while the shortest con-nects the C(2) and C(3) ring atoms whose tempera-ture factors show unusually large values. Two C_{sp^3}—O distances associated with two hydroxyl groups at C(3) and C(8) do not differ significantly [1·419 (6) and 1·428 (6) Å, respectively] despite the different involvement of these two groups in hydro-gen bonding.

Fig. 2 illustrates the molecular packing as viewed down the x axis. Hydrogen-bonded molecules form layers perpendicular to the x axis. The hydroxyl group at C(8) acts as a proton donor to the screw-axis-related (y direction) lactone O atom C(12), and as an acceptor of protons in a hydrogen bond with a screw-axis-related (z direction) C(3) hydroxy O atom. The C(3)—H(O3), C(3)···O(8^i) and H(O3)···O(8^i) distances are 0·99 (5), 2·957 (5) and 2·11 (5) Å, respectively, while the O(3)—H(O3) ···O(8^i) angle is 143 (3)°. The C(8)—H(O8), C(8)···O(12^{ii}) and H(O8)···O(12^{ii}) distances are 0·88 (5), 2·734 (4) and 1·89 (5) Å, respectively, while the O(8)—H(O8)···O(12^{ii}) angle is 159 (3)° [symmetry code: (i) $-\frac{3}{2} - x, -y, z - \frac{1}{2}$; (ii) $-1 - x$, $\frac{1}{2} + y, -\frac{1}{2} - z$].

Fig. 1. View of the β-face of the molecule of 8-epiisolipidiol and atom-numbering scheme. Thermal ellipsoids are drawn at the 40% probability level. H atoms are represented by spheres of arbitrary size.

Fig. 2. Packing diagram viewed along x. Hydrogen bonds are indicated by dashed lines. The smallest circles represent the hydroxyl H atoms.

References

ASHER, J. D. M. & SIM, G. A. (1965). J. Chem. Soc. pp. 1584–1594.

BARBETTI, P., CASINOVI, C. G., SANTURBANO, B. & LONGO, R. (1979). Collect. Czech. Chem. Commun. 44, 3123–3127.

BOHLMANN, F. & GUPTA, R. K. (1982). Phytochemistry, 21, 1799–1800.

FISHER, N. H., OLIVIER, E. J. & FISHER H. D. (1979). In Progress in the Chemistry of Organic Natural Products, Vol. 38, edited by W. H. HERZ, H. GRIESEBACH & G. W. KIRBY. New York: Springer Verlag.

GONZALEZ, A. G., GARCIA MARRERO, B. & BRETON I. L. (1970). An. Quim. 66, 799–811.

HENDRICKSON, J. B. (1963). Tetrahedron, 19, 1387–1396.

JASKÓLSKI M. (1982). Collected Abstracts, Symposium on Organic Crystal Chemistry, edited by Z. KAŁUSKI, p. 70. A. Mickiewicz Univ., Poznań, Poland.

JOHNSON, C. K. (1965). ORTEP. Report ORNL-3794. Oak Ridge National Laboratory, Tennessee, USA.

KISIEL, W. (1983a). Pol. J. Chem. 57, 139–145.

KISIEL, W. (1983b). Planta Med. 49, 246–247.

KISIEL, W. (1984). Phytochemistry, 23, 1955–1958.

LEHMANN, M. S. & LARSEN, F. K. (1974). Acta Cryst. A30, 580–584.

MAIN, P., FISKE, S. J., HULL, S. E., LESSINGER, L., GERMAIN, G., DECLERCQ, J.-P. & WOOLFSON, M. M. (1980). MULTAN80. A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data. Univs. of York, England, and Louvain, Belgium.
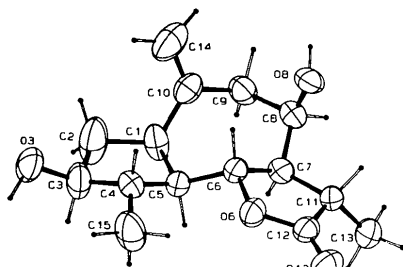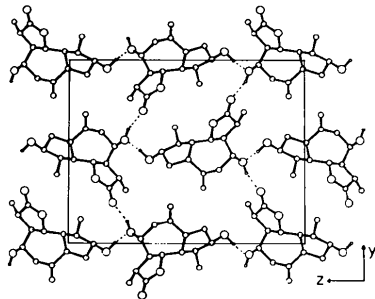
MASSANET, G. M., COLLADO, I. G., MACIAS, F. A., LUIS F. R. & VERGARA, C. (1984). *Phytochemistry*, **23**, 912–913.

MIYASE, T., YAMADA, M. & FUKUSHIMA, S. (1987). *Chem. Pharm. Bull.* **35**, 1969–1974.

MOTHERWELL, W. D. S. & CLEGG, W. (1978). *PLUTO*. Program for plotting molecular and crystal structures. Univ. of Cambridge, England.

NISHIMURA, K., MIYASE, T., UENO, A., NORO, T., KUROYANAGI, M. & FUKUSHIMA, S. (1985). *Chem. Pharm. Bull.* **33**, 3361–3368.

RYCHLEWSKA, U. (1985). *Acta Cryst.* C41, 540–542.

SHELDRICK, G. M. (1976). *SHELX76*. Program for crystal structure determination. Univ. of Cambridge, England.

THIESSEN, W. E. & HOPE, H. (1970). *Acta Cryst.* B26, 554–562.

Catemeric Hydrogen Bonding in (+)- and (±)-endo-Camphorcarboxylic Acid

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Abstract. 4,7,7-Trimethyl-3-oxobicyclo[2.2.1]heptane-2-endo-carboxylic acid (I), (+)-$C_{11}H_{16}O_3$, M_r = 196·246, monoclinic, $P2_1$, a = 10·712 (3), b = 6·724 (3), c = 7·136 (3) Å, β = 95·07 (3)°, V(234 K) = 512·0 (4) Å^3, Z = 2, D_m(295 K) = 1·25 (1), D_x[295 K; V = 515·0 (5) Å^3] = 1·266 g cm^{-3}, λ(Mo $K\alpha$) = 0·71069 Å, μ = 0·98 cm^{-1}, F(000) = 212, T = 234 (1) K, R = 0·058 for 638 observed reflections. (II), (±)-$C_{11}H_{16}O_3$, M_r = 196·246, monoclinic, $P2_1/c$, a = 10·849 (2), b = 6·751 (3), c = 14·248 (2) Å, β = 94·96 (1)°, V(252 K) = 1039·6 (5) Å^3, Z = 4, D_m(295 K) = 1·24 (1), D_x[295 K; V = 1046·0 (6) Å^3] = 1·246 g cm^{-3}, λ(Mo $K\alpha$) = 0·71069 Å, μ = 0·96 cm^{-1}, F(000) = 424, T = 252 (1) K, R = 0·065 for 1290 observed reflections. In both the (+)-enantiomer (I) and the racemate (II) the crystal is composed of single-strand helical chains parallel to the b axis, produced by infinite repetition of a hydrogen bond linking the carboxylic acid of one molecule with the ketone of an adjacent screw-related molecule, so that each hydrogen-bonding helix contains molecules of only one chirality. The packing in (II), whose c cell dimension is doubled relative to (I), corresponds to stacked pairs of ($P2_1$) cells packed as in (I), with alternating chirality in the c direction.

Introduction. Our exploration of hydrogen-bonding patterns in keto carboxylic acids (Leiserowitz, 1976; Vanderhoff, Thompson & Lalancette, 1986; Lalancette, Slifer & Thompson, 1989; Lalancette, Vanderhoff & Thompson, 1990) has led us to examine the title compounds. Our attention was drawn to these materials for several specific reasons. The geometry of β-keto acids appears attractive for internal hydrogen bonding. However, to our knowledge no evidence for this in the solid state has ever appeared. There is considerable literature treating the putative existence and importance of such hydrogen bonding in solution, in part because it has been implicated indirectly in the thermal instability of these compounds (Hay & Bond, 1967; Grande & Rosenfeld, 1980). Their thermal decarboxylation is known to proceed by way of a six-centered internal hydrogen transfer, whose obvious precursor would be the corresponding internally hydrogen-bonded structure (Logue, Pollack & Vitullo, 1975). However, evidence also exists in favor of other mechanisms (Ferris & Miller, 1963; Kayser, Brault, Pollack, Bantia & Sadoff, 1983). As a class, β-keto carboxylic acids are usually so thermally unstable that they are seldom available commercially. Not only was the title structure an exception, but both enantiomers were available, thus placing the racemate at our disposal as well. We were interested not merely in the hydrogen-bonding pattern, but in seeing whether it would be altered by the presence *versus* the absence of the second enantiomer and the change in space group required (Eliel & Kofron, 1953; Walborsky, Barash, Young & Impastato, 1961; Simpson & Marsh, 1966).

Experimental. The (+)-enantiomer [(I); Baptista (1976)] was purchased from Aldrich Chemical Co. (m.p. 393–396 K) and recrystallized from water by slow evaporation at 295 K; densities were measured by flotation in carbon tetrachloride–cyclohexane. An elongated platelet 1·40 × 0·09 × 0·20 mm was mounted on a glass fiber; attempts to cleave these crystals were unsuccessful. Data ($2\theta_{max}$ = 60°, $-15 \leq h \leq 15$,