*Tetrahedron* Vol. 42, No. 21, pp. 6003 to 6009, 1986
Printed in Great Britain.

0040-4020/86 $3.00+.00

# The Structures of Vulgarin and its Isomers —A Reinvestigation

Berhanu Abegaz,[a] Francisco Camps,[b*] José Coll,[b] Miguel Feliz,[c]
Ulla Jacobsson,[d*] Carlos Miravitlles,[e] Elias Molins,[e]
and Jordi Torramilans.[b]

[a]Department of Chemistry, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia; [b]Departamento de Química Orgánica Biológica, Centro de Investigación y Desarrollo, Jorge Girona Salgado, 18-26. 08034-Barcelona, Spain; [c]Departament de Química Orgànica, Facultat de Química (U.B.), Martí i Franquès, 1. 08028-Barcelona, Spain; [d]Department of Organic Chemistry, Royal Institute of Technology, S-100 44 Stockholm, Sweden; [e] Instituto de Gencia de Materiales (C.S.I.C.), Martí i Franquès, s/n. 08028-Barcelona, Spain.

(*Received in UK* 18 *August* 1986)

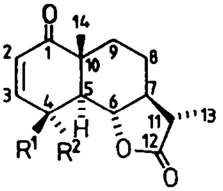
**Abstract**– The green parts of *Artemisia rehan*, Chiov (Asteraceae) were found to contain vulgarin. The $^{1}H$ and $^{13}C$ NMR spectra of vulgarin and 4-*epi*vulgarin were unambiguously assigned based on COSY and $^{1}H$–$^{13}C$ correlation experiments and an X-ray investigation settled the configuration. Furthermore, the compounds barrelin and judaicin were proved to be identical with vulgarin.

## Introduction

A compound was isolated from *Artemisia rehan*, Chiov[1] and it was believed to be identical with or closely related to vulgarin. Vulgarin (**1**) was first reported in 1961 as a constituent of some *Artemisia* species. Geissman and Ellestad[2] coined the name vulgarin after the source *Artemisia vulgaris* L., while Rybalko and Dolejš[3] investigated *Artemisia taurica* Willd. and isolated a compound which they assigned the same structure as that of vulgarin (**1**) but named it tauremisin. Those discrepancies were clarified already in the initial reports.[2,3] However, screening the literature today reveals confusing information. Thus, inconsistencies in the spectroscopic data have led to different names of the same compound. We initiated an investigation in order to clarify the situation.

## Results

The essential oil obtained by steam distillation of *Artemisia rehan*, which grows in Ethiopia, has recently been investigated.[1] In the present study the green parts of the plant were collected



1 $R^1$=Me $R^2$=OH
2 $R^1$=OH $R^2$=Me

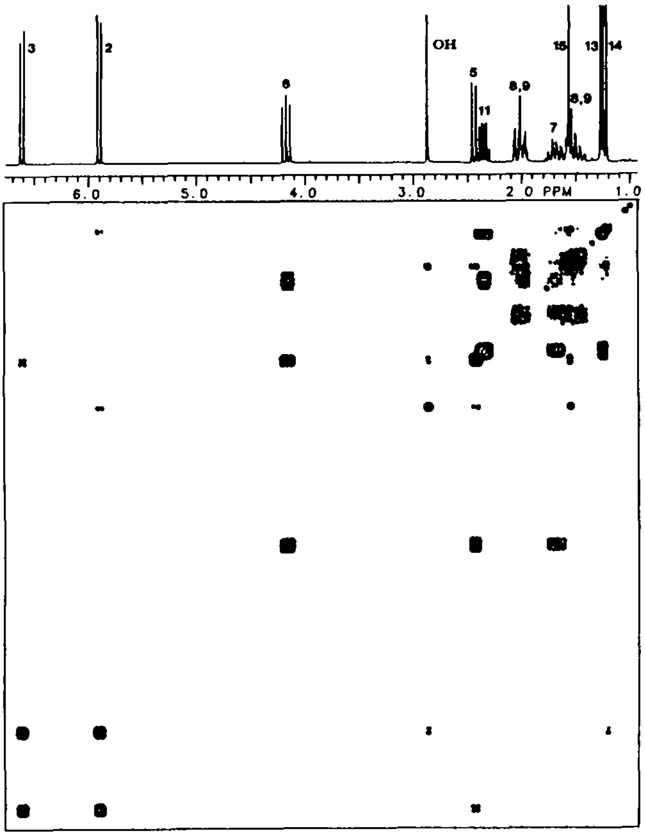


**Figure 1.** $^1$H–$^1$H COSY-90 of vulgarin (**1**).

and extracted with chloroform to give white crystals, mp 178–178.5 °C.[4] $^1$H and $^{13}$C NMR data of this compound and comparison with an authentic sample of vulgarin (**1**) showed that it was identical with vulgarin(**1**). The sample was investigated more thoroughly by two-dimensional NMR-techniques in order to assign the $^1$H and $^{13}$C NMR spectra. The $^1$H–$^1$H correlation was determined by a COSY-90 experiment[5] (see Figure 1). The assignment of the proton shifts is indicated in the one-dimensional spectrum shown along one axis. The assignments are straightforward except for the protons in the 8- and 9-positions. However, it can clearly be seen from the $^1$H–$^{13}$C COSY[6] (see Figure 2) that the two protons at each position appear at separate shifts with one pair overlapping the other. Further, axial protons are generally more shielded than equatorial.[7] The $^1$H and $^{13}$C shift assignments, which are based on these two COSY experiments, are reported in Table 1.

A sample of 4-*epi*vulgarin (**2**)[8] has also been investigated, and the results are shown in Table 1 and Figure 2. The $^1$H–$^{13}$C shift correlation map shown in Figure 2 clearly shows the influence of 15-Me being in the α- or β-position. Since the two diastereomers **1** and **2** were available, we investigated the configuration at C-4 by both steady state and transient nuclear Overhauser effect (NOE) measurements.[9,10] NOE's were observed between 14-Me, 15-Me and

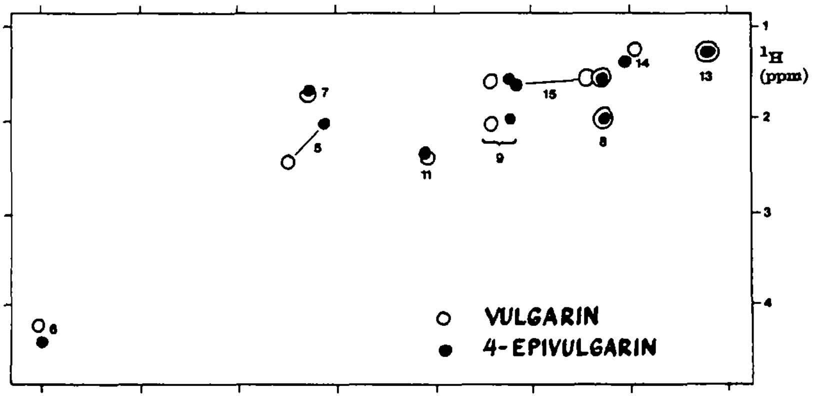


**Figure 2.** Map of the $^1$H–$^{13}$C COSY data of vulgarin (**1**) and 4-*epi*vulgarin (**2**).

H-6 in vulgarin and only between 14-Me and H-6 in 4-*epi*vulgarin (see Figure 3). These results confirm that the 15-Me group is situated $\beta$ in vulgarin and $\alpha$ in 4-*epi*vulgarin.

Due to some discrepancies in the literature concerning the spectroscopic data, vulgarin seems to have appeared under a series of different names. Thus, samples of vulgarin (*A. rehan*, Chiov,[1] *A. canariensis*, Lees[11]), barrelin (*A. barrelieri*, Besser),[12] judaicin (*A. judaica* L)[13] and tauremisin (*A. taurica*, Willd)[3] were investigated by $^1$H NMR. The samples were shown to be identical when $^1$H NMR spectra were run in the two complementary solvents chloroform-$d_1$ and benzene-$d_6$.

**Table 1.** $^1$H and $^{13}$C NMR data (ppm) of the compounds **1** and **2** in chloroform-*d*. Multiplicities are given within parentheses and coupling constants in Hz.[a]

| | $^1$H NMR | | $^{13}$C NMR | |
|---|---|---|---|---|
| | **1** | **2** | **1** | **2** |
| 1 | | | 201.6 | 203.1 |
| 2 | 5.91(d), $J = 10.6$ | 5.90(d), $J = 10.1$ | 125.7 | 125.3 |
| 3 | 6.62(d), $J = 10.6$ | 6.51(d), $J = 10.1$ | 151.6 | 150.2 |
| 4 | | | 70.1 | 68.2 |
| 5 | 2.45(d), $J = 11.4$ | 2.03(d), $J = 11.0$ | 54.6 | 51.0 |
| 6 | 4.18(dd), $J = 11.6, 10.3$ | 4.35(t), $J = 10.5$ | 79.6 | 79.2 |
| 7 | 1.70(m) | 1.62–1.76(m) | 52.4 | 52.3 |
| 8 | *eq* ($\alpha$) 2.0(m)<br>*ax* ($\beta$) 1.49(m) | *eq* ($\alpha$) 1.98(m)<br>*ax* ($\beta$) 1.50–1.57(m) | 22.7 | 22.8 |
| 9 | *eq* ($\beta$) 2.04(ddd), $J = 12.3, 2.9$<br>*ax* ($\alpha$) 1.57(m) | *eq* ($\beta$) 1.98(m)<br>*ax* ($\alpha$) 1.50–1.57(m) | 34.2 | 32.5 |
| 10 | | | 46.2 | 45.9 |
| 11 | 2.37(dq), $J = 12.5, 6.8$ | 2.34(dq), $J = 12.3, 6.6$ | 40.6 | 40.8 |
| 12 | | | 178.2 | 179.0 |
| 13 | 1.27(d), $J = 6.6$ | 1.26(d), $J = 6.59$ | 12.5 | 12.5 |
| 14 | 1.23(s) | 1.33(s) | 19.8 | 20.6 |
| 15 | 1.57(s) | 1.61(s) | 23.8 | 31.7 |
| OH | 2.88(s) | 1.67(s) | | |

[a] The assignments are based on $^1$H–$^1$H and $^1$H–$^{13}$C COSY experiments.

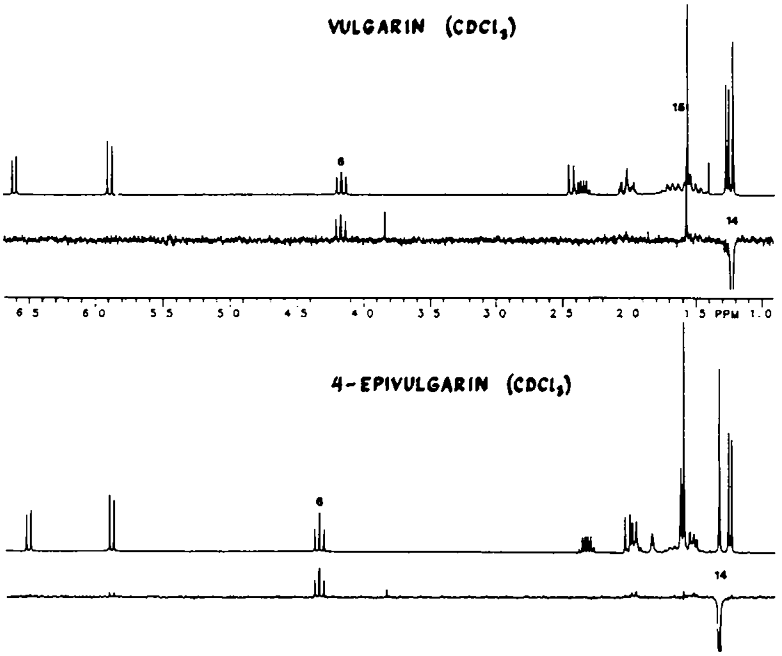


**Figure 3.** Transient NOE difference spectra (lower trace) of vulgarin and 4-*epi*vulgarin. A 320 ms selective 180° Gaussian pulse has been applied on the 14-Me protons followed by a composite 90° observe pulse after a delay of 700 ms.

An X-ray study was also carried out on a sample of vulgarin from *Artemisia canariensis* Lees. The structure† was solved by direct methods (MULTAN 11/82)[14] and refined by full-matrix least squares methods using the SHELX-76[15] program to a final R value of 0.066.

A summary of data collection parameters, atomic coordinates, temperature factors, bond distances, bond angles and selected torsion angles are given in Tables 2–7. The mean distances of the bonds (C-C: 1.517(32); C-O: 1.416(53); and C=O: 1.226(10) Å) are within the accepted values.

Ring A shows a flattened boat conformation, where C(1) to C(4) and C(10) define a pseudoplanar region (equation of the mean plane: $0.2111x+0.6640y-0.7173z=-7.2527$; r.m.s.d.: 0.048) and C(5) is puckered 0.57(1) Å below it. On the other hand, ring B shows a regular chair conformation, whereas the $\gamma$-lactone ring adopts an envelope conformation.

The coordinates of the hydrogen atoms located in the difference Fourier synthesis confirm the expected relative positions deduced from the molecule conformation and agree with the reported configuration.[16]

The overall shape of the skeleton can be described by the torsion angles around the ring junction bonds, namely C(1)–C(10)–C(5)–C(6) (178.3°) and C(9)–C(10)–C(5)–C(4) (171.8°) for the two cyclohexane rings, and C(5)–C(6)–C(7)–C(11) (−165.9°) and O(6)–C(6)–C(7)–C(8) (−171.2°) for the $\gamma$-lactone to ring B junction.

The shortest intermolecular contacts are C(10)...O(1)$^{i}$ = 3.273(8) Å ($i = .5+x, .5-y, 1.-z$), C(15)...O(12)$^{ii}$= 3.222(8) Å and O(4)...O(12)$^{ii}$ = 2.930(8) Å ($ii = 2.-x, .5+y, 1.5-z$).

Table 2. Crystal data and summary of data collection.

$C_{15}H_{20}O_4$, Mr=264
Crystal dimensions: 0.20 x 0.20 x 0.30 mm
Orthorhombic, $P2_12_12_1$
Z = 4
a = 7.625(7) Å
b = 9.017(4) Å
c = 19.645(7) Å
v = 1350.7 Å$^3$
$D_x$ = 1.388 g cm$^{-3}$
$\mu$ = 0.966 cm$^{-1}$

$MoK_\alpha$ ($\lambda$ =0.71069 Å)
T = 298 K
Scan width 1.0 + 0.35 tanΘ
Standard reflection (113)
Decay of standard 0.9 %
Reflections measured 2605 ($2\theta$ range 2–50°)
Independent reflections 1389
Observed reflections 1067 with $I > 2\sigma(I)$
hkl range: -9<h<9, 0<k<10, 0<l<23

Table 3. Fractional atomic coordinates with anisotropic thermal parameters (x $10^4$) and their standard deviations for non-hydrogen atoms.

| | X | Y | Z | $B_{eq}$ | $U_{11}$ | $U_{22}$ | $U_{33}$ | $U_{23}$ | $U_{13}$ | $U_{12}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 2545(8) | 1131(8) | 5953(3) | 3.61 | 323(30) | 560(36) | 491(29) | 175(28) | -26(26) | -57(29) |
| C2 | 2306(8) | 2365(8) | 6412(3) | 4.24 | 250(31) | 682(43) | 681(35) | 122(34) | -22(27) | 3(32) |
| C3 | 3603(9) | 2955(8) | 6779(3) | 3.98 | 369(33) | 610(39) | 533(31) | 47(31) | 20(26) | 48(30) |
| C4 | 5461(7) | 2338(7) | 6796(3) | 2.96 | 160(22) | 526(31) | 441(25) | -24(26) | 32(21) | -34(25) |
| C5 | 5487(6) | 781(6) | 6507(3) | 2.55 | 124(21) | 466(29) | 380(23) | 35(22) | 1(21) | -36(22) |
| C6 | 7257(7) | 117(7) | 6359(3) | 2.84 | 229(26) | 480(30) | 370(25) | 11(23) | -30(21) | -29(23) |
| C7 | 7175(7) | -1510(6) | 6224(3) | 2.81 | 222(26) | 391(26) | 455(26) | -25(25) | -8(22) | -48(23) |
| C8 | 6125(9) | -1839(8) | 5590(3) | 3.81 | 402(33) | 586(39) | 460(31) | -113(29) | -51(27) | -66(30) |
| C9 | 4321(8) | -1121(7) | 5670(3) | 3.60 | 315(27) | 544(34) | 508(30) | -50(29) | -75(26) | -97(27) |
| C10 | 4388(6) | 530(7) | 5840(3) | 3.07 | 99(22) | 643(38) | 426(27) | 21(27) | -73(21) | -113(25) |
| C11 | 9153(7) | -1933(7) | 6281(3) | 2.90 | 142(24) | 452(30) | 506(28) | 19(24) | 42(22) | -14(20) |
| C12 | 9670(7) | -915(7) | 6837(3) | 3.26 | 219(25) | 492(31) | 528(30) | 6(27) | -76(24) | 48(25) |
| C13 | 9582(11) | -3517(9) | 6421(4) | 4.43 | 390(37) | 608(43) | 687(42) | -11(37) | -98(35) | 6(34) |
| C14 | 5019(8) | 1412(9) | 5210(3) | 4.04 | 373(33) | 793(49) | 370(29) | 74(32) | -54(24) | -83(31) |
| C15 | 6692(9) | 3470(8) | 6457(4) | 3.78 | 328(33) | 430(34) | 681(39) | -23(32) | 63(31) | -160(27) |
| O1 | 1301(5) | 636(6) | 5622(3) | 4.28 | 245(19) | 606(27) | 775(28) | 139(23) | -191(19) | -133(20) |
| O4 | 5882(6) | 2288(5) | 7499(2) | 3.91 | 385(22) | 633(27) | 469(20) | -51(24) | -4(18) | -3(24) |
| O6 | 8534(5) | 238(5) | 6915(2) | 3.04 | 212(18) | 471(21) | 471(21) | -50(18) | -99(16) | -27(16) |
| O12 | 10957(6) | -980(5) | 7204(2) | 4.50 | 381(24) | 613(28) | 716(27) | -56(23) | -211(21) | 76(21) |

## Discussion

The NMR and X-ray data presented in this paper conclusively settle the configuration of vulgarin (**1**), which is in accordance with earlier reported results.[2,3] Thus, the 14- and 15-methyl groups are situated in $\beta$-positions while the 11-methyl group is situated in an $\alpha$-position.

Furthermore, barrelin, judaicin and tauremisin were shown to be identical with vulgarin since their $^1H$ nmr spectra in chloroform-*d* and benzene-$d_6$, respectively, were superimposable. The compounds were isolated from different *Artemisia* species. Ohno *et al.*[17] reported the $^{13}C$ shift $\delta$ 22.7 for the 15-Me of vulgarin isolated from *A. ludoviciana*. Since all the other $^{13}C$ shifts are identical with those of vulgarin, the reported value is in error or the shifts represent another compound.

---

† Calculated and observed structure factors are deposited with the Cambridge Crystallographic Data Centre, Lensfield Road, Cambridge CB2 1EW, U.K.

**Table 4.** Fractional atomic coordinates ($\times 10^3$) with their standard deviations with the equivalent temperature factors for hydrogen atoms.

| | X(a) | Y(b) | Z(c) | |
|---|---|---|---|---|
| H2 | 1240(107) | 2796(79) | 6344(32) | 3.96 |
| H3 | 3385(100) | 3829(82) | 7176(31) | 3.96 |
| H4 | 5913(116) | 1717(84) | 7593(42) | 3.96 |
| H5 | 4820(98) | 381(79) | 6860(35) | 3.96 |
| H6 | 7915(96) | 545(77) | 5948(34) | 3.96 |
| H7 | 3355(108) | 3049(83) | 8406(36) | 3.96 |
| H11 | 9780(103) | -1659(77) | 5887(34) | 3.96 |
| H81 | 6052(97) | -2948(84) | 5484(31) | 3.96 |
| H82 | 6621(107) | -1441(80) | 5245(38) | 3.96 |
| H91 | 3718(103) | -1439(81) | 5240(34) | 3.96 |
| H92 | 3692(107) | -1520(82) | 6024(34) | 3.96 |
| H131 | 9203(101) | -3812(79) | 6853(37) | 3.79 |
| H132 | 10617(114) | -3630(80) | 6506(31) | 3.79 |
| H133 | 9326(102) | -4047(83) | 6029(33) | 3.79 |
| H141 | 4788(93) | 2704(77) | 5222(32) | 3.79 |
| H142 | 4541(103) | 1213(75) | 4810(33) | 3.79 |
| H143 | 6518(104) | 1046(76) | 5110(32) | 3.79 |
| H151 | 6483(99) | 4405(78) | 6659(34) | 3.79 |
| H152 | 6470(100) | 3574(81) | 5977(33) | 3.79 |
| H153 | 7959(108) | 3152(81) | 6460(34) | 3.79 |

**Table 5.** Non-hydrogen bond distances (in Å) with their standard deviations.

| | | |
|---|---|---|
| C1 | –C10 | 1.523(8) |
| C5 | –C10 | 1.572(7) |
| C9 | –C10 | 1.526(9) |
| C14 | –C10 | 1.548(8) |
| C2 | –C1 | 1.444(10) |
| O1 | –C1 | 1.233(7) |
| C3 | –C2 | 1.334(10) |
| C4 | –C3 | 1.523(8) |
| C5 | –C4 | 1.514(8) |
| C15 | –C4 | 1.539(8) |
| O4 | –C4 | 1.418(7) |
| C6 | –C5 | 1.505(7) |
| C7 | –C6 | 1.492(8) |
| O6 | –C6 | 1.468(6) |
| C8 | –C7 | 1.511(8) |
| C11 | –C7 | 1.560(7) |
| C9 | –C8 | 1.529(9) |
| C12 | –C11 | 1.480(9) |
| C13 | –C11 | 1.490(10) |
| O6 | –C12 | 1.362(7) |
| O12 | –C12 | 1.219(7) |

The 4-*epi*vulgarin showed very similar $^1H$ and $^{13}C$ NMR data compared with those of vulgarin except for the methyl group in the 15-position. The large downfield shift of the 15-methyl group in the $^{13}C$ NMR spectrum (*cf.* Table 1), when compared with vulgarin, is consistent with a methyl group in the $\alpha$-position. The NOE measurements (*cf.* Figure 3) unambiguously settle the $\beta/\alpha$-relationships of the 15-methyl group of vulgarin (1) and 4-*epi*vulgarin (2), respectively.

The shift data presented in Table 1 are unequivocally assigned based on $^1H$–$^1H$ and $^1H$–$^{13}C$ COSY experiments. Thus, a few NMR assignments of 1 and 2 reported by Metwally *et al.*[18] must be corrected. The shifts for the protons H-8$\beta$ and H-9$\alpha$ of 1 have been revised and the shift of the 13-Me in 2 should be $\delta$ 1.26 and not $\delta$ 1.58. Furthermore, the C-11 shift of 2 is reported to be at $\delta$ 40.1 while it should be at $\delta$ 40.8.

## Experimental

NMR. The NMR-spectra were measured on Bruker WP200 and Varian XL200 and XL300 spectrometers. Unless otherwise stated the $^1H$ and $^{13}C$ NMR-spectra were recorded in deuteriochloroform with tetramethylsilane as an internal standard. COSY 90: 16 transients of 512 complex points each were measured for each of 512 $t_1$ increments. Spectral widths were 1200 Hz in both dimensions. $^1H$–$^{13}C$ COSY: The employed pulse sequence was reported elsewhere.[6] The delays $\Delta_1$ and $\Delta_2$ were set to 3.5 and 2 ms, respectively. 1024 transients of 1024 complex points each were measured for each of 64 $t_1$ increments. Spectral widths were 5630 Hz in the $f_2$ and 1200 Hz in the $f_1$ dimension. NOE: The samples for the NOE-measurements were treated several times by the freeze-pump-thaw cycle before vacuum-sealing the tubes. The NOE difference technique was used as described by Hall *et al.*,[9] and the spectra were recorded with the decoupler turned off during pulse and acquisition preceded by 5 s of irradiation.

Table 6. Non-hydrogen bond angles (in degrees) with their standard deviations.

| | | | |
|---|---|---|---|
| C5 | –C10 | –C1 | 108.7(5) |
| C9 | –C10 | –C1 | 110.4(5) |
| C9 | –C10 | –C5 | 109.9(5) |
| C14 | –C10 | –C1 | 102.7(5) |
| C14 | –C10 | –C5 | 115.3(4) |
| C14 | –C10 | –C9 | 109.7(5) |
| C2 | –C1 | –C10 | 118.8(5) |
| O1 | –C1 | –C10 | 120.3(6) |
| O1 | –C1 | –C2 | 120.7(6) |
| C3 | –C2 | –C1 | 123.4(6) |
| C4 | –C3 | –C2 | 123.8(7) |
| C5 | –C4 | –C3 | 110.1(5) |
| C15 | –C4 | –C3 | 108.4(5) |
| C15 | –C4 | –C5 | 116.4(5) |
| O4 | –C4 | –C3 | 104.2(5) |
| O4 | –C4 | –C5 | 109.4(5) |
| O4 | –C4 | –C15 | 107.7(5) |
| C4 | –C5 | –C10 | 116.0(5) |
| C6 | –C5 | –C10 | 105.0(4) |
| C6 | –C5 | –C4 | 117.0(4) |
| C7 | –C6 | –C5 | 112.8(5) |
| O6 | –C6 | –C5 | 114.9(4) |
| O6 | –C6 | –C7 | 103.5(4) |
| C8 | –C7 | –C6 | 111.2(5) |
| C11 | –C7 | –C6 | 100.8(5) |
| C11 | –C7 | –C8 | 121.6(5) |
| C9 | –C8 | –C7 | 108.0(5) |
| C8 | –C9 | –C1 | 113.9(5) |
| C12 | –C11 | –C7 | 99.1(5) |
| C13 | –C11 | –C7 | 117.4(5) |
| C13 | –C11 | –C12 | 113.6(5) |
| O6 | –C12 | –C11 | 112.8(4) |
| O12 | –C12 | –C11 | 128.3(6) |
| O12 | –C12 | –O6 | 118.8(5) |
| C12 | –O6 | –C6 | 106.3(4) |

Table 7. Selected torsion angles (in degrees).

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| C10 | C1 | C2 | C3 | -4.28 | C3 | C4 | C5 | C10 | 43.47 |
| C1 | C2 | C3 | C4 | -4.41 | O6 | C6 | C7 | C11 | -41.00 |
| C2 | C3 | C4 | C5 | -15.37 | C6 | C7 | C11 | C12 | 36.23 |
| C1 | C10 | C5 | C4 | -50.89 | C7 | C11 | C12 | O6 | -20.01 |
| C5 | C10 | C9 | C8 | -56.78 | C7 | C6 | O6 | C12 | 29.81 |
| C9 | C10 | C5 | C6 | 57.43 | C11 | C12 | O6 | C6 | -5.23 |
| C5 | C10 | C1 | C2 | 30.06 | C1 | C10 | C5 | C6 | 178.30 |
| C10 | C5 | C6 | C7 | -62.34 | C9 | C10 | C5 | C4 | -171.76 |
| C5 | C6 | C7 | C8 | 63.88 | C5 | C6 | C7 | C11 | -165.88 |
| C6 | C7 | C8 | C9 | -54.98 | O6 | C6 | C7 | C8 | -171.25 |
| C7 | C8 | C9 | C10 | 53.68 | | | | | |

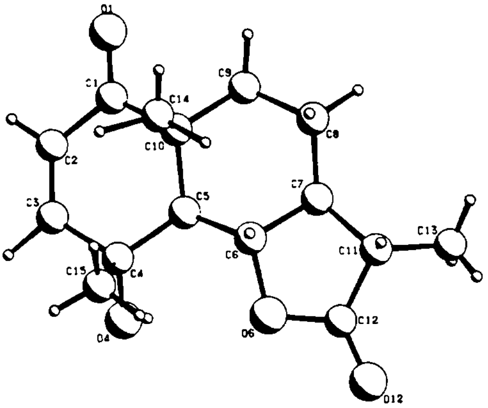


Figure 4. Perspective view of vulgarin (1).

**X-ray.** Cell parameters and intensities were measured on an Enraf-Nonius CAD 4 diffractometer using a crystal of 0.20 x 0.20 x 0.30 mm. The unit cell was measured by centering automatically 25 high angle independent reflections and refining the orientation matrix and unit cell parameters by least-squares. The intensities were corrected for Lorentz and polarization but not for absorption. The last cycle of anisotropic refinement for non-hydrogen atoms with all independent observed reflections converged to the final $R = 0.066$ and $Rw = 0.069$ with $Rw = [\sum w(\Delta F)^2/\sum wF_0^2]^{1/2}$ where $w = 2.1765/[\sigma^2(F_0) + 0.003566(F_0^2)]$. The scattering factors were taken from International Tables for X-ray Crystallography.[19] The molecular structure as depicted in Figure 4 was obtained with the PLUTO drawing program.[20]

## Acknowledgements

The authors thank Dr. B.M. Fraga (vulgarin), Dr. M. Nicoletti (barrelin), Dr. S.M. Khafagy (judaicin), Dr. G. Snatzke (tauremisin, a sample which originates from a Czech research group[3]) and Dr. M. Ando (synthetic vulgarin and 4-*epi*vulgarin) for kindly supplying us the samples as indicated. The authors are particularly indepted to Dr. T. Nishida, Swedish Tobacco Company, for fruitful discussions and for measurements of the 2D and transient NOE spectra (Varian XL300). One of us (B. A.) acknowledges the "Swedish Agency for Research Cooperation with Developing Countries" (SAREC) for financial assistance.

## References

1. Abegaz, B. and Yohannes, P.G. (1982) *Phytochemistry* **21**, 1791.
2. Geissman, T.A. and Ellestad, G.A. (1962) *J. Org. Chem.* **27**, 1855.
3. Rybalko, K.S. and Dolejš, L. (1961) *Coll. Czech. Chem. Commun.* **26**, 2909.
4. Abegaz, B., unpublished results.
5. Nagayama, K., Kumar, A., Wüthrich, K. and Ernst, R.R. (1980) *J. Magn. Res.* **40**, 321; Bax, A. and Freeman, R. (1981) *J. Magn. Res.* **44**, 542.
6. Bax, A. and Morris, G.A. (1981) *J. Magn. Res.* **42**, 501.
7. Kagan, H.B. (Ed.) "Stereochemistry, Spectrometric Methods," (1977); Vol 1, p. 99.
8. Ando, M., Akahane, A. and Takase, K. (1978) *Bull. Chem. Soc. Japan* **51**, 283; Ando, M., Tajima, K. and Takase, K. (1979) *Bull. Chem. Soc. Japan* **52**, 2737.

9. Hall, L.D. and Sanders, J.K.M. (1980) *J. Am. Chem. Soc.* **102**, 5703.

10. Bauer, C., Freeman, R., Frenkiel, T., Keeler, J. and Shaka, A.J. (1984) *J. Magn. Res.* **58**, 442; Shaka, A.J., Bauer, C. and Freeman, R. (1984) *J. Magn. Res.* **60**, 479.

11. Breton, J.L., Camps, F., Coll, J., Eguren, L., Gavin, J.A., González, A.G., Martorell, X., Miravitlles, C., Molins, E. and Torramilans, J. (1985) *Tetrahedron* **41**, 3141.

12. Villar, A., Zafra-Polo, M.C., Nicoletti, M. and Galeffi, C. (1983) *Phytochemistry* **22**, 777.

13. Khafagy, S.M. and Tosson, S. (1968) *Planta med.* **16**, 446.

14. Main, P., Fiske, S.J., Hull, S.F., Lessinger, L., Germain, G., Declercq, J.P. and Woolfson, M.M. "Multan 11/82. A System of Computer Programs for the Automatic Solution of Crystal Structures from X-ray Diffraction Data," (1982); Universities of York (U.K.) and Louvain (Belgium).

15. Sheldrick, G.M. "SHELX. Program of Crystal Structure Determination," (1976); University of Cambridge (U.K.).

16. Klyne, W. and Buckingham, J. "Atlas of Stereochemistry," (1978); Chapman and Hall (London). Vol. 1, p. 96.

17. Ohno, N., Gershenzon, J., Roane, C. and Mabry, T.J. (1980) *Phytochemistry* **19**, 103.

18. Metwally, M.A., Jakupovic, J., Youns, M.I. and Bohlmann, F. (1985) *Phytochemistry* **24**, 1103.

19. International Tables for X-ray Crystallography, Vol. IV (1974); Kynoch Press (Birmingham).

20. Motherwell, W.D.S. and Clegg, W. "Pluto 78. Program for Crystal Structure Representation," (1978); University of Cambridge (U.K.).