8. B. G. Savinov, Carotene [in Russian], Kiev (1948), p. 151.
9. P. Karrer, Organische Chemie, 13th ed., G. Thieme, Stuttgart (1959).
10. É. I. Gigienova, N. T. Ul'chenko, and A. U. Umarov, Maslob.-Zhir. Prom., No. 11, 12 (1976).
11. Handbook on Methods of Investigation, Technical and Chemical Control, and the Accounting of Production in the Oils and Fats Industry [in Russian], Vol. 1, Book 1, Leningrad (1967), p. 890.
12. V. A. Devyatnin, Methods of Chemical Analysis in the Production of Vitamins [in Russian], Moscow (1964).
13. A. N. Umanskaya, N. N. Safronova, N. K. Nadirov, R. Kh. Khafizov, and R. F. Sakaeva, Prikl. Biokhim. Mikrobiol., 9, 468 (1973).

THE STRUCTURE OF FETERIN — A NEW TERPENOID COUMARIN FROM *Ferula teterrima*

M. E. Perel'son, A. I. Sokolova,
and Yu. E. Sklyar

UDC 547.9:582.89

The isolation from the roots of *Ferula teterrima* Kar. et Kir. (Umbelliferae) of four terpenoid coumarins — badrakemin acetate, samarcandin acetate, badrakemone, and badrakemin — has been reported by us previously [1]. On further study of the plant, we have isolated a new terpenoid coumarin which we have called feterin, with the composition $C_{26}H_{32}O_6$, mp 155-158°C, $[\alpha]_D^{20}$ −52° (c 1.02; $CHCl_3$), M^+ 440.

Feterin has a UV spectrum that is characteristic for umbelliferone derivatives [2]. In the IR spectrum (Fig. 1) there is a broad carbonyl band (1710-1720 cm^{-1}) showing the presence of an ester grouping, and the band of an OH group (3545 cm^{-1}). The hydroxy group in feterin is secondary, as is confirmed by its capacity for being acetylated under mild conditions, and also by the PMR spectrum (Fig. 2). From the empirical formula of feterin and the presence of one double bond in the terpenoid part (PMR spectrum) it follows that its sesquiterpene fragment has a bicyclic structure. The PMR spectrum of feterin is similar to that of badrakemin, which shows that their structures are similar, but from the multiplicity of the signal of the proton geminal to the hydroxy group it follows that, in contrast to badrakemin, it is equatorial. As also in the spectrum of badrakemin, there are the signals of three methyl groups attached to quarternary carbon atoms, and of $>C=CH_2$ and $>CH-CH_2-OAr$ groups. Feterin also differs from badrakemin by the fact that it contains an acetoxy group, as is shown by the corresponding signals of a methyl group and of a proton geminal to an acetoxy group (one-proton sextet with its center at 5.18 ppm).

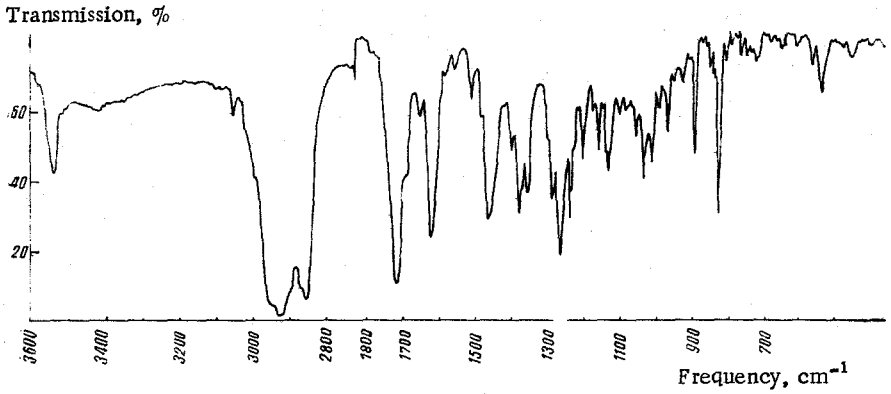

Fig. 1. IR spectrum of feterin (mull in paraffin oil).

All-Union Scientific-Research Institute of Medicinal Plants, Moscow. Translated from Khimiya Prirodnykh Soedinenii, No. 3, pp. 318-322, May-June, 1978. Original article submitted December 16, 1977.

0009-3130/78/1403-0263$07.50

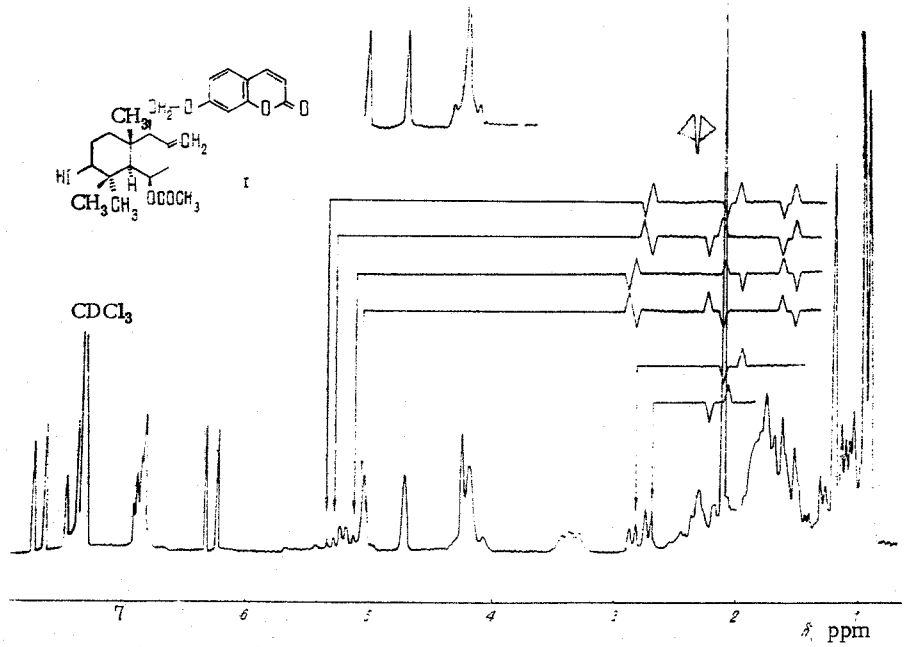

Fig. 2. PMR spectrum of feterin in $CDCl_3$. At the top — fragment of the INDOR spectrum on the components of the sextet at 5.18 ppm and of the quartet at 2.7 ppm, and also a fragment of the double resonance spectrum with ν_2 = 229 Hz (2.99 ppm).

The nature of the splitting and the value of the coupling constants of the signal show the following:

a) There are three protons — two methylenic and one methinic — in the α positions to the acetoxy group.

b) The proton geminal to the acetoxy group is axial, and the group itself is equatorial.

c) The methine proton in the α position is also axial.

The parameters of the spectra of the methylene and methine protons were determined from the INDOR spectra on the components of the sextet; the same method showed the existence of spin—spin couplingwith the protons of the methylene group (see Fig. 2). The chemical shift of the methine proton (1.56 ppm) shows that it is attached to a saturated tertiary carbon atom having no electronegative substituents. At the same time, the values of the chemical shifts of the protons of the methylene group (2.18 and 2.77 ppm) and of the geminal coupling constant (13.5 Hz) show the presence of a double bond in the α position for the acetoxy group is 4'.

The structure of ring A was also confirmed by double-resonance spectra. Irradiation of the sample with a second radiofrequency field at the resonance frequency of the protons of the 1'-CH_2 group (δ 4.20 ppm) led to a change in the spectrum in the 2.29 ppm region, which shows the presance of the signal from the proton at C_1' in this region.

Irradiation of this proton with a second radiofrequency field led, in the first place, to a fusion of the lines of the multiplet from 1'-CH_2 and, in the second place, to a decrease in the width and an increase in the peak intensity of the signals from the 2'=CH_2 group (4.69 and 5.02 ppm) (see Fig. 2).

The latter shows the presence of long-range spin—spin coupling between the C_1' proton and the protons of a exocyclic methylene group, which fully agrees with the formula suggested for feterin.

The correctness of this formula was finally confirmed by a study of the PMR spectra of feterin with additions of europium tris(dipivaloylmethanate) as shift reagent. The results obtained also permitted the configuration at C_1' to be established. The principles of the method of shift reagents have been given in several reviews [3, 4] and its use for the study of the structure and stereochemistry of terpenoid coumarins has been discussed in a number of our preceding papers [5-8].

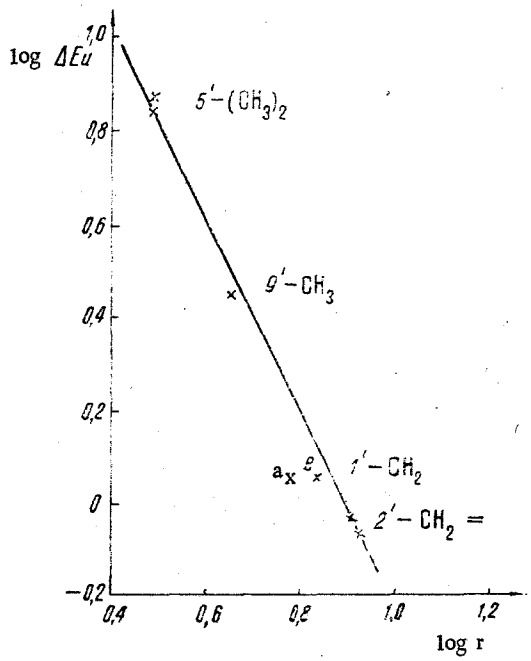

Fig. 3. Logarithmic dependence of ΔEu on r for a series of feterin protons. "a" and "e" are points corresponding to the axial and equatorial orientations of the 1'-CH_2 group.

Figure 3 shows a graph of the logarithmic dependence of the magnitude of the reduced shift (ΔEu) on the distance of the corresponding protons to the oxygen atom of the hydroxy group,* which is the most active coordination center for the given molecule [9]. It can be seen in Fig. 3 that the points corresponding to the protons of the methyl groups at C_5' and C_9', and also to the protons of the exocyclic methylene group are located on a straight line. This is evidence of the fact that the model used for determining the distances does actually represent the feterin molecule.

The tangent of the angle of slope of the straight line obtained by treating the experimental values by the method of least squares is −2.08, which coincides with the values of this magnitude for other terpenoid coumarins [8].

Two points have been plotted on the graph for the 1'-CH_2 group, corresponding to its equatorial and axial orientations. The point corresponding to the equatorial variant lies closer to the straight line, which shows the equatorial orientation of the 1'-methylene group. This orientation is also indicated by the use of the rule established [8] for terpenoid coumarins containing an exocyclic methylene group in position 2'. According to this rule, where the 1'-methylene group has the equatorial orientation it gives in the PMR spectrum a two-proton multiplet, and the 2'=CH_2 group appears in the form of two broadened singlets with a distance from one to the other of 0.37 ppm. If the 1'-CH_2 group is axial, it gives two one-proton quartets, the chemical shift between which is 0.29-0.31 ppm; in this case, the signals from the 2'=CH_2 group are located at a distance of 0.1 ppm from one another. In the spectrum of feterin, the 1'-CH_2 group gives a two-proton multiplet, and the signals from the 2'=CH_2 group have a distance from one another of 0.33 ppm, which shows the equatorial orientation of the methylene group at C_1'.

Thus, the structure and relative configuration of feterin can be represented by formula (I) (see Fig. 2).

EXPERIMENTAL

The IR spectrum of feterin (mull in paraffin oil) was obtained on a UR-20 spectrophotometer, the UV spectrum in ethanol on a Hitachi EPS-3T spectrophotometer, and the PMR spectra on a Varian HA-100D (100 MHz) spectrometer in $CDCl_3$ at 20°C; 0 — TMS (internal standard).

For the measurements of the PMR spectra with additions of $Eu(DPM)_3$ (Merck product) we used a 0.010 M solution of feterin. The spectra of solutions with molar ratios of reagent

*The distances were measured on Dreiding models with an accuracy of not less than 0.1 Å; the equatorial orientation of the 6'-OH group and the trans linkage of the rings of the decalin nucleus were assumed.

to substance of, respectively, 0.11, 0.28, 0.44, and 0.61 were measured. The value of the reduced shift (ΔEu), representing $\Delta\delta = \delta Eu(DMP)_3 - \delta CDCl_3$ at a molar ratio of reagent to substance of 1, were calculated by extrapolation.

For chromatographic separation we used alumina (activity grade II). Thin-layer chromatography was performed on Silufol in the petroleum ether–ethyl acetate (1:1) system. The melting point of feterin was determined on a Kofler block. The elementary analysis corresponded to the calculated figures.

Isolation of Feterin. The dried comminuted roots of *Ferula teterrima* cellected in Eastern Kazakhstan close to Lake Sassykkul' (3 kg) was extracted with 40 liters of acetone, and the extract was evaporated. This gave 129.6 g of a syrupy residue, part of which (55 g) was adsorbed on 250 g of alumina and deposited on a column (80 × 150 mm) with 750 g of alumina. Elution was carried out with petroleum ether–ethyl acetate with a rising gradient of the latter. When fractions 91-101 (eluted with a 20% solution of ethyl acetate in petroleum ether) were evaporated, 580 mg of small colorless crystals were obtained with the composition $C_{26}H_{32}O_6$ (M^+ 440, mp 155-158°C, $[\alpha]_D^{20}$ −52° (c 1.02; $CHCl_3$), R_f 0.15.

UV spectrum: λ_{max}^{EtOH} 216, 252.5, 324 nm (log ε 3.97; 3.29; 3.98 respectively), λ_{min} 260 (log ε 3.13).

PMR spectrum: 6.27, d, 1 H, $J_{3,4}$ = 9.5 Hz (H_3); 7.64, d, 1 H, $J_{4,3}$ = 9.5 Hz (H_4); 7.37, d, 1 H, $J_{5,6}$ = 9.0 Hz (H_5); 6.88, q, 1 H, $J_{6,5}$ = 9.0 Hz, $J_{6,8}$ = 2.5 Hz (H_6); 6.79, d, 1 H, $J_{8,6}$ = 2.5 Hz (H_8); 4.20, m, 2 H (C_1'–CH_2); 4.69, ur, 1 H, and 5.02, ur, 1 H (C_2'–CH_2=); 2.18, q, 1 H, $J_{3'a,4'}$ = 11.0 Hz, $J_{3'a,3'e}$ = 13.5 Hz (C_3'–H^a);* 2.77, q, 1 H, $J_{3'e,3'a}$ = 13.5 Hz, $J_{3'e,4'}$ = 5.0 Hz (C_3'–H^e); 5.18, sex, 1 H, $J_{4',3'a}$ = 11.0 Hz, $J_{4',3'e}$ = 5.0 Hz, $J_{4',10'}$ = 12.0 Hz (C_4'–H); 2.06, s, 3 H (C_4'–$OCOCH_3$); 0.89, s, 3 H, and 1.18, s, 3 H (C_5–$(CH_3)_2$);† 3.34, q, 1 H, $J_{6',7'a}$ = 8.0 Hz, $J_{6',7'e}$ = 5.0 Hz (C_6'–H); 0.93, s, 3 H (C_9'–CH_3);† 1.56, d, 1 H, $J_{10',4'}$ = 12.0 Hz (C_{10}'–H).*

Feterin Acetate. A solution of 160 mg of feterin in 10 ml of anhydrous pyridine was treated with 10 ml of acetic anhydride and a sufficient amount of calcined sodium acetate. The reaction mixture was left for a day and was then poured into a beaker containing 200 ml of cold water. The resulting solution was treated with diethyl ether (3 × 25 ml), and the ethereal layers were separated off, dried, and evaporated. This gave an oily product, $C_{28}H_{32}O_7$, R_f 0.33.

PMR spectrum: 6.23, d, 1 H, $J_{3,4}$ = 9.5 Hz (H_3); 7.63, d, 1 H, $J_{4,3}$ = 9.5 Hz (H_4); 7.36, d, 1 H, $J_{5,6}$ = 9.0 Hz (H_5); 6.82, q, 2H, $J_{6,5}$ = 9.0 Hz, $J_{6,8}$ = 2.5 Hz, $J_{8,6}$ = 2.5 Hz (H_6 and H_8); 4.19, m, 2 H (C_1'–CH_2); 4.68, ur, 1 H, and 5.01, ur, 1 H (C_2'–CH_2=); 4.54, m, 1 H (C_6'–H); 5.16, sex, 1 H (C_4'–H); 2.78, q, 1H, and 2.12, q, 1 H (C_3'–$(H)_2$); 2.05, s, 6 H (C_4',$_6'$–$(OCOCH_3)_2$); 1.64, d, 1 H, $J_{10',4'}$ = 12.0 Hz (C_{10}'–H); 1.04, s, 3 H (C_9'–CH_3); 0.95, s, 6 H (C_5'–$(CH_3)_2$).

SUMMARY

From the roots of *Ferula teterrima* Kar. et Kir. a new terpenoid coumarin — feterin — has been isolated with the formula $C_{26}H_{32}O_6$, mp 155-158°C, $[\alpha]_D^{20}$ −52.02° (chloroform), M^+ 440, the structure and relative configuration of which have been established with the aid of the INDOR method and on the basis of a study of the PMR spectra in the presence of the paramagnetic shift reagent $Eu(DMP)_3$.

LITERATURE CITED

1. A. I. Sokolova, Yu. E. Sklyar, and M. G. Pimenov, Khim. Prirodn. Soedin., 134 (1977).
2. M. E. Perel'son, Yu. N. Sheinker, and A. A. Savina, The Spectra and Structures of Coumarins, Chromones, and Xanthones [in Russian], Moscow (1975), p. 231.
3. R. Von Ammon and R. D. Fischer, Angew. Chem., 84, 737 (1972).
4. I. Ya. Slonim and A. Kh. Bulai, Usp. Khim., 42, 11 (1976).
5. M. E. Perel'son, A. A. Kir'yanov, Yu. E. Sklyar, and V. V. Vandyshev, Khim. Prirodn. Soedin., 726 (1973).
6. M. E. Perel'son, V. V. Vandyshev, and Yu. E. Sklyar, Khim. Prirodn. Soedin., 248 (1975).

*The parameters were determined with the aid of the INDOR method.
†The assignments were made on the basis of the results of spectra with additions of $Eu(DPM)_3$.

7. M. E. Perel'son, A. I. Ban'kovskii, and N. E. Ermatov, Khim. Prirodn. Soedin., 703 (1975).
8. M. E. Perel'son, A. A. Kir'yanov, A. I. Ban'kovskii, N. P. Kir'yalov, and T. V. Bukreeva, Khim. Prirodn. Soedin., 442 (1976).
9. H. Hart and J. M. Love, Tetrahedron Lett., 625 (1971).

THE STRUCTURES OF FEROCAULIN, FEROCAULININ, FEROCAULIDIN, AND FEROCAULICIN

Z. A. Kuliev and T. Kh. Khasanov

UDC 547.9:582.89

A number of terpenoid coumarins have been isolated previously from the roots of *Ferula conocaula* Korov. [1-6]. From the roots of this plant collected in the village of Chashma, Leninabad oblast, TadzhSSR, we have isolated four new coumarin derivatives which we have called ferocaulin (I), ferocaulinin (II), ferocaulidin (III), and ferocaulicin (IV).

The UV spectra of substances (I-IV) show maxima characteristic for derivatives of 7-hydroxycoumarin, as was confirmed by the formation of umbelliferone (V) on the acid hydrolysis of (I-IV). The IR spectra of (I-III) show absorption bands due to the presence of aromatic nucleus, the carbonyl group of an α-pyrone and a carbonyl group in a six-membered ring, a double bond, and a hydroxy group.

Ferocaulin (I), with the composition $C_{24}H_{28}O_5$, has a mass spectrum [m/e 396 (M^+), 381 $(M-15)^+$, 378 $(M-H_2O)^+$, 235 $(M-ArO)^+$, 162 $(ArOH)^+$], similar to that of terpenoid coumarins of the iresane series [7, 8]. The composition of the terpenoid moiety ($C_{15}H_{24}O_2$), the presence in the PMR spectrum of the signals of four methyl groups (Table 1), and the nature of the fragmentation in the mass spectrum indicate that this moiety of ferocaulin has the iresane skeleton and contains hydroxy and carbonyl groups and a double bond.

The dehydrogenation of ferocaulin with selenium led to 1,2,5,6-tetramethylnaphthalene (VI), the formation of which confirms that (I) belongs to the terpenoid coumarins of the iresane series and shows that the carbonyl or the hydroxy group is present at C_6' [9-12]. The signal of the hemihydroxy proton of the PMR spectrum of (I) is found at 4.40 ppm (1 H, ΣJ = 10 Hz). The resonance of the latter in such a weak field as compared with other terpenoid coumarins having a double bond in the bicyclic terpene system — conferol [2], moschatol [13], feropolidin [14], and mogoltacin [15]— shows that the methine proton at the carbon to which the hydroxy group is attached is located close to the double bond. In view of the presence of an olefinic proton and a vinylmethyl group, and also of the multiplicity of the C_1'—CH_2OAr signal, the double bond in the terpenoid substituent must be located at C_2'—C_3'. Consequently, the hydroxy group is at C_4'. From the values of the CSs of the methyl groups (see Table 1), and also from the results of selenium dehydrogenation, the carbonyl group occupies the C_6' position. According to the facts given above, ferocaulin has the structure (I), as is confirmed by the passage from ferocaulin to conferdione (VII) [4] by oxidation with chromium trioxide. The product of this oxidation was a substance with the composition $C_{24}H_{26}O_5$, mp 150-152°C, M^+ 394, and with IR and PMR spectra identical with those of conferdione.

Ferocaulinin (II) has the composition $C_{24}H_{28}O_5$ (M^+ 396), and the mass spectrum shows the peaks of ions with m/e 378 $(M-H_2O)^+$, 363 $(M-H_2O-CH_3)^+$, 217 $(M-ArO-H_2O)^+$ and 162 $(ArOH)^+$.

A comparison of the compositions and UV, IR, PMR, and mass spectra of (I) and (II) shows that they are isomeric compounds. The PMR spectrum of ferocaulinin differs from that of (I) by the value of the CS and the half-width of the signals of the hemihydroxylic and olefinic protons, and also by the CSs of the methyl groups. In the spectrum of ferocaulinin the methine proton at the carbon atom to which the hydroxy group is attached is represented by a multiplet at 4.28 ppm (ΣJ = 17 Hz). The large value of the half width of the C_4'—M signal in (II) as compared with (I) shows that ferocaulinin is an epimer of ferocaulin, and the hydroxy

Institute of the Chemistry of Plant Substances, Academy of Sciences of the Uzbek SSR, Tashkent. Translated from Khimiya Prirodnykh Soedinenii, No. 3, pp. 322-327, May-June, 1978. Original article submitted December 30, 1977.

0009-3130/78/1403-0267$07.50