

of C=O and aromatic C=C absorption bands and was identical with that of an authentic sample of sucrose.

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ACKNOWLEDGMENTS AND ADDRESSES

Received June 17, 1968, from the *Department of Medicinal Chemistry, College of Pharmacy, University of Minnesota, Minneapolis, MN 55455*

Accepted for publication November 19, 1968.

This work was supported by grant HE 07101 from the National Institutes of Health, U. S. Public Health Service, Bethesda, MD

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Coumarins X: Spectral Studies on Some Linear Furanocoumarins

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Abstract □ Observations on the IR, UV, and NMR spectral data of some substituted psoralen-type linear furanocoumarins are presented as an aid to their differentiation.

Keyphrases □ Furanocoumarins, linear—spectral studies □ NMR spectroscopy—structure, identification □ UV spectrophotometry—structure, identification □ IR spectrophotometry—structure, identification

During an investigation of the coumarin content of *Sphenosciadium capitellatum* (A. Gray) a series of biogenetically closely-related methyl or isoprenyl ether-substituted psoralen-type (I) linear furanocoumarins has been obtained (1). The present paper reports the

direct comparison of their spectral properties together with those of certain other closely related compounds (VIII, IX, and X) in order to permit their ready differentiation. The results are summarized in tabular form and are discussed as to the significant differences.

DISCUSSION

NMR Spectral Comparison—The results of NMR studies are summarized in Table I. The chemical shifts and coupling constants of C₂-H, C₄-H, C₄'-H, and C₅'-H of isoimperatorin (II), isopimpinellin (VII), and imperatorin (VI) have been reported previously by Sheinker *et al.* (2) and Abu-Mustafa *et al.* (3), respectively. However, the former measured II, VI, and VII in CCl₄ and reported $J_{4',5'}$ = 2 c.p.s., whereas the latter measurements were in CDCl₃ and $J_{4',5'}$

Table I—NMR Comparison of Furanocoumarins

No.	Compd.	Chemical Shifts (τ)										Coupling Constants (c.p.s.)		
		—OCH ₃ s ^a	$\begin{array}{c} \text{CH}_3 \\ \diagup \\ \text{C} \\ \diagdown \\ \text{CH}_3 \end{array}$ s	—OCH ₂ d ^b	—CH= t ^c	3-H d	4-H d	5-H s	8-H s	4'-H d	5'-H d	J-CH ₂ , —CH=	J _{3,4}	J _{4',5'}
II	Isoimperatorin		8.30 8.20	5.14	4.50	3.82	1.92		2.95	3.09	2.47	7	10	2
III	Oxypeucedanin		8.66 8.58			3.71	1.80		2.84	3.03	2.38		10	2
IV	Cnidilin	5.87	8.33 8.22	5.21	4.44	3.74	1.85			3.07	2.38	7	10	2
V	Phellopterin	5.87	8.32	5.20	4.43	3.80	1.94			3.05	2.41	7	10	2
VI	Imperatorin		8.29	5.05	4.44	3.71	2.27	2.71		3.23	2.33	7	10	2
VII	Isopimpinellin	5.86				3.79	1.97			3.07	2.44		10	2

^a s = singlet. ^b d = doublet. ^c t = triplet.

Table II—UV Comparison of Furanocoumarins

II Isoimperatorin m μ log ϵ		III Oxypeucedanin m μ log ϵ		IV Cnidilin m μ log ϵ		V Phellopterin m μ log ϵ		VI Imperatorin m μ log ϵ		VII Isopimpinellin m μ log ϵ	
$\lambda_{max.}$		$\lambda_{max.}$		$\lambda_{n.o.x.}$		$\lambda_{max.}$		$\lambda_{max.}$		$\lambda_{max.}$	
223	4.37	222	4.23	223	4.36	223	4.37	219	4.49	223	4.43
243	4.19s. ^f	242	4.10s.	242	4.11	242	4.08	245	4.42s.	242	4.17
250	4.25	250	4.16	249	4.12	249	4.07	249	4.44	248	4.17
259	4.19	258	4.08s.	270	4.20	269	4.20	264	4.20s.	269	4.27s.*
268	4.18	267	4.04s.	313	4.02	273	4.20s.* ^g	301	4.15	273	4.27
309	4.15	308	4.02			313	4.02			313	4.10
$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$	
235	4.12	233	3.99	238	4.08	238	4.07	233	4.25	238	4.15
254	4.18	254	4.08s.	245	4.10	245	4.06	263	4.20s.	245	4.16
264	4.17	263	4.04s.	254	4.04	254	3.99	276	3.86	254	4.08
276	3.63	276	3.53	286	3.76	286	3.73			286	3.82
VIII Bergapten ^a m μ log ϵ		IX Xanthotoxin ^b m μ log ϵ		X Byakangelicol ^c m μ log ϵ		XI Pimpinellin ^d m μ log ϵ		XII Isobergapten ^e m μ log ϵ			
$\lambda_{max.}$		$\lambda_{max.}$		$\lambda_{max.}$		$\lambda_{max.}$		$\lambda_{max.}$			
223	4.33	219	4.48	223	4.36	222	4.38	250	4.29		
243	4.16s.	245	4.44s.	242	4.11	254	4.40	305	4.01		
249	4.21	249	4.46	249	4.11	305	4.01				
259	4.18	262	4.23s.	268	4.20						
268	4.24	301	4.16	273	4.20s.*						
311	4.14			313	4.03						
$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$		$\lambda_{min.}$			
234	4.10	232	4.23	238	4.08	235	4.15				
254	4.14	262	4.23s.	245	4.09	276	3.71				
263	4.17	276	3.90	254	4.02						
276	3.62			286	3.74						

^a Obtained from the studies reported in Reference 8. ^b Marketed by Nutritional Biochemicals Corporation, Cleveland, Ohio. ^c Kindly supplied by Dr. K. Hata, Kyoto University, Kyoto, Japan. ^d Kindly supplied by Dr. H. Mitsuhashi, Hokkaido University, Hokkaido, Japan. ^e Data transferred from Reference 9. No minima were reported in this publication. ^f s. = shoulder. ^g s.* = shoulder which could be considered part of a broad peak.

= 3 c.p.s. From Table I with measurements made in CDCl₃ the following conclusions could be drawn.

The chemical shifts assigned to the C₃, C₄, C_{4'}, and C_{5'} protons are characteristic of the linear furanocoumarins with the coupling constant between C₃-H and C₄-H being 10 c.p.s., whereas for C_{4'}-H and C_{5'}-H, it is 2 c.p.s.

The upfield position of C₈-H in II and III, in contrast to the C₅ aromatic proton as seen in VI, is in keeping with the diamagnetic shift of an aromatic proton adjacent to an oxygen atom as already mentioned by Bredenberg *et al.* (4), Bottomley (5), Sheinker *et al.* (2), and Fisher *et al.* (6, 7).

The isoprenyl ether group in the 5-position (II, III, and IV) or 8-position (V and VI) of the linear furanocoumarin ring can be

differentiated readily since the gem-dimethyl groups of the former show a doublet due to an apparently dissimilar magnetic environment created, perhaps, by an anisotropic effect due to the 3,4-double bond, while the latter shows a singlet indicating a similar magnetic environment for both methyls. The chemical shift of the gem-dimethyls in V is almost identical to the chemical shift of one of the methyls of IV, indicating a deshielding effect on the other methyl by about 0.11 p.p.m. The same phenomenon is apparent in the spectra of II and VI.

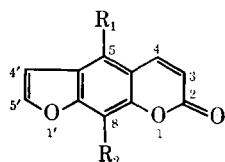
UV Spectral Comparison—The UV spectral comparisons are summarized in Table II which clearly indicates the following conclusions.

The linear furanocoumarins (II, III, IV, V, VII, VIII, IX, and X)

Table III—IR Comparison of Furanocoumarins

No.	Compd.	ν CH ^a cm. ⁻¹	α -Pyrone C=O cm. ⁻¹	Aromatic C=C cm. ⁻¹	Characteristic Peak of Furans, cm. ⁻¹
II	Isoimperatorin	3125, 3100, 3050	1724	1623, 1600, 1575, 1540	885 (sp. ^b m. ^c)
III	Oxypeucedanin	3130, 3110, 3050	1728	1620, 1600, 1575, 1545	885 (sp. m.)
IV	Cnidilin	3120, 3078, 3025	1715	1620s., ^d 1600s., 1587, 1540	880 (sp. m.)
V	Phellopterin	3130, 3100, 3050	1724	1620s., 1600s., 1580, 1545	880 (sp. m.)
VI	Imperatorin	3100, 3075, 3025	1715, 1705	1620, 1580, 1535	870 (sp. sg. ^e)
VII	Isopimpinellin	3120, 3080, 3050	1745, 1715	1600s., 1580, 1540	875 (sp. m.)
VIII	Bergapten	3100, 3070, 3050	1726	1620, 1602s., 1575, 1540s.	885 (sp. sg.)
IX	Xanthotoxin	3110, 3080, 3040	1705	1620, 1580, 1540	875 (sp. m.)
X	Byakangelicol	3130, 3100, 3070	1735	1620s., 1602s., 1585, 1545	885 (sp. m.)

^a Substituted furan, benzene, and α -pyrone rings. Peaks above 3100 cm.⁻¹ may reasonably be assigned to furan CH-stretching frequencies (L. H. Briggs and L. D. Colebrook, *J. Chem. Soc.*, 1960, 2458). ^b sp. = sharp. ^c m. = medium. ^d s. = shoulder. ^e sg. = strong.



I, $R_1 = H$; $R_2 = H$

II, $R_1 = O-CH_2-CH=C(CH_3)_2$; $R_2 = H$

III, $R_1 = O-CH_2-CH(O-CH_3)-C(CH_3)_2$; $R_2 = H$

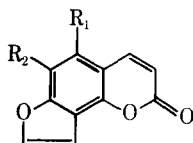
IV, $R_1 = O-CH_2-CH=C(CH_3)_2$; $R_2 = OCH_3$

V, $R_1 = OCH_3$; $R_2 = O-CH_2-CH=C(CH_3)_2$

VI, $R_1 = H$; $R_2 = O-CH_2-CH=C(CH_3)_2$

VII, $R_1 = OCH_3$; $R_2 = OCH_3$
 VIII, $R_1 = OCH_3$; $R_2 = H$
 IX, $R_1 = H$; $R_2 = OCH_3$

X, $R_1 = OCH_3$; $R_2 = O-CH_2-CH(O-CH_3)-C(CH_3)_2$



XI, $R_1 = OCH_3$; $R_2 = OCH_3$
 XII, $R_1 = OCH_3$; $R_2 = H$

and angular furanocoumarins (XI and XII) show distinctly different spectra. The λ_{max} at 242–245 $m\mu$ and about 260–270 $m\mu$ which are characteristic of the former are absent in the latter.

The monosubstitution of either C_5 or C_8 of the aromatic ring (II, III, VI, VIII, and IX) gives spectra which are different from those of disubstituted ones (IV, V, VII, and X). Thus, the λ_{max} at about 260 $m\mu$ and λ_{min} at 276 $m\mu$ found in the monosubstituted type are absent in the disubstituted compounds whereas the latter show a characteristic λ_{max} at 273 $m\mu$ and λ_{min} at 286 $m\mu$.

The disubstituted compounds revealed virtually identical spectra regardless of the substituents.

The C_5 (II, III, VIII) and C_8 (VI, IX) monosubstituted compounds can be readily differentiated since the former show a λ_{max} at about 268 $m\mu$ and λ_{min} at 254 $m\mu$ which are absent in the latter, whereas the latter gave a characteristic λ_{max} at 301 $m\mu$ which was found at 308–311 $m\mu$ in the former.

The nature of the substituents [$-O-CH_2-CH=C(CH_3)_2$,

$-O-CH_2-CH(O-CH_3)-C(CH_3)_2$, or OCH_3] has little influence on the λ_{max} or λ_{min} since almost identical spectra are found for II, III, and VIII and for VI and IX, respectively.

IR Spectral Comparison—The IR spectral comparisons are summarized in Table III and indicate these conclusions.

Usually a triplet at about 3025–3130 cm^{-1} (ν CH of substituted furan, benzene, and α -pyrone rings), an aromatic C=C in the region 1535–1623 cm^{-1} , a characteristic furan ring peak at 870–885 cm^{-1} (10) due to the out-of-plane deformation vibrations of the C—H bonds as suggested by Perel'son (11), and an α -pyrone C=O were found in these linear furanocoumarins.

The position of the C=O stretching band of the α -pyrone was apparently determined by the inductive effect of the substituents at the 5- and 8-positions. When an OCH_3 or isoprenyl ether group is attached at C_5 and the C_8 is not substituted, the C=O band shifts to a frequency higher than 1720 cm^{-1} through the inductive effect as seen in II, III, and VIII. Where C_5 and C_8 are both substituted by different groups, OCH_3 , if present, is the predominant group which directs the inductive effect.

If OCH_3 is attached to the 5-position as in V and X, the frequency of the C=O would be higher than 1720 cm^{-1} , but if it is at the 8-position as in IV, a lower frequency (lower than 1720 cm^{-1}) was obtained. The same situation was observed when C_8 but not C_5 was substituted by an alkoxy group as in VI and IX, the C=O frequency being reduced to 1705 cm^{-1} .

An internal compensation of the inductive effect might be suggested to account for the reduction of the C=O frequency when OCH_3 is substituted at the 8-position.

EXPERIMENTAL

NMR spectra (Table I) were determined on a recording spectrometer¹ in deuteriochloroform ($CDCl_3$) using tetramethylsilane (TMS) as the internal standard.

UV spectra (Table II) were determined on a recording spectrophotometer,² in 95% ethanol and expressed in λ_{max} and λ_{min} .

IR spectra (Table III) were determined on an infrared spectrophotometer³ in mineral oil and expressed in cm^{-1} .

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ACKNOWLEDGMENTS AND ADDRESSES

Received June 17, 1968 from the *Department of Medicinal Chemistry, College of Pharmacy, University of Minnesota, Minneapolis, MN 55455*

Accepted for publication November 19, 1968.

This work was supported in whole by grant No. HE 07101 from the National Institutes of Health, U. S. Public Health Service, Bethesda, MD

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¹ Varian Associates A-60.

² Cary, model 14.

³ Perkin-Elmer 237B grating.