Chemical constituents of the physodes of brown algae. Characterization by ^{1}H and ^{13}C nuclear magnetic resonance spectroscopy of oligomers of phloroglucinol from Fucus vesiculosus (L.)

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Chemical constituents of the physodes of brown algae. Characterization by ^{1}H and ^{13}C nuclear magnetic resonance spectroscopy of oligomers of phloroglucinol from *Fucus vesiculosus* (L.)[1]

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Alcoholic extracts of *Fucus vesiculosus* contain small quantities of low molecular weight polyphenols derived from phloroglucinol and 2,2',4,4',6,6'-hexahydroxybiphenyl. [1]H and ^{13}C nmr were used to identify two of these as 4-(2'',4'',6''-trihydroxyphenoxy)-2,2',4',6,6'-pentahydroxybiphenyl and 4-(2''-(2''',4''',6'''-trihydroxyphenoxy)-4'',6''-dihydroxyphenoxy)-2,2',4', 6,6'-pentahydroxybiphenyl.
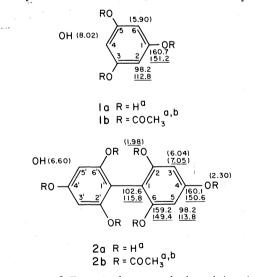
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Les produits obtenus par extractions alcooliques du *Fucus vesiculosus* contiennent des petites quantités de polyphénols de bas poids moléculaires dérivés du phloroglucinol et de l'hexahydroxy-2,2',4,4',6,6' biphényle. On a utilisé la rmn ^{1}H et ^{13}C pour en identifier deux qui sont le (trihydroxy-2'',4'',6'' phénoxy)-4 pentahydroxy-2,2',4',6,6' biphényle et le [(trihydroxy-2''',4''',6''' phénoxy)-2'' dihydroxy-4'',6'' phénoxy]-4 pentahydroxy-2,2',4',6,6' biphényle.

[Traduit par le journal]

Introduction

In 1892 it was demonstrated (1) that brown algal subcellular bodies, called physodes, gave a fiery red colour with the Lindt reagent (vanillin–HCl). This distinctive reaction led to the generally accepted belief that brown algae contained phloroglucinol **1a** or related compounds (2).[3] Chemical evidence that brown algal cells produce **1a**, however, was lacking until quite recently when it was demonstrated in hydrolysates of the tannins of *Sargassum ringgoldianum* (3), exudates of *Fucus vesiculosus* (4), and in the direct extracts of seventeen algal species (5). In a previous communication (6) we showed that extracts of Nova Scotian *F. vesiculosus* contained **1a** and

2,2',4,4',6,6'-hexahydroxybiphenyl **2a** ('dimer'), other oligomers, and high molecular weight polymers composed of **1a** and **2a**. Glombitza *et al.* (7) have independently identified the peracetylated derivatives of **1a** and **2a** in acetylated

extracts of *F. vesiculosus*, and also claimed the presence of a terphenyl and two quaterphenyls presumably derived from residues of **1a**. However, on the basis of their published data it is

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[3]In the structures illustrated the superscripts *a–f* refer to the following: *a*, numbers in parentheses are δ (TMS) (ppm); numbers not in parentheses are δ_c (TMS or TSP) (ppm); underlined numbers refer to R = CH$_3$CO; numbers not underlined to R = H; *b*, resonances for ^{13}C nuclei in CH$_3$CO— groups have not been individually assigned; *c*, data from ref. 13; *d*, data from ref. 8; *e*, data from ref. 19; ^{13}C resonances were reassigned by comparison with **5**b, using the substituent effect of a CH$_3$CO$_2$ group at C-4' (from **9** and **10**, see text); *f*, data from ref. 17.

difficult to assess the validity of the latter structures. Structure **3b** has also been proposed (8) and ether linked derivatives of **1a** have been identified in the extracts of the brown seaweeds *Bifurcaria bifurcata* (9, 10) and *Halidrys siliquosa* (11). We now report ^{1}H and ^{13}C nuclear magnetic resonance (nmr) evidence for the structures of two compounds, isolated from the extracts of *F. vesiculosus*, containing **1a** and **2a** linked through oxygen in the ratio of 1:1 (**3a**) and 2:1 (**4a**).

3a   R = H[a]

3b   R = COCH$_3$[a,b]

3c   R = Si(CH$_3$)$_3$

Experimental

^{1}H nmr spectra were recorded at 100 MHz with a Varian HA-100 continuous-wave spectrometer, and ^{13}C nmr spectra with a Varian XL-100/15 pulse Fourier-transform instrument (25.16 MHz, spectral width 5120 Hz, acquisition time 0.8 to 1.6 s, flip angle 40°, ^{1}H-decoupling field strength $\gamma H_2/2\pi = 3800$ Hz, internal ^{2}H pulse lock). Broadband ^{1}H-decoupling from ^{13}C was accomplished by phase modulation of the decoupling field from 0 to 180° at 150 Hz (12). High-resolution (h.r.) ^{13}C spectra were recorded with retained nuclear Overhauser enhancement by applying the decoupling field for 1.6 s between data acquisition periods (13).

Mass spectra were obtained from a Consolidated Electrodynamics Corporation 21-110B spectrometer, and precise masses were measured by the peak matching method using an ion in the spectrum of perfluorokerosene as a standard.

Fucus vesiculosus (L.) was collected near Morris Point, Halifax Co., Nova Scotia and its alcoholic extracts were fractionated on Avicel columns as described in our earlier report (6). Compounds in the acetone eluate were purified by repeated preparative chromatography on layers of SilicAR TLC-7GF (Mallinckrodt) until chromatographically homogenous on silica gel or polyamide tlc plates (6). Bands were detected by ultraviolet absorption (254 nm) or by spraying guide strips with vanillin–HCl. Final purification was accomplished on columns (1.5 × 15 cm) of Woelm polyamide developed with methanol–water (3:1 v/v). Typically 70 mg of **3a** and 40 mg of **4a** could be recovered in this manner from 8 kg of fresh alga. Acetates were prepared routinely (6), and the trimethylsilyl ethers used for mass spectrometry were formed using Tri-Sil (Pierce Chemical Co.). Compounds **2a**, **2b** (6), and **5b** (14) were synthesized.
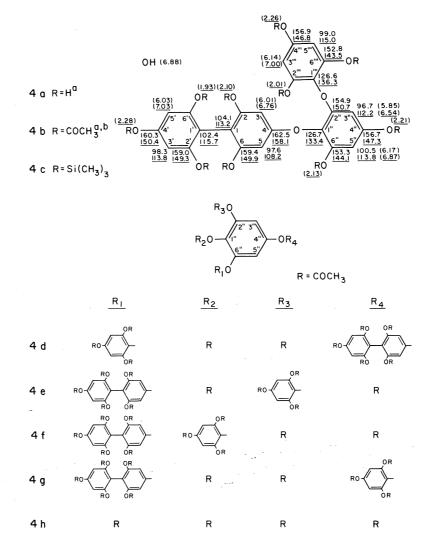
Proton chemical shifts, δ (ppm) referenced to tetra-

methylsilane (TMS) contained in a concentric tube in the case of the hydroxy compounds (solvent H$_2$O), or to internal TMS (acetylated derivatives in acetone-d_6), are enclosed in parentheses. ^{13}C chemical shifts (δ_c) of the hydroxy compounds were referenced to internal sodium 3-trimethylsilylpropionate 2,2,3,3-d_4 (TSP) (solvent H$_2$O containing a small amount of HOD); the shifts of the acetylated compounds (solvent acetone-d_6) to internal TMS.

Results and Discussion[3]

Precise mass measurements of the molecular ions observed as intense peaks in the mass spectra of the trimethylsilyl derivatives (**3c**, **4c**) of the unknowns **3a** and **4a** established the molecular formula $C_{42}H_{78}O_9Si_8$ (m/e 950.3788 ± 0.0029; calcd.: 950.37996) for **3c** and $C_{54}H_{98}O_{12}Si_{10}$ (m/e 1218.471 ± 0.004; calcd.: 1218.475) for **4c**. Thus **3a** possesses eight hydroxy groups and the molecular formula $C_{18}H_{14}O_9$, while **4a** contains ten hydroxy groups and has a molecular formula of $C_{24}H_{18}O_{12}$ (15). The molecular ions in the mass spectra of **3a**, **3b**, **4a**, and **4b** were of low intensity.

^{1}H and ^{13}C chemical shift data from our experiments and other sources as indicated are shown on the structural diagrams, with the data for acetylated derivatives being underlined. Spin–spin coupling constants $J_{^{13}C^1H}$ measured from high-resolution ^{13}C spectra are listed in Table 1.

A comparison of the ^{1}H nmr spectra data for **3b** with those for the model compounds **2b**, **5b**, and **7b** showed that three resonances (δ 2.03–2.06, 6H, CH$_3$CO$_2$; δ 2.25–2.27, 3H, CH$_3$CO$_2$; δ 7.02–7.04, 2H, aromatic H), were common to the spectra of **3b**, **5b**, and **7b**. The signals originated from hydrogens associated with a 2,4,6-triacetoxyphenoxy residue in the case of both **5b** and **7b**, thus the presence of this structural unit may be inferred for **3b**. The five resonances remaining for **3b** were consistent with the presence of a biphenyl ring system substituted as in **2b**, but possessing a 2,4,6-triacetoxyphenoxy substituent at C-4. Three of the signals (δ 1.93, 6H, CH$_3$CO$_2$ at C-2′,C-6′; δ 2.28, 3H, CH$_3$CO$_2$ at C-4′; δ 7.07, 2H, H-3′,H-5′) were essentially identical to those obtained for **2b** (δ 1.98, δ 2.30, and δ 7.05), thus confirming the presence, and substitution pattern, of one of the biphenyl rings. The shift of the signal for the remaining two chemically equivalent aromatic hydrogens of **3b** (δ 6.76) closely resembled that for H-2′,H-6′ of **7b** (δ 6.72), which would be almost unaffected if the acetoxy group attached to C-4′ was replaced

OH (6.88)

4 a R = H[a]

4 b R = COCH$_3$[a,b]

4 c R = Si(CH$_3$)$_3$

R = COCH$_3$

	R$_1$	R$_2$	R$_3$	R$_4$
4 d		R	R	
4 e		R		R
4 f			R	R
4 g		R	R	
4 h	R	R	R	R

by a phenyl substituent (16). Each of the **3b** hydrogens (H-3, H-5) would, therefore, lie between a phenoxy and an acetoxy (δ 2.13, 3H) substituent, like H-2′ and H-6′ of **7b**. The presence of only two signals with chemical shifts δ ≧ 2.20 from acetoxy methyl groups in **3b** excluded the possibility of a 3,4,5-triacetoxy-phenoxy substituent as in **7b**, the spectrum of which contains three such signals. In both **5b** and **7b**, a phenoxy substituent shields the protons of adjacent acetoxy groups. This eliminates **6a** and **6b** as possible structures. The combined ^{1}H nmr results favour structure **3a** for the unknown and **3b** for its acetate derivative.

The structures of **3a** and **3b** were finally established by comparing their ^{13}C spectra with those for the model compounds **1a**, **1b**, **2a**, **2b**, **5a**, and **5b**. All of the model compounds possessed symmetry elements which resulted in a reduction in the number of signals observed for the aromatic carbons. Thus the ^{13}C spectra of **1a** and **1b** contained only two resonances for such carbons, the one arising from those bearing hydrogen being easily recognized because it was split by one-bond ^{13}C–H spin–spin coupling

5 a R = H[a]

5 b R = COCH$_3$[a,b,c]

TABLE 1. ^{13}C–^{1}H spin–spin couplings (±0.4 Hz) for **3a**, **3b**, **4a**, **4b** and model compounds **1a**, **1b**, **2a**, **2b**, **5a**, **5b***

	C-1,1′	C-2,2′,6,6′	C-3,3′,5,5′	C-4,4′			C-2,4,6	C-1,3,5
2a	^3J5.3t	ma	^1J160.0d ^3J4.7d	^2J3.5t	**1a**		^1J160.5d ^3J4.6t	m,$w_{1/2}\simeq9$
2b	^3J5.5t	mb	^1J168.3d ^3J5.0d	^2J5.0t	**1b**		^1J167.6d ^3J4.9t	$^2J\simeq4.0$t $^4J\simeq3.0$d

	C-4′	C-3′,5′	C-2′,6′	C-1′	C-1	C-2,6	C-3,5	C-4
5a	†	†	^1J161.9d $^3J4\pm1$t	†	†	†	^1J161.6d ^3J5.3d	†
5b	^1J167.9d ^3J5.3t	mb	^1J165.9d ^3J4.7t	^2J4.4t	^3J7.4t	mb	^1J168.1d ^3J5.6d	^2J5.3t

	C-1′	C-2′,6′	C-3′,5′	C-4′	C-1	C-2,6	C-3,5	C-4	C-1″	C-2″,6″	C-3″,5″	C-4″
3a	^3J5.0t	ma	^1J160.1d ^3J5.0d	^2J3.7t	^3J5.0t	ma	^1J161.4d ^3J4.0d	^2J3.8t	^3J7.3t	ma	^1J161.1d ^3J5.1d	^2J3.8t
3b	^3J5.0t	mb	^1J168.7d ^3J5.0d	^2J5.0t	^3J5.0t	mb	^1J166.2d ^3J5.0d	^2J4.7t	^3J7.3t	mb	^1J168.1d ^3J5.6d	^2J5.3t

	C-1′	C-2′,6′	C-3′,5′	C-4′	C-1	C-2,6	C-3,5	C-4	C-1‴	C-2‴,6‴	C-3‴,5‴	C-4‴
4a	^3J4.9t	ma	^1J160.3d ^3J4.7d	^2J3.5t	^3J5.1t	ma	^1J161.9d ^3J4.6d	^2J4.1t	^3J7.1t	ma	^1J160.7d ^3J5.0d	^2J4.3t
4b	^3J5.5t	mb	^1J168.3d ^3J5.0d	^2J4.8t	$^3J5\pm1$t	mb	^1J166.2d $^3J5\pm1$d	$^2J5\pm1$d	^3J7.5t	mb	^1J168.4d ^3J5.0d	^2J5.5t

	C-1″	C-2″	C-3″	C-4″	C-5″	C-6″
4a	^3J7.2t	^2J or ^4J3.8d	^1J161.6d ^3J5.3d	^2J4.3t	^1J161.2d ^3J5.6d	^2J or ^4J3.7d
4b	^3J7.2t	m	$^1J170\pm2$d ^3J5.5d	^2J5.2t	^1J168.3d ^3J5.0d	m

*For the carbons of acetate groups, spin–spin coupling constants (Hz) were: ^{13}CH$_3$, $^1J_{CH}$ 130.4q; ^{13}C=O, ^2J 6.9q. ma: characteristic multiplet (doublet of doublets) due to coupling to one *ortho* and one *para* proton in h.r. spectra of hydroxy compounds; mb: similar multiplet for acetylated compounds; m: multiplet; d: doublet; t: triplet; q:quartet; $w_{1/2}$ line width at half height.

†Poor S/N due to insufficient material for h.r. spectrum.

($^1J_{CH}$) in the h.r. spectra, and occurred at higher field than the signal due to the ring carbons bonded to oxygen, in accord with known ^{13}C substituent effects (17). Similarly, four resonances were observed for the biphenyl ring carbons of **2a** and **2b**, the two at highest field arising from quaternary carbons (C-1, C-1′) and carbons carrying hydrogens (C-3, C-3′, C-5, C-5′; $^1J_{CH}$). The remaining resonances due to the two types of carbon bonded to oxygen occurred at low field as expected, and could be assigned because the signal for C-2, C-2′, C-6, and C-6′ was about twice the intensity of the one arising from C-4 and C-4′, the relative intensities of the two sets of resonances being independent of the conditions used to record the spectra.

Compound **5b** was synthesized in 5% yield following Glombitza et al. (14). Its ^{13}C spectrum contained three signals arising from aromatic carbons bearing hydrogen. Two which appeared as doublets ($^1J_{CH}$) of triplets ($^3J_{CH}$ to two hydrogens) could be assigned to C-4′ (δ_c 110.5) and C-2′,C-6′ (δ_c 107.6), the relative intensity of the former resonance being approximately half that of the latter, a result independent of experimental conditions. The signal for C-3,C-5 was a doublet ($^1J_{CH}$) of doublets ($^3J_{CH}$ to one hydrogen) as expected. Resonances at δ_c 167.9 to δ_c 168.5 were readily ascribed to the acetoxyl carbonyl carbons, and one at δ_c 158.1 clearly belonged to C-1′ (the corresponding carbon in diphenyl ether resonates at δ_c 157.9 (17)). A low-intensity signal at δ_c 136.5 could be ascribed to the poorly-relaxed carbon C-1, which is shielded by a *para* and two *ortho* acetoxy substituents. The resonance at δ_c 151.6 could be assigned to C-3′, C-5′ as their chemical shift should not differ significantly from that of C-1,C-3,C-5 (δ_c 151.2) in **1b**, the *meta* substituent effects of acetoxy and phenoxy groups being small (17). The remaining

support for this assignment is provided by the spectrum of diphenyl ether (17), where C-2,C-6 (δ_c 119.3) is shielded to a greater extent than C-4 (δ_c 123.6). It is reasonable to assume that the corresponding carbons in **5b** would show comparable differences in chemical shift. A similar analysis assigned the resonances in the ^{13}C spectrum of **5a**, although there was insufficient sample for a h.r. spectrum of the carbons not bonded to hydrogen.

The 18 carbons of **3a** gave rise to 12 resonances in the aromatic region of the ^1H broadband-decoupled ^{13}C spectrum. This is consistent with the ^1H nmr results discussed above which showed that **3a** was symmetrical, and indirectly but unequivocally established the presence of at least six pairs of chemically equivalent aromatic carbons. Twelve resonances for the aromatic carbons were also observed in the high resolution ^{13}C spectrum of **3b**, but the ^1H broadband-decoupled ^{13}C spectrum contained only ten resonances due to superposition of signals (C-1 hidden by C-3′,C-5′ and C-1′ by C-3″,C-5″).

It was apparent from the ^{13}C chemical shift and spin–spin coupling data (Table 1) that **3a** (**3b**) possessed three sets of aromatic carbons. Each set contained two chemically non-equivalent, plus two pairs of chemically equivalent, carbons and gave rise to four resonances. The ^{13}C data for one set of carbons (**3a**, **3b**; C-1′ through C-6′) was virtually identical to that for **2a** (**2b**), and that of another set (**3a**, **3b**; C-1 through C-6) differed only slightly, and predictably (see comments on chemical shift calculations below). Similarly the ^{13}C data for the carbons in the remaining set (**3a**, **3b**; C-1″ through C-6″) were almost indistinguishable from those obtained for C-1 through C-6 of **5a** (**5b**).

6a R = H

6b R = COCH₃

7a R = H^a

7b R = COCH₃^{a,b,d,e}

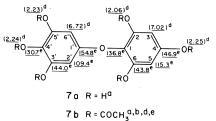two resonances at δ_c 146.8 and δ_c 143.7 were assigned to C-4 and C-2,C-6, respectively. the relative intensity of the former signal being approximately half that of the latter under a variety of experimental conditions. Additional

The ^{13}C chemical shifts expected for C-1 through C-6 of **3a** and **3b** were calculated from the known chemical shifts for **1a**, **1b**, **2a**, **2b**, **5a**, and **5b** as follows. Comparison of **1a,1b** and **5a,5b** yields the changes in chemical shift at all

the carbons of **1a,1b** due to replacement of one hydroxy (or acetoxy) substituent by a 2,4,6-trihydroxy (or triacetoxy) phenoxy group: at the directly bonded carbon +2.2(+6.9) ppm; *ortho* −1.0(−5.2) ppm; *meta* 0.0(+0.4) ppm; *para* +1.6(−2.3) ppm. These chemical shift changes applied to **2a,2b** for the same change of substitution at C-4 predict the following chemical shifts for C-1 through C-6 of **3a,3b**. The close correspondence of measured and predicted (in parentheses) shifts provides further support for the ^{13}C resonance assignments and the structures: **3a** C-1 104.2 (104.2), C-2,C-6 159.4 (159.2), C-3,C-5 97.4 (97.2), C-4 162.5 (162.3); **3b** C-1 113.9 (113.5), C-2,C-6 150.0 (149.8), C-3,C-5 108.8 (108.6), C-4 157.7 (157.5).

In addition, hydrogen to deuterium exchange in D_2O eliminated ^{13}C–^{1}H spin–spin coupling from all resonances except those assigned to C-1 through C-6 of **3a**, which partially retained coupling. This confirms that the latter carbons belonged to the same ring. The centre ring of **3a** would be expected to exchange hydrogen less rapidly, as it provides less opportunity for keto–enol tautomerism. The combined evidence therefore establishes that **3a** is 4-(2″,4″,6″-trihydroxyphenoxy)-2,2′,4′,6,6′,-pentahydroxybiphenyl.

The ^{1}H nmr spectrum for **4a** (solvent acetone-d_6) contained three singlet resonances at δ 6.01, 6.03, and 6.14 due to three pairs of chemically equivalent aromatic hydrogens. Two of these (δ 6.01, 6.03) corresponded closely to the signals for hydrogens at C-3, C-3′, C-5, C-5′ of **2a** and C-3, C-3′, C-5, C-5′, C-3″, C-5″ of **3a**, while the third (δ 6.14) was similar apart from a small downfield shift. The spectrum also contained an AB multiplet for two *meta*-coupled aromatic hydrogens (centroid δ 6.01, Δν 32.7 Hz, $^3J_{HH}$ 2.8 Hz) and a broad OH signal (δ 6.88) integrating for 10 protons.

The ^{13}C spectrum of **4a** contained 18 resonances, 12 of which corresponded almost exactly in chemical shift, relative intensity (recorded under widely varying conditions), and ^{13}C–H coupling (Table 1) with the resonances for **3a**. This information combined with the known molecular formula established that **4a** contained 2,2′,4′,6,6′-pentahydroxybiphenoxy and 2,4,6-trihydroxyphenoxy residues, which were asymmetrically substituted on another aromatic ring containing $C_6H_4O_3$. Similarly the ^{13}C spectrum of **4b** supported these conclusions.

The presence of two *meta*-coupled hydrogens limits the choice of structure of the acetylated material to five possibilities, **4b**, and **4d** to **4g**. The choice of **4b** as the correct structure was based on a comparison of the measured ^{13}C chemical shifts for the carbons of the asymmetrically substituted aromatic ring (C-1″ to C-6″) with predicted shifts derived from measurements of acetylated model compounds, as follows. Firstly, three independent predictions were made of the ^{13}C shifts for **4h**.

(*a*) The average effect of replacement of an acetoxy substituent on a ring by a 2,4,6-triacetoxyphenoxy group was estimated by comparing the measured $δ_c$ values for **1b**, **5b**; **2b**, **3b**; **1b**, **8** (18); **5b**, **8** (18): at substituent +6.9 ± 0.2 ppm; *ortho* −5.4 ± 0.4 ppm; *meta* +0.4 ± 0.2 ppm; *para* −2.6 ± 0.7 ppm. This information was then used to predict the ^{13}C chemical shifts for **4h** by applying the substituent effects above, in reverse, to allow for substitution of an acetoxy group at C-1′ of **7b**.

(*b*) The measured shifts of **5b** and **7b** were compared to estimate the substituent effects of acetoxy-substitution at C-4′ of **5b** and these were applied to predict the result of substitution of an acetoxy group at C-2 of **1b**.

(*c*) **1b** and **9** were compared to obtain the effects of acetoxy substitution at C-5 of **9**, and these were used to predict the effect of acetoxy substitution at C-5 of **10**. The averages of these predictions (*a,b,c*) of the $δ_c$ values for **4h** were: C-1″ 132.2 ± 0.9; C-2″,6″ 143.3 ± 0.6; C-3″,5″ 114.4 ± 0.5; C-4″ 147.5 ± 0.6 ppm. When these values were compared with the measured $δ_c$ values for C-1″ to C-6″ of **3b**, the effect of replacing an acetoxy substituent by a (2,2′,4′,6,6′)-pentaacetoxy biphenoxy group was obtainable: at substituent +4.4(±0.9); *ortho* +0.5(±0.6); *meta* +0.8(±0.5); *para* −0.6(±0.6) ppm. The predicted $δ_c$ for **4h** and the substituent effects above were used to predict the chemical shifts for the five alternative structures **4b**, **4d** to **4g**. For example, $δ_c$ for C-1″ of **4b** is given by $δ_c$ for C-1″ of **4h** (132.2 ppm), plus the effect of replacing the acetoxy substituent at C-1″ with a 2,2′,4′,6,6′-pentaacetoxy biphenoxy group (+4.4 ppm) and the effect of replacing the *ortho*-acetoxy at C-2″ by a 2,4,6-triacetoxyphenoxy substituent (−5.4 ppm). The total, 131.2 ppm, is the predicted $δ_c$. The nearest experimental $δ_c$ values for this ring are compared with predictions in Table 2, which also shows the sum of
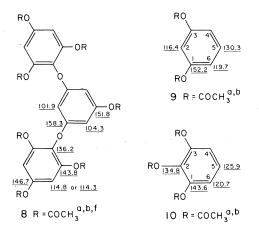
TABLE 2. Comparison of experimental δ_c (ppm) for C-1″ through C-6″ of **4b**, **4d–g** with nearest predicted values

Experimental δ_c (ppm)	Nearest predicted δ_c for alternative structures (ppm)				
	4b	**4d**	**4e**	**4f**	**4g**
112.2	109.8 C-3″	109.5 C-5″	108.4 C-3″	114.2 C-3″	108.4 C-3″
113.8	112.6 C-5″	112.3 C-3″	112.3 C-5″	115.3 C-5″	109.5 C-5″
133.4	131.2 C-1″	126.2 C-1″	127.3 C-1″	138.7 C-2″	130.1 C-1″
144.1	144.2 C-6″	144.5 C-2″	148.1 C-6″	139.6 C-1″	144.5 C-2″
147.3	147.3 C-4″	151.0 C-6″	148.7 C-4″	142.3 C-6″	148.1 C-6″
150.7	150.7 C-2″	152.3 C-4″	151.0 C-2″	145.7 C-4″	155.2 C-4″
$\Sigma \,|(\text{Exptl.} - \text{predicted})|$	5.9	17.1	17.1	23.3	17.3

TABLE 3. Predicted δ_c for C-1″ to C-6″ of **4a** and **4b** (ppm)

		C-1″	C-2″	C-3″	C-4″	C-5″	C-6″
4a	Predicted	125.7	155.2	98.0	156.9	100.5	153.0
	Measured	126.7	154.9	96.7	156.7	100.5	153.3
4b	Predicted	131.2	150.7	109.8	147.3	112.6	144.2
	Measured	133.4	150.7	112.2	147.3	113.8	144.1

8 R = COCH₃ᵃ,ᵇ,ᶠ

9 R = COCH₃ᵃ,ᵇ

10 R = COCH₃ᵃ,ᵇ

the absolute magnitudes of the differences between predicted and experimental values. Thus, structure **4b** is clearly favoured. The predicted shifts for **4b** (or **4a**) may also be calculated from the experimental shifts for **3b** (**3a**) and the substituent effects under (a) above (or the corresponding substituent effect for replacement of OH by a 2,4,6-trihydroxyphenoxy substituent, estimated from experimental data for **1a,5a**; **2a,3a**), again giving close agreement (Table 3) with the other predicted shifts (Table 2, structure **4b**) and with the experimentally measured values.

F. vesiculosus from Nova Scotia has been shown to contain 4-(2″,4″,6″-trihydroxyphenoxy)-2,2′,4′,6,6′-pentahydroxybiphenyl **3a** and 4-(2″-(2‴,4‴,6‴-trihydroxyphenoxy)-4″,6″-dihydroxyphenoxy)-2,2′,4′,6,6′-pentahydroxybiphenyl **4a** in addition to compounds **1a** and **2a** (6). If a terphenyl or quaterphenyls (7) were present in our extracts, their trimethylsilyl ethers should appear at m/e 1022 and 1362, respectively. In fact, only a trace of an otherwise unidentified compound appeared at m/e 1022, and no m/e 1362 ion was observed following gc/ms (Ragan and Craigie, unpublished) and high resolution ms with photoplate ion beam integration. Similarly, the ether linked C_{12} and C_{18} polyphloroglucinols reported from *Bifurcaria bifurcata* (9, 10), *Cystoseira tamariscifolia* (14), *Halidrys siliquosa* (11), and *Laminaria ochroleuca* (18) must occur only in minute quantities, if at all, in our *F. vesiculosus*.

Acknowledgments

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