Reactivity of Carbohydrate Radicals Derived from Iodo Sugars and Dibenzoyl Peroxide. Homolytic Heteroaromatic and Aromatic Substitution, Reduction, and Oxidation

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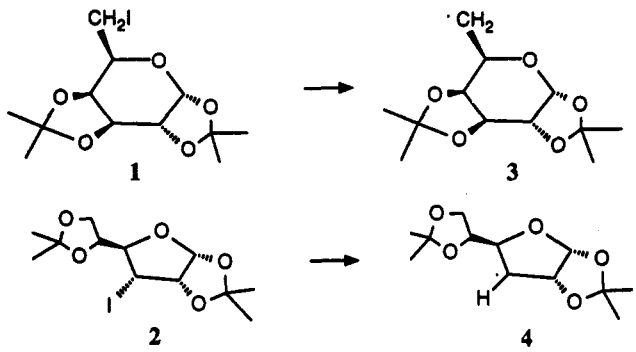
Received December 11, 1991

Introduction

In recent years many reactions of carbohydrate radicals appeared in the literature.[1] However, few intermolecular reactions of synthetic interest involving radicals at nonanomeric centers have been reported; for example, Giese studied the stereoselectivity of carbohydrate five-membered cyclic radicals in addition reactions,[2a] and Branchaud obtained branched-chain monosaccharides via cross-coupling reactions.[2b]

From iodo sugars 1 and 2, radicals 3 and 4 were selectively generated, through reaction with a phenyl radical.[3] Alkyl

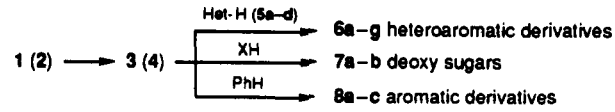


radicals lacking electron-withdrawing groups in the α position, such as 3 and 4, usually react as nucleophilic radicals in aromatic substitutions,[4] and their addition to electron-rich substrates is both slow and nonselective.[5,6]

Results

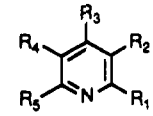
Scheme I summarizes the functionalizations of 1 and 2 through radicals 3 and 4. Starting with the bases **5a–d**,

Scheme I



XH = CH_3CN, dihydrobenzene derivatives, 1 (2).

Scheme II



5a–d, 6a–g

5a: $R_1 = R_2 = R_3 = H$; $R_4–R_5 = (CH)_4$ ⇒ **6a**: $R_1 = 3$; $R_2 = R_3 = H$; $R_4–R_5 = (CH)_4$
5a: $R_1 = R_2 = R_3 = H$; $R_4–R_5 = (CH)_4$ ⇒ **6b**: $R_1 = R_2 \equiv H$; $R_3 = 3$; $R_4–R_5 = (CH)_4$
5b: $R_1 = R_2 = H$; $R_3 = CH_3$; $R_4–R_5 = (CH)_4$ ⇒ **6c**: $R_1 = 3$; $R_1 = H$; $R_3 = CH_3$; $R_4–R_5 = (CH)_4$
5c: $R_1 = CH_3$; $R_2 = R_3 = H$; $R_4–R_5 = (CH)_4$ ⇒ **6d**: $R_1 = CH_3$; $R_2 = H$; $R_3 = 3$; $R_4–R_5 = (CH)_4$
5d: $R_1 = R_2 = R_4 = R_5 = H$; $R_3 = CN$ ⇒ **6e**: $R_1 = 3$; $R_2 = R_4 = R_5 = H$; $R_3 = CN$
5a: $R_1 = R_2 = R_3 = H$; $R_4–R_5 = (CH)_4$ ⇒ **6f–g**: $R_1 = R_2 = H$; $R_3 = 4$; $R_4–R_5 = (CH)_4$

sugar–heteroaromatic cross-coupling reactions provide compounds **6a–g**, eq 1 and Scheme II. Table I reports the

$$\text{Het-H (5a–d)} + (PhCOO)_2 + 1\ (2) \rightarrow \text{6a–g} + PhI + PhCOOH + CO_2 \quad (1)$$

quantitative data; the heteroaromatic bases **5a–d** are converted with good yields into the corresponding derivatives of 6-iodogalactose **1**, **6a–e**, both in benzene and acetonitrile, whereas the heteroaromatic derivatives of 3-iodofuranose **2**, **6f–g**, are formed in lower yields. The product distributions reported in the table indicate that **3** and **4** are scavenged by the protonated heteroaromatic bases in different ways. Heteroaromatic trapping of **3** is significant (entries 1, 2, 3, 5, and 6), even though the deoxy sugar **7a** is almost always formed in significant amounts and the aromatic derivative **8a** is also formed in benzene (entries 5 and 6). In contrast, **4** does not react at all with 4-methylquinoline, while with 2-methylquinoline and quinoline small amounts are trapped. Entries 4 and 7 represent two experiments involving quinoline: the two diastereoisomers **6f** and **6g** are formed by attack at position 4 (89%); derivative **9**, resulting from attack on the aromatic ring at position 8, is the other isolated derivative (11%). No attack occurs at position 2. In these experiments, the main reaction of **4** is iodine abstraction leading to the epimer of **2**, the 3-iodoglucofuranose **10**; different amounts of deoxy sugar **7b** and aromatic derivatives **8b–c**, when generated in benzene, complete the product distribution. The substitions by **3** and **4** on benzene, when used as solvent, have been studied as a new radical arylation pathway for carbohydrates, eq 2. Quantitative data are

$$PhH + (PhCOO)_2 + 1\ (2) \rightarrow \text{8a–c} + PhI + PhCOOH + CO_2 \quad (2)$$

reported in Table II. The hydrogen abstraction process leading to deoxy sugars **7a–b** is an undesirable competitive reaction. The highest yield of **8b–c** (entries 1 and 2) are obtained in dilute solutions and in the presence of $Cu(OAc)_2{\cdot}H_2O$, conditions that minimize the contribution

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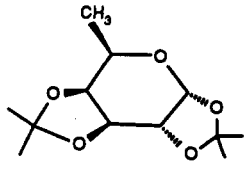
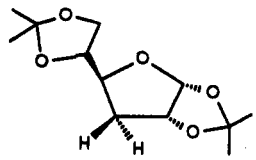


7a



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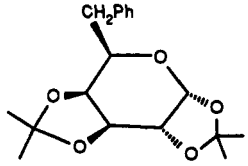
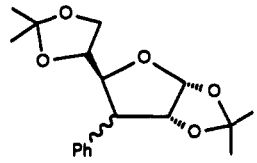
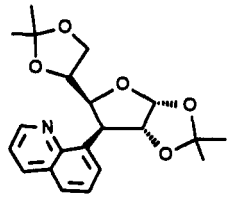


8a



8b-c



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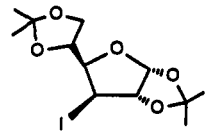

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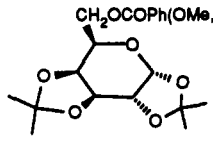

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from the hydrogen abstraction reaction. Figure 1 shows the combined effect of the solution concentration and of Cu(II) on the ratio between **8b–c** and **7b**; no electron-transfer oxidation of **4** is observed in the presence of Cu(II). The yields of **8a** do not exceed 70%, even in the presence of Cu(II) and in dilute solution (entries 3 and 4) as, in this case, Cu(II) oxidizes **3** to **11**. Figures 2 and 3 show the effects of the concentration and of Cu(II) on the optimization of aromatic substitution by **3**. Figure 3 illustrates the limitations on the use of Cu(II), for while it minimizes hydrogen abstraction, it also introduces electron-transfer oxidation.

In the reported experiments we found that Cu(II) reacts in very different ways with **3** and **4**, and we encountered no difficulties of complexation with carbohydrate.[7] Under typical conditions,[8] which generally lead to significant electron-transfer oxidation on unsubstituted alkyl radicals by Cu(II), some of our experiments confirmed the different oxidizabilities of **3** and **4**.

Table III gives the quantitative data for the reductions of **1** and **2** in acetonitrile through hydrogen abstraction by **3** and **4**; disappointingly, the yields of the converted sugars did not reach the levels of the conversions.

Discussion

In the heteroaromatic substitution, both the chemoselectivity and regioselectivity of **3** are typical of a weak nucleophilic radical; in contrast **4** does not react as a nucleophile. Among the many observations which support this conclusion is the regioselectivity that **4** displays in the presence of quinoline. Steric hindrance is clearly not a determining factor, as **4** adds to the most hindered position on the protonated heteroaromatic ring, as well as to the benzene ring.[4,5]

Both **3** and **4** add to benzene, in spite of the fact that hydrogen abstraction occurs simultaneously. A good question to ask is "what is the source of hydrogen in benzene?". In acetonitrile it is easy to explain the formation of deoxy sugars, as the solvent itself is a source of hydrogen,[9] but what happens in benzene? One hypothesis could be that the carbohydrates themselselves, in preference over the starting iodo sugars, undergo hydrogen abstraction. In this case, the importance of hydrogen abstraction might depend on the concentration of the starting iodo sugar. The graphics in Figures 1 and 2 indicate that this hypothesis is reasonable, but also suggest that large amounts of benzene are related to increases in hydrogen abstraction, perhaps due to the presence of significant amounts of dihydrobenzene derivatives[10] in dilute solutions. As Cu(II) eliminates dihydrobenzene derivatives,[11] the curves in the presence of Cu(II) represent only the effect of the concentration of the iodo sugar and demonstrate that both iodo sugars and dihydrobenzene derivatives are sources of hydrogen. The experiments in deuterated benzene are in perfect agreement with this conclusion, as deuterated and nondeuterated deoxy sugars are formed simultaneously in different ratios depending on the Cu(II) concentration. Furthermore, the poor recovery of the sugars in the experiments to obtain deoxy sugars in acetonitrile confirms that hydrogen abstraction does occur to some extent on the carbohydrates themselves.

Radical **3** is partially oxidized by Cu(II); in this electron-transfer oxidation **3** appears to be similar to nucleophilic primary alkyl radicals.[6,12] Radical **4** reacts to a much greater extent with benzene and is not oxidized at all by Cu(II). This finding is consistent with electrophilic character for **4**.[6] Its large change in polar character in comparison with alkyl radicals is evident considering their low reactivity toward benzene ($k \cong 10^2$ M^{-1} s^{-1} for the addition of *n*-Bu; and no reaction for *t*-Bu)[5] and their high oxidation rates by Cu(II) salts ($k \cong 10^6$–10^8 M^{-1} s^{-1}).[9,12]

Conclusion

The reactivities of both **3** and **4** appear to be dependent on the cyclic structure, primarily through the electron-withdrawing and field effects of the five oxygen atoms. Compared with simple unsubstituted alkyl radicals, all five oxygen atoms, especially the one in the β position, reduce the nucleophilic character of **3**. Radical **4**, with two oxygen atoms in the β position, is so different from unsubstituted alkyl radicals that it seems reasonable to call it electrophilic in nature.

Experimental Section

Materials and General Methods. 4-Methylquinoline 99%, quinoline 98%, trifluoroacetic acid, Cu(II) acetate monohydrate

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Table I. Homolytic Heteroaromatic Substitution

entry	base, mol/L	solvent	CF_3COOH, mol/L	iodo sugar, mol/L	$(PhCOO)_2$, mol/L	convn[a] %	yield,[b] % 6a–g	product distribution[c] 6a–g	7a–b	8a–c	10
1	**5b**, 0.1	CH_3CN	0.18	1, 0.15	0.27	100	**6c**, 81	1	**7a**, 0.8		
2	**5c**, 0.07	CH_3CN	0.14	1, 0.1	0.1	72	**6d**, 90	1	**7a**, 0.5		
3	**5d**, 0.08	CH_3CN	0.24	1, 0.11	0.08	50	**6e**, 85	1	**7a**, –		
4	**5a**, 0.4	CH_3CN	0.8	**2**, 1.2	0.8	30	**6f–g**, 90	1	**7b**, 1.0		3.2
5	**5c**, 0.17	benzene	0.34	1, 0.25	0.34	80	**6d**, 82	1	**7a**, 0.4	**8a**, 0.2	
6	**5a**, 0.25	benzene	0.5	1, 0.37	0.5	87	**6a–b**, 70[d]	1	**7a**, 0.17	**8a**, 0.1	
7	**5a**, 0.4	benzene	0.8	**2**, 1.2	0.8	20	**6f–g**, 90	1	**7b**, 1.5	**8b–c**, 0.6	4.4

[a] Conversions are referred to the heteroaromatic bases. [b] Yields are calculated on the converted heteroaromatic bases. [c] The molar ratios are reported, giving the arbitrary value 1 to the heteroaromatic derivatives. [d] Isomer distribution: 36% **6a**; 64% **6b**.

Table II. Homolytic Aromatic Substitution in Benzene

entry	iodo sugar, mol/L	$(PhCOO)_2$, mol/L	Cu^{2+}, mol/L	convn[a] %	yields,[b] % 8a–c	7a–b	11
1	**2**, 0.05	0.10	0.02	84	**8b–c**, 93[c]	**7b**, 7	
2	**2**, 0.05	0.10	0.01	77	**8b–c**, 84[c]	**7b**, 16	
3	1, 0.13	0.13	0.013	57	**8a**, 50	**7a**, 14	26
4	1, 0.06	0.06	0.006	47	**8a**, 67	**7a**, 10	23
5	1, 0.1	0.1		67	**8a**, 30	**7a**, 36	

[a] Conversions are referred to the iodo sugars. [b] Yields are calculated on the converted iodo sugars. [c] Diastereoisomers distribution: 70% **8b**, 30% **8c**.

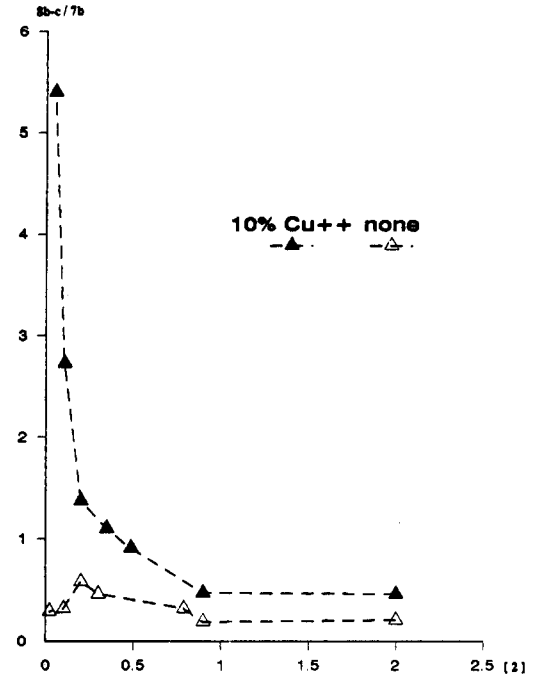

Figure 1. Homolytic aromatic substitution/reduction for radical **4**, depending on the concentration of the starting iodo sugar, in the presence or in the absence of $Cu(OAc)_2$.

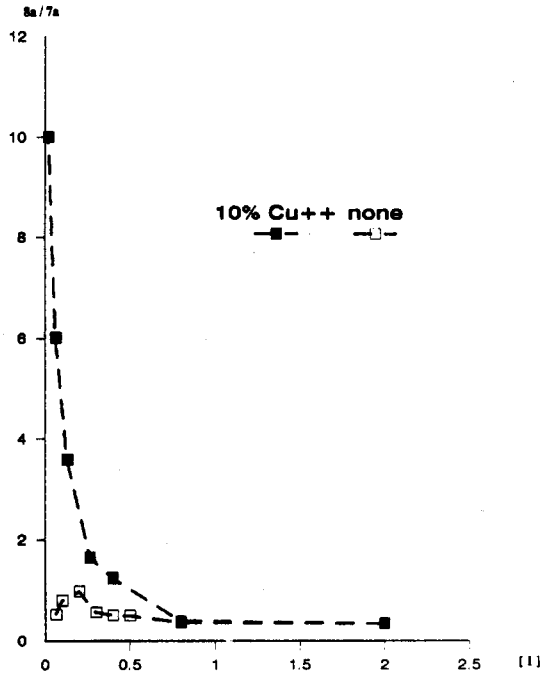

Figure 2. Homolytic aromatic substitution/reduction for radical **3**, depending on the concentration of the starting iodo sugar, in the presence or in the absence of $Cu(OAc)_2$.

99%, triphenylphosphine, imidazole, iodine, and dibenzoyl peroxide, 25%, are from Aldrich Co. 1,2:3,4-Di-*O*-isopropylidene-D-galactopyranose, 99%, 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose, 98%, deuterated acetonitrile, and benzene are also from Aldrich Co. 2-Methylquinoline, 97%, and 4-cyanopyridine, 98%, are from Janssen Co.; acetonitrile and benzene were dried over molecular sieves, 0.4 nm, Merck. Anhydrous dibenzoyl peroxide was obtained by recrystallization of the commercial product in $CHCl_3$/MeOH = 1/1.

Preparation of Iodo Sugars. 1,2:3,4-Di-*O*-isopropylidene-D-galactopyranose and 1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose are easily converted into the corresponding iodo sugars **1** and **2**.[13] The crude reaction mixtures were purified by flash chromatography on 230–400-mesh silica gel. GLC analyses were recorded with a capillary gas chromatograph equipped with a capillary column CP-Sil 5 CB. NMR spectra were recorded at 300 MHz; assignments were made by both mono- and bidimensional approaches. Spectra were obtained in $CDCl_3$ solutions, chemical shifts are reported in parts per million (ppm) from internal tetramethylsilane, and coupling constants (*J*) are reported in hertz.

Homolytic Heteroaromatic Substitution. An anhydrous benzene or acetonitrile solution of the starting iodo sugar, dibenzoyl peroxide, trifluoroacetic acid, and heteroaromatic base at concentrations given in Table I was refluxed until the dibenzoyl peroxide completely disappeared as confirmed by TLC and KI solution spot test (6–10 h). The reactions in benzene were washed with 10% aqueous Na_2CO_3 solution and with water and then dried over $MgSO_4$. Reactions in acetonitrile were slowly poured into a cold 10% aqueous Na_2CO_3 solution; the solutions thus obtained were extracted with methylene chloride and dried. After evaporation of the solvents, the reaction products **6a–g** were isolated by flash chromatography (eluant hexane–ethyl acetate).

(13) Garegg, P. J; Samuelsson, B. *J. Chem. Soc., Perkin Trans. 1* **1980**, 2866.

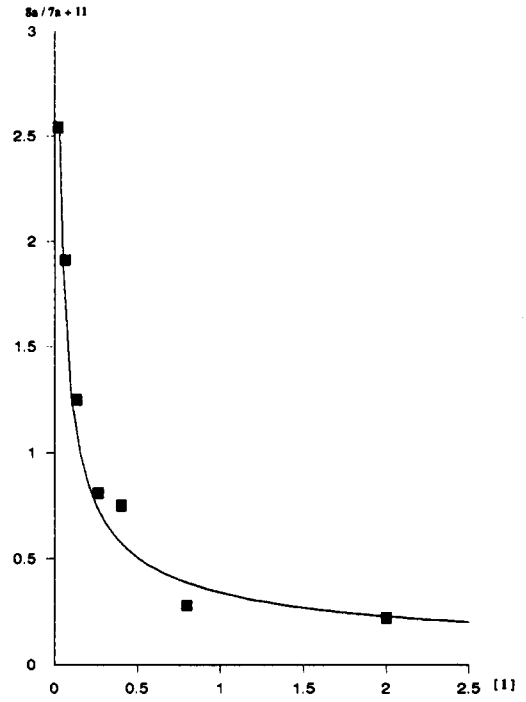

Figure 3. Homolytic aromatic substitution/(reduction + oxidation) for radical **3**, depending on the concentration of the starting iodo sugar, in the presence of $Cu(OAc)_2$.

Table III. Reduction in CH_3CN

entry	iodo sugar, mol/L	$(PhCOO)_2$, mol/L	convn,[a] %	yields,[b] % 7a–b
1	1, 0.07	0.135	100	**7a**, 41
2	**2**, 0.036	0.072	100	**7b**, 63

[a] Conversions are referred to the starting iodo sugars. [b] Yields are based on the converted iodo sugars.

Any subsequent reaction mixtures were methylated with an ethereal solution of diazomethane and analyzed by GLC.

Homolytic Aromatic Substitution. An anhydrous benzene solution of the starting iodo sugar, dibenzoyl peroxide, and $Cu(OAc)_2 \cdot H_2O$ at the concentrations given in Table II was refluxed until the dibenzoyl peroxide completely disappeared (6–10 h). The reaction products were isolated by flash chromatography (eluant hexane–ethyl acetate), **8a–c**. For the reactions with heteroaromatic bases, before analysis by GLC, the carboxylic groups (in this case only benzoic acid) were methylated with an ethereal solution of diazomethane.

Hydrogen Abstraction. An anhydrous acetonitrile solution of the starting iodo sugar and dibenzoyl peroxide, Table III, was refluxed until the dibenzoyl peroxide completely disappeared (6–10 h). After evaporation of the solvent, the products were isolated by flash chromatography, **7a–b** (eluant hexane–ethyl acetate). The reaction mixtures were quantitatively analyzed by GLC, following methylation with an ethereal solution of diazomethane.

Reactions with $Cu_2(OAc) \cdot H_2O$. Some examples of the described procedures were performed in the presence of Cu(II) acetate. Before injecting the methylated samples, the Cu(II) salts were eliminated on a very short silica gel column, using ethyl ether as eluant.

Reactions in Deuterated Solvents. Some examples of the described procedures were conducted in deuterated solvents; they were analyzed by ^1H and ^2H NMR and GC mass spectroscopy.

1,2:3,4-Di-*O*-isopropylidene-6-deoxy-6-iodo-α-D-galactopyranose (1): ^1H NMR (300.13 MHz) δ 1.33, 1.35, 1.45, 1.55 (4 s, 4 × 3 H, CCH_3), 3.20 (dd, 1 H, H-6a, J_{6a-6b} = 10 Hz), 3.32 (dd, 1 H, H-6b), 3.94 (m, 1 H, H-5, J_{5-6} = 7 Hz), 4.35 (dd, 1 H, H-2, J_{2-3} = 1.5 Hz), 4.4 (dd, 1 H, H-4, J_{4-5} = 1.5 Hz), 4.61 (dd, 1 H, H-3, J_{3-4} = 8 Hz), 5.54 (d, 1 H, H-1, J_{1-2} = 5 Hz); ^{13}C NMR (75.47 MHz) δ 2.3 (C-6), 24.4, 24.8, 25.9, 26.0, 68.9, 70.5, 71.1, 71.5, 96.7 (C-1), 108.8, 109.5; mass spectrum, *m/e* 370 (M^+, 3), 355 (M^+ – 15, 100), 297 (95).

1,2:5,6-Di-*O*-isopropylidene-3-deoxy-3-iodo-α-D-allofuranose (2): ^1H NMR (300.13 MHz) δ 1.35, 1.5, 1.55 (4 s, 4 × 3 H, CCH_3), 3.78 (dd, 1 H, H-3, J_{2-3} = 4.5 Hz, J_{3-4} = 10 Hz), 4.07 (dd, 1 H, H-6b, J_{5-6} = 6.5 Hz, J_{6a-6b} = 8.2 Hz), 4.15 (dd, 1 H, H-6a), 4.27 (dd, 1 H, H-4, J_{4-5} = 3.5 Hz), 4.34 (m, 1 H, H-5), 4.61 (dd, 1 H, H-2, J_{1-2} = 3.7 Hz), 5.82 (d, 1 H, H-1); ^{13}C NMR (75.47 MHz) δ 19.2 (C-3), 26.8, 66.4, 76, 82, 82.4, 112 (C-1), 110.4, 112; mass spectrum, *m/e* 370 (M^+, 0.1), 355 (M^+ – 15, 100), 297 (11).

6-Deoxy-6-(2′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-galactopyranose (6a): isolated by flash chromatography on silica gel (EtOAc–hexane, 6:4); ^1H NMR (300.13 MHz) δ 1.20, 1.30, 1.42, 1.45 (4 s, 4 × 3 H, CCH_3), 3.10–3.30 (m, 2 H, H-6a, 6b, J_{6a-6b} = 15.3 Hz), 4.20–4.25 (m, 2 H, H-2, H-4), 4.45–4.50 (m, 1 H, H-5, J_{5-6a} = 8.6 Hz, J_{5-6b} = 4.1 Hz), 4.55 (dd, 1 H, H-3, J_{3-4} = 7.9 Hz, J_{2-3} = 2.4 Hz), 5.40 (d, 1 H, H-1, J_{1-2} = 4.9 Hz), 7.32 (d, 1 H, H-3′, $J_{3'-4'}$ = 9 Hz), 7.35–7.60 (2 m, 2 H, H-6′, H-7′), 7.65 (d, 1 H, H-4′), 7.9–8.0 (m, 2 H, H-5′, H-8′); mass spectrum, *m/e* 371 (M^+, 24), 356 (M^+ – 15, 41), 313 (6), 298 (18), 284 (100), 210 (47), 205 (82), 171 (29). Anal. Calcd for $C_{21}H_{25}O_5N$: C, 67.92; H, 6.74; N, 3.77. Found: C, 67.91; H, 6.74; N, 3.78.

6-Deoxy-6-(4′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-galactopyranose (6b): isolated by flash chromatography on silica gel (EtOAc–hexane, 1:1); ^1H NMR (300.13 MHz) δ 1.20, 1.30, 1.32, 1.45 (4 s, 4 × 3 H, CCH_3), 3.20–3.40 (m, 2 H, H-6a, 6b, J_{6a-6b} = 14.1 Hz), 4.00 (dd, 1 H, H-4, J_{3-4} = 7.99 Hz, J_{4-5} = 1.9 Hz), 4.16 (m, 1 H, H-5, J_{5-6a} = 6.6 Hz, J_{5-6b} = 6.73 Hz), 4.23 (dd, 1 H, H-2, J_{1-2} = 5 Hz, J_{2-3} = 2.5 Hz), 4.50 (dd, 1 H, H-3), 5.49 (d, 1 H, H-1), 7.40 (d, 1 H, H-3′), 7.46–7.60 (2 m, 2 H, H-6′, H-7′), 7.9–8.02 (m, 2 H, H-5′, H-8′), 8.75 (d, 1 H, H-2′, $J_{2'-3'}$ = 4.5 Hz); mass spectrum, *m/e* 371 (M^+, 100), 356 (M^+ – 15, 69), 313 (28), 298 (34), 210 (47), 171 (75). Anal. Calcd for $C_{21}H_{25}O_5N$: C, 67.92; H, 6.74; N, 3.77. Found: C, 67.90; H, 6.74; N, 3.78.

6-Deoxy-6-(4′-methyl-2′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-galactopyranose (6c): isolated by flash chromatography on silica gel (EtOAc–hexane, 6:4); ^1H NMR (300.13 MHz) δ 1.25, 1.35, 1.55 (3 s, 3 H, 3 H, 6 H, CCH_3), 2.70 (s, 3 H, Het-CH_3), 3.15–3.30 (m, 2 H, H-6a, 6b), 4.29 (dd, 1 H, H-4, J_{4-5} = 1.5 Hz, J_{3-4} = 7.5 Hz), 4.31 (dd, 1 H, H-2, J_{1-2} = 5 Hz, J_{2-3} = 2.5 Hz), 4.59 (m, 1 H, H-5), 4.64 (dd, 1 H, H-3), 5.47 (d, 1 H, H-1), 7.25 (s, 1 H, H-3′), 7.4–7.7 (2 t, 2 H, H-5′, H-6), 7.9–8.1 (2 d, 2 H, H-7′, H-8′); mass spectrum, *m/e* 385 (M^+, 45), 370 (M^+ – 15, 60), 298 (100), 157 (95); exact mass measured 385.188 (calculated for $C_{22}H_{25}NO_5$ 385.189).

6-Deoxy-6-(2′-methyl-4′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-galactopyranose (6d): isolated by flash chromatography on silica gel (EtOAc–hexane, 1:1); ^1H NMR (300.13 MHz) δ 1.30, 1.38, 1.4, 1.58 (4 s, 4 × 3 H, CCH_3), 3.31 (dd, 1 H, H-6a, J_{5-6a} = 6.5 Hz, J_{6a-6b} = 15 Hz), 3.42 (dd, 1 H, H-6b, J_{5-6b} = 7.2 Hz), 4.11 (dd, 1 H, H-4, J_{3-4} = 7.7 Hz, J_{4-5} = 1.5 Hz), 4.24 (m, 1 H, H-5), 4.31 (dd, 1 H, H-2, J_{2-3} = 2.2 Hz), 4.58 (dd, 1 H, H-3), 5.58 (d, 1 H, H-1), 7.40 (s, 1 H, H-3′), 7.45–7.7 (2 t, 1 H, H-6′, H-7′), 8.02 (2 d, 2 H, H-5′, H-8′); mass spectrum, *m/e* 385 (M^+, 52), 370 (M^+ – 15, 20), 171 (28), 157 (100), 113 (29), 100 (35), 71 (55). Anal. Calcd for $C_{22}H_{27}O_5N$: C, 68.57; H, 7.01; N, 3.64. Found: C, 68.61; H, 6.98; N, 3.62.

6-Deoxy-6-(4′-cyano-2′-pyridyl)-1,2:5,6-di-*O*-isopropylidene-α-D-galactopyranose (6e): isolated by flash chromatography on silica gel (EtOAc–hexane, 8:2); ^1H NMR (300.13 MHz) δ 1.30, 1.37, 1.49, 1.51 (4 s, 4 × 3 H, CCH_3), 3.07 (dd, 1 H, H-6a, J_{5-6a} = 5.4 Hz, J_{5-6b} = 9.0 Hz, J_{6a-6b} = 14.0 Hz), 3.19 (dd, 1 H, H-6b), 4.20 (dd, 1 H, H-4, $J_{3'-4}$ = 7.8 Hz, J_{4-5} = 2.0 Hz), 4.31 (dd, 1 H, H-2, J_{1-2} = 5.0 Hz, J_{2-3} = 2.5 Hz), 4.32 (m, 1 H, H-5), 4.64 (dd, 1 H, H-3), 5.48 (d, 1 H, H-1), 7.35 (dd, 1 H, H-5′), 7.55 (s, 1 H, H-3′), 8.7 (dd, 1 H, H-6′); mass spectrum, *m/e* 346 (M^+, 2), 331 (M^+ – 15, 52), 273 (37), 259 (39), 185 (100); IR spectrum wavenumber 2300 cm^{-1} (C≡N). Anal. Calcd for $C_{18}H_{22}O_5N_2$: C, 62.42; H, 6.36; N, 8.09. Found: C, 62.44; H, 6.45; N, 8.01.

3-Deoxy-3-(4′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (6f): isolated by flash chromatography on silica gel (EtOAc–hexane, 7:3); ^1H NMR (300.13 MHz) δ 0.88, 1.37, 1.65 (3 s, 3 H, 6 H, 3 H, CCH_3), 3.49 (m, 1 H, H-5), 3.76–3.85 (2 m, 2 × 1 H, H-6a, 6b), 4.37 (d, 1 H, H-3, J_{3-4} = 5 Hz), 4.54 (dd, 1 H, H-4, J_{4-5} = 7.5 Hz), 4.79 (d, 1 H, H-2, J_{1-2} = 3.7 Hz), 6.18 (d, 1 H, H-1), 6.98 (d, 1 H, H-3′, $J_{2'-3'}$ = 4.0 Hz), 7.58–7.74 (2 m,

2 H, H-6′, H-7′), 8.13–8.20 (m, 2 H, H-5′, H-8′), 8.84 (d, 1 H, H-2′); mass spectrum *m/e* 371 (M^+, 16), 356 (M^+ – 15, 34), 313 (6), 298 (6), 269 (M^+ – 101, 18), 212 (26), 184 (100). Anal. Calcd for $C_{21}H_{25}O_5N$: C, 67.92; H, 6.74; N, 3.77. Found: C, 67.91; H, 6.76; N, 3.75.

3-Deoxy-3-(4′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (6g): isolated by flash chromatography on silica gel (EtOAc–hexane, 8:2); ^{1}H NMR (300.13 MHz) δ 1.10, 1.20, 1.25, 1.45 (4 s, 4 × 3 H, CCH_3), 3.65–3.75 (m, 2 H, H-6a, 6b), 3.90 (dd, 1 H, H-3), 4.15 (m, 1 H, H-5), 4.70 (dd, 1 H, H-4), 4.85 (dd, 1 H, H-2), 6.0 (d, 1 H, H-1), 7.36 (d, 1 H, H-3′, $J_{2'-3'}$ = 3 Hz), 7.56–7.68 (2 m, 2 H, H-6′, H-7′), 7.95–8.15 (2 m, 2 H, H-5′, H-8′), 8.82 (d, 1 H, H-2′); mass spectrum, *m/e* 371 (M^+, 16), 356 (M^+ – 15, 31), 341 (M^+ – 30, 16), 313 (22), 264 (47), 212 (41), 184 (100). Anal. Calcd for $C_{21}H_{25}O_5N$: C, 67.92; H, 6.74; N, 3.77. Found: C, 67.95; H, 6.81; N, 3.79.

6-Deoxy-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (7a):[14] isolated by flash chromatography on silica gel (EtOAc–hexane, 9:1); ^{13}C NMR (75.47 MHz) δ 15.94 (C-6), 24–26 (CH_3), 63.49, 70.37, 70.96, 73.54, 96.56 (C-1), 108.25, 108.95; mass spectrum, *m/e* 229 (M^+ – 15, 52), 171 (8), 129 (10), 113 (72), 100 (54), 83 (100).

3-Deoxy-1,2:5,6-di-*O*-isopropylidene-α-D-*ribo*-hexofuranose (7b):[14] isolated by flash chromatography on silica gel (EtOAc–hexane, 7:3); ^{13}C NMR (75.47 MHz) δ 25–27 (CH_3), 35 (C-3), 67 (C-6), 77 (C-5), 79 (C-4), 81 (C-2), 106 (C-1), 109, 112; mass spectrum, *m/e* 229 (M^+, 15, 60), 143 (67), 111 (89), 101 (43), 85 (100).

6-Deoxy-6-phenyl-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (8a): isolated by flash chromatography on silica gel (EtOAc–hexane, 9:1); ^{1}H NMR (300.13 MHz) δ 1.32, 1.36, 1.50, 1.52 (4 s, 4 × 3 H, CCH_3), 2.97 (d, 2 H, H-6, J_{5-6} = 7.2 Hz), 3.97 (m, 1 H, H-5), 4.06 (dd, 1 H, H-4, J_{3-4} = 8.0 Hz, J_{4-5} = 2.0 Hz), 4.31 (dd, 1 H, H-2, J_{1-2} = 5.2 Hz, J_{2-3} = 2.4 Hz), 4.55 (dd, 1 H, H-3), 5.56 (d, 1 H, H-1), 7.15–7.35 (m, 5 H, C_6H_5); mass spectrum, *m/e* 305 (M^+ – 15, 28), 262 (31), 229 (15), 91 (100); exact mass measured 305.140 (calculated for $C_{17}H_{21}O_5$ 305.139). Anal. Calcd for $C_{18}H_{24}O_5$: C, 67.5; H, 7.5. Found: C, 67.49; H, 7.5.

3-Deoxy-3-phenyl-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (8b): isolated by flash chromatography on silica gel (EtOAc–hexane, 9:1); ^{1}H NMR (300.13 MHz) δ 1.14, 1.34, 1.40, 1.58 (4 s, 4 × 3 H, CCH_3), 3.49 (d, 1 H, H-3, J_{3-4} = 4.5 Hz), 3.56 (m, 1 H, H-5, J_{5-6a} = J_{5-6b} = 6 Hz), 3.71–3.84 (2 m, 2 H, H-6a, H-6b, J_{6a-6b} = 8.5 Hz), 4.36 (dd, 1 H, H-4, J_{4-5} = 8.5 Hz), 4.74 (d, 1 H, H-2, J_{1-2} = 3.5 Hz), 6.06 (d, 1 H, H-1), 7.1–7.2 (m, 2 H, H-2′, H-6′), 7.3–7.5 (m, 3 H, H-3′, H-4′, H-5′); ^{13}C NMR (75.47 MHz) δ 136.7 (C-1′), 128.9, 128.4, 127 (C-4′), 105.8 (C-1), 86.2, 81, 73.6, 67.3 (C-6), 53.5 (C-3), 26.8, 26.7, 26, 25.2; mass spectrum *m/e* 305 (M^+ – 15, 63); 219 (74), 187 (33), 161 (100); exact mass measured 305.141 (calculated for $C_{17}H_{21}O_5$ 305.139).

3-Deoxy-3-phenyl-1,2:5,6-di-*O*-isopropylidene-α-D-allofuranose (8c): isolated by flash chromatography on silica gel (EtOAc–hexane, 8:2); ^{1}H NMR (300.13 MHz) δ 1.20, 1.21, 1.25, 1.31 (4 s, 4 × 3 H, CCH_3), 3.12 (dd, 1 H, H-3, J_{3-4} = 10.7 Hz), 3.57 (dd, 1 H, H-6b, J_{6a-6b} = 8.2 Hz), 3.87 (dd, 1 H, H-6a), 4.25 (m, 1 H, H-5, J_{5-6} = 6.7 Hz), 4.55 (dd, 1 H, H-4, J_{4-5} = 3.7), 4.70 (dd, 1 H, H-2, J_{1-2} = 3.6 Hz, J_{2-3} = 4.1 Hz), 5.93 (d, 1 H, H-1), 7.2–7.4 (m, 5 H, C_6H_5); mass spectrum, *m/e* 305 (M^+ – 15, 26), 219 (37), 187 (18), 161 (100). Anal. Calcd for $C_{18}H_{24}O_5$: C, 67.5; H, 7.5. Found: C, 67.51; H, 7.49.

3-Deoxy-3-(8′-quinolyl)-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (9): ^{1}H NMR (300.13 MHz) δ 0.85, 1.40, 1.60 (3 s, 3 H, 6 H, 3 H, CCH_3), 3.34 (m, 1 H, H-5, J_{4-5} = 8.85 Hz, J_{5-6a} = 5.99 Hz, J_{5-6b} = 5.97 Hz), 3.70 (dd, 1 H, H-6a, J_{6a-6b} = 8.5 Hz), 3.83 (dd, 1 H, H-6b); 4.30 (d, 1 H, H-3, J_{3-4} = 4.9 Hz), 4.51 (dd, 1 H, H-4, J_{4-5} = 8.84 Hz), 4.86 (d, 1 H, H-2, J_{1-2} = 3.79 Hz), 6.20 (d, 1 H, H-1), 7.08 (dd, 1 H, H-7′, $J_{6'-7'}$ = 7.6 Hz, $J_{5'-7'}$ = 0.97 Hz), 7.43 (dd, 1 H, H-3′, $J_{2'-3'}$ = 3.82 Hz, $J_{3'-4'}$ = 8.85 Hz), 7.67 (dd, 1 H, H-6′, $J_{5'-6'}$ = 8.57 Hz), 8.06 (dd, 1 H, H-5′, $J_{4'-5'}$ = 0.82 Hz), 8.54 (dd, 1 H, H-4′, $J_{3'-4'}$ = 8.7 Hz), 8.94 (dd, 1 H, H-2′).

3-Deoxy-3-iodo-1,2:5,6-di-*O*-isopropylidene-α-D-glucofuranose (10):[14] isolated by flash chromatography on silica gel (EtOAc–hexane, 9:1); ^{13}C NMR (75.47 MHz) δ 25, 26.3, 26.7, 27 (CH_3), 34 (C-3), 67.3 (C-6), 79 (C-5), 79.3 (C-4), 88.3 (C-2), 105 (C-1), 109.6, 112.7; mass spectrum, *m/e* 355 (M^+ – 15, 5), 237 (14), 185 (33), 159 (50), 110 (33), 101 (M^+ – 269, 100).

6-Acetyl(benzoyl)-1,2:3,4-di-*O*-isopropylidene-α-D-galactopyranose (11).[15] Spectra of these products are compared with the spectra of their authentic samples.

Acknowledgment. We gratefully acknowledge the financial support of C.N.R. (Consiglio Nazionale delle Ricerche): Progetto Finalizzato Chimica Fine 2 and Comitato Nazionale Ricerche Tecnologiche.

Supplementary Material Available: ^{1}H NMR (300.13 MHz) and ^{13}C NMR (75.47 MHz) spectra of **8b** and ^{1}H NMR (300.13 MHz) spectra of **6c** and **9** (9 pages). This material is contained in libraries on microfiche, immediately follows this article in the microfilm version of the journal and can be ordered from the ACS; see any current masthead page for ordering information.

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