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Homo-C-nucleoside analogs III. Studies on the base-catalyzed dehydrative cyclization of 4-(D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole ☆

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ABSTRACT

Treatment of 4-(D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole with one molar equivalent of 2,4,6-triisopropylbenzenesulfonyl chloride (TIBSCl) in pyridine solution afforded the homo-C-nucleoside analog; 4-(2,5-anhydro-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole in 54% yield and 4-(α-D-arabinopyranosyl)-2-phenyl-2*H*1,2,3-triazole analog in 3% yield. The 4-(5-*O*-triisopropylbenzenesulfonyl)-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole analog was isolated as an intermediate and identified as its tetra-*O*-acetyl derivative. The 4-(5-chloro-5-deoxy-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole analog was isolated as a byproduct. The structure and anomeric configuration of the products were determined by acylation, NMR spectroscopy, and mass spectrometry.

1. Introduction

We have recently been interested[2–6] in the synthesis of C-nucleoside analogs by dehydrative cyclization of heterocyclic polyhydroyalkyl analogs. The acid-catalyzed dehydrative cyclization of tetrahydroxyalkyl heterocyclic analogs[4–7] is stereospecific giving furanosyl C-nucleoside analogs having the trans arrangement of the base moiety and the 2′-hydroxyl group as the predominant anomer. The acid-catalyzed dehydrative cyclization of pentahydroxyalkyl heterocycles[2,3] is stereorandom, giving a mixture of anomeric pyranosyl and furanosyl C-nucleoside analogs.

The base-catalyzed dehydrative cyclization of tetrahydroxyalkyl heterocycles[8–10] in pyridine solution with one molar equivalent of *p*-toluenesulfonyl chloride is an internal S_N2 stereospecific process giving furanosyl heterocyclic C-nucleoside analogs without inversion at C-1′ of the tetrahydroxyalkyl chain. This method has the advantage of producing rare C-nucleoside analogs having a cis arrangement of the base moiety and the 2′-hydroxyl group. The base-catalyzed dehydrative cyclization of the corresponding pentahydroxyalkyl heterocycles[1,11] in pyridine solution gives homo-C-nucleoside analogs having a carbon bridge between the base moiety and the furanosyl part, by 2,5-dehydrative cyclization. This method has been used before for the synthesis of similar heterocyclic homo-C-nucleosides.[12,13] The 2,5-dehydrative cyclization process is highly affected[12–15] by the configuration of the acyclic polyhydroxyalkyl chain. The 2,5-dehydrative cyclizations of 4-(D-*galacto*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole[11] and 4-(D-*gluco*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole[1] using *p*-toluenesulfonyl chloride in pyridine solution to give the corresponding homo-C-nucleoside analogs have been studied.

In this work, the dehydrative cyclization of 4-(D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (**1**) using the sterically hindered triisopropylbenzenesulfonyl chloride in pyridine solution is evaluated. The products of the reaction were isolated and identified by acylation, NMR spectroscopy, and mass spectrometry (MS).

2. Results and discussion

Treatment of **1** with one molar equivalent of 2,4,6-triisopropylbenzenesulfonyl chloride (TIBSCl) in pyridine solution afforded the homo-C-nucleoside analog, 4-(2,5-anhydro-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (**3**), in 54% yield. The bulky TIBSCl is specific for substitution only at the primary hydroxyl group. Acetylation of **3** gave the tri-*O*-acetyl derivative **4**. Its ^{1}H NMR spectrum (Table 1) showed three signals corresponding to three *O*-acetyl groups. Comparison of the ^{1}H NMR spectrum of **3** and **4** (Table 1) revealed a downfield shift of H-1′, H-3′, and H-4′ due to α-acetylation at these positions, in accord with 2,5-cyclization. Similarly, comparison of the acyclic pentaacetyl derivative **2** and the cyclic triacetyl derivative **4** showed an upfield shift of H-2′ and H-5′ for compound **4** due to the absence of α-acetylation at these positions supporting 2,5-cyclization for compound **4** (Scheme 1).

Additional evidence for the 2,5-cyclization was obtained from the ^{13}C NMR spectra of compounds **3** and **4** (Table 2). The C-2′ signal of **4** (having two acetoxyl groups at the β-position) was shifted

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upfield (δ 79.2) than that of **3** (δ 81.8). Similarly the C-5 signal for **4** (having one β-acetoxyl group) showed an upfield shift (δ 70.8) relative to that for **3** (δ 72.4**)**. On the other hand, the chemical shift of the anomeric carbon C-2′ for compounds **3** and **4** was shifted downfield from the rest of the glycosyl carbons, in accord with the proposed 2,5-anhydro ring structure. The chemical shift of C-5′ for **3** is observed downfield (δ 72.4) from the expected chemical shift for a primary carbon atom carrying a hydroxyl group (δ 60–64) in 1,4-furanosides,[1] which excludes the possibility of 1,4-cyclization.

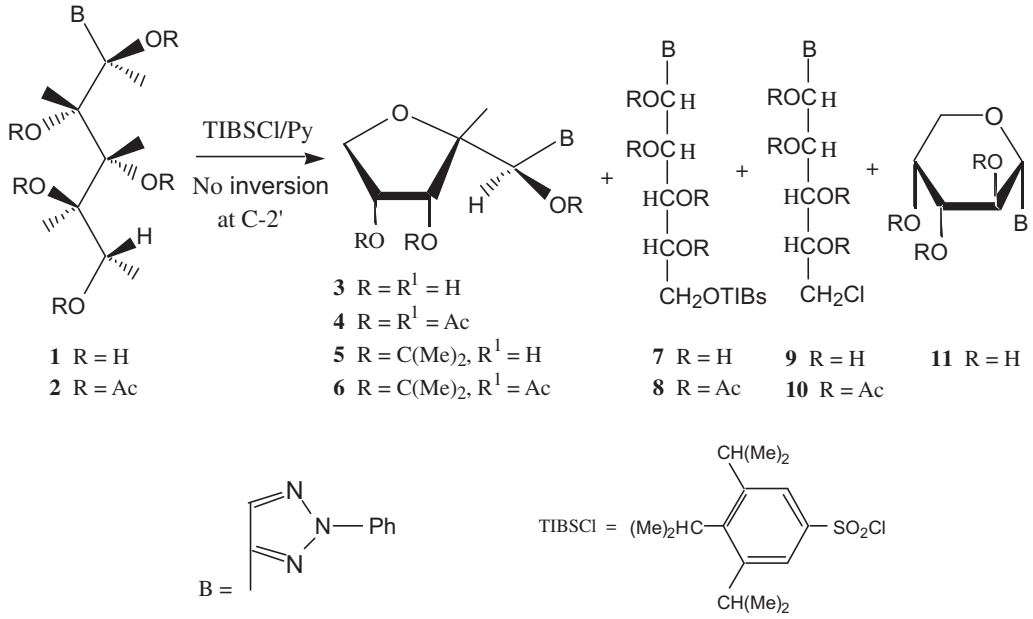
The assignment of the anomeric configuration of **3** could not be obtained from the value of the coupling constant ($J_{2',3'}$ 4.6 Hz) or from that of its acetyl derivative **4** ($J_{2',3'}$ 3.8 Hz). Its 2,3-*O*-isopropylidene derivative **5** showed the anomeric proton H-2′ as a doublet of doublets at δ 3.87 having a coupling constant of $J_{2',3'}$ 3.8 Hz. The chemical shift difference of Δδ 0.217 (1.564−1.347) for the two methyl signals of the 2,2-dimethyldioxolane ring suggests[16] a β-D-configuration for the furanosyl ring formed. Similar results were observed for the *gluco* analog,[1] which has a similar anomeric configuration. However, the 1-*O*-acetyl-2,3-*O*-isopropylidene derivative **6** showed the anomeric proton H-2′ as a doublet of doublets at δ 4.10 having a coupling constant of $J_{2',3'}$ 7.7 Hz in accord[17] with the cis arrangement of H-2′ and H-3′. The chemical shift difference of the two methyl signals of the 2,2-dimethyldioxolane ring Δδ 0.115 (1.441–1.326) is in accord with the α-D-configuration of the glycofuranosyl ring formed.

Additional evidence of the α-D-configuration of the glycofuranosyl ring formed was obtained from the ^{13}C NMR spectrum of **5**. The two methyl signals of the 2,2-dimethyldioxolane ring were shown at δ 25.992 and δ 24.466, having a Δδ 1.526. These values are closer[17,18] to the values expected for α-D-anomers (δ 26.3 ± 2 and δ 24.9 ± 3; Δδ 1.4) than those for the β-D-anomers (δ 25.5 ± 2 and δ 27.5 ± 2; Δδ 2.0). The chemical shift of the acetonide carbon (δ 112.7) for **5** is in the range of the values for the α-anomers (δ 112–113) instead of those for the β-anomers (δ 113–114).

Table 1
^{1}H NMR chemical shifts (δ) and first-order coupling constants (J Hz) for compounds **1–6**, and **8–10**

	Glycosyl part									2-Phenyl-2*H*-1,2,3-triazole			
Compound	H-1′	H-2′	H-3′	H-4′	H-5′	H-5″	(OH)	OAc	CMe_2	H-5	H-*O*	H-*m*	H-*p*
1[a]	4.73d $J_{1',2'}$ 9.2	3.92d $J_{2',3'}$ 0.0	3.69d $J_{3',4''}$ 8.4	3.48m	3.62dd $J_{5',5'}$ 3.1	3.41dd $J_{4',5''}$ 6.6	5.47d *J* 6.1 4.46d *J* 5.4 4.35t 4.28d *J* 4.6 4.27d *J* 3.9			7.94s	7.96d	7.53t	7.36t
2[b]	6.05d $J_{1',2'}$8.4	5.79dd $J_{2',3'}$2.3	5.64dd $J_{3',4'}$ 9.1	5.12m	4.23dd $J_{4',5'}$ 3.1 $J_{5',5''}$12.2	4.12dd $J_{4',5''}$4.5		2.09 2.08 2.06 2.06 1.95		7.79s	7.97d	7.53t	7.36t
3[b]	5.29d $J_{1',2'}$ 6.2	4.23at $J_{2',3'}$4.6	4.45at *J* 5.4	4.36m	→3.89m←		*			7.87s	7.98d	7.44t	7.32t
4[b]	6.23d $J_{1',2'}$9.2	4.68dd $J_{2',3'}$ 3.8	5.72t $J_{3',4'}$ 4.6	5.41m	4.13dd $J_{4',5'}$7.6 $J_{5',5''}$9.2	3.87dd $J_{4',5''}$9.2		2.13s (1′Ac) 2.04s 2.04s (3′,4′Ac)		7.87s	8.06d *J* 7.7	7.47t	7.35t
5[b]	5.30d $J_{1',2'}$6.2	3.87dd $J_{2',3'}$3.8	4.90dd $J_{3',4'}$6.1	4.83q $J_{4',5'}$6.2	4.14dd $J_{4',5'}$ 0.0 $J_{5',5''}$10.7	3.58dd $J_{4',5''}$3.8	*		1.564s 1.347s — Δδ 0.217	7.89s	8.05d	7.45t	7.33t
6[b]	6.20d $J_{1',2'}$9.1	4.10 $J_{2',3'}$7.7	→4.822s←		4.06d	3.54d *J* 10.7		2.10s	1.441s 1.326s — Δδ 0.115	7.88s	8.05d	7.45t	7.26t
8[b,c]	5.99d $J_{1',2'}$9.1	5.76dd $J_{2',3'}$2.3	5.69dd $J_{3',4'}$ 2.3	5.09m	→4.15m←			2.09s 2.07s 2.00s 1.89s		7.78s	8.01d	7.46t	7.34t
9[a]	4.59d $J_{1',2'}$9.2	3.94d $J_{2',3'}$0.0	3.73m	→3.69m←		3.85d *J* 9.2	5.51d $J_{1',OH}$5.7 5.04d $J_{2',OH}$5.1 4.53d $J_{3',OH}$7.7 8.1d $J_{4',OH}$			7.97s	7.56d	7.55t	7.38t
10[b]	5.16d $J_{1',2'}$3.3	5.46d $J_{2',3'}$1.4	5.40d $J_{3',4'}$3.9	4.50m	4.37 $J_{4',5'}$4.7	4.26 $J_{4',5'}$ 7.1		2.13s 2.08s 2.02s		7.82	8.02	7.45	7.32

[a] In DMSO-d_6 at 500 MHz.
[b] In $CDCl_3$ at 500 MHz; at = apparent triplet.
[c] TIBS group at δ 7.17s (ar 2H), δ 2.89 m, 1H, isopropyl CH, and δ 1.24 d isopropyl CH_3 groups.
* Exchangeable in $CDCl_3$.



Scheme 1. Dehydrative cyclization of 4-(D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (**1**), under basic conditions.

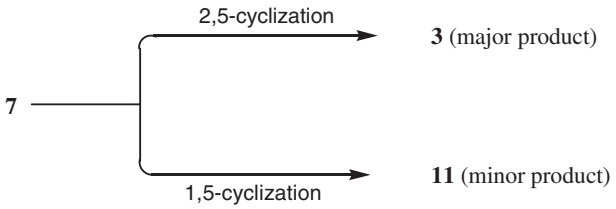
Table 2
^{13}C NMR chemical shift (δ) for compounds **1**–**6** at 125 MHz

Compd	Glycosyl part								2-Phenyl-2*H*-1,2,3-triazole					
	C-1′	C-2′	C-3′	C-4′	C-5′	Ac		CMe_2	C-4	C-5	C-a	C-*o*	C-*m*	C-*p*
						CO	CH_3							
1[a]	66.4	72.0	69.9	71.8	64.4				139.9	135.4	153.8	120.0	130.0	127.8
2[b]	65.3	69.6	67.5	68.0	61.9	170.8	21.0							
						170.1	20.9							
						169.7	20.8							
						169.6	20.7							
						169.4	20.7							
3[b]	67.2	81.8	72.5	71.9	72.4				139.7	134.4	149.4	119.0	129.4	127.8
4[b]	64.9	79.2	71.6	76.9	70.8	170.3	20.9		139.7	135.6	145.9	119.2	129.4	127.8
						170.1	20.6							
						169.4	20.6							
5[b]	66.3	88.3	81.0		73.1			25.992	139.9	135.4	146.8	119.2	129.2	127.6
								24.466						
								—						
								$\Delta\delta$ 1.526						
								>C 112.7						
6[b]	65.7	82.3	80.9	80.3	73.4	169.5	21.1	25.974	139.9	135.4	146.8	119.2	129.2	127.6
								24.952						
								—						
								$\Delta\delta$ 1.022						
								>C 112.7						

[a] In DMSO-d_6.
[b] In $CDCl_3$.

The anomeric configuration of **3** was ascertained from the NOE difference for its acetyl derivative **4**, which showed an enhancement (3.6%) at H-4′ upon irradiation at H-2′. Similarly, irradiation at H-4′ showed enhancement (3.4%) at H-2′. This indicates the presence of H-2′ and H-4′ at the same face of the α-D-*erythro*-pentofuranosyl ring. Compound **3** is therefore obtained from **1** without inversion at C-2′.

The intermediate 4-(5-*O*-triisopropylbenenesulfornyl-5-deoxy-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (**7**) was isolated in the early fractions of the silica gel column and identified as its tetraacetyl derivative **8**. The ^{1}H NMR spectrum of **8** showed four signals corresponding to four acetyl groups. The 5′-*O*-triisopropylbenzenesulfonyl group was indicated by the presence of a singlet at δ 7.17 with an intensity of two protons and an upfield doublet at δ 1.24 corresponding to the methyl signals of the isopropyl groups. Its mass spectrum showed the correct molecular ion at *m/z* 729. Purification of **7** on PLC plates resulted in simultaneous cyclization of **7** giving **3** as a major product and 4-(α-D-arabinopyranosyl)-2-phenyl-2*H*-1,2,3-triazole (**11**) as a minor product (see Scheme 2). Compound **3** is formed from **7** by intramolecular S_N2 attack of the suitably disposed 2′-OH on the powerful leaving group at C-5′ giving the furanosyl 2,5-anhdro derivative as the major kinetic product. The S_N2 attack of 1′-OH to C-5′ gives the 1,5-anhydropyranosyl analog **11** as a thermodynamic minor product. Compound **11** has been isolated[2] from the acid-catalyzed dehydrative cyclization of **1**.



Scheme 2. Simultaneous cyclization of 4-(5-*O*-triisopropylbenzenesulfonyl-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole **7**.

The dehydrative cyclization of 4-(pentahydroxypentyl-1-yl)-2-phenyl-2*H*-1,2,3-triazole analogs, in general, takes place in basic medium by the 2,5-dehydrative cyclization process, which is a more favorable process. This transformation takes place through the formation of a 5′-intermediate giving carbon-bridged homo-C-nucleoside analogs. The 5′-intermediate is favorably attacked by O-2′ rather than by O-1′ in basic medium. However, in acid medium the 1′-OH attack is the more favorable process giving 1,4-furanosyl and 1,5-pyranosyl anomeric pairs.

The byproduct 5-chloro-5-deoxy analog **9** was isolated from the reaction mixture. Its ^{1}H NMR spectrum showed four doublets exchangeable by deuteration, corresponding to four secondary hydroxyl groups. Acetylation of **9** gave the tetra-*O*-acetyl derivative **10**. The position of the chlorine atom was ascertained by the downfield shift of the geminal protons H-5′, H-5″ for **9** compared to that of **1**. The formation of **9** is explained by the nucleophilic substitution of the triisopropylbenzenesulfonyl group at **7** by the chloride anion liberated in the reaction mixture. Similar chloro analogs were isolated from the reaction mixture of the dehydrative cyclization of 4-(D-*gluco*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazol,[1] the D-*arabino*-analog,[8] and from the reaction of tetritols[19,20] with *p*-toluenesulfonyl chloride in pyridine solution.

3. Conclusions

The base-catalyzed dehydrative cyclization of 4-(D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole with 2,4,6-triisopropylbenzenesulfonyl chloride in pyridine solution afforded the homo-C-nucleoside analog; 4-(2,5-anhydro-D-*manno*)-2-phenyl-2*H*-1,2,3-triazole as a major product. The dehydrative cyclization in basic medium takes place through the formation of the acyclic 5-arylsulfonyl analog that preferentially undergoes internal 2,5-S_N2 cyclization giving the homo-C-nucleoside analog as the major kinetic product. A minor thermodynamic product, 4-(α-D-arabino-pyranosyl)-2-phenyl-2*H*-1,2,3-triazole is obtained by 1,5-S_N2 cyclization. The dehydrative cyclization process takes place without inversion at C-2′. The acyclic 5-chloro-5-deoxy analog is isolated as a byproduct from the reaction mixture.

4. Experimental

4.1. General methods

Melting points were determined with a Fisher–Johns instrument. Evaporations were performed under diminished pressure below 60 °C. Thin-layer chromatography (TLC) was conducted on Silica Gel G (Kieselgel G, E. Merck) with solvent **A** (4:1 EtOAc–hexane), **B** (3:1 EtOAc–hexane), **C** (1:3 EtOAc–hexane), and **D** (2:3 EtOAc–hexane). Compounds were detected under short-wave UV light at 254 nm. PLC was conducted on Silica Gel G (E. Merck 0.2 mm). Optical rotations and ORD measurements were obtained at 20 ± 2 °C with Perkin–Elmer 241 and Jasco P1030 polarimeters (10 cm, 1 mL micro cell). ^{1}H NMR spectra were recorded with a Jeol JNM ECA 500 MHz Delta 2, NMR spectrometer. ^{1}H NMR chemical shifts were assigned by 2D NMR experiments. ^{13}C NMR spectra were recorded with a Jeol JNM ECA 500 MHz, at 125.7 MHz. ^{13}C NMR chemical shifts were assigned by HMQC experiments. Mass spectra were recorded with a Finnigan 4021 and Shimadzu GC–MS-QP 1000 EX low-resolution EI–CI spectrometer at 70 eV. High-resolution mass spectra were recorded with a VG analytical model 70-250 spectrometer, and electrospray-ionization MS (ESIMS) was carried out on a Microtof instrument. Combustion analyses were performed at M-H-W Laboratories, Phoenix, Az 85016, USA.

4.2. Treatment of 1 with 2,4,6-triisopropylbenzenesulfonyl chloride

4-(D-*manno*-Pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole[2] (**1**, 0.5 g, 1.7 mmol) in anhyd pyridine (10 mL) was treated with TIBSCl (565 mg, 1.9 mmol) at room temperature with stirring for 48 h. The mixture was evaporated to a syrup. Traces of pyridine were removed by spin co-evaporation with toluene. The dry syrup was applied to a column (2.5 × 46 cm) of Silica Gel 60 and flash eluted with solvent **A**. Fractions (15 mL) were collected, and identical fractions were combined. Fractions 3–5 showed a more mobile zone that was collected and evaporated to dryness giving 2-phenyl-4-(5-*O*-triisopropylbenzenesulfonyl-D-*manno*-pentitol-1-yl)-2-*H*-1,2,3-triazole (**7**) as a syrup, (yield 112 mg; 22%), R_f 0.70 (A). Further purification of **7** on PLC plates resulted in the formation of two spots at the R_f of **3** (major) and **11** (minor). The crude product was identified by acetylation.

4.3. 2-Phenyl-4-(1,2,3,4-tetra-*O*-acetyl-5-*O*-triisopropylbenzenesulfonyl-D-*manno*-pentitol-1-yl)-2*H*,1,2,3-triazole (8)

The dry syrup of compound **7** (12 mg) was acetylated with a 1:1 mixture of pyridine–Ac_2O (2 mL) for 12 h at room temperature and evaporated to dryness. The dry syrup was spin co-evaporated with toluene to remove traces of pyridine. The residual syrup was chromatographed on a short column of silica gel (1 × 10 cm) and eluted with solvent B. It gave **8** as a colorless syrup (yield 15 mg). For ^{1}H NMR data, see Table 1, EIMS (selected ions): *m/z* 730 (1, MH), 729 (1, M), 462 (0.01, M−TIBS), 446 (1, M−TIBSO), 285 (6, TIBS), 283 (17, TIBS−2H), 241 (34), 225 (34), 187 (13, $BCHOHCH_2$; where B = 2-phenyl-2*H*-1,2,3-triazole), 174 (27, BCHOH), 145 (9, BH), and 43 (100, CH_3CO). HRMS $[M+H]^+$ calcd for $C_{36}H_{48}N_3OS$: *m/z* 730. 3026; found, *m/z* 730. 3004.

4.4. 4-(5-Chloro-5-deoxy-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (9)

Compound **9** was eluted at fractions 6–8 from the silica gel column (solvent **A**). The fractions were collected, evaporated to dryness giving a colorless syrup (yield 49 mg, 10%) that was recrystallized from $CHCl_3$–hexane as colorless needles: mp 176–177 °C, R_f 0.46 (A); $[\alpha]_D$ −21.7 (*c* 0.482, MeOH); ORD (MeOH); $[\varphi]_{589}$ −68.2°, $[\varphi]_{578}$ −70.8°, $[\varphi]_{546}$ −81.2°, $[\varphi]_{346}$ −151.3°, $[\varphi]_{365}$ −270.8°. For ^{1}H NMR data see Table 1; EIMS (selected ions): *m/z*: 315 (0.2, M^{37}), 313 (0.7, M^{35}), 295 (0.1, M−H_2O), 277 (0.2, M−2H_2O), 259 (0.2, M−3H_2O), 216 ($BCHOHCH_2CH_2CO$), 204 (1.4, BCHOHCHOH), 175 (80, BCH_2OH), 174 (100, BCHOH), 173 (14, BCHO), 172 (2, BCO), 158 (5, BCH_2), 117 (2, B−HCN), 93 (13, $PhNH_2$), 92 (12, PhNH), 91 (19, PhN), and 77 (21, Ph). Anal. Calcd for $C_{13}H_{16}ClN_4$: C, 49.77; H, 5.14; N, 13.39. Found: C, 49.68; H, 5.30; N, 13.28.

4.5. 2-Phenyl-4-(1,2,3,4-tetra-*O*-acetyl-5-chloro-5-deoxy-D-*manno*-pentitol-1-yl)-2*H*-1,2,3-triazole (10)

Compound **9** (10 mg) was treated with a 1:1 mixture of pyridine–Ac_2O (2 mL) and kept overnight at room temperature. The mixture was processed as described for compound **8**. It gave a colorless syrup. R_f 0.29 (solvent **C**). For ^1H NMR spectral data see Table 1; EIMS (selected ions): *m/z* 484 (0.1, ^{37}MH), 483 (0.3, ^{37}M), 482 (0.2, ^{35}MH), 481 (0.7, ^{35}M), 422 (0.2, M−OAc), 319 (7, M−AcO−AcOH−Ac), 277 (6, M−AcO−AcOH−2 Ac), 258 (8), 217 (6, $BCHOHCH_2CHO$), 216 (12, $BCHOHCH_2CO$), 187 (3, BCH_2CHO), 174 (21, BCHOH), 173 (3, BCHO), 145 (1, BH), 144 (0.2, B), 103 (3, B−HCN), 91 (6, PhN), 77 (5, Ph), and 43 (100, CH_3CO); HREIMS $[M]^+$ calcd for $C_{21}H_{24}{}^{35}ClN_3O_8$: *m/z* 481.1252; found, *m/z* 481.1239.

4.6. 4-(2,5-Anhydro-D-*manno*-pentitol)-2-phenyl-2*H*-1,2,3-triazole (3)

Compound **3** was eluted from the column after compound **9** (solvent A). Fractions 10–30, which were identical, were collected and evaporated to dryness to give a colorless syrup, (yield 270 mg, 54%); R_f 0.23 (B). $[\alpha]_D^{20}$ +3.5 (*c* 1.12, MeOH). For ^1H and ^{13}C NMR data see Tables 1 and 2; EIMS: *m/z* 278 (13, MH), 277 (4, M), 260 (12, M−OH), 200 (10, M−Ph), 188 (14, $BHCH_2CHO$), 176 (17, $BHCH_2OH$), 175 (100, BCH_2OH), 174 (90, BCHOH), 173 (97, BCHO), 172 (10, BCO), 158 (11, BCH_2), 146 (5, BH_2), 145 (2, BH), 117 (6, B−HCN), 103 (9, M−CHOH), 92 (1, PhNH), 91 (48, PhN), 86 (74, M−BCHOH−OH), and 77 (41, Ph); HRMS $[M]^+$ calcd for $C_{13}H_{15}N_3NaO_4$: *m/z* 300.0967; found, *m/z* 300.0967.

4.7. 4-(1,3,4-Tri-*O*-acetyl-2,5-anhydro-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (4)

Compound **3** (10 mg) was acetylated with a 1:1 mixture of pyridine–Ac_2O (2 mL) for 24 h at room temperature. The reaction mixture was worked up as described for **8** and purified on a short column (1 × 10 cm) by eluting with solvent **C** to give a colorless syrup (yield 15 mg); R_f 0.44 (**C**). For ^1H and ^{13}C NMR data see Tables 1 and 2); EIMS (selected ions): *m/z* 404 (3, MH), 403 (1, M), 241 (14, M−OAc−AcOH−Ac), 216 (5, BCHOAc), 188 (11, $BHCH_2CHO$), 187 (100, BCH_2CHO), 174 (10, BCHOH), 173 (11, BCHO), 127 (28, M−BCHOAc−AcOH), 91 (12, PhN), 85 (48, M−BCHOAc−AcOH−CH_2CO), 77 (9, Ph), 68 (12), and 43 (85,CH_3CO); HRCIMS $[M]^+$ calcd for $C_{19}H_{21}N_3O_7$: *m/z* 403. 1379; found, *m/z* 403. 1373.

4.8. 4-(2,5-Anhydro-3,4-*O*-isopropylidene-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (5)

Compound **3** (25 mg) was dissolved in dry acetone (30 mL) and treated with *p*-toluenesulfonic acid (12 mg). The mixture was kept at room temperature for 48 h with monitoring of the reaction by TLC. The mixture was then poured onto an ice-cold, saturated solution of sodium hydrogen carbonate and extracted with $CHCl_3$, and the organic layer was washed with water, dried over anhyd $MgSO_4$, and evaporated to dryness to give a colorless syrup that was purified by chromatography on PLC silica gel plates, eluting with solvent **A**. The more mobile spot was scraped off the plate and extracted with EtOAc. The solvent was evaporated, giving a chromatographically pure syrup; (yield 19 mg); R_f 0.64 (**B**). For ^1H and ^{13}C NMR data see Tables 1 and 2; EIMS (selected ions); *m/z* 318 (50, MH), 317 (21, M), 302 (18, M−CH_3) 300 (25), 242 (20, M−CH_3−AcOH), 224 (11), 187 (4, BCHCHOH), 175 (70, BCHOH), 174 (100, BCHOH), 173 (26, HCHO), 145 (9, BH), 144 (68, B), 143 (27), 126 (62), 92 (22, PhNH), 91 (35, phN), 86 (90, MH−BCHOH−CH_3COCH_3), 77 (35, Ph), 69 (60, protonated furan), 68 (11, furan), 59 (57, CH_3COO), 58 (28, CH_3COCH_3), and 43 (72, CH_3CO), HRMS $[M]^+$ calcd for $C_{16}H_{19}NaN_3$: *m/z* 340.1273; found, *m/z* 340.1273.

4.9. 4-(1-*O*-Acetyl-2,5-anhydro-3,4-*O*-isopropylidene-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (6)

Compound **5** (10 mg) was acetylated with a 1:1 mixture of pyridine–Ac_2O (2 mL) for 24 h. The mixture was worked up as described for **8** to give a syrup that was purified on a short column (1 × 10 cm) of silica gel using solvent A as an eluent, giving **6** as a colorless syrup, (yield 15 mg). For ^1H and ^{13}C NMR data see Tables 1 and 2; EIMS (selected ions): *m/z* 360 (27, MH), 359 (45, M), 344 (36, M−CH_3), 300 (46, M−OAc), 299 (37, M−AcOH), 284 (7, M−CH_3−AcOH), 256 (23, M−AcOH−Ac), 242 (39, M−CH_3COCH_3−OAc), 240 (20, M−AcOH−OAc), 224 (20, M−CH_3COCH_3−OAc−H_2O), 187 (10, BCHCHOH), 175 (23, BCH_2OH), 174 (100, BCHOH), 173 (21, BCHO), 172 (19, BCO), 158 (14, BCH_2), 14 (8, B), 143 (65, B−H), 91 (29, PhN), 85 (24), 77 (29, ph), 69 (28, protonated furan), and 68 (4, Furan); HRMS $[M]^+$ calcd for $C_{18}H_{21}N_3NaO_5$: *m/z* 382.1379; found, *m/z* 382.1373.

4.10. 4-(α-D-Arabinopyranosyl)-2-phenyl-2*H*-1,2,3-triazole (11)

Compound **11** was eluted in the last fractions of the silica gel column after elution of compound **3**. Identical fractions 32–55 were collected and evaporated to dryness giving a colorless syrup (yield 16 mg; 3%): R_f 0.09 (solvent **B**). Recrystallization from MeOH–toluene gave colorless needles: mp 130–132 °C (lit[2,21] mp 134–135 °C).

4.11. 4-(1,2,3,4,5-Penta-*O*-acetyl-D-*manno*-pentitol-1-yl)-2-phenyl-2*H*-1,2,3-triazole (2)

Compound **2** was prepared by acetylation of **1** (50 mg) with a 1:1 mixture of Ac_2O–pyridine (4 mL) for 48 h at room temperature. The solution was processed as described for **10** to give a colorless syrup (yield 70 mg) that was recrystallized from EtOAc–hexane as colorless elongated plates mp 114–116 °C, $[\alpha]_D$ −4.5 (*c* 1.02, $CHCl_3$), (Lit[22] mp 115–116 °C, $[\alpha]_D$ −5 (*c* 0.96 $CHCl_3$).

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