Synthesis of New Optically Active D-Glucosamine–Pyrrole Derivatives

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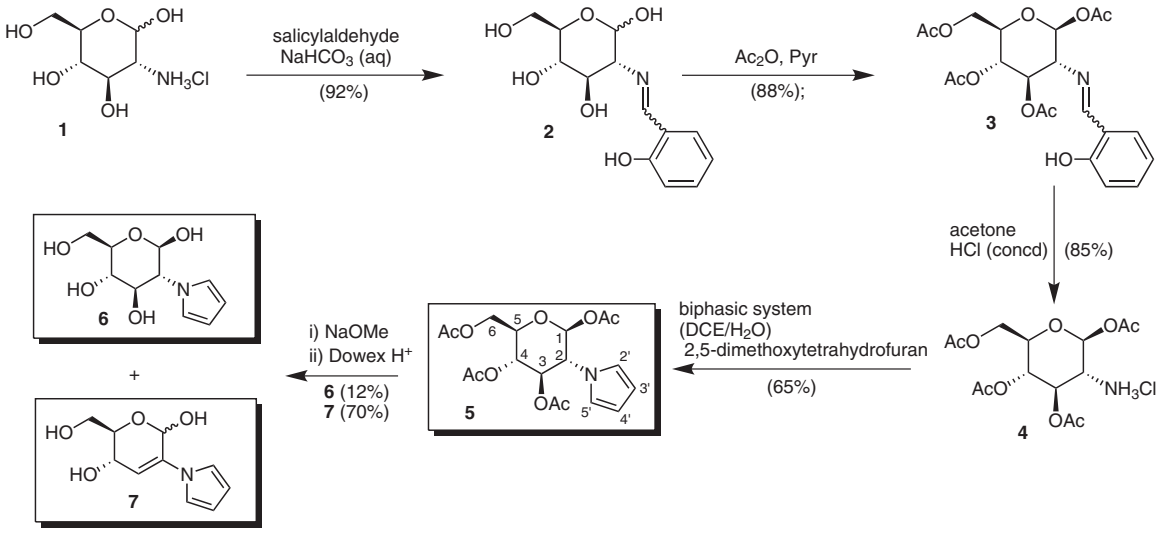
Abstract: From D-glucosamine hydrochloride was synthesized, for the first time, three new optically active derivatives of D-glucosamine–pyrrole with the pyrrole group unsubstituted in the 2- and 5-positions. New *N*-benzylpyrrole–D-glucosamine derivatives were also prepared from the same substrate.

Key words: glycosides, heterocycles, pyrroles, chirality, D-glucosamine

Chiral pyrrole derivatives are significant compounds in flavors, aromas,[1] pharmaceuticals[2], as well as in material science, where they serve as chiral conducting polymers precursor monomers.[3,4] Thus, in the last twenty five years a great deal of attention has focused on electrodes covered with chiral conducting polymers[5,6] due to their possibility to induce chirality in prochiral molecules, as demonstrated in organic electrosynthesis.[7–9] In addition, analytical applications for these electrodes, including chiral recognition, have been developed.[10–12] Despite interest in using chiral pyrroles in these important applications, their use is limited by the synthesis of suitable and inexpensive chiral pyrrole units.

In the present study, D-glucosamine (**1**) was selected because it is an economical and abundant source of chirality. Due to its availability in pure form and at low cost, it has been used as a chiral template for the synthesis of glycopeptides and other interesting bioactive compounds.[13,14] Furthermore, there is only one previous example in the literature, published by Boons,[15] concerning the synthesis of a D-glucosamine–pyrrole derivative. Nevertheless, the pyrrole they synthesized was substituted at positions 2 and 5, thereby inhibiting polymerization.[4] Considering the importance of these chiral molecules as potential monomers in conducting polymer synthesis, we report a new approach to the synthesis of chiral pyrrole derivatives that are free of substitution, using D-glucosamine as a starting material.

All the initial efforts to obtain the 2-deoxy-2-(1*H*-pyrrol-1-yl)-β-D-glucopyranose (**6**), using **1** and 2,5-dimethoxytetrahydrofuran through the typical Paal–Knorr synthesis conditions (AcOH, reflux) and Boons methodology[15] failed, yielding an intractable mixture of compounds. Nevertheless, the synthesis of the pyrrole derivatives **5**, **6**,



Scheme 1 Synthesis of D-glucosamine–pyrrole derivatives **5**, **6**, and **7**

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and **7** was performed via the tetraacetylated D-glucosamine hydrochloride **4** (Scheme 1).

Thus, the preparation of **4** from **1** required the protection of the amino group with salicylaldehyde in aqueous sodium hydrogen carbonate solution,[16] which afforded isomeric imines **2** in 92% yield. The acetylation of the hydroxy groups in **2** using acetic anhydride/pyridine produced **3** in high yield. The further hydrolysis of the imine using concentrated hydrochloric acid in acetone afforded the protected glucosamine **4** containing a free amino group in 85% yield.[17]

The reaction between **4** and 2,5-dimethoxytetrahydrofuran under biphasic conditions[18] (H_2O/DCE), afforded the acetylated glucosamine pyrrole **5** in 65% yield. This procedure has almost equivalent yields (45% for the four reactions) compared to the 2,5-dimethylated pyrrole–glucosamine derivative reported by the Boons method (51%).[15] The hydrolysis of the acetyl groups in **5** in basic medium after further treatment with an acid exchange resin[19] provided pyrrole **6** in 12% yield. Additionally, the pyrrole derivative **7** was isolated in 70% yield as an anomeric mixture (1:1). Probably the use of a milder ester hydrolysis method, such as the use of trimethyltin hydroxide,[20] could produce **6** in higher yield. This procedure furnished the first synthesis of three new optically active derivatives of D-glucosamine–pyrrole **5**, **6**, and **7**. This synthetic method has the advantage of using simple chemical reactions and inexpensive reagents, features that facilitate scale-up. In order to confirm that **7** was generated during the basic or acid medium treatment, **6** was reacted under the same condition used for the ester hydrolysis of **5**. TLC showed clean transformation of **6** into **7** in 30 minutes. The proposed mechanism for this transformation is shown in Scheme 2. Similar mechanisms have been proposed for the dehydration of other glucosides.[21,22]

This first family of heterocyclic chiral compounds is characterized by the direct linkage between the pyrrole and the sugar moiety, without modification of the D-glucosamine stereochemistry. The ^{1}H NMR coupling constants establish that all the substituents of **5** and **6** are equatorial. Additional support for this conclusion was obtained from X-ray diffraction, which established the structure of **5** depicted in Figure 1. It is also interesting to observe that the unit cell packing (Figure 2) is ordered having two pyrrole units parallel and perpendicular to the glucosamine group probably by a π–π interaction that stabilized the unit cell, whereas all the acetate groups are equatorial relative to the pyran ring plane in order to avoid steric hindrance.

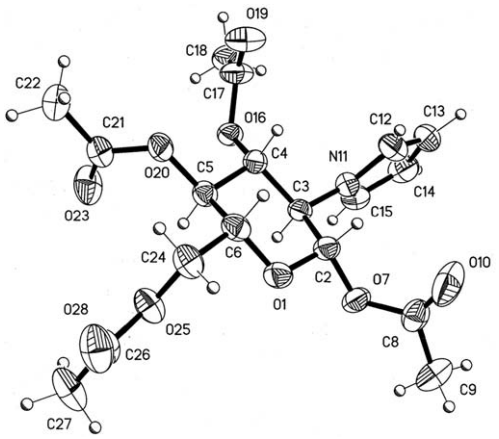
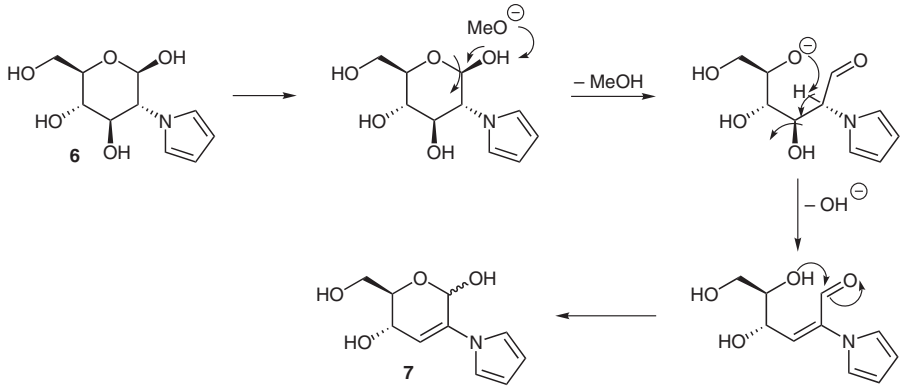


Figure 1 X-ray crystal structure of compound 1,3,4,6-tetra-*O*-acetyl-2-amino-2-deoxy-2-(1*H*-pyrrol-1-yl)-β-D-glucopyranose (**5**)

Compound **5** has an optical rotation value of $[\alpha]_D$ +62 (*c* 0.15, MeOH), in agreement with the rotation sign observed in the D-glucosamine hydrochloride (**1**). Circular dichroism spectra of **5** showed a positive maxima at λ = 221 nm. Pyrrole **6**, similar to **5**, has an optical rotation value of same sign observed for D-glucosamine hydrochloride {$[\alpha]_D$ +73.6 (*c* 0.19, MeOH)}. Its circular dichroism also showed maxima at 215 and 221 nm. These results confirmed that the optical activity of β-D-glucosamine used as the starting material is conserved in the pyrrole derivatives. Compound **7** showed low optical activity, probably due to epimerization at C2 and the loss of two chiral carbons when the double bond was generated.

Considering the importance of the chiral pyrroles, it was decided to synthesize a second family of D-glucosamine heterocyclic derivatives. Thus, our interest was focused on developing a simple method to produce chiral pyrroles **8** and **9** using **4** as the starting material (Scheme 3). Therefore, 4-(1*H*-pyrrol-1-yl)benzaldehyde was prepared via Paal–Knorr reaction with 2,5-dimethoxytetrahydrofuran



Scheme 2 Proposed mechanism for the formation of compound **7**

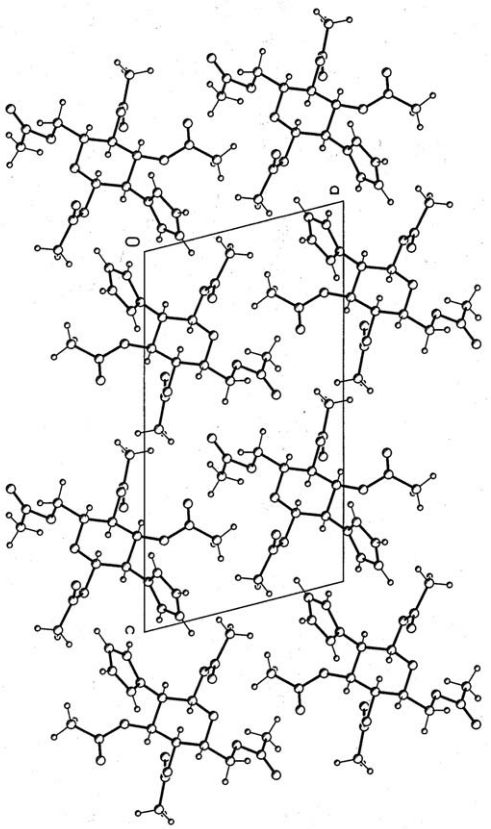
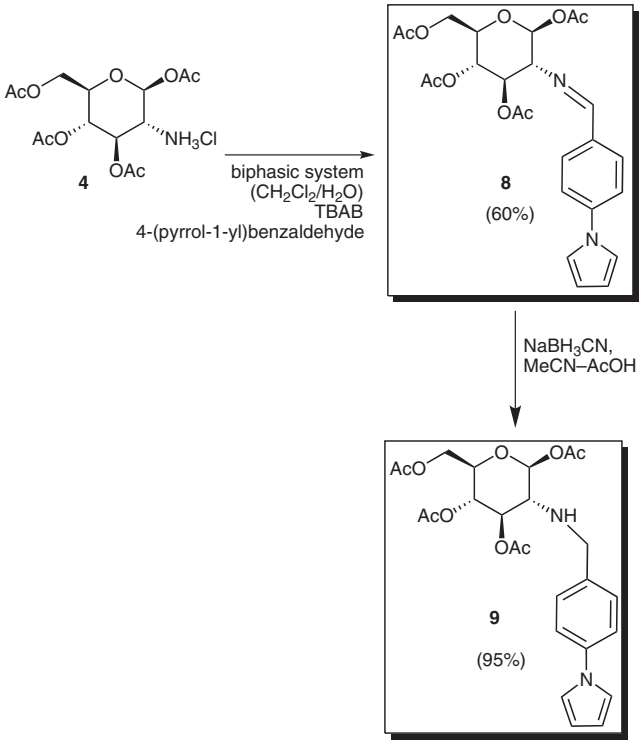


Figure 2 Unit cell of the crystal 1,3,4,6-tetra-*O*-acetyl-2-amino-2-deoxy-2-(1*H*-pyrrol-1-yl)-β-D-glucopyranose (**5**)



Scheme 3 Synthesis of derivatives containing the 4-(1*H*-pyrrol-1-yl)benzyl unit coupled to the D-glucosamine moiety

and 4-aminobenzaldehyde, this last obtained from the reduction of the 4-nitrobenzaldehyde with tin(II) chloride.[23] The imine **8** was synthesized in a biphasic media under strong stirring using tetrabutylammonium bromide as a phase-transfer agent in 60% yield. The imine of **8** showed an optical rotation value of $[\alpha]_D$ +26 (*c* 0.4, MeOH), in agreement with the D-glucosamine hydrochloride (**1**). It also showed a positive maxima at λ = 206 nm. The selective imino reduction to amino derivative **9** was achieved with sodium cyanoborohydride/acetonitrile and a catalytic amount of acetic acid in 57% yield. This derivative showed an $[\alpha]_D$ +21 (*c* 0.4, MeOH), with a positive maxima in CD at λ = 210 nm. As far as we know, both products **8** and **9** have no precedents in the chemical literature and this procedure corresponds to their first synthesis. Thus, with this method we were able to prepare new D-glucopyranose–pyrrole derivatives with a benzylic spacer between both chemical units.

In this paper the synthesis of two new families of optically active pyrroles containing a glucopyranose group, starting from β-D-glucosamine derivative is reported. The first family has the pyrrole ring directly attached to the sugar moiety whereas the second family has a benzylic spacer between them. The synthesized pyrroles have positions 2 and 5 free and could be used for oxidative polymerization reactions in material science. Notwithstanding the use of classical reactions during the synthesis, which is an additional advantage, this is a suitable method for the synthesis of chiral pyrroles with reasonable yields on a multigram scale.

D-Glucosamine hydrochloride, salicylaldehyde, and 2,5-dimethoxytetrahydrofuran were of the highest purity available and were used as received from commercial suppliers. Melting points are uncorrected and were determined using a Fisher-Johns apparatus. EI-MS were obtained at 70 eV by direct inlet and HRMS were obtained by FAB^+ technique. ^1H NMR (500 MHz or 300 MHz) and ^{13}C NMR (125 MHz or 75 MHz) spectra were recorded using TMS as the internal standard in the solvent noted. TLC was performed on aluminum sheets pre-coated with silica gel; Flash column chromatography was carried out on silica gel (0.030–0.075 mm) using hexanes–EtOAc mixtures. X-ray crystal structure determination was carried out at 298 K using wavelength equal to 0.71073 Å.

1,3,4,6-Tetra-*O*-acetyl-2-amino-2-deoxy-β-D-glucopyranose Hydrochloride (4)

White crystals (EtOAc–MeOH); mp 225–230 °C (dec) [Lit.[17] 230 °C (dec)].

IR (KBr): 3300–2500 (br), 2002, 1761, 1594, 1513, 1433, 1365, 1201, 1038, 898, 666, 639, 600 cm^{-1}.

^1H NMR (300 MHz, CD_3OD): δ = 5.88 (d, *J* = 8.7 Hz, 1 H, H1), 5.37 (dd, *J* = 10.5, 9.3 Hz, 1 H, H3), 5.08 (dd, *J* = 10.2, 9.3 Hz, 1 H, H4), 4.82 (s, 3 H, NH_3^+), 4.3 (dd, *J* = 12.6, 4.5 Hz, 1 H, H6), 4.11 (dd, *J* = 12.6, 2.7 Hz, 1 H, H6), 4.03 (m, 1 H, H5), 3.62 (dd, *J* = 10.5, 9 Hz, 1 H, H2), 2.19 (s, 3 H, CH_3CO), 2.09 (s, 3 H, CH_3CO), 2.029 (s, 3 H, CH_3CO), 2.022 (s, 3 H, CH_3CO).

^{13}C NMR (75 MHz, CD_3OD): δ = 172.1, 171.9, 171.1, 170.0, 91.6, 74.0, 72.1, 69.3, 62.6, 54.4, 20.7, 20.6, 20.45 (2 C).

MS (EI): *m/z* (%) = 347 ($[M - HCl]^+$, 9), 305 (3), 287 (24), 245 (21), 227 (13), 199 (10), 185 (31), 168 (14), 156 (16), 138 (12), 125 (18), 114 (83), 101 (38), 96 (32), 72 (63), 59 (53), 43 (100).

HRMS (FAB$^+$): *m*/*z* [M – HCl]$^+$ calcd for $C_{14}H_{21}NO_9$: 348.1295; found: 348.1293.

1,3,4,6-Tetra-*O*-acetyl-2-amino-2-deoxy-2-(1*H*-pyrrol-1-yl)-β-D-glucopyranose (5)

In a round-bottomed flask fitted with a condenser, **4** (2.8 g, 7.3 mmol), H_2O (35 mL), DCE (30 mL), and 1,5-dimethoxytetrahydrofuran were added. The mixture was refluxed and magnetically stirred, vigorously, for 45 min. The reaction was neutralized with sat. $NaHCO_3$ soln and the organic compounds were separated by extraction with DCE (3 × 25 mL). The combined organic extracts were dried ($MgSO_4$) and concentrated using a rotary evaporator under vacuum. The product was purified by column chromatography to give **5** (1.9 g, 65%) as a white amorphous solid. Recrystallization (Et_2O–hexanes) gave a white foamy product; mp 107–108 °C. From slow evaporation of a soln of **5** (acetone–hexane), monocrystals were obtained and the X-ray crystal structure was obtained (vide infra).

$[\alpha]_D$ +62 (*c* 0.15, MeOH); CD λ_{max} = 221 nm.

IR ($CHCl_3$): 3050, 2950, 1754, 1485, 1425, 1367, 1283, 1077, 1044, 903 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 6.64 (t, *J* = 2.1 Hz, 2 H, H2′), 6.12 (t, *J* = 2.1 Hz, 2 H, H3′), 5.95 (d, *J* = 9 Hz, 1 H, H1), 5.56 (dd, *J* = 11.1, 9.3 Hz, 1 H, H3), 5.16 (dd, *J* = 10.2, 9.3 Hz, 1 H, H4), 4.37 (dd, *J* = 12.0, 4.2 Hz, 1 H, H6), 4.11 (dd, *J* = 12.0, 2.1 Hz, 1 H, H6), 3.62 (dd, *J* = 11.1, 9 Hz, 1 H, H2), 3.98 (m, 1 H, H5), 2.1 (s, 3 H, CH_3CO), 2.04 (s, 3 H, CH_3CO), 1.98 (s, 3 H, CH_3CO), 1.86 (s, 3 H, CH_3CO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 170.4, 169.5, 169.3, 168.4, 119.5, 109.2, 92.1, 72.8, 72.1, 68.3, 61.9, 61.5, 20.6, 20.5 (2 C), 20.1.

MS (EI): *m*/*z* (%) = 397 ([M]$^+$, 82), 338 (11), 260 (25), 235 (7), 218 (18), 190 (24), 188 (21), 176 (26), 164 (25), 146 (18), 134 (29), 130 (43), 122 (58), 109 (24), 97 (9), 80 (12), 68 (17), 43 (100).

HRMS (FAB$^+$): *m*/*z* [M]$^+$ calcd for $C_{18}H_{23}NO_9$: 397.1373; found: 397.1365.

Monocrystal data for X-ray diffraction:[24] *T* = 298(2) K; λ = 0.71073 Å; crystal system: monoclinic; space group $P2_1$; unit cell dimensions: *a* = 9.180(1) Å, *α* = 90°, *b* = 6.701(1) Å, *β* = 104.501(3)°, *c* = 16.909(2) Å, *γ* = 90°; volume: 1007.0(2) Å^3; *Z* = 2; density (calcd): 1.311 mg/m^3; absorption coefficient: 0.106 mm^{-1}; *F*(000) = 420; crystal size/color/shape: 0.276 × 0.176 × 0.034 mm/colorless/plates; θ range for data collection = 1.24 to 25.33°; index ranges: $-11 \le h \le 10$, $-8 \le k \le 8$, $-20 \le l \le 20$; reflections collected: 8501; independent reflections: 2008 [R_{int} = 0.0638]; completeness to θ = 25.33° 99.9%; absorption correction: semi-empirical from equivalents; max. and min. transmission: 0.99592 and 0.97444; refinement method: full-matrix least-squares on F^2; data/restraints/parameters: 2008/245/343; goodness-of-fit on F^2: 1.022; final *R* indices [$I > 2\sigma(I)$]: *R*1 = 0.0529, *wR*2 = 0.0971; *R* indices (all data): *R*1 = 0.0941, *wR*2 = 0.1114; largest diff. peak and hole: 0.133 and –0.133 e Å^{-3}; remarks: main residue disorder: 24%.

2-Deoxy-2-(1*H*-pyrrol-1-yl)-β-D-glucopyranose (6) and 2,3-Dideoxy-2-(pyrrol-1-yl)-D-*erythro*-hex-2-enopyranose (7)

Na metal (50 mg, 2.1 mmol) was cut in small pieces and added to a one-necked round-bottomed flask (dried overnight) containing anhyd MeOH (15 mL). The flask was closed with a septa and was maintained under N_2 with a balloon under magnetic stirring. When the Na had reacted completely, **5** (795 mg, 2 mmol) was added to the soln and the mixture was stirred at r.t. for 1 h; TLC showed complete disappearance of **5** and the presence of 2 new compounds of higher polarity [TLC (silica gel, EtOAc): R_f = 0.70 (**6**), 0.50 (**7**)]. MeOH was evaporated under high vacuum and the residue was redissolved in H_2O (10 mL) and treated with resin Dowex 50W H$^+$ (2 g) for 1 min. After this period the resin was filtered and rinsed with H_2O (5 mL). H_2O was evaporated under high vacuum at 50–60 °C and the residue dissolved in acetone and adsorbed on Celite. The mixture of products was separated by flash column chromatography (silica gel, EtOAc–hexanes, 50:50). Compound **6** (51 mg, 12%) was eluted first and the second, **7** (300 mg, 70%), was obtained after concentration of the fractions.

2-Deoxy-2-(1*H*-pyrrol-1-yl)-β-D-glucopyranose (6)

White powder; mp 135–136 °C.

$[\alpha]_D$ +73.6 (*c* 0.19, MeOH); CD λ_{max} = 215, 221 nm.

IR (KBr): 3439, 3404, 3112, 2950, 1489, 1287, 1122, 1074, 1038, 1005, 956, 840, 733 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$ + 1 drop DMSO-d_6): δ = 7.37 (s, 1 H, exch D_2O, OH), 6.68 (t, *J* = 2.1 Hz, 2 H, H2′), 6.16 (t, *J* = 2.1 Hz, 2 H, H3′), 5.61 (s, 1 H, H1), 4.97 (dd, *J* = 5.9, 5.9 Hz, 1 H, H4), 4.56 (s, 1 H, H2), 4.71 (d, *J* = 5.9 Hz, 1 H, H3), 4.4 (br s, 3 H, exch D_2O, 3 OH), 4.26 (ddd, *J* = 5.9, 5.4, 4.8 Hz, 1 H, H5), 4.02 (dd, *J* = 9.6, 4.8 Hz, 1 H, H6), 3.80 (dd, *J* = 9.6, 5.4 Hz, 1 H, H6).

^{13}C NMR (75 MHz, $CDCl_3$ + 1 drop DMSO-d_6): δ = 118.9, 108.8, 103.4, 88.03, 84.4, 74.01 (t), 70.81, 70.70.

MS (EI): *m*/*z* (%) = 211 ([M$^+$ – H_2O], 100), 182 (8), 166 (12), 150 (22), 136 (13), 122 (14), 118 (17), 104 (17), 93 (30), 80 (43), 68 (62), 67 (27), 55 (18).

HRMS (FAB$^+$): *m*/*z* [M$^+$ – H_2O] calcd for $C_{10}H_{13}NO_4$: 212.0923; found: 212.0921.

2,3-Dideoxy-2-(1*H*-pyrrol-1-yl)-D-*erythro*-hex-2-enopyranose (7)

Transparent oil; mixture of C2 anomers.

IR ($CHCl_3$): 3379 (br), 2931, 2891, 1671, 1489, 1370, 1315, 1074 (br), 731 cm^{-1}.

^{1}H NMR (300 MHz, acetone-d_6): δ = 7.1 (q, *J* = 2.1 Hz, 2 H, H2′ epimer A), 7.05 (t, *J* = 2.1 Hz, 2 H, H2′ epimer B), 6.24 (m, 1 H, H3 epimer A), 6.17 (s, 1 H, H1 epimer B), 6.14 (q, *J* = 2.1 Hz, 2 H, H3′ epimer A), 6.11 (t, *J* = 2.1 Hz, 2 H, H3′ epimer B), 6.03 (d, *J* = 1.2 Hz, 1 H, H1 epimer A), 6.01 (dd, *J* = 4.5, 5.1 Hz, 1 H, H3 epimer B), 5.75 (m, 1 H, 5-OH), 4.92 (ddd, *J* = 5.7, 4.2, 1.5 Hz, 1 H, H4 epimer A), 4.84 (ddd, *J* = 4.5, 1.8, 0.6 Hz, 1 H, H4 epimer B), 3.9–3.5 (m, 3 H, H5 and H6 both epimers).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.9, 139.3, 120.1, 110.6, 110.5, 109.6, 108.5, 100.4, 99.7, 85.5, 84.6, 75.5, 74.5, 64.2, 64.0.

MS (EI): *m*/*z* (%) = 211 ([M$^+$ – H_2O] 100), 182 (8), 166 (12), 150 (22), 136 (13), 122 (14), 118 (17), 104 (17), 93 (30), 80 (43), 68 (62), 67 (27), 55 (18).

HRMS (FAB$^+$): *m*/*z* [M]$^+$ calcd for $C_{10}H_{13}NO_4$: 212.0923; found: 212.0921.

1,3,4,6-Tetra-*O*-acetyl-2-deoxy-2-{[4-(1*H*-pyrrol-1-yl)benzylidene]amino}-β-D-glucopyranose (8)

To a round-bottomed flask were added **4** (1 g, 2.62 mmol), $NaHCO_3$ (137 mg), TBAB (100 mg), 4-(1*H*-pyrrol-1-yl)benzaldehyde (448 mg, 2.6 mmol), CH_2Cl_2 (5 mL), and H_2O (5 mL). The mixture was magnetically stirred, vigorously, for 48 h. The organic compounds were separated by extraction with CH_2Cl_2 (3 × 15 mL). The combined organic extracts were dried (Na_2SO_4), filtered over Celite, and concentrated on a rotary evaporator under vacuum. The product was purified by column chromatography to give **8** (786 mg, 60%) as an amorphous solid. Recrystallization (acetone–hexane) gave a white product; mp 191–192 °C.

$[\alpha]_D$ +26 (*c* 0.4, CH_2Cl_2); CD λ_{max} = 206 nm.

IR (KBr): 2922, 2876, 1746, 1215, 1075, 1038 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.4 (s, 1 H, H2′), 7.78 (d, *J* = 4.3 Hz, 2 H, H4′), 7.42 (d, *J* = 4.3 Hz, 2 H, H5′) 7.13 (t, *J* = 2.1 Hz, 2 H, H8′), 6.37 (t, *J* = 2.1 Hz, 2 H, H9′), 5.95 (d, *J* = 9 Hz, 1 H, H1), 5.46 (dd, *J* = 11.1, 9.3 Hz, 1 H, H3), 5.16 (dd, *J* = 10.2, 9.3 Hz, 1 H, H4), 4.37 (dd, *J* = 12.0, 4.2 Hz, 1 H, H6), 4.17 (dd, *J* = 12.0, 2.1 Hz, 1 H, H6), 4.15 (m, 1 H, H5), 3.51 (dd, *J* = 11.1, 9 Hz, 1 H, H2), 2.1 (s, 3 H, CH_3CO), 2.04 (s, 3 H, CH_3CO), 2.03 (s, 3 H, CH_3CO), 1.89 (s, 3 H, CH_3CO).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 170.4, 169.7, 169.3, 168.5, 163.8, 143.2, 132.6, 131.4, 129, 123.9, 120.0, 119.7, 119, 111.2, 93.2, 73.3, 73.1, 73, 68.4, 62.0, 20.6, 20.5, 20.3.

MS (EI): *m*/*z* (%) = 500 ([M]$^+$, 20), 440 (62), 398 (20), 355 (18), 339 (21), 295 (16), 267 (48), 250 (28), 225 (52), 212 (23), 156 (70), 43 (100), 18 (41).

HRMS (FAB$^+$): *m*/*z* [M]$^+$ calcd for $C_{25}H_{28}N_2O_9$: 501.1873; found: 501.1867.

UV (MeOH): λ = 300, 219.5, 205 nm.

1,3,4,6-Tetra-*O*-acetyl-2-deoxy-2-{[4-(1*H*-pyrrol-1-yl)benzyl]amino}-β-D-glucopyranose (9)

A 2-mL syringe was charged with **8** (1 g, 2 mmol) dissolved in anhyd MeCN (1 mL) and this soln was slowly added to a 25-mL magnetically stirred round-bottomed flask containing $NaBH_3CN$ (320 mg, 5.09 mmol) in MeCN (5 mL). The flask was under N_2 atmosphere (balloon) during the reaction. The pH of the soln was adjusted to approx. 5–7 with glacial AcOH (4 drops). The reaction was stirred at r.t. for 45 min; TLC showed complete disappearance of **8** [TLC (hexane–EtOAc, 1:1): R_f = 0.50 (**8**), 0.40 (**9**)]. The soln was diluted with CH_2Cl_2 and washed with sat. $NaHCO_3$ soln and brine. Organic phase collected was dried (Na_2SO_4), filtered over Celite, concentrated on a rotary evaporator under vacuum and dried overnight (house vacuum). Compound **9** (953 mg, 95%) was obtained as a viscous yellow oil.

$[\alpha]_D$ +21 (*c* 0.4 MeOH); CD λ_{max} = 210 nm.

IR (KBr): 3358, 3141, 2925, 1705, 1522, 1369, 1328, 1224, 1114, 1070, 1044 cm^{-1}.

^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.32 (d, *J* = 4.3 Hz, 2 H, H4′), 7.26 (d, *J* = 4.3 Hz, 2 H, H5′) 7.13 (t, *J* = 2.1 Hz, 2 H, H8′), 6.34 (t, *J* = 2.1 Hz, 2 H, H9′), 6.60 (d, *J* = 9 Hz, 1 H, H1), 5.10 (dd, *J* = 11.1, 9.3 Hz, 1 H, H3), 5.00 (dd, *J* = 10.2, 9.3 Hz, 1 H, H4), 4.30 (dd, *J* = 12.0, 4.2 Hz, 1 H, H6), 4.09 (dd, *J* = 12.0, 2.1 Hz, 1 H, H6), 3.89 (m, 1 H, H5), 3.83 (d, 2 H, H2′), 2.95 (dd, *J* = 11.1, 9 Hz, 1 H, H2), 2.1 (s, 3 H, CH_3CO), 2.07 (s, 3 H, CH_3CO), 2.03 (s, 3 H, CH_3CO), 2.02 (s, 3 H, CH_3CO), 2.0 (s, 1 H, H1′).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 170.8, 170.6, 169.6, 169.0, 139.9, 137.3, 129.2, 120.5, 119.2, 110.4, 94.9, 73.9, 72.6, 68.3, 61.8, 60.3, 51.5, 21, 20.6.

MS (EI): *m*/*z* (%) = 502 ([M]$^+$ 1), 442 (4), 425 (1), 411 (1), 383 (1), 323 (1), 295 (1), 256 (3), 231 (2), 214 (14), 171 (11), 156 (100), 128 (5), 43 (20), 18 (5).

HRMS (FAB$^+$): *m*/*z* [M]$^+$ calcd for $C_{25}H_{30}N_2O_9$: 503.2030; found: 503.2034.

UV (MeOH): λ = 257, 206 nm.

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