Supporting Information

First Efficient Stereoselective *O*-Glycosylation of Hydroxamic acid

Mickaël Thomas, Jean-Pierre Gesson and Sébastien Papot*

*UMR6514, Synthèse et Réactivité des Substances Naturelles, Université de Poitiers et CNRS,
40, Av. du Recteur Pineau, 86022 Poitiers, France*

Table of Contents.

Title Page	S1
General Techniques	S3
Experimental Section	S4-S17
¹ H and ¹³ C NMR spectra of 9a	S18-S19
¹ H and ¹³ C NMR spectra of 9b	S20-S21
¹ H and ¹³ C NMR spectra of 9c	S22-S23
¹ H and ¹³ C NMR spectra of 9d	S24-S25
¹ H and ¹³ C NMR spectra of 9e	S26-S27
¹ H and ¹³ C NMR spectra of 13a	S28-S29
¹ H and ¹³ C NMR spectra of 13b	S30-S31
¹ H and ¹³ C NMR spectra of 13c	S32-S33
¹ H and ¹³ C NMR spectra of 13d	S34-S35
¹ H and ¹³ C NMR spectra of 14a	S36-S37

^1H and ^{13}C NMR spectra of 14b	S38-S39
^1H and ^{13}C NMR spectra of 15a	S40-S41
^1H and ^{13}C NMR spectra of 15b	S42-S43
^1H and ^{13}C NMR spectra of 16a	S44-S45
^1H and ^{13}C NMR spectra of 16b	S46-S47
^1H and ^{13}C NMR spectra of 17a	S48-S49
^1H and ^{13}C NMR spectra of 17b	S50-S51
^1H - ^1H COSY and ^{13}C - ^1H COSY of 13a	S52-S53
^1H - ^1H COSY and ^{13}C - ^1H COSY of 13b	S54-S55
^1H - ^1H COSY and ^{13}C - ^1H COSY of 13c	S56-S57
^1H - ^1H COSY and ^{13}C - ^1H COSY of 13d	S58-S59
^1H - ^1H COSY and ^{13}C - ^1H COSY of 14b	S60-S61
^1H - ^1H COSY and ^{13}C - ^1H COSY of 15b	S62-S63
^1H - ^1H COSY and ^{13}C - ^1H COSY of 16b	S64-S65
^1H - ^1H COSY and ^{13}C - ^1H COSY of 17b	S66-S67

General Techniques :

^1H NMR and ^{13}C NMR spectra were taken in CDCl_3 at 300 MHz and 75 MHz respectively. Chemical shifts were given in part per million (ppm) relative to CDCl_3 (7.27 and 77.00 ppm respectively) as internal standard.

NMR multiplicities are reported using the following abbreviations.

(s: singlet, d: doublet, t: triplet, q: quartet, m: multiplet, br: broad, J : coupling constants in Hertz.)

Optical rotations were measured on a polarimeter.

The reactions were monitored by thin layer chromatography carried out on 0.2 mm silica gel 60 Å plates.

Flash column chromatography separation were performed using 15-40 μm silica gel. CH_2Cl_2 were distilled from P_2O_5 . 4 Å molecular sieves were dried at 130 °C during one week. Chemicals and reagents were commercially available and used as received.

Experimental Section :

General Procedure for the preparation of glycosyl trifluoroacetimidate donors **9**:

To a solution of 1-hydroxy sugar in dry CH_2Cl_2 (2.1 mmol/10 mL) were added successively *N*-aryl trifluoroacetimidoyl chloride (2 equiv.) and K_2CO_3 (2 equiv.). The solution was stirred overnight at room temperature. The reaction mixture was then evaporated to dryness and quickly subjected to flash column chromatography to give the desired glycosyl trifluoroacetimidate donor **9**.

2,3,4,6-Tetra-*O*-acetyl-D-glucopyranosyl 1-(*N*-phenyl)-2,2,2-trifluoroacetimidate (**9a**)

9a was prepared according to the general procedure described above using 2.2 g (6.3 mmol) of 2,3,4,6-tetra-*O*-acetyl-D-glucose, 2.64 g of *N*-aryl trifluoroacetimidoyl chloride (12.6 mmol) and 1.74 g (12.6 mmol) of K_2CO_3 in 30 mL of dichloromethane. The reaction was stirred overnight at room temperature and then evaporated to dryness. Purification by flash column chromatography (EtOAc/PE, 4:6) gave a white solid (3.24 g, 99 %). m.p. 63.2 °C; $[\alpha]_{\text{D}}^{25}$: +41 (c 0.1, CHCl_3); $^1\text{H NMR}$ (CDCl_3 , 300 MHz): 7.32 (t, 2H, $J = 7.7$ Hz), 7.14 (t, 1H, $J = 7.5$ Hz), 6.84 (d, 2H, $J = 7.7$ Hz), 5.78 (br s, 1H), 5.29-5.13 (m, 3H), 4.26 (dd, 1H, $J = 12.5, 4.4$ Hz), 4.12 (d, 1H, $J = 11.4$ Hz), 3.76 (br s, 1H), 2.08 (s, 6H), 2.03 (s, 6H); $^{13}\text{C NMR}$ (CDCl_3 , 75 MHz): 171.0, 170.6, 169.7, 169.4, 143.3, 129.2, 125.1, 119.6, 94.9, 73.1, 72.9, 70.6, 68.1, 61.8, 21.0 (x2), 20.9, 20.8.

2,3,4,6-Tetra-*O*-acetyl-D-galactosyl 1-(*N*-phenyl)-2,2,2-trifluoroacetimidate (9b)

9b was prepared according to the general procedure described above using 130 mg (0.37 mmol) of 2,3,4,6-tetra-*O*-acetyl-D-galactose, 156 mg of *N*-aryl trifluoroacetimidoyl chloride (0.75 mmol) and 103 mg (0.75 mmol) of K₂CO₃ in 3 mL of dichloromethane. The reaction was stirred overnight at room temperature and then evaporated to dryness. Purification by flash column chromatography (EtOAc/PE, 4:6) gave a white solid (179 mg, 93 %). m.p. 116.6 °C; [α]²⁵_D: +59.1 (c 0.22, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 7.32 (t, 2H, *J* = 7.8 Hz), 7.14 (t, 1H, *J* = 7.7 Hz), 6.84 (d, 2H, *J* = 7.7 Hz), 5.75 (br s, 1H), 5.50-5.40 (m, 2H), 5.09 (d, 1H, *J* = 9.0 Hz), 4.16 (d, 2H, *J* = 6.4 Hz), 3.98 (br s, 1H), 2.18 (s, 3H), 2.09 (s, 3H), 2.01 (s, 3H), 2.00 (s, 3H); ¹³C NMR (CDCl₃, 75 MHz): 170.6, 170.5, 170.3, 169.4, 143.3, 129.2, 125.0, 119.5, 95.4, 72.2, 71.0, 68.2, 67.1, 61.4, 21.0, 20.9 (x3).

2,3,4,6-Tetra-*O*-acetyl-D-mannopyranosyl 1-(*N*-phenyl)-2,2,2-trifluoroacetimidate (9c)

9c was prepared according to the general procedure described above using 200 mg (0.58 mmol) of 2,3,4,6-tetra-*O*-acetyl-D-mannose, 242 mg of *N*-aryl trifluoroacetimidoyl chloride (1.16 mmol) and 160 mg (1.16 mmol) of K₂CO₃ in 5 mL of dichloromethane. The reaction was stirred overnight at room temperature and then evaporated to dryness. Purification by

flash column chromatography (EtOAc/PE, 3:7) gave a colourless oil 241 mg (80 %). $[\alpha]_D^{25}$: +15.8 (c 0.24, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 7.32 (t, 2H, *J* = 7.2 Hz), 7.13 (t, 1H, *J* = 7.2 Hz), 6.84 (dd, 2H, *J* = 7.8, 2.5 Hz), 6.24 (br s, 0.5 H), 5.98 (br s, 0.5H), 5.72 (s, 0.5H), 5.49 (s, 0.5H), 5.40 (br s, 1H), 5.32 (t, 0.5H, *J* = 9.6 Hz), 5.20-5.12 (m, 0.5H, *J* = 9.9Hz), 4.38-4.26 (m, 1H), 4.26-4.06 (m, 1.5H), 3.81 (br s, 0.5H), 2.21 (s, 1.5H), 2.18 (s, 1.5H), 2.12 (s, 1.5H), 2.11 (s, 1.5H), 2.08 (s, 1.5H), 2.06 (s, 1.5H), 2.03 (s, 3H) ; ¹³C NMR (CDCl₃, 75 MHz): 170.6 (x2), 170.2, 169.8, 169.7, 166.0 (x2), 143.0, 142.8, 128.9 (x2), 124.8, 124.7, 119.3, 119.2, 93.3, 73.4, 71.0, 70.1, 68.7, 67.8, 67.1, 65.7, 65.4, 62.2, 62.1, 20.8, 20.7 (x2), 20.6.

2,3,4,6-Tetra-*O*-acetyl-D-glucuronsyl 1-(*N*-phenyl)-2,2,2-trifluoroacetimidate (9d)

9d was prepared according to the general procedure described above using 879 mg (2.63 mmol) of methyl 2,3,4-tri-*O*-acetyl-D-glucuronate, 1.1 g of *N*-aryl trifluoroacetimidoyl chloride (5.26 mmol) and 726 mg (5.26 mmol) of K₂CO₃ in 13 mL of dichloromethane. The reaction was stirred overnight at room temperature and then evaporated to dryness. Purification by flash column chromatography (EtOAc/PE, 4:6) gave a white solid (1.26 g, 95 %). m.p. 51.2 °C; $[\alpha]_D^{25}$: +14.3 (c 0.1, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 7.32 (t, 2H, *J* = 7.6 Hz), 7.14 (t, 1H, *J* = 7.6 Hz), 6.85 (d, 2H, *J* = 7.6 Hz), 5.93 (br s, 1H), 5.41-5.19 (m, 3H), 4.17 (br s, 1H), 3.77 (s, 3H), 2.09 (s, 3H), 2.05 (s, 6H); ¹³C NMR (CDCl₃, 75 MHz): 169.9, 169.3, 169.0, 166.9, 142.8, 128.8, 124.7, 119.2, 94.0, 73.0, 71.0, 70.0, 68.4, 53.0, 20.6, 20.5, 20.4.

2,3,5-Tri-*O*-acetyl-D-ribofuranosyl 1-(*N*-phenyl)-2,2,2-trifluoroacetimidate (9e**)**

9e was prepared according to the general procedure described above using 872 mg (3.16 mmol) of 2,3,5-tri-*O*-acetyl-D-ribose, 1.32 g of *N*-aryl trifluoroacetimidoyl chloride (6.30 mmol) and 872 mg (6.30 mmol) of K₂CO₃ in 15 mL of dichloromethane. The reaction was stirred overnight at room temperature and then evaporated to dryness. Purification by flash column chromatography (EtOAc/PE, 3:7) gave a white solid (1.24 g, 87 %). m.p. 66.1 °C; $[\alpha]_D^{25}$: +15.6 (c 0.5, CHCl₃); **¹H NMR** (CDCl₃, 300 MHz): 7.30 (t, 2H, *J* = 7.3 Hz), 7.11 (t, 1H, *J* = 7.5 Hz), 6.83 (d, 2H, *J* = 7.6 Hz), 6.32 (br s, 1H), 5.55 (d, 1H *J* = 4.8 Hz), 5.45 (t, 1H, *J* = 6.9 Hz), 4.50-4.39 (m, 2H), 4.22-4.13 (m, 1H), 2.14 (s, 3H), 2.10 (s, 3H), 2.09 (s, 3H); **¹³C NMR** (CDCl₃, 75 MHz): 171.0, 170.0, 169.7, 143.7, 129.1, 124.8, 119.8, 101.5, 80.4, 74.5, 70.6, 63.3, 21.0, 20.9, 20.8.

General Procedure for the glycosylation of hydroxamic acids:

A mixture of the donor either **8** or **9** (1.0 equiv.), hydroxamic acid (1.5 equiv.) and freshly activated 4 Å molecular sieves (4 g/mmol) in anhydrous dichloromethane (10 mL/mmol) was stirred at room temperature for 1 h under N₂ to remove a trace of water, and then cooled to -20°C. TMSOTf (1.0 equiv.) was added. The mixture was then allowed to warm up to room temperature. After stirring for 3h, the reaction was quenched by the addition of Et₃N (1 mL/mmol). The resulting mixture was filtered through Celite and MgSO₄. The filtrate was concentrated under reduced pressure and then subjected to flash column chromatography.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-benzhydroxamoyl-β-D-glucopyranose (**13a**)

13a was prepared according to the general procedure described above using 260 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 103 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography (MeOH/CH₂Cl₂, 1:100) gave a white amorphous solid (227 mg, 0.484 mmol, 97%, 100% β determined by ¹H NMR). m.p. 82.1-83.5 °C; [α]_D²⁵: -24.5 (c 0.2, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 9.61 (br s, 1H), 7.68 (d, 2H, *J* = 7.8 Hz), 7.45 (t, 1H, *J* = 7.3 Hz), 7.35 (t, 2H, *J* = 7.7 Hz), 5.23 (t, 1H, *J* = 9.4 Hz), 5.10 (t, 1H, *J* = 8.15 Hz), 5.04 (t, 1H, *J* = 9.4 Hz), 4.91 (d, 1H, *J* = 8.0 Hz), 4.22 (dd, 1H, *J* = 12.5, 4.4 Hz), 4.10 (dd, 1H, *J* = 12.4, 2.3 Hz), 3.73 (ddd, 1H, *J* = 9.9, 4.4, 2.3 Hz), 2.08 (s, 3H), 1.99 (s, 3H), 1.95 (s, 3H), 1.94 (s, 3H); ¹³C NMR (CDCl₃, 75 MHz): 171.1, 170.7, 170.4, 169.8, 166.7, 132.6, 131.5, 129.1 (x2), 127.6 (x2), 103.9, 72.7, 72.6, 69.7, 68.4, 62.1, 21.1 (x2), 20.9 (x2); HMRS (ESI)

calcd for $C_{21}H_{25}NO_{11}Na$ (M+Na): 490.1325, found: 490.1337, calcd for $C_{21}H_{25}NO_{11}K$ (M+K): 506.1065, found: 506.1073.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-(phenylcarbamoyl)heptydroxamoyl- β -D-glucopyranose (13b)

13b was prepared according to the general procedure described above using 130 mg (0.25 mmol) of glycosyl trifluoroacetimidate, 99 mg (0.37 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 2.5 mL of anhydrous dichloromethane. Purification by silica gel column chromatography (MeOH/CH₂Cl₂, 1.5:100 then 3:100) gave a white solid (133 mg, 0.22 mmol, 90%, 100% β determined by ¹H NMR). m.p. 68.0 °C; [α]_D²⁵: - 36.4 (c 0.22, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 9.45 (br s, 1H), 8.04 (br s, 1H), 7.54 (d, 2H, *J* = 7.7 Hz), 7.29 (t, 2H, *J* = 7.7 Hz), 7.08 (t, 1H, *J* = 7.2 Hz), 5.27 (t, 1H, *J* = 9.5 Hz), 5.09 (t, 2H, *J* = 9.5 Hz), 4.82 (d, 1H, *J* = 8.1 Hz), 4.20 (dd, 1H, *J* = 12.5, 4.3 Hz), 4.17 (d, 1H, *J* = 12.2 Hz), 3.70 (d, 1H, *J* = 8.8 Hz), 2.34 (t, 2H, *J* = 7.3 Hz), 2.11-2.01 (m, 14H), 1.72-1.62 (m, 4H), 1.45-1.22 (m, 4H); ¹³C NMR (CDCl₃, 75 MHz): 172.2, 171.1, 170.6 (x2), 170.4, 169.9, 138.6, 129.3 (x2), 124.5, 120.3 (x2), 103.9, 72.7, 72.6, 69.6, 68.4, 62.0, 37.6 (x2), 28.9 (x2), 25.7 (x2), 21.1 (x2), 21.0 (x2); HMRS (ESI) calcd for $C_{28}H_{38}N_2O_{12}Na$ (M+Na): 617.2322, found: 617.2325; calcd for $C_{28}H_{38}N_2O_{12}K$ (M+K): 633.2062.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-phenylacethydroxamoyl- β -D-glucopyranose (13c)

13c was prepared according to the general procedure described above using 260 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 114 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by silica gel column chromatography (EtOAc/PE, 5:5 then 6:4) gave a white solid (234 mg, 0.48 mmol, 97 %, 100% β determined by ^1H NMR). m.p. 134.1 °C; $[\alpha]_{\text{D}}^{25}$: - 20.4 (c 0.22, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 8.46 (br s, 1H), 7.41-7.21 (m, 5H), 5.26 (t, 1H, J = 9.6 Hz), 5.08 (t, 2H, J = 8.2 Hz), 4.81 (d, 1H, J = 8.2 Hz), 4.28 (dd, 1H, J = 14.1, 5.1 Hz), 4.13 (d, 1H, J = 12.1 Hz), 3.81-3.45 (m, 3H), 2.12 (s, 3H), 2.08 (s, 3H), 2.03 (s, 6H); ^{13}C NMR (CDCl_3 , 75 MHz): 171.0, 170.4, 169.8, 133.6, 129.7 (x2), 129.4 (x2), 128.0, 103.9, 72.7, 72.6, 69.5, 68.2, 61.9, 21.1 (x2), 21.0 (x2); HMRS (ESI) calcd for $\text{C}_{22}\text{H}_{27}\text{NO}_{11}\text{Na}$ ($\text{M}+\text{Na}$): 504.1482, found: 504.1477; calcd for $\text{C}_{22}\text{H}_{27}\text{NO}_{11}\text{K}$ ($\text{M}+\text{K}$): 520.1221, found: 520.1210.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-acethydroxamoyl- β -D-glucopyranose (**13d**)

13d was prepared according to the general procedure described above using using 260 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 57 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography ($\text{MeOH}/\text{CH}_2\text{Cl}_2$, 3:100 then 6:100) gave a colourless oil (197 mg, 0.48 mmol, 97%, 100% β determined by ^1H NMR). $[\alpha]_{\text{D}}^{25}$: + 100.9 (c 0.11, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 9.09 (br s, 1H), 5.20 (t, 1H, J = 9.4 Hz), 5.03 (t, 2H, J = 9.4 Hz),

4.76 (d, 1H, $J = 7.9$ Hz), 4.22 (dd, 1H, $J = 12.8, 3.5$ Hz), 4.12 (d, 1H, $J = 12.3$ Hz), 3.71 (d, 1H, $J = 8.9$ Hz), 2.14-1.88 (m, 15H); ^{13}C NMR (CDCl_3 , 75 MHz): 171.1, 170.4 (x2), 169.8, 168.9, 104.0, 72.7 (x2), 69.5, 68.3, 62.0, 30.1, 21.1 (x2), 21.0, 20.3; HMRS (ESI) calcd for $\text{C}_{16}\text{H}_{23}\text{NO}_{11}\text{Na}$ ($\text{M}+\text{Na}$): 428.1169, found: 428.1164; calcd for $\text{C}_{16}\text{H}_{23}\text{NO}_{11}\text{K}$ ($\text{M}+\text{K}$): 444.0908, found: 444.0902.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-benzhydroxamoyl- β -D-galactopyranose (14a)

14a was prepared according to the general procedure described above using 260 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 103 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography (EtOAc/PE, 4:6 and 5:5) gave a white solid (188 mg, 0.40 mmol, 80 %, 100% β determined by ^1H NMR). m.p. 66.4 °C; $[\alpha]^{25}_{\text{D}}$: -25 (c 0.2, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 9.24 (s, 1H), 7.76 (d, 1H, $J = 7.5$ Hz), 7.55 (t, 1H, $J = 7.1$ Hz), 7.46 (t, 2H, $J = 7.3$ Hz), 5.45 (d, 1H, $J = 3.5$ Hz), 5.36 (dd, 1H, $J = 10.5, 10.2$ Hz), 5.12 (dd, 1H, $J = 10.5, 2.8$ Hz), 4.93 (d, 1H, $J = 8.2$ Hz), 4.24-4.14 (m, 2H), 4.00 (t, 1H, $J = 6.4$ Hz), 2.22 (s, 3H), 2.17 (s, 3H), 2.05 (s, 3H), 2.01 (s, 3H); ^{13}C NMR (CDCl_3 , 75 MHz): 171.1, 170.8, 170.5, 170.4, 167.0, 132.9, 131.8, 129.2 (x2), 127.6 (x2), 104.6, 71.7, 70.9, 67.3, 68.8, 61.5, 21.3, 21.1, 21.0 (x2); HMRS (ESI) calcd for $\text{C}_{21}\text{H}_{25}\text{NO}_{11}\text{Na}$ ($\text{M}+\text{Na}$): 490.1325, found: 490.1325.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-(phenylcarbamoyl)heptydroxamoyl - β -D-galactopyranose (14b)

14b was prepared according to the general described above using 130 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 99 mg (0.37 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography (MeOH/CH₂Cl₂, 3:100 and 6:100) gave a colourless oil (103 mg, 0.17 mmol, 69 %, 100% β determined by ¹H NMR). m.p. 49.1 °C; [α]_D²⁵: -30 (c 0.13, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 8.73 (br s, 1H), 7.56-7.48 (m, 3H), 7.30 (t, 2H, *J* = 7.6 Hz), 7.09 (t, 1H, *J* = 7.3 Hz), 5.41 (dd, 1H, *J* = 2.8, 0.9 Hz), 5.25 (dd, 1H, *J* = 10.5, 8.1 Hz), 5.08 (dd, 1H, *J* = 10.4, 3.0 Hz), 4.76 (d, 1H, *J* = 8.1 Hz), 4.22-4.08 (m, 2H), 3.97 (t, 1H, *J* = 6.8 Hz), 2.35 (t, 2H, *J* = 7.2 Hz), 2.15 (s, 6H), 2.05 (s, 3H), 1.99 (s, 3H), 1.78-1.57 (m, 6H), 1.46-1.30 (m, 4H); ¹³C NMR (CDCl₃, 75 MHz): 171.8, 170.9, 170.5, 170.3, 138.5, 128.4 (x2), 124.5, 120.1 (x2), 104.3, 71.7, 70.9, 67.2, 67.1, 61.5, 37.8 (x2), 28.8 (x2), 25.6 (x2), 21.3, 21.1, 21.0, 20.9; HMRS (ESI) calcd for C₂₈H₃₈N₂O₁₂Na (M+Na): 617.2322, found: 617.2336.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-benzhydroxamoyl-α-D-mannopyranose (**15a**)

15a was prepared according to the general procedure describe above using 260 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 103 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash

column chromatography (EtOAc/PE, 6:4) gave a white solid (216 mg, 0.46 mmol, 92 %, 100% α determined by ^1H NMR). m.p. 149.8 °C; $[\alpha]_{\text{D}}^{25}$: +50.5 (c 0.22, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 9.75 (br s, 1H), 7.75 (d, 2H, $J = 7.4$ Hz), 7.50 (t, 1H, $J = 7.5$ Hz), 7.40 (t, 2H, $J = 7.7$ Hz), 5.44 (s, 1H), 5.38-5.28 (m, 2H), 5.22 (s, 1H), 4.80 (br s, 1H), 4.27 (dd, 1H, $J = 12.6, 4.5$ Hz), 4.17-4.04 (m, 1H), 2.12 (s, 3H), 2.06 (s, 3H), 2.00 (s, 3H), 1.95 (s, 3H); ^{13}C NMR (CDCl_3 , 75 MHz): 171.2, 170.5, 170.4, 170.2, 167.7, 132.9, 131.6, 129.1 (x2), 127.6 (x2), 102.2, 70.5, 69.7, 68.3, 65.9, 62.7, 21.2, 21.1 (x2), 20.8; HMRS (ESI) calcd for $\text{C}_{21}\text{H}_{25}\text{NO}_{11}\text{Na}$ (M+Na): 490.1325, found: 490.1330, calcd for $\text{C}_{21}\text{H}_{25}\text{NO}_{11}\text{K}$ (M+K): 506.1055, found: 506.1070.

2,3,4,6-Tetra-*O*-acetyl-1-*O*-(phenylcarbamoyl)heptydroxamoyl- α -D-mannopyranose (15b)

15b was prepared according to the general describe above using 130 mg (0.25 mmol) of glycosyl trifluoroacetimidate, 99 mg (0.37 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 2.5 mL of anhydrous dichloromethane. Purification by flash column chromatography ($\text{MeOH}/\text{CH}_2\text{Cl}_2$, 3:100 then 6:100) gave a white solid (125 mg, 0.21 mmol, 84 %, 100% α determined by ^1H NMR). m.p. 132.1 °C; $[\alpha]_{\text{D}}^{25}$: + 26.7 (c 0.24, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 9.60 (br s, 1H), 7.98 (br s, 1H), 7.53 (d, 2H, $J = 7.8$ Hz), 7.30 (t, 2H, $J = 8.5$ Hz), 7.09 (t, 1H, $J = 7.3$ Hz) , 5.44-5.30 (m, 2H), 5.27 (dd, 1H, $J = 10.0, 3.5$ Hz), 5.07 (d, 1H, $J = 1.5$ Hz), 4.68 (br s, 1H), 4.24 (dd, 1H, $J = 12.5, 3.8$ Hz), 4.13 (dd, 1H, $J =$

12.6, 2.5 Hz), 2.35 (t, 2H, $J = 7.2$ Hz), 2.15-2.00 (m, 14H), 1.79-1.56 (m, 4H), 1.44-1.22 (m, 4H); ^{13}C NMR (CDCl_3 , 75 MHz): 172.0, 171.0, 170.1, 169.9, 169.7, 138.1, 129.0 (x2), 124.2, 119.9 (x2), 101.5, 69.9, 69.2, 67.7, 65.4, 62.2, 37.2, 32.6, 28.3, 28.1, 25.2, 24.8, 20.8 (x2), 20.7 (x2); HMRS (ESI) calcd for $\text{C}_{28}\text{H}_{38}\text{N}_2\text{O}_{12}\text{Na}$ ($\text{M}+\text{Na}$): 617.2322, found: 617.2317, calcd for $\text{C}_{28}\text{H}_{38}\text{N}_2\text{O}_{12}\text{K}$ ($\text{M}+\text{K}$): 633.2062, found: 633.2078.

Methyl 2,3,4-tri-*O*-acetyl-1-*O*-benzhydroxamoyl- β -D-glucopyranosyluronate (16a)

16a was prepared according to the general procedure described above using 253 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 103 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography (AcOEt/PE , 4:6 and 5:5) gave a white solid (181 mg, 0.40 mmol, 80%, 100% β determined by ^1H NMR). m.p. 180.2 °C, $[\alpha]_{\text{D}}^{25}$: - 12.8 (c 0.18, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 7.81 (d, 2H, $J = 7.0$ Hz), 7.56 (t, 1H, $J = 7.2$ Hz), 7.46 (t, 2H, $J = 7.1$ Hz), 5.41 (t, 1H, $J = 8.6$ Hz), 5.35 (t, 1H, $J = 7.1$ Hz), 5.26 (t, 1H, $J = 5.08$ Hz), 5.16 (d, 1H, $J = 4.8$ Hz), 4.29 (d, 1H, $J = 8.6$ Hz), 3.79 (s, 3H), 2.17 (s, 3H), 2.08 (s, 3H), 2.07 (s, 3H); ^{13}C NMR (CDCl_3 , 75 MHz): 170.1, 170.0, 169.9, 169.6, 166.1, 132.7, 131.7, 129.1 (x2), 127.6 (x2), 103.5, 72.9, 70.9, 70.1, 68.1, 53.6, 21.1, 21.0, 20.9; HMRS (ESI) calcd for $\text{C}_{20}\text{H}_{23}\text{NO}_{11}\text{Na}$ ($\text{M}+\text{Na}$): 476.1169, found: 476.1157, calcd for $\text{C}_{20}\text{H}_{23}\text{NO}_{11}\text{K}$ ($\text{M}+\text{K}$): 492.0908, found: 492.0917.

Methyl 2,3,4-tri-*O*-acetyl-1-*O*-(phenylcarbamoyl)heptydroxamoyl- β -D-glucopyranosyluronate (16b)

16b was prepared according to the general procedure described above using 127 mg (0.25 mmol) of glycosyl trifluoroacetimidate, 99 mg (0.37 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 2.5 mL of anhydrous dichloromethane. Purification by flash column chromatography (MeOH/CH₂Cl₂, 3:100 then 6:100) gave a white solid (110 mg, 0.19 mmol, 76%, 100% β determined by ¹H NMR). m.p. 105.1 °C; [α]_D²⁵: - 35.9 (c 0.22, CHCl₃); ¹H NMR (CDCl₃, 300 MHz): 9.57 (s, 1H), 7.59 (s, 1H), 7.54 (d, 2H, *J* = 7.9 Hz), 7.31 (t, 2H, *J* = 6.9 Hz), 7.09 (t, 1H, *J* = 7.3 Hz), 5.39-5.20 (m, 2H), 5.12 (m, 1H), 4.96 (m, 1H), 4.19 (d, 1H, *J* = 8.6 Hz), 3.75 (s, 3H), 2.35 (t, 2H, *J* = 7.2 Hz), 2.21-1.99 (m, 11H), 1.90-1.57 (m, 4H), 1.46-1.30 (m, 4H); ¹³C NMR (CDCl₃, 75 MHz): 171.9, 170.2, 169.9, 138.5, 129.3 (x2), 124.5, 120.2 (x2), 103.3, 72.8, 71.2, 70.0, 68.5, 53.6, 37.7, 33.2, 30.1, 28.8, 28.7, 25.6, 21.1, 21.0, 20.9; HMRS (ESI) calcd for C₂₇H₃₇N₂O₁₂ (M+H): 581.2346, found: 581.2351, calcd for C₂₇H₃₆N₂O₁₂Na (M+Na): 603.2166, found: 603.2170, calcd for C₂₇H₃₆N₂O₁₂K (M+K): 619.1905, found: 619.1937.

2,3,5-Tri-*O*-acetyl-1-*O*-benzhydroxamoyl-β-*D*-ribofuranose (17a)

17a was prepared according to the general procedure described above using 225 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 103 mg (0.75 mmol) of hydroxamic acid, 2 g of

activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography (EtOAc/PE, 60:40) gave a colourless oil (160 mg, 0.40 mmol, 81 %, 100% β determined by ^1H NMR). $[\alpha]^{25}_{\text{D}}$: -25 (c 0.2, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 7.80 (d, 2H, $J = 7.2$ Hz), 7.48 (t, 1H; $J = 7.2$ Hz), 7.39 (t, 2H, $J = 7.6$ Hz), 5.52 (d, 1H, $J = 5.4$ Hz), 5.44 (s, 1H), 5.32 (t, 1H, $J = 5.9$ Hz), 4.66-4.53 (m, 1H), 4.36-4.26 (m, 1H), 4.21 (dd, 1H, $J = 12.01, 2.93$ Hz), 2.08 (s, 3H), 2.07 (s, 3H), 2.02 (s, 3H); ^{13}C NMR (CDCl_3 , 75 MHz): 171.9, 169.7, 169.2, 165.2, 132.1, 131.3, 128.6 (x2), 127.3 (x2), 108.4, 81.0, 73.1, 71.2, 64.8, 21.1, 20.5, 20.4; HMRS (ESI) calcd for $\text{C}_{18}\text{H}_{21}\text{NO}_9\text{Na}$ (M+Na): 418.1140, found: 418.1118, calcd for $\text{C}_{18}\text{H}_{21}\text{NO}_9\text{K}$ (M+K): 434.0853, found: 434.0847.

2,3,5-Tri-*O*-acetyl-1-*O*-(phenylcarbamoyl)heptydroxamoyl- β -D-ribofuranose (17b)

17b was prepared according to the general procedure described above using 225 mg (0.50 mmol) of glycosyl trifluoroacetimidate, 198 mg (0.75 mmol) of hydroxamic acid, 2 g of activated 4 Å molecular sieves in 5 mL of anhydrous dichloromethane. Purification by flash column chromatography (MeOH/ CH_2Cl_2 , 1.5:100, 3:100 then 4.5:100) gave a colourless oil (180 mg, 0.34 mmol, 69 %, 100% β determined by ^1H NMR). $[\alpha]^{25}_{\text{D}}$: -22 (c 0.18, CHCl_3); ^1H NMR (CDCl_3 , 300 MHz): 9.70 (s, 1H), 8.20 (s, 1H), 7.55 (d, 2H, $J = 7.8$ Hz), 7.27 (t, 2H, $J = 8.0$ Hz), 7.06 (t, 1H, $J = 7.3$ Hz), 5.43 (d, 1H, $J = 5.0$ Hz), 5.32-5.26 (m, 2H), 4.56-4.42 (m, 1H), 4.38-4.26 (m, 1H), 4.21 (dd, 1H, $J = 11.7, 2.7$ Hz), 2.34 (t, 2H), 2.22-2.02 (m, 11H), 1.70-1.61 (m, 4H), 1.44-1.22 (m, 4H); ^{13}C NMR (CDCl_3 , 75 MHz): 171.9, 171.7, 171.0, 169.7, 169.3, 138.4, 128.8 (x2), 124.0, 119.9 (x2), 108.2, 80.7, 72.9, 71.2, 64.8, 37.3, 32.9,

28.7, 28.6, 25.3, 25.0, 21.0, 20.7, 20.4; HMRS (ESI) calcd for $C_{25}H_{34}N_2O_{10}Na$ (M+Na):
545.2111, found: 545.2117, calcd for $C_{25}H_{34}N_2O_{10}K$ (M+K): 561.1850, found: 561.1838.

S25

S49

13a

13c