SUPPLEMENTAL INFORMATION

Chemistry

Experiment Procedures

General: Unless otherwise noted, all reactants or reagents including dry solvents were obtained from commercial suppliers and used as received. Unless otherwise noted, all reactions were performed with dry solvents under an atmosphere of nitrogen in dried glassware using standard vacuum-line techniques. All work-up and purification procedures were carried out with reagent-grade solvents in air. Analytical thin-layer chromatography (TLC) was performed using E. Merck silica gel 60 F_{254} precoated plates (0.25 mm). The developed chromatogram was analyzed by UV lamp (254 nm). Flash column chromatography was performed with E. Merck silica gel 60 (230–400 mesh). Preparative thin-layer chromatography (PTLC) was performed using Wako gel B5-F silica coated plates (0.75 mm) prepared in our laboratory. A reverse phase thin-layer chromatography (TLC) was performed using E. Merck silica gel 60 RP-18 $F_{254}S$ precoated plates (0.25 mm). The high-resolution mass (HRMS) spectra were conducted on Thermo Fisher Scientific Exactive. Nuclear magnetic resonance (NMR) spectra were recorded on a JEOL JNM-ECA-400 (^{1}H 400 MHz, ^{13}C 100 MHz) and JEOL JMN-ECA-600II with Ultra COOL^{TM} probe (^{1}H 600 MHz, ^{13}C 150 MHz) spectrometer. Chemical shifts for ^{1}H NMR are expressed in parts per million (ppm) relative to tetramethylsilane (δ 0.00 ppm). Chemical shift for ^{13}C NMR are expressed in ppm relative to $CDCl_3$ (δ 77.0 ppm). Data are reported as follows: chemical shift, multiplicity (s = singlet, d = doublet, dd = doublet of doublets, t = triplet, m = multiplet, br = broad signal), coupling constant (Hz), and integration.

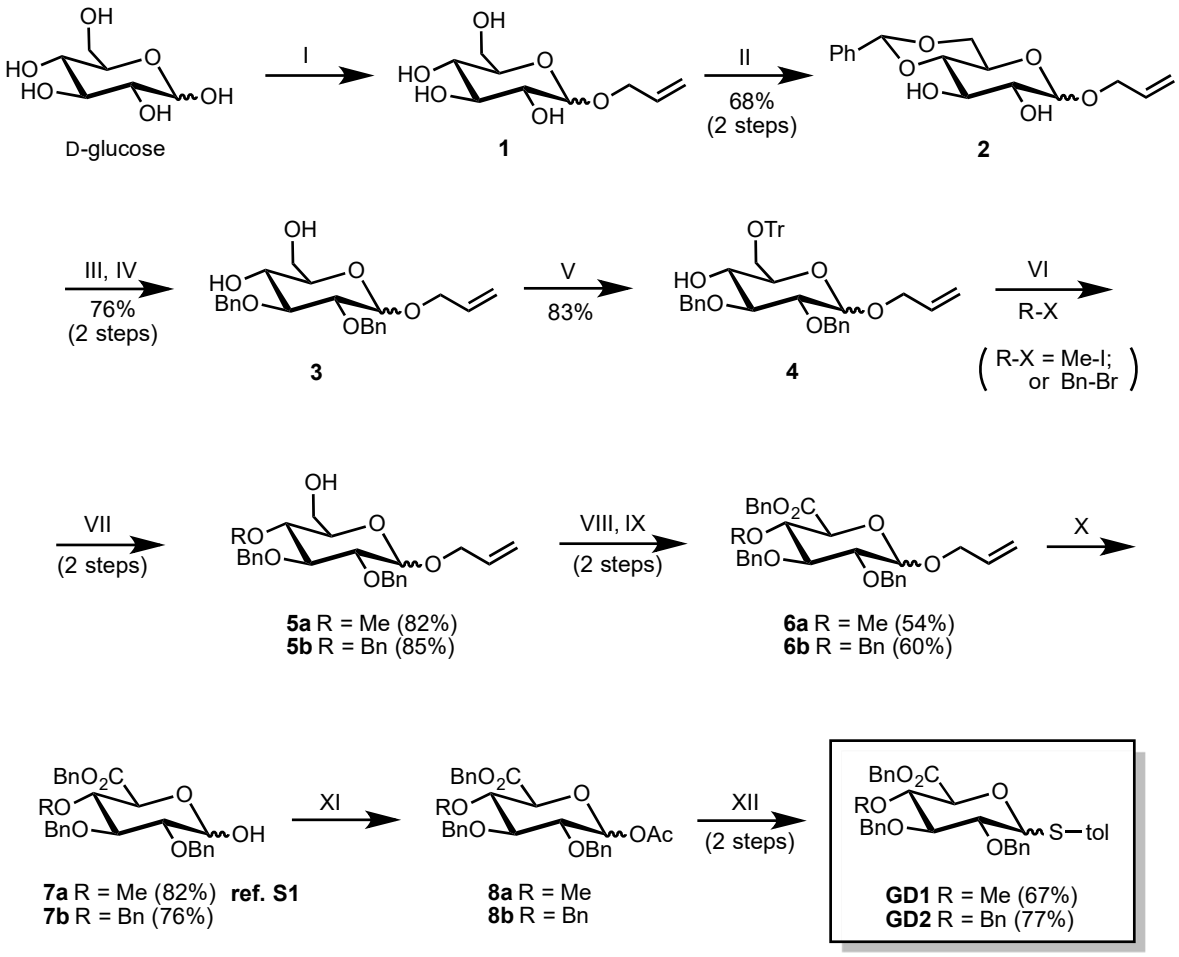


Fig S1. Synthesis of glycosyl donors **GD1** and **GD2**

Reagents and reaction conditions: I) acetyl chloride, allyl alcohol, 70°C, 10 h; II) $TsOH \oplus H_2O$, benzaldehyde dimethyl acetal, 50°C, 3 h; III) NaH, benzyl bromide (BnBr), DMF, 0°C then room temperature (RT), overnight; IV) $TsOH \oplus H_2O$, MeOH, CH_2Cl_2, RT; V) TrCl, DMAP, pyridine, 50°C, overnight; VI) NaH, R-X (methyl iodide or BnBr), DMF, 0°C then RT, overnight; VII) $TsOH \oplus H_2O$, MeOH, CH_2Cl_2, RT; VIII) AZADO, (diacetoxyiodo)benzene, buffer, CH_2Cl_2, 0°C, 3 h; IX) $KHCO_3$, BnBr, tetrabutylammonium iodide (TBAI), DMF, RT, 4 h; X) $PdCl_2$, sodium acetate, H_2O, acetic acid, RT, 48 h; XI) Ac_2O, Et_3N, CH_2Cl_2, RT, 4 h; XII) 4-MeC_6H_4-SH (tol-SH), $BF_3 \oplus Et_2O$, CH_2Cl_2, 0°C to RT, 3 h.

Ts = tosyl, DMF = N,N-dimethylformamide, Tr = triphenylmethyl, DMAP = N,N-dimethyl-4-aminopyridine, AZADO = 2-aza-adamantane N-oxyl.

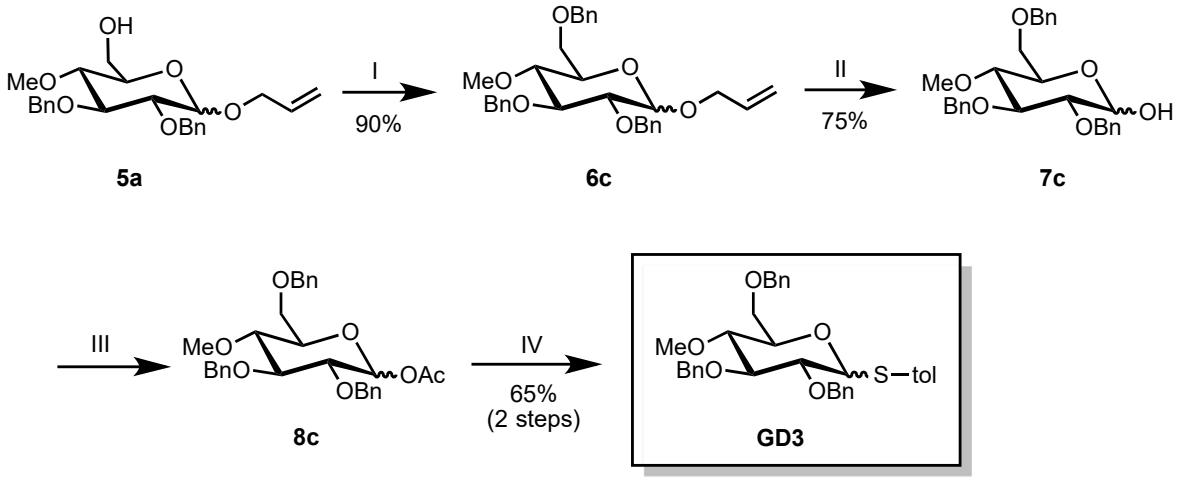


Fig S2. Synthesis of glycosyl donor **GD3**

Reagents and reaction conditions: I) NaH, BnBr, DMF, 0°C then RT, overnight; II) $PdCl_2$, sodium acetate, H_2O, acetic acid, RT, 48 h; III) Ac_2O, Et_3N, CH_2Cl_2, RT, 4 h; IV) 4-MeC_6H_4-SH (tol-SH), $BF_3 \oplus Et_2O$, CH_2Cl_2, 0°C to RT, 3 h.

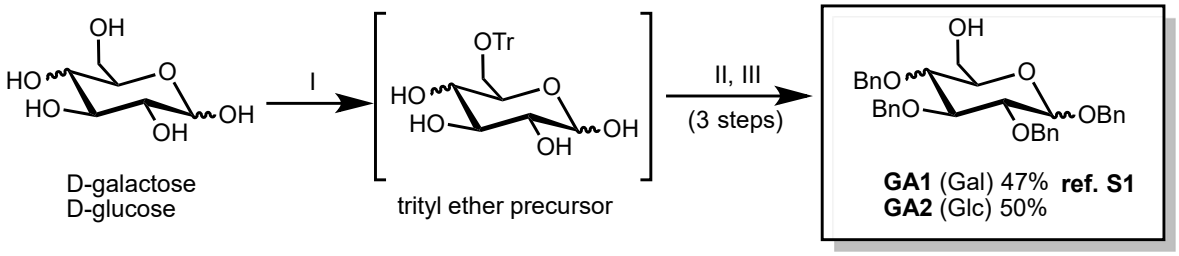


Fig S3. Synthesis of glycosyl acceptor **GA1** and **GA2**

Reagent and reaction conditions: I) TrCl, pyridine, 50°C, overnight; II) BnBr, NaH, DMF, 0°C then RT, 8 h; III) $TsOH \oplus H_2O$, MeOH, CH_2Cl_2, RT.

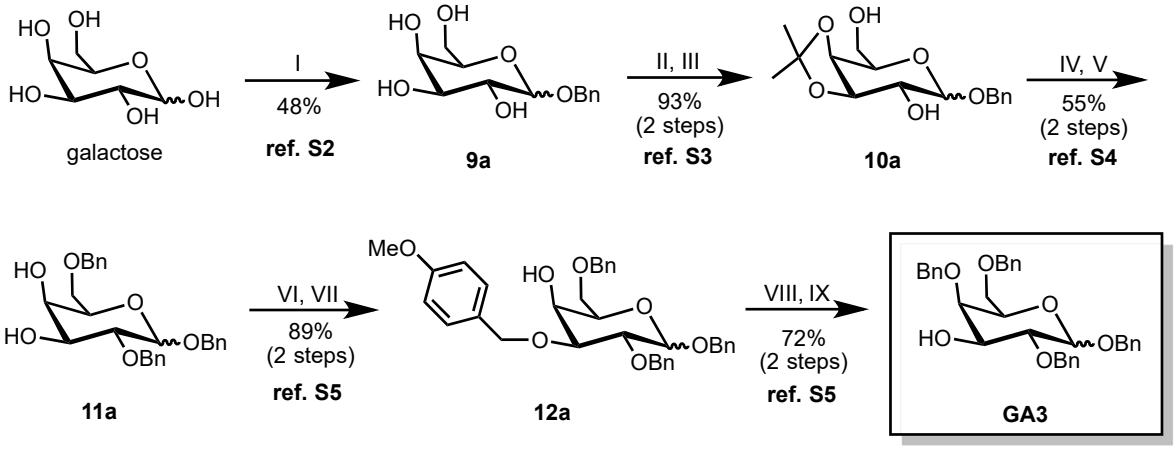


Fig S4. Synthesis of glycosyl acceptor **GA3**

Reagents and reaction conditions: I) BnBr, NaH, DMF, 0°C then RT, 3 h; II) (±)-CSA, acetone dimethylacetal, RT, overnight; III) MeOH, H_2O, reflux, 48 h; IV) BnBr, NaH, DMF, 0°C then RT, overnight; V) HOAc, H_2O, 65°C, 2 h; VI) Bu_2SnO, MeOH, reflux, overnight; VII) PMB-Cl, TBAB, MS4Å, benzene, reflux, 6 h; VIII) BnBr, NaH, DMF, 0°C then RT, overnight; IX) DDQ, CH_2Cl_2, H_2O, RT, 1 h.

CSA = camphorsulfonic acid, TBAB = tetrabutylammonium bromide, PMB-Cl = *para*-methoxy benzyl chloride, MS = molecular sieves, DDQ = 2,3-dichloro-5,6-dicyano-1,4-benzoquinone.

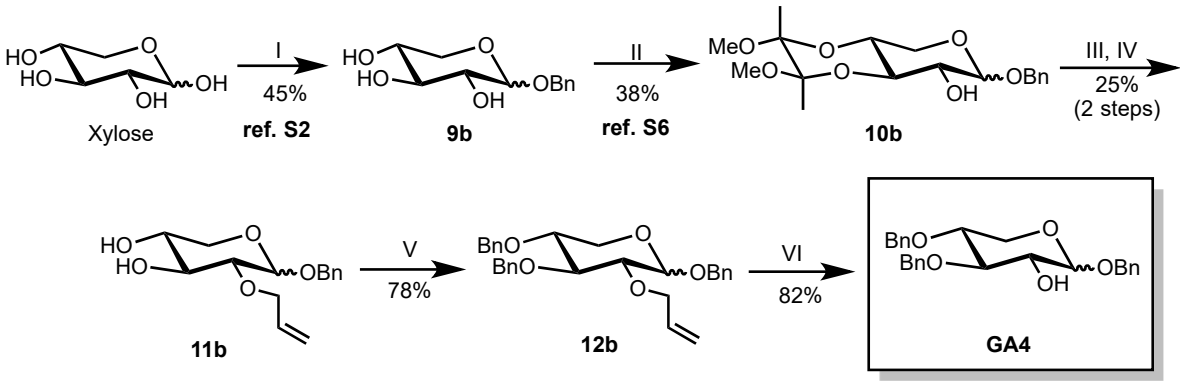
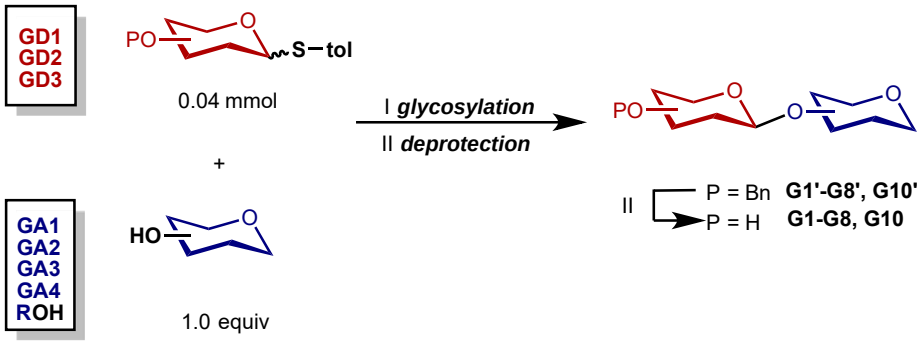
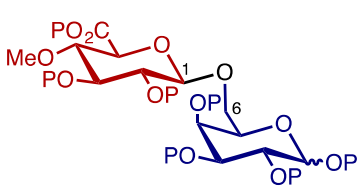


Fig S5. Synthesis of glycosyl acceptor **GA4**

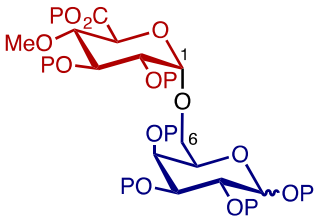
Reagents and reaction conditions: I) BnBr, NaH, DMF, 0°C then RT, 3 h; II) 2,3-butanedione, trimethyl orthoformate, (±)-CSA, MeOH, reflux, 20 h; III) allyl

bromide, NaH, DMF, 0°C then RT, 3 h; IV) TFA, CH_2Cl_2, RT, 15 min; V) BnBr, NaH, DMF, 0°C then RT, overnight; VI) $PdCl_2$, sodium acetate, H_2O, acetic acid, RT, 48 h. TFA = trifluoroacetic acid

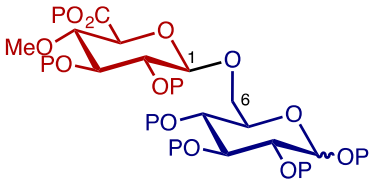




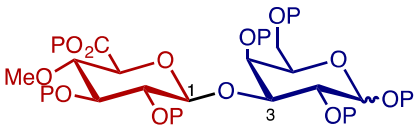
G1' 17% (70%, β:α = 1:3)
G1 95% 4-Me-GlcA-β(1,6)Gal



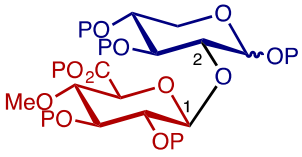
G2' 52% (70%, β:α = 1:3)
G2 95% 4-Me-GlcA-α(1,6)Gal



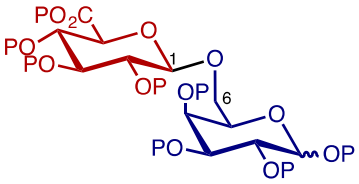
G3' 14% (56%, β:α = 1:3)
G3 96% 4-Me-GlcA-β(1,6)Glc



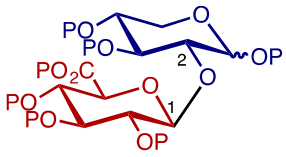
G4' 12% (60%, β:α = 1:4)
G4 81% 4-Me-GlcA-β(1,3)Gal



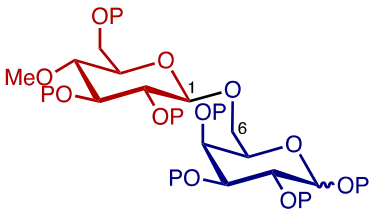
G5' 11% (55%, β:α = 1:4)
G5 83% 4-Me-GlcA-β(1,2)Xyl



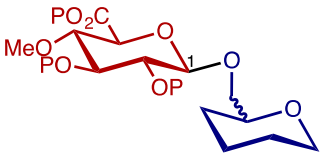
G6' 14% (72%, β:α = 1:4)
G6 90% GlcA-β(1,6)-Gal



G7' 10% (52%, β:α = 1:4)
G7 87% GlcA-β(1,2)Xyl



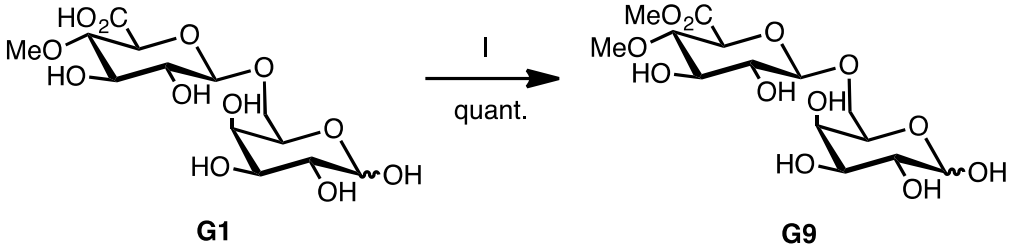
G8' 11% (67%, β:α = 1:5)
G8 quant. 4-Me-Glc-β(1,6)Gal



G10' 16% (82%, β:α = 1:4)
G10 quant. 4-Me-GlcA-β-pyran

Fig S6. Programmable glycosylation of glycosyl donor and acceptor, the yields of glycosylation product **G'** and the deprotection product **G** (the total yield of two anomers and ratio of β:α is shown in parenthesis)

Reagent and reaction conditions: I) NIS, TfOH (cat.), CH_2Cl_2, -40 °C then RT, 4 h; II) $Pd(OH)_2/C$, H_2 atm., EtOAc, MeOH, RT, overnight.



G1 **G9**

Fig S7. Synthesis of 4,6-Me-GlcA-β(1,6)-Gal (**G9**)

Reagents and reaction conditions: I) $TMSCHN_2$, MeOH, toluene, RT, 30 min

$TMSCHN_2$ = trimethylsilyldiazomethane

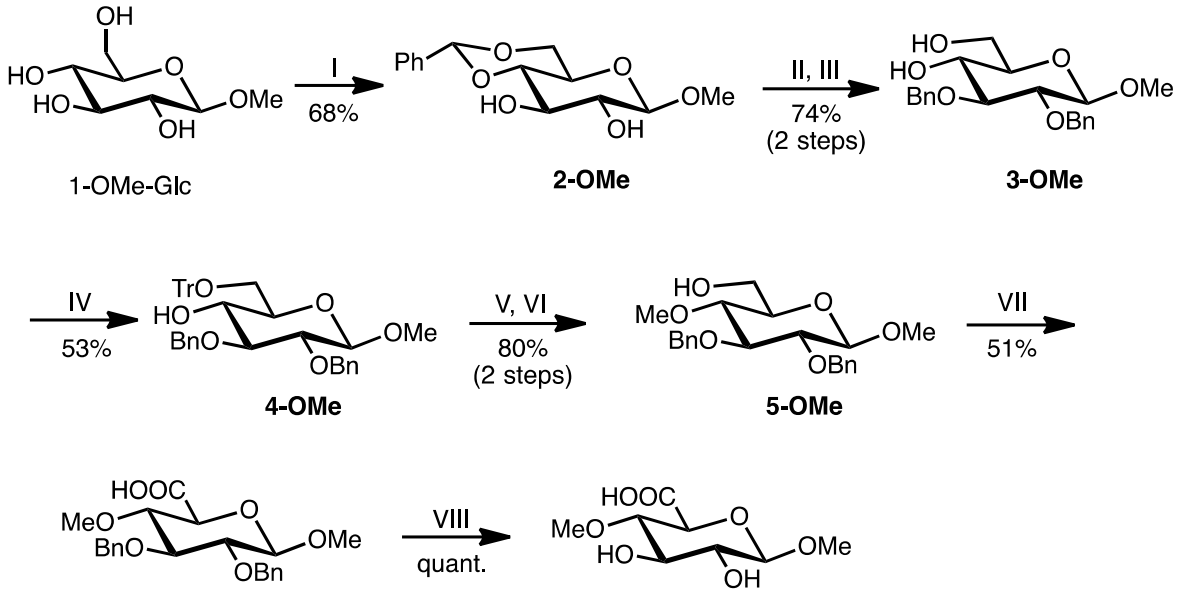
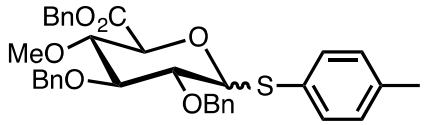


Fig S8. Synthesis of 4-Me-GlcA-β-OMe (**G11**)

Reagents and reaction conditions: I) TsOH⊕H_2O, benzaldehyde dimethyl acetal, 50°C, 3 h; II) NaH, benzyl bromide (BnBr), DMF, 0°C then room temperature (RT), overnight; III) TsOH⊕H_2O, MeOH, CH_2Cl_2, RT; IV) TrCl, DMAP, pyridine, 50°C, overnight; V) NaH, Me-I, DMF, 0°C then RT, overnight; VI) TsOH⊕H_2O, MeOH, CH_2Cl_2, RT; VII) AZADO, (diacetoxyiodo)benzene, buffer, CH_2Cl_2, 0°C, 3 h; VIII) $Pd(OH)_2$/C, H_2 atm., EtOAc, MeOH, RT, overnight.

Preparation of glycosyl donor GD1 (Fig. S1)

Benzyl(2*S*,3*S*,4*S*,5*R*)-4,5-bis(benzyloxy)-3-methoxy-6-(*p*-tolylthio)tetrahydro-2*H*-pyran-2-carboxylate



GD1

The treatment of **7a** (ref. 1S) (239 mg, 0.50 mmol) with acetic anhydride (2 mL) and triethylamine (2 mL) under ambient condition smoothly afforded the corresponding acetyl glycoside **8a** within 4 h (the completion of the reaction was

monitored by TLC). The reaction mixture was concentrated *in vacuo*, yielding a viscous residue, which was further purified by flash column chromatography (hexane/EtOAc = 5:1) to give **8a** as an oil liquid.

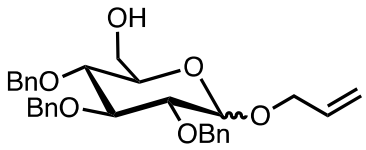
A dry CH_2Cl_2 was added to a Schlenk tube containing **8a** (ca. 0.50 mmol) and Tol-SH (74.0 mg, 0.60 mmol, 1.2 equiv.) under a N_2 atmosphere, and the reaction mixture was cooled down to 0 °C before catalytic amount of $BF_3 \oplus Et_2O$ 1M in Et_2O (10 *μ*L, 0.01 mmol, 0.02 equiv.) was added dropwise to the mixture. The reaction mixture was stirred for 3 h at RT and then cooled to 0 °C before 100 *μ*L of triethylamine was added slowly to quench the reaction. After that, the mixture was allowed to increase to RT and concentrated *in vacuo*. The resultant viscous residue was subjected to silica gel column chromatography (hexane/EtOAc = 5:1) to afford **GD1** as a colorless viscous liquid (mixture of two anomers) in 195 mg (0.34 mmol, 67% yield in 2 steps).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.30 (s, 3H), 2.32 (s, 1H, these two singlets are –Me in –tolyl group of two anomers), 3.37 (s, 1H), 3,41 (s, 3H, these two singlets are 4-O-Me group of two anomers), 3.48–3.51 (m, 1H), 3.57–3.59 (m, 0.3H), 3.76–3.84 (m, 2H) 4.56–4.92 (m, 6H), 5.21 (q, *J* = 12.4 Hz, 2.5H), 5.48 (d, *J* = 5.2 Hz, 0.7H), 7.01 (d, *J* = 7.9 Hz, 1.9H), 7.05 (d, *J* = 7.9 Hz, 0.7H), 7.29–7.37 (m, 23H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.1, 60.5, 60.6, 67.1, 67.2, 70.8, 72.6, 75.4, 75.6, 75.7, 77.9, 79.0, 80.0, 80.7, 81.1, 81.5, 85.8, 87.9, 88.2, 127.6, 127.8(5), 127.9, 128.1, 128.2, 128.3, 128.3(8), 128.4(2), 128.5, 129.7, 132.8, 133.1, 135.2, 137.5, 137.7,138.2, 138.5, 98.7, 127.7, 127.9, 128.0, 128.2, 128.4, 137.3, 137.4, 137.7, 138.2, 138.5, 169.1.

Preparation of glycosyl donor GD2 (Fig. S1)

((2*S*,3*R*,4*S*,5*R*)-6-(Allyloxy)-3-benzyl-4,5-bis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methanol



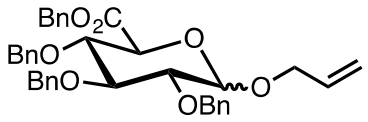
5b

To a stirred solution of trityl ether **4** [ref. S1] (2.57 g, 4.0 mmol) in DMF (60 mL), a 60% dispersion of NaH in mineral oil (240 mg, 6.0 mmol, 1.5 equiv.) was added at 0°C. After stirring the mixture for 30 min, benzyl bromide (BnBr: 710 μL, 6.0 mmol) was added, and the resultant mixture was stirred for a further 3 h at RT. After adding MeOH (1.5 equiv.) to stop the reaction, the reaction mixture was extracted three times with H_2O/EtOAc/hexane (2:1:1, 15 mL) to remove DMF, and dried over Na_2SO_4. After filtration of the organic layer, the mixture was concentrated in *vacuo*. The resultant crude product was dissolved in MeOH/CH_2Cl_2 (1:1, 30 mL) to obtain a yellow solution, which was treated with TsOH·H_2O (10 mol%) and stirred at RT for 6 h. $NaHCO_3$ was added to neutralize the solution and the resultant yellow solution was concentrated in *vacuo*, and then subjected to flash column chromatography (hexane/EtOAc = 3:1) to yield alcohol **5b** as a yellow syrup (1.67 g, 3.4 mmol, 85% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.50–3.56 (m, 2H), 3.65–3.78 (m, 3H), 3.97–4.06 (m, 2H), 4.14 (dd, *J* = 13.2, 5.2 Hz, 1H), 4.65 (dd, *J* = 12.0, 5.2 Hz, 2H), 4.74–4.91 (m, 4H) 4.93–5.02 (m, 1H), 5.23 (d, *J* = 10.4 Hz, 1H), 5.33 (d, *J* = 17.2 Hz, 1H), 5.88–5.97 (m, 1H), 7.29–7.37 (m, 15H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 61.8, 68.2, 70.8, 73.2, 75.0, 75.7, 79.9, 81.9, 95.6, 118.2, 127.8, 127.9, 128.0, 128.3, 128.3(8), 128.4(2), 133.6, 138.1, 138.7.

Benzyl(2*S*,3*S*,4*S*,5*R*)-6-(allyloxy)-3,4,5-tris(benzyloxy)tetrahydro-2*H*-pyran-2-carboxylate



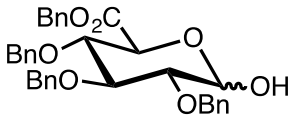
6b

To a solution of **5b** (980 mg, 2.0 mmol,) in CH_2Cl_2 (4 mL) and buffer (Na_2HPO_4/NaH_2PO_4, pH = 7), iodobenzene diacetate (1.29 g, 4.0 mmol) was added at 0°C, followed by addition of 2-azaadamantane *N*-oxyl (AZADO: 15.0 mg, 0.1 mmol, 0.1 equiv.). The mixture was stirred at the same temperature (the completion of the reaction was monitored by TLC). After 2 h, **5b** was consumed and then the reaction mixture was extracted three times with CH_2Cl_2 and water. The organic layer was dried over Na_2SO_4 and the solvent was removed *in vacuo*. A yellow liquid was obtained, to which was added dry DMF (5 mL), followed by $KHCO_3$ (1.0 g, 10.0 mmol, 5.0 equiv.), BnBr (710 *μ*L, 6.0 mmol, 3.0 equiv.), and tetrabutylammonium iodide (TBAI: 74.0 mg, 0.20 mmol, 0.1 equiv.). After stirring at RT for 3 h, the reaction mixture was extracted three times with EtOAc/H_2O (1:1, 10 mL). The organic layer was concentrated *in vacuo*, and the residue was purified by silica gel column chromatography (hexane/EtOAc = 5:1) to yield **6b** as a colorless oil liquid (713 mg, 1.2 mmol, 60% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.57–3.63 (m, 1H), 3.74 (t, *J* = 10.0 Hz, 1H), 3.99–4.06 (m, 2H), 4.18 (dd, *J* = 13.2, 5.2 Hz, 1H), 4.26–4.32 (m, 1H), 4.42–4.47 (m, 1H), 4.62–4.67 (m, 1H), 4.71–4.85 (m, 4H), 4.92–4.99 (m, 1H), 5.11–5.23 (m, 3H), 5.28–5.35 (m, 1H), 5.86–5.96 (m, 1H), 7.10–7.15 (m, 2H), 7.21–7.25 (m, 3H), 7.29–7.34 (m, 15H)

^{13}C NMR ($CDCl_3$, 100 MHz) δ 67.2, 68.6, 70.5, 73.4, 75.0, 75.8, 79.2, 79.6, 81.3, 96.1, 118.7, 127.6, 127.7, 127.8(8), 127.9(2), 128.1, 128.2, 128.3, 128.3(7), 128.4(1), 128.5, 133.2, 135.0, 137.8, 137.9, 138.5, 169.5

Benzyl(2*S*,3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-6-hydroxytetrahydro-2*H*-pyran-2-carboxylate



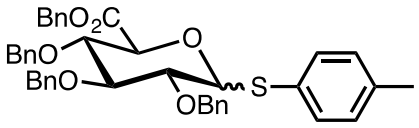
7b

A mixture of **6b** (594 mg, 1.0 mmol), sodium acetate (205 mg, 2.5 mmol, 2.5 equiv.), $PdCl_2$ (212 mg, 1.2 mmol, 1.2 equiv.), and aqueous acetic acid (acetic acid/H_2O = 11:1, 12 mL) was stirred at RT for 48 h. After removing acetic acid and water in *vacuo*, the residue was subjected to silica gel column chromatography (hexane/EtOAc = 3:1) to afford **7b** as a white amorphous solid (421 mg, 0.76 mmol, 76% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.11 (s, 1H), 3.60 (dd, *J* = 9.2, 3.2 Hz, 1H), 3.76 (t, *J* = 9.6 Hz, 1H), 3.95–4.03 (m, 1H), 4.49 (dd, *J* = 16.0, 9.6 Hz, 2H), 4.65–4.80 (m, 4H), 4.86–4.93 (m, 1H), 5.09–5.23 (m, 3H), 7.12–7.15 (m, 2H), 7.25–4.26 (m, 3H), 7.29–7.32 (m, 15H)

^{13}C NMR ($CDCl_3$, 100 MHz) δ 67.2, 70.5, 73.3, 74.8, 75.6, 79.1, 79.3, 80.6, 91.5, 127.6, 127.7, 127.9, 128.0, 128.0(5), 128.1(1), 128.2, 128.3, 128.5, 128.6, 134.9, 137.5, 137.7, 138.3, 169.6

Benzyl(2*S*,3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-6-(*p*-tolylthio)tetrahydro-2*H*-pyran-2-carboxylate



GD2

Same procedures as the preparation of **GD1**: treatment of **7b** (277 mg, 0.50 mmol) with acetic anhydride (2 mL) and triethylamine (2 mL) under ambient condition, smoothly afforded the corresponding acetyl glycoside **8b** within 4 h (the completion of the reaction was monitored by TLC). The reaction mixture was concentrated *in vacuo*, yielding a viscous residue, which was subjected to flash column chromatography (hexane/EtOAc = 5:1) to give **8b** as an oil liquid,.

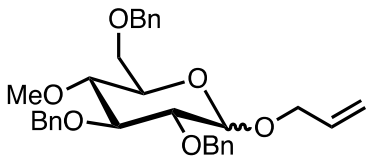
A dry CH_2Cl_2 was added to a Schlenk tube containing **8b** (ca. 0.50 mmol) and Tol-SH (74.0 mg, 0.60 mmol, 1.2 equiv.) under a N_2 atmosphere, and the reaction mixture was cooled down to 0 °C before catalytic amount of $BF_3 \oplus Et_2O$ 1M in Et_2O (10 μL, 0.01 mmol, 0.02 equiv.) was added dropwise to the mixture. The reaction was stirred for 3 h at RT and cooled to 0 °C before 100 μL of triethylamine was added slowly to quench the reaction. After that, the mixture was allowed to increase to RT and concentrated *in vacuo*, afforded a viscous residue, which was purified by silica gel column chromatography (hexane/EtOAc = 5:1) to afford **GD2** as a colorless viscous liquid as a mixture of two anomers (254 mg, 0.39 mmol, 77% yield in 2 steps).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.31 (s), 2.33 (s) (3H) (these two singlets are –Me in –tolyl group of two anomers), 3.49 (t, *J* = 9.2 Hz), 3.69 (t, *J* = 9.2 Hz) (1H) (these two triplets are one isomeric proton from two anomers) 3.81–3.86 (m, 1H), 3.89–3.95 (m, 1H), 4.49–4.62 (m, 1H), 4.67–4.97 (m, 6H), 5.09–5.22 (m, 2H), 5.51 (s, 1H), 7.02–7.08 (m, 2H), 7.13–7.17 (m, 2H), 7.28–7.40 (m, 20H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.1, 67.2, 67.3, 70.9, 72.6, 75.0, 75.1, 75.4, 75.8, 75.9, 78.1, 79.0, 79.1(5), 79.2(2), 80.1, 81.6, 85.9, 87.9, 88.3, 127.7, 127.7(7), 127.8(0), 128.0, 128.2, 128.3, 128.3(6), 128.4(4), 128.5, 128.6, 128.9, 129.5, 129.7, 132.8, 133.1, 135.1, 137.5, 137.7, 137.8, 137.9, 138.1, 138.4, 168.0, 169.1.

Preparation of glycosyl donor GD3 (Fig. S2)

Benzyl(2*S*,3*S*,4*S*,5*R*)-3,4,5-tris(benzyloxy)-6-(*p*-tolylthio)tetrahydro-2*H*-pyran-2-carboxylate



6c

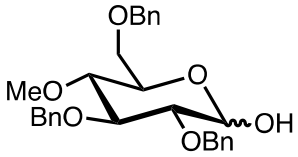
To a stirred solution of trityl ether **5a** [ref. S1] (828 mg, 2.0 mmol) in DMF (30 mL), a 60% dispersion of NaH in mineral oil (120 mg, 3.0 mmol, 1.5 equiv.) was added at

0°C. After stirring the mixture for 30 min, benzyl bromide (355 *μ*L, 3.0 mmol, 1.5 equiv.) was added, and the resultant mixture was stirred for a further 3 h at RT. MeOH (1.5 equiv.) was then added to stop the reaction. The reaction mixture was extracted three times with H_2O/EtOAc/hexane (2:1:1, 10 mL) to remove DMF, and dried over Na_2SO_4. After filtration of the organic layer, the mixture was concentrated in *vacuo*. The resultant crude product was purified by flash column chromatography (hexane/EtOAc= 3:1) to yield **6c** as a colorless oil liquid (907 mg, 0.18 mmol, 90% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.46 (s, 3H), 3.48–3.55 (m, 1H), 3.61–3.74 (m, 4H), 3.89 (t, *J* = 9.6 Hz, 1H), 3.98–4.03 (m, 1H), 4.13–4.18 (m, 1H), 4.49–4.65 (m, 3H), 4.74–4.81 (m, 3H), 4.88–4.96 (m, 1H), 5.10 (dd, *J* = 1.6, 1.0 Hz, 1H), 5.28–5.33 (m, 1 H), 5.88–5.98 (m, 1H), 7.27–7.40 (m, 15H)

^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.6, 68.1, 68.5, 70.2, 73.2, 73.4, 75.6, 79.4, 79.6, 82.0, 95.6, 118.1, 127.5, 127.6, 127.8, 127.9, 128.0, 128.1, 128.2(5), 128.2(8), 128.3, 133.7, 138.0, 138.2, 138.9

(3*R*,4*S*,5*R*,6*R*)-3,4-Bis(benzyloxy)-6-((benzyloxy)methyl)-5-methoxytetrahydro-2*H*-pyran-2-ol



7c

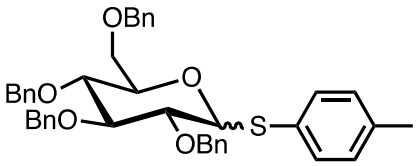
A mixture of **6c** (504 mg, 1.0 mmol), sodium acetate (205 mg, 2.5 mmol, 2.5 equiv.), $PdCl_2$ (212 mg, 1.2 mmol, 1.2 equiv.), and aqueous acetic acid (acetic acid/H_2O = 11:1, 12 mL) was stirred at RT for 48 h. After removing acetic acid and water in *vacuo*, the residue was subjected to silica gel column chromatography (hexane/EtOAc = 3:1) to afford **7c** as a white amorphous solid (348 mg, 0.75 mmol, 75% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.28–3.38 (m, 1H), 3.47 (s, 3H), 3.51–3.55 (m, 1H),

3.63–3.74 (m, 2H), 3.85 (t, *J* = 9.6 Hz, 1H), 3.91–3.95 (m, 1H), 4.50–4.95 (m, 7H), 5.20 (d, *J* = 3.6 Hz, 1H), 7.29–7.39 (m, 15H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.6, 68.6, 70.1, 73.1, 73.4, 75.5, 79.5, 79.6, 79.7, 81.5, 91.2, 127.5(7), 127.6(3), 127.8, 127.9, 128.0, 128.1, 128.3, 128.4, 130.1, 137.8, 138.6

(3*R*,4*S*,5*R*,6*R*)-3,4-Bis(benzyloxy)-6-((benzyloxy)methyl)-5-methoxy-2-(*p*-tolylthio)tetrahydro-2*H*-pyran



GD3

Same procedures as the preparation of **GD1** and **GD2** (Fig. S1): treatment of **7c** (232 mg, 0.50 mmol) with acetic anhydride (2 mL) and triethylamine (2 mL) under ambient condition, smoothly afforded the corresponding acetyl glycoside **8c** within 4 h (the completion of the reaction was monitored by TLC). The reaction mixture was concentrated *in vacuo*, yielding a viscous residue, which was subjected to flash column chromatography (hexane/EtOAc = 5:1) to give **8c** as an oil liquid.

A dry CH_2Cl_2 was added to a Schlenk tube containing **8c** (ca. 0.50 mmol) and Tol-SH (74.0 mg, 0.60 mmol, 1.2 equiv.) under a N_2 atmosphere. The reaction mixture was cooled down to 0 °C before catalytic amount of $BF_3{\oplus}Et_2O$ 1M in Et_2O (10 *μ*L, 0.01 mmol, 0.02 equiv.) was added dropwise to the mixture. The mixture was stirred for 3 h at RT and cooled to 0 °C before 100 *μ*L of triethylamine was added slowly to quench the reaction. After that, the mixture was allowed to increase to RT and concentrated *in vacuo* to afford a viscous residue which was purified by silica gel column chromatography (hexane/EtOAc = 5:1) to afford **GD3** as a colorless viscous liquid as a mixture of two anomers (158 mg, 0.33 mmol, 65% yield in 2 steps).

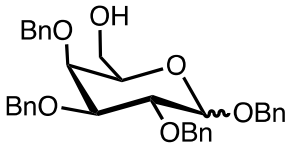
^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.29 (s), 2.31 (s) (3H) (these two singlets are –Me in –

tolyl group of two anomers), 3.49 (s), 3.51 (s) (3H) (these two singlets are –Me in 4–O-Me group of two anomers) 3.57–3.65 (m, 1H), 3.72–3.85 (m, 2H), 4.26 (dd, *J* = 8.0, 2.0 Hz 1H), 4.45 (d, *J* = 12.4 Hz, 1H), 4.56–4.89 (m, 6H), 4.96 (d, *J* = 10.8 Hz, 1H), 5.55 (d, *J* = 5.2 Hz, 1H), 7.01–7.06 (m, 2H), 7.28–7.38 (m, 17H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 21.3, 60.9, 68.8, 69.3, 71.2, 72.6, 73.5, 75.5, 75.8, 75.9, 79.2, 79.3, 79.7, 79.9, 80.7, 82.6, 86.8, 87.5, 87.7, 127.7, 127.9, 128.0, 128.1, 128.1(7), 128.2(4), 128.3, 128.4, 128.5, 128.6, 129.8, 130.8, 132.2, 132.8, 137.3, 137.9, 138.2, 138.6, 138.9

Preparation of glycosyl donor GA1 and GA2 (Fig. S3)

((2*R*,3*S*,4*S*,5*R*)-3,4,5,6-Tetrakis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methanol



GA1

Triphenylmethyl chloride (306 mg, 1.1 mmol) was added to a stirred solution of D-galactose (180 mg, 1.0 mmol) in pyridine (2 mL), and the mixture was heated at 50 °C for overnight to afford a yellow suspension. MeOH (1.5 equiv.) was added to quench the reaction, affording yellow solution, which was concentrated *in vacuo*. The resultant syrup was purified by flash column chromatography (EtOAc/MeOH = 4:1) to give crude trityl ether, a white fluffy solid, as the precursor of **GA1**, which can be used for next step.

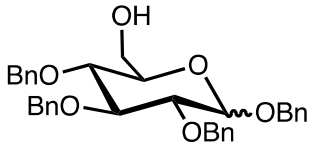
A stirred suspension of crude trityl ether in dry DMF (5 mL) was added NaH (60% in mineral oil, 60.0 mg, 1.5 mmol) in 2 portions at 0 °C, and stirred for 30 min, followed by treatment of benzyl bromide (178 *μ*L, 1.5 mmol, 1.5 equiv.), stirred for 8 h at RT, MeOH (1.5 equiv.) was added to quench the reaction slowly until no gas was formed. After extracted 2 times with EtOAc/H_2O (1:1, 10 mL), the organic layer was concentrated *in vacuo*. The CH_2Cl_2/MeOH solution of the yielded mixture was added TsOH·H_2O (15 mol%) then it was stirred at RT for overnight. The solution

was neutralized with $NaHCO_3$, and organic solvent was removed in *vacuo* to afford a crude viscous liquid. Column chromatography (hexane/EtOAc = 3:1) yielded glycosyl acceptor **GA1** (254 mg, 0.47 mmol, 47% yield) as a white solid.

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.13–2.16 (m, 1H), 3.58–3.67 (m, 2H), 3.72–3.78 (m, 1H), 4.06–4.10 (m, 2H), 4.34 (t, *J* = 7.2 Hz, 1H), 4.48 (dd, *J* = 12.4, 7.2 Hz, 2H), 4.56–4.65 (m, 3H), 4,71–4.83 (m, 3H), 4.98 (d, *J* = 2.0 Hz, 1H), 7.27–7.36 (m, 20H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 61.5, 69.1, 72.3, 72.7, 81.0, 83.8, 98.7, 127.7, 127.9, 128.0, 128.2, 128.4, 137.3, 137.4, 137.7, 138.3.

((2*R*,3*R*,4*S*,5*R*)-3,4,5,6-Tetrakis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methanol



GA2

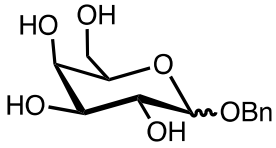
GA2 as a white solid (270 mg, 0.50 mmol, 50% yield) was prepared from D-glucose (180 mg, 1.0 mmol) in the same procedures as **GA1** described above.

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.85 (t, *J* = 7.2 Hz, 1H), 3.34–3.39 (m, 1H), 3.49 (t, *J* = 8.0 Hz, 1H), 3.57 (t, *J* = 9.6 Hz, 1H), 3.67–3.73 (m, 2H), 3.85–3.90 (m, 1H), 4.56–4.88 (m, 6H), 4.91–5.00 (m, 3H), 7.25–7.38 (m, 20H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 62.0, 71.6, 74.9(5), 75.0(2), 75.7, 77.5, 82.3, 84.5, 102.8, 127.6, 127.7, 127.8(5), 127.9(1), 128.0, 128.1, 128.3, 128.4, 128.5, 137.2, 137.9, 138.2, 138.4.

Preparation of glycosyl donor GA3 (Fig. S4)

(3*R*,4*S*,5*R*,6*R*)-2-(Benzyloxy)-6-(hydroxymethyl)tetrahydro-2*H*-pyran-3,4,5-triol



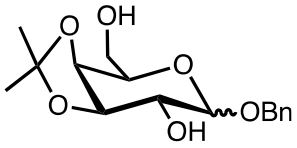
9a

To a stirred solution of D-glucose [ref. S2] (1.8 g, 10.0 mmol) in DMF (30 mL), a 60% dispersion of NaH in mineral oil (400 mg, 10.0 mmol, 1.0 equiv.) was added at 0°C. After stirring the mixture for 30 min, benzyl bromide (BnBr: 140 μL, 1.2 mmol, 1.2 equiv.) was added to the resultant mixture, stirred for a further 3 h at RT; MeOH (1.2 equiv.) was then added to stop the reaction. The reaction mixture was concentrated in *vacuo*, followed by flash column chromatography (EtOAc/MeOH = 4:1) to yield **9a** as an amorphous white solid (1.30 g, 4.8 mmol, 48% yield).

^{1}H NMR (CD_3OD, 400 MHz) δ 3.30 (t, *J* = 1.2 Hz, 1H), 3.43–3.51 (m, 2H), 3.58 (dd, *J* = 10.0, 8.0 Hz, 1H), 3.71–3.89 (m, 4H), 4.30 (d, *J* = 8.0 Hz, 1H), 4.65 (d, *J* = 12.0 Hz, 1H), 4.83–4.94 (m, 3H), 7.25–7.33 (m, 3H), 7.41 (d, *J* = 7.2 Hz, 2H).

^{13}C NMR (CD_3OD, 100 MHz) δ 62.5, 70.2, 71.6, 72.5, 74.9, 76.6, 103.8, 128.6, 129.1, 129.2, 139.1

(3a*S*,4*R*,7*R*,7a*R*)-6-(Benzyloxy)-4-(hydroxymethyl)-2,2-dimethyltetrahydro-4*H*-[1,3]dioxolo[4,5-*c*]pyran-7-ol



10a

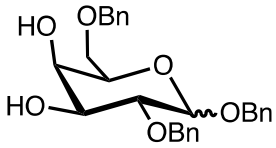
(±)-CSA (51.0 mg, 0.22 mmol, 0.05 equiv.) was added to a solution of **9a** (1.20 g, 4.4 mmol) in acetone dimethtylacetal (35 mL) and the solution was stirred overnight at room temperature. The reaction mixture was treated with triethylamine and concentrated to a residue, which was then dissolved in a mixture of MeOH/H_2O 10:1 (35 mL) and refluxed for 48 h. The reaction mixture was concentrated to a residue, which was subjected to silica gel column chromatography (hexane/EtOAc = 1:1) to yield **10a** as a white solid (1.27 g, 4.1 mmol, 93% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.35 (s, 3H), 1.52 (s, 3H), 1.61 (d, *J* = 3.6 Hz, 1H), 2.04–2.08 (m, 1H), 2.44 (q, *J* = 2.0 Hz, 1H), 3.62 (td, *J* = 8.4, 2.4 Hz, 1H), 3.82–3.87 (m, 2H), 3.96–4.01 (m, 1H), 4.09 (dd, *J* = 7.2, 5.6 Hz, 1H), 4.15 (dd, *J* = 5.2, 2.0 Hz,

1H), 4.29 (d, *J* = 8.4 Hz, 1H), 4.66 (d, *J* = 12.0 Hz, 1H), 4.92 (d, *J* = 12.0 Hz, 1H), 7.30–7.38 (m, 5H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 26.3, 28.1, 62.4, 71.3, 73.5, 73.6, 73.9, 78.8, 101.2, 110.4, 128.1, 128.2, 128.5, 136.8

(2*R*,3*R*,4*S*,5*R*)-5,6-Bis(benzyloxy)-2-((benzyloxy)methyl)tetrahydro-2*H*-pyran-3,4-diol



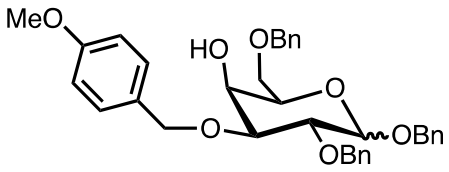
11a

A stirred suspension of **10a** (1.24 g, 4.0 mmol) in dry DMF (10 mL) was added NaH (60% in mineral oil, 400 mg, 10.0 mmol, 2.5 equiv.) in 2 portions at 0 °C, and stirred for 2 h, followed by treatment of benzyl bromide (1.2 mL, 10.0 mmol, 2.5 equiv.), stirred for 8 h at RT, MeOH (1.5 equiv.) was added to quench the reaction slowly until no gas was formed. After extracted 2 times with EtOAc/H_2O (1:1, 10 mL), the organic layer was concentrated *in vacuo*. Aqueous acetic acid (60%) was added to the crude residue, stirred at 65°C for 2 h. Most solvent was removed in *vacuo* before $NaHCO_3$ and MeOH was added to neutralize the residual HOAc. The mixture was stirred for 30 min and then concentrated in *vacuo* to afford a crude viscous, followed by column chromatography (hexane/EtOAc = 1:1), yielded **11a** (990 mg, 2.2 mmol, 55% yield) as a white solid.

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.47 (d, *J* = 2.8 Hz, 1H), 2.57 (d, *J* = 2.8 Hz, 1H), 3.55–3.59 (m, 2H), 3.63 (t, *J* = 5.6 Hz, 1H), 3.76–3.84 (m, 2H), 4.01 (s, 1H), 4.48 (d, *J* = 7.6 Hz, 1H), 4.61 (s, 2H), 4.66 (d, *J* = 11.6 Hz, 2H), 4.98 (dd, *J* = 11.6, 4.0 Hz, 2H), 7.29–7.39 (m, 15H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 68.9, 69.3, 70.9, 73.1, 73.3, 73.7, 74.6, 79.1, 102.4, 127.6(9), 127.7(4), 127.8, 127.8(5), 127.9(1), 128.1, 128.4, 128.4, 128.5, 137.3, 137.8, 138.2.

(2*R*,3*S*,4*S*,5*R*)-5,6-Bis(benzyloxy)-2-((benzyloxy)methyl)-4-((4-methoxybenzyl)oxy) tetrahydro-2*H*-pyran-3-ol



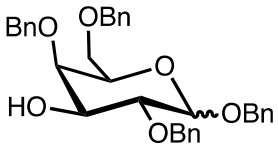
12a

A mixture of **11a** (900 mg, 2.0 mmol) and dibutyltin oxide (600 mg, 2.4 mmol, 1.2 equiv.) in methanol (10 mL) was refluxed for 10 h with stirring. The solvent was removed and dried in *vacuo*. To the residue in dry benzene (10 mL) was added *para*-methoxy benzyl chloride (PMB-Cl: 540 *μ*L, 4.0 mmol, 2.0 equiv.), MS4Å (0.4 g) and tetrabutylammonium bromide (TBAB: 322 mg, 1.0 mmol, 0.5 equiv.), refluxed for 6 h. The mixture was concentrated in *vacuo*, followed by column chromatography (hexane/EtOAc = 3:1), yielded **12a** as a viscous oil liquid (1.01 g, 1.8 mmol, 89% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.47 (dd, *J* = 9.6, 3.2 Hz, 1H), 3.57 (q, *J* = 5.2 Hz, 1H), 3.69 (dd, *J* = 9.6, 8.0 Hz, 1H), 3.76–3.84 (m, 5H), 4.00 (s, 1H), 4.46–4.47 (m, 1H), 4.61–4.74 (m, 7H), 4.90–5.00 (m, 2H), 6.84 (dd, *J* = 6.8, 2.0 Hz, 2H), 7.24–7.38 (m, 17H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 55.2, 68.9, 70.9, 72.7, 73.5, 74.4, 75.2, 79.6, 82.0, 102.8, 113.7, 127.4(7), 127.5(2), 127.6, 127.8, 127.9, 128.1, 128.2, 128.3, 128.3(5), 128.4(1), 129.2, 130.6, 137.6, 137.9, 138.6, 138.7, 159.1.

(3*R*,4*S*,5*R*,6*R*)-2,3,5-Tris(benzyloxy)-6-((benzyloxy)methyl)tetrahydro-2*H*-pyran-4-ol



GA3

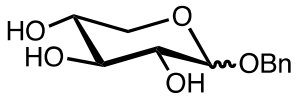
A stirred suspension of **12a** (620 mg, 2.0 mmol) in dry DMF (5 mL) was added NaH (60% in mineral oil, 200 mg, 5.0 mmol, 2.5 equiv.) in 2 portions at 0 °C, and stirred for 2 h, followed by treatment of benzyl bromide (600 *μ*L, 5.0 mmol, 2.5 equiv.), stirred for 8 h at RT, MeOH (1.5 equiv.) was added to quench the reaction slowly until no gas was formed and organic solvent was removed in *vacuo.* The mixture was dissolved in CH_2Cl_2 and washed with 2M HCl and then with saturated $NaHCO_3$ solution, dried over Na_2SO_4 and then concentrated. Water (1 mL) was added to the resultant mixture in CH_2Cl_2 (15 mL) followed by addition of 2.3-dichloro-5.6-dicyanobenzoquinone (DDQ: 680 mg, 3.0 mmol 1.5 equiv.) under stirring. The mixture was stirred for 1 h at room temperature and the completion of the reaction was monitored by TLC. CH_2Cl_2 was filtered and the residue was repeatedly washed with CH_2Cl_2. Filtrates were collected, washed with $NaHCO_3$ solution, dried over Na_2SO_4 and then concentrated. The residue was subjected to silica gel column chromatography (hexane/EtOAc = 5:1), yielded **GA3** as an oil liquid (775 mg, 1.4 mmol, 72% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.26 (d, *J* = 3.2 Hz, 1H), 3.60–3.67 (m, 5H), 3.87 (s, 1H), 4.44–4.53 (m, 3H), 4.62–4.69 (m, 3H), 4.79 (d, *J* = 11.6 Hz, 1H), 4.96 (q, *J* = 6.0 Hz, 2H), 7.29–7.37 (m, 20H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 68.7, 70.8, 73.5, 73.6, 74.0, 74.6, 74.9, 75.4, 79.6, 102.5, 127.6, 127.7, 127.8, 128.1, 128.2(5), 128.2(8), 128.4, 137.4, 137.8, 138.3, 138.4

Preparation of glycosyl donor GA4 (Fig. S5)

(3*R*,4*S*,5*R*)-2-(Benzyloxy)tetrahydro-2*H*-pyran-3,4,5-triol



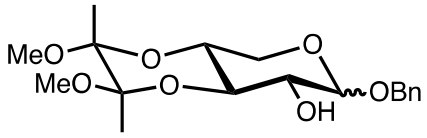
9b

To a stirred solution of D-xylose [ref. S2] (3.0 g, 20.0 mmol) in DMF (30 mL), a 60% dispersion of NaH in mineral oil (800 mg, 20.0 mmol, 1.0 equiv.) was added in 3 portions at 0°C. After stirring the mixture for 30 min, benzyl bromide (BnBr: 280 *μ*L, 2.4 mmol, 1.2 equiv.) was added to the resultant mixture, stirred for a further 3 h at RT; MeOH (1.2 equiv.) was then added to stop the reaction. The reaction mixture was concentrated in *vacuo*, followed by flash column chromatography (EtOAc/MeOH = 4:1) to yield **9b** as an amorphous white solid (2.16 g, 9.0 mmol, 45% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.10 (s, 1H), 3.18–3.23 (m, 1H), 3.39–3.46 (m, 1H), 3.58–3.69 (m, 1H), 3.84–3.99 (m, 1H), 4.33–4.37 (m, 1H), 4.45 (d, *J* = 12.0 Hz, 1H), 4.54 (d, *J* = 12.0 Hz, 1H), 4.71 (d, *J* = 12.0 Hz, 1H), 4.83 (d, *J* = 12.0 Hz, 1H), 5.30 (s, 1H), 7.27–7.33 (m, 5H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 61.7, 65.2, 69.1, 69.5, 69.8, 70.9, 71.8, 73.0, 74.3, 76.0, 97.5, 102.1, 127.9, 128.0, 128.1, 128.4, 136.9.

(2*R*,3*R*,4a*R*,8*R*,8a*R*)-7-(Benzyloxy)-2,3-dimethoxy-2,3-dimethylhexahydro-5*H*-pyrano[3,4-*b*][1,4]dioxin-8-ol



10b

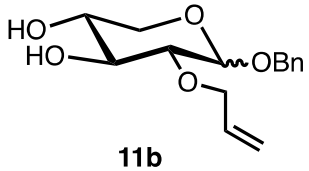
To a solution of **9b** [ref. S6] (1.92 g, 8.0 mmol) in MeOH (30 mL), trimethyl orthoformate (4.4 mL, 40.0 mmol, 5.0 equiv.), 2,3-butanedione (1 mL, 12.0 mmol, 1.5 equiv.), and (±)-CSA (200 mg) were added and the mixture was refluxed for 20 h under an argon atmosphere, cooled to room temperature and neutralized by the addition of triethylamine (1 mL). Solvents were evaporated under reduced pressure and the residue was purified by silica gel column chromatography (hexane/EtOAc =

3:1) to afford **10b** as a white solid (1.06 g, 3.0 mmol, 38% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.30 (s, 3H), 1.35 (s, 3H), 3.27 (s, 3H), 3.30 (s, 3H), 3.43 (t, *J* = 9.8 Hz, 1H), 3.57–3.67 (m, 2H), 3.78–3.84 (m, 1H), 3.93 (q, *J* = 5.2 Hz, 1H), 4.36 (d, *J* = 9.8 Hz, 1H), 4.60 (d, *J* = 7.6 Hz, 1H), 4.90 (d, *J* = 7.6 Hz, 1H), 7.31–7.37 (m, 5H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 17.5, 17.6, 47.9, 64.1, 65.8, 71.1, 71.3, 72.2, 99.4, 99.7, 103.2, 128.0, 128.2, 128.5, 136.8.

(3*R*,4*S*,5*R*)-5-(Allyloxy)-6-(benzyloxy)tetrahydro-2*H*-pyran-3,4-diol



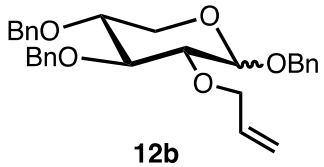
11b

To a stirred solution of **10b** (1.0 g, 2.8 mmol) in DMF (5 mL), a 60% dispersion of NaH in mineral oil (110 mg, 2.8 mmol, 1.0 equiv.) was added in 3 portions at 0°C. After stirring the mixture for 30 min, allyl bromide (250 *μ*L, 3.0 mmol, 1.1 equiv.) was added to the resultant mixture, stirred for a further 3 h at RT; MeOH (1.0 equiv.) was then added to stop the reaction. The reaction mixture was concentrated in *vacuo*. To a solution of the residue in dichloromethane (10 mL) was added 95% aqueous trifluoroacetic acid (5 mL) and the whole mixture was stirred for 15 min. Solvents were evaporated in *vacuo* and the residue was immediately purified by column chromatography (hexane/EtOAc = 1:1) to afford **11b** as a white solid (196 mg, 0.70 mmol, 25% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.35 (dd, *J* = 6.8, 4.8 Hz, 1H), 3.49 (dd, *J* = 12.0, 6.4 Hz, 1H), 3.71 (dd, *J* = 10.4, 4.8 Hz, 2H), 4.08–4.16 (m, 2H), 4.27 (dd, *J* = 12.8, 5.6 Hz, 1H), 4.59 (d, *J* = 11.6 Hz, 1H), 4.69 (d, *J* = 4.4 Hz, 1H), 4.86 (d, *J* = 12.0 Hz, 1H), 5.19–5.29 (m, 2H), 5.84–5.94 (m, 1H), 7.30–7.39 (m, 5H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 63.3, 69.2, 70.4, 72.5, 77.9, 100.3, 118.0, 127.9, 128.0, 128.1, 128.5, 134.0, 136.7

(3*R*,4*S*,5*R*)-3-(Allyloxy)-2,4,5-tris(benzyloxy)tetrahydro-2*H*-pyran



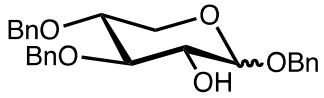
12b

To a stirred solution of **11b** (168 mg, 0.60 mmol) in DMF (5 mL), a 60% dispersion of NaH in mineral oil (60.0 mg, 1.5 mmol, 2.5 equiv.) was added at 0°C. After stirring the mixture for 30 min, benzyl bromide (BnBr: 180 *μ*L, 1.5 mmol, 2.5 equiv.) was added to the resultant mixture, stirred for a further 3 h at RT; MeOH (1.2 equiv.) was then added to stop the reaction. The reaction mixture was concentrated in *vacuo*, followed by flash column chromatography (EtOAc/MeOH = 5:1) to yield **12b** as a viscous oil liquid (215 mg, 0.47 mmol, 78% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.20 (dd, *J* = 11.6, 6.0 Hz, 1H), 3.05 (dd, *J* = 9.2, 8.0 Hz, 1H), 3.52 (t, *J* = 9.2 Hz, 1H), 3.57–3.63 (m, 1H), 3.94 (dd, *J* = 11.6, 5.2 Hz, 1H), 4.18–4.23 (m, 1H), 4.40 (d, *J* = 7.6 Hz, 2H), 4.62 (d, *J* = 12.0 Hz, 2H), 4.74 (d, *J* = 11.6 Hz, 1H), 4.81–4.93 (m, 3H), 5.16 (dt, *J* = 10.4 Hz, 1.2 Hz, 1H), 5.26 (dt, *J* = 17.2 Hz, 2.4 Hz, 1H), 5.89–5.97 (m, 1H), 7.28–7.38 (m, 15H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 63.9, 71.0, 73.4, 73.8, 75.6, 77.7, 81.5, 83.7, 103.1, 116.9, 127.6, 127.7, 127.8, 128.0, 128.3, 128.3(6), 128.4(1), 135.0, 137.4, 138.2, 138.6.

(3*R*,4*R*,5*R*)-2,4,5-Tris(benzyloxy)tetrahydro-2*H*-pyran-3-ol



GA4

A mixture of **12b** (184 mg, 0.40 mmol), sodium acetate (82.0 mg, 1.0 mmol, 2.5 equiv.), $PdCl_2$ (85.0 mg, 0.48 mmol, 1.2 equiv.), and aqueous acetic acid (acetic acid/H_2O = 11:1, 6 mL) was stirred at RT for 48 h. After removing acetic acid and water in *vacuo*, the residue was subjected to silica gel column chromatography

(hexane/EtOAc = 3:1) to afford **GA4** as a white amorphous solid (138 mg, 0.33 mmol, 82% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.74 (s, 1H), 3.35 (dd, *J* = 12.0, 8.0 Hz, 1H), 3.55–3.63 (m, 4H), 4.03 (dd, *J* = 11.6, 3.6 Hz, 1H), 4.46 (d, *J* = 6.0 Hz, 1H), 4.60–4.71 (m, 3H), 4.80–4.89 (m, 3H), 7.28–7.35 (m, 15H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 62.4, 70.5, 72.1, 72.8, 74.1, 80.9, 101.6, 127.6, 127.8, 127.9, 128.3(5), 128.4(0), 128.5, 137.2, 137.8, 138.4.

Typical procedure of glycosylation of GD and GA followed by deprotection for G1-G8 and G10 (Fig. S6)

Glycosylation

A 20 mL oven-dried Schlenk tube was charged with thioglycoside **GD1** (25.0 mg, 0.04 mmol) and glycosyl acceptor **GA1** (23.0 mg, 1.0 equiv.) and dry CH_2Cl_2 (2 mL). The mixed solution was cooled down to –40 °C, N-iodosuccinimide (NIS; 18.0 mg, 0.08 mmol, 2.0 equiv.) was added until totally dissolved, followed by 2 *μ*L of TfOH. The reaction mixture was allowed to warm to RT slowly. After that, it was cooled to 0 °C before triethylamine was added to neutralize the mixture. The mixture was concentrated *in vacuo* and purified by column chromatography (hexane/EtOAc = 5:1) to yield the mixture of two anomers (28.1 mg, 0.03 mmol, 70% yield). After TLC isolation with $CHCl_3$/MeOH (40:1), the pure form of the β anomer (**G1'**, precursor of **G1**) was isolated as the minor product, along with α anomer (**G2'**, precursor of **G2**) as the major one.

Deprotection

A 20 mL Schlenk tube was charged with isolated **G1'** (7.0 mg) in MeOH/EtOAc (1:1 v/v, 2 mL) under N_2, then added $Pd(OH)_2$/C (10%) (7.0 mg), H_2 gas was later charged and replace the N_2 by air pump vacuum/H_2 exchange, the reaction mixture

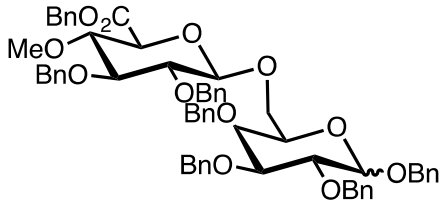
was stirred at room temperature for overnight, the completion of the reaction was monitored by LC-MS. The mixture was subjected to filtration by passing through a packed Celite® cake, to remove $Pd(OH)_2/C$, the crude residue was obtained after removing the solvent *in vacuo*, followed by reverse phase TLC (H_2O), afforded the corresponding product **G1** as a white solid (2.5 mg, 95%). In the same procedure, the reaction of **G2'** (α anomer of **G1'**, 7.0 mg) yielded **G2** as white solid (2.5 mg, 95%).

The NMR spectra of isolated disaccharide in D_2O was difficult to identify each signal to corresponding proton, nevertheless, the absence of aromatic proton in ^{1}H-NMR spectra was obviously observed which helped us to confirm the completion of the removal of all benzyl groups. The formation of desired disaccharide **G** was confirmed via HRMS showing the consistence of the found value with exact mass calculated**.**

Other disaccharides **G3**–**G8** and **G10** were synthesized in the same procedure through a glycosylation of corresponding **GD** and **GA**, followed by a hydrogenative deprotection.

The yield and additional information of each disaccharide was listed in Fig. S6.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-4,5-bis(benzyloxy)-3-methoxy-6-(((2*R*,3*S*,4*S*,5*R*)-3,4,5,6-tetrakis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylate



G1'

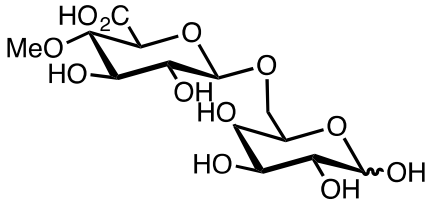
Glycosylation of **GD1** and **GA1** (β)

^{1}H NMR ($CDCl_3$, 600 MHz) δ 3.31 (s, 3H), 3.46 (t, *J* = 6.4 Hz, 1H), 3.50–3.51 (m,

2H), 3.67–3.70 (m, 1H), 3.75–3.78 (m, 2H), 3.98–4.02 (m, 2H), 4.09–4.11 (m, 1H), 4,35 (t, *J* = 7.2 Hz, 1H), 4.40 (d, *J* = 7.2 Hz, 1H), 4.45 (dd, *J* = 2.0, 12.8 Hz, 2H), 4.53–4.58 (m, 3H), 4,65–4.75 (m, 5H), 4.83 (d, *J* = 11.0 Hz, 1H), 4.88–5.02 (m, 2H), 5.14 (d, *J* = 8.0 Hz, 1H), 5.17 (d, *J* = 8.1 Hz, 1H), 7.19–7.29 (m, 35H).

^{13}C NMR ($CDCl_3$, 150 MHz) δ 60.5, 67.1, 68.5, 69.9, 72.1, 72.3, 73.1, 74.3, 74.7, 75.5, 79.2, 80.1, 80.6, 81.1, 81.4, 83.6, 83.9, 98.1, 103.9, 127.3, 127.5, 127.6, 127.7, 127.8, 127.9, 128.2, 128.3, 128.4, 135.1, 137.4, 138.0, 138.1, 138.3, 138.4, 168.4.

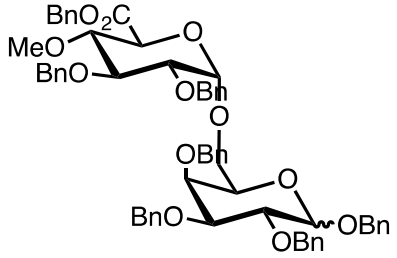
(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-Dihydroxy-3-methoxy-6-(((2*R*,3*R*,4*S*,5*R*)-3,4,5,6-tetrahydroxytetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G1 4-Me-GlcA-β(1,6)Gal

HRMS (ESI) *m/z* calcd for $C_{13}H_{21}O_{12}$ $[M–H]^-$: 369.1028, found: 369.1022.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*S*)-4,5-bis(benzyloxy)-3-methoxy-6-(((2*R*,3*S*,4*S*,5*R*)-3,4,5,6-tetrakis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylate



G2'

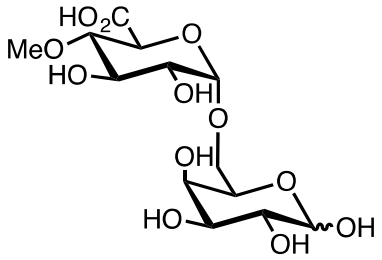
Glycosylation of **GD1**+**GA1** (α)

^{1}H NMR ($CDCl_3$, 600 MHz) δ 3.33 (s, 3H), 3.37–3.41 (m, 2H), 3.50 (dd, *J* = 9.6, 3.4

Hz, 1H), 3.70 (dd, *J* = 9.6, 6.9 Hz, 1H), 3.85–3.88 (m, 2H), 3.98–4.00 (m, 4H), 4.34 (d, *J* = 6.9 Hz, 1H), 4.51–4.57 (m, 2H), 4.65–4.76 (m, 6H), 4.83–4.87 (m, 3H), 4.91 (d, *J* = 11.7 Hz, 2H), 5.17 (d, *J* = 12.4 Hz, 1H), 5.23 (d, *J* = 12.4 Hz, 2H) 7.24–7.41 (m, 35H)

^{13}C NMR ($CDCl_3$, 150 MHz) δ 60.6, 67.1, 68.0, 68.9, 69.5, 70.3, 73.0, 73.4, 73.5, 74.5, 75.3, 75.7, 76.4, 79.0, 79.1, 81.3, 81.8, 95.6, 97.7, 127.50, 127.55, 127.63, 127.69, 127.77, 127.86, 127.9, 128.1, 128.21, 128.26, 128.34, 128.4, 128.5, 135.2, 137.3, 138.0, 138.45, 138.5, 138.8, 169.8.

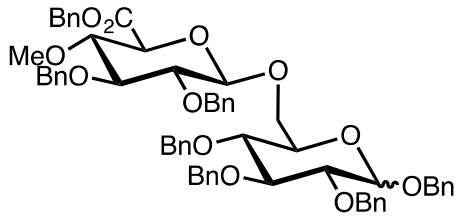
(2*S*,3*S*,4*R*,5*R*,6*S*)-4,5-Dihydroxy-3-methoxy-6-(((2*R*,3*R*,4*S*,5*R*)-3,4,5,6-tetrahydroxytetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G2 4-Me-GlcA-α(1,6)Gal

HRMS (ESI) *m/z* calcd for $C_{13}H_{21}O_{12}$ $[M–H]^-$: 369.1028, found: 369.1037.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-4,5-bis(benzyloxy)-3-methoxy-6-(((2*R*,3*R*,4*S*,5*R*)-3,4,5,6-tetrakis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylate



G3'

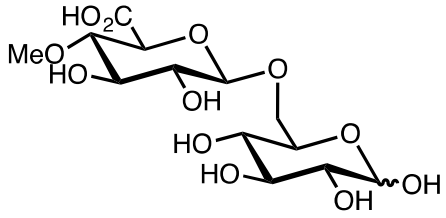
Glycosylation of **GD1**+**GA2** (β)

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.34 (s, 3H), 3.38–3.41 (m, 1H), 3.45–3.52 (m, 4H),

3.58 (t, *J* = 6.0 Hz, 1H), 3.62–3.68 (m, 1H), 3.76–3.79 (m, 1H), 4.02–4.09 (m, 1H), 4.36 (q, *J* = 4.8 Hz, 1H), 4.24–4.44 (m, 1H), 4.47–4.53 (m, 3H), 4.62–4.64 (m, 1H), 4.68–4.79 (m, 4H), 4.81–4.85 (m, 2H), 4.91–4.99 (m, 3H), 5.20–5.24 (m, 2H), 7.15–7.39 (m, 35H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.7, 67.3, 68.8, 68.9, 70.2, 71.2, 73.0, 74.5, 74.6, 75.0, 75.0(5), 75.1(3), 75.8, 78.0, 78.3, 79.9, 81.1(6), 81.2(3), 81.4, 81.5, 82.0, 82.3, 83.9, 84.0, 84.7, 95.2, 102.7, 104.1, 104.2, 127.6, 127.7, 127.7(8), 127.8(2), 127.9, 128.0, 128.1, 128.2, 128.3, 128.4, 128.5(0), 128.5(4), 128.5(8), 128.6(0), 128.6(3), 128.7, 128.8, 129.0, 135.3, 137.2, 137.6, 138.0, 138.2, 138.3, 138.3(6), 138.4(2), 138.6, 139.0, 168.4, 168.6.

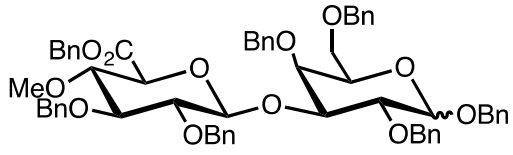
(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-Dihydroxy-3-methoxy-6-(((2*R*,3*S*,4*S*,5*R*)-3,4,5,6-tetrahydroxytetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G3 4-Me-GlcA-β(1,6)Glc

HRMS (ESI) *m/z* calcd for $C_{13}H_{22}O_{12}Na$ $[M+Na]^+$: 393.1003, found: 393.0994.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-4,5-bis(benzyloxy)-3-methoxy-6-(((3*R*,4*S*,5*S*,6*R*)-2,3,5-tris(benzyloxy)-6-((benzyloxy)methyl)tetrahydro-2*H*-pyran-4-yl)oxy)tetrahydro-2*H*-pyran-2-carboxylate



G4'

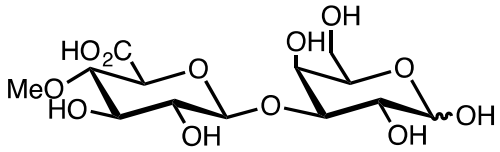
Glycosylation of **GD1**+**GA3** (β)

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.28 (s, 3H), 3.41 (t, *J* = 9.6 Hz, 1H), 3.47–3.60 (m,

5H), 3.67 (d, *J* = 10.0 Hz, 1H), 3.82–3.87 (m, 2H), 3.94 (t, *J* = 9.6 Hz, 1H), 4.36–4.46 (m, 4H), 4.53–4.67 (m, 3H), 4.74–4.83 (m, 4H), 4.90 (t, *J* = 12.4 Hz, 2H), 4.99 (d, *J* = 11.2 Hz, 1H), 5.10–5.14 (m, 2H), 7.22–7.40 (m, 35H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.4, 66.8, 68.7, 70.5, 71.0, 73.3, 73.4, 74.2, 74.5, 74.7, 75.5, 79.2, 80.5, 81.2, 82.0, 97.1, 103.2, 127.2, 127.6, 127.7(5), 127.8(0), 127.9(0), 127.9(2), 128.0, 128.1, 128.2, 128.3, 128.3(7), 128.4(3), 135.3, 137.4, 137.7, 138.0, 138.3(7), 138.4(3), 169.9.

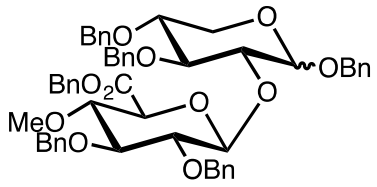
(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-Dihydroxy-3-methoxy-6-(((3*R*,4*S*,5*S*,6*R*)-2,3,5-trihydroxy-6-(hydroxymethyl)tetrahydro-2*H*-pyran-4-yl)oxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G4 4-Me-GlcA-β(1,3)Gal

HRMS (ESI) *m/z* calcd for $C_{13}H_{22}O_{12}Na$ $[M+Na]^+$: 393.1003, found: 393.1001.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-4,5-bis(benzyloxy)-3-methoxy-6-(((3*R*,4*S*,5*R*)-2,4,5-tris(benzyloxy)tetrahydro-2*H*-pyran-3-yl)oxy)tetrahydro-2*H*-pyran-2-carboxylate



G5'

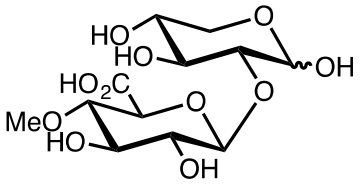
Glycosylation of **GD1**+**GA4** (β)

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.35 (s, 3H), 3.39–3.54 (m, 3H), 3.59–3.64 (m, 2H), 3.67–3.73 (m, 1H), 3.79–3.81 (m, 1H), 3.94–4.05 (m, 1H), 4.53–4.58 (m, 2H), 4.60–4.65 (m, 2H), 4.74–4.84 (m, 5H), 4.87–4.91 (m, 1H), 5.15–5.28 (m, 3H), 7.22–7.41 (m, 30H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.5, 63.2, 67.1, 70.0, 72.9, 74.2, 74.9, 75.0, 75.5,

75.6, 77.9, 78.4, 81.1, 82.1, 83.4, 83.9, 101.4, 102.7, 127.4, 127.5, 127.6, 127.8(7), 127.9(1), 128.1(5), 128.2(2), 128.3, 128.4, 128.5, 128.6, 128.7, 137.7, 137.9, 138.3, 168.3.

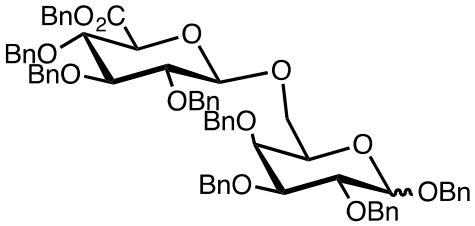
(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-Dihydroxy-3-methoxy-6-(((3*R*,4*S*,5*R*)-2,4,5-trihydroxytetrahydro-2*H*-pyran-3-yl)oxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G5 4-Me-GlcA-β(1,2)Xyl

HRMS (ESI) *m/z* calcd for $C_{12}H_{20}O_{11}Na$ $[M+Na]^+$: 363.0898, found: 363.0888.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-3,4,5-tris(benzyloxy)-6-(((2*R*,3*S*,4*S*,5*R*)-3,4,5,6-tetrakis(benzyloxy)tetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylate



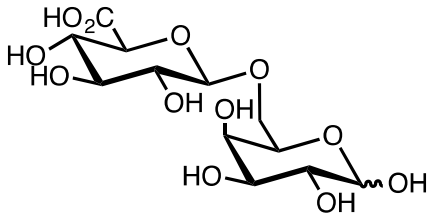
G6'

Glycosylation of **GD2**+**GA1** (β) $C_{68}H_{68}O_{12}$

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.50 (t, *J* = 8.8 Hz, 1H), 3.61 (t, *J* = 8.8 Hz, 1H), 3.69 (dd, *J* = 8.4, 7.6 Hz, 1H), 3.79–3.88 (m, 3H), 3.98–4.04 (m, 2H), 4.11 (dd, *J* = 10.8, 2.4 Hz, 1H), 4.36 (t, *J* = 7.2 Hz, 1H), 4.42–4.48 (m, 4H), 4.53–4.59 (m, 3H), 4.66–4.76 (m, 6H), 4.85–4.93 (m, 3H), 5.09 (s, 2H), 7.09–7.30 (m, 40H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 67.2, 68.6, 69.9, 72.2, 72.4, 73.1, 74.5, 74.8, 75.0, 75.7, 79.3, 80.1, 80.6, 81.6, 83.7, 84.0, 98.1,104.0, 127.4, 127.6, 127.6(8), 127.7(4), 127.8, 128.0, 128.2, 128.3, 128.3(5), 128.3(9), 128.5, 135.0, 137.4(5), 137.5(3), 137.8, 138.1, 138.3, 138.4, 168.4.

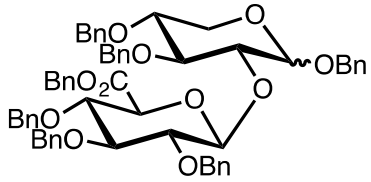
(2*S*,3*S*,4*S*,5*R*,6*R*)-3,4,5-Trihydroxy-6-(((2*R*,3*R*,4*S*,5*R*)-3,4,5,6-tetrahydroxytetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G6 GlcA-*β*(1,6)-Gal

HRMS (ESI) *m/z* calcd for $C_{12}H_{20}O_{12}Na$ $[M+Na]^+$: 379.0847, found: 379.0864.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-3,4,5-tris(benzyloxy)-6-(((3*R*,4*S*,5*R*)-2,4,5-tris(benzyloxy)tetrahydro-2*H*-pyran-3-yl)oxy)tetrahydro-2*H*-pyran-2-carboxylate



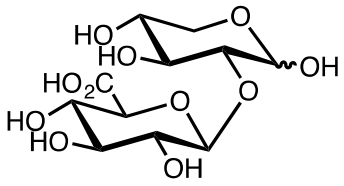
G7'

Glycosylation of **GD2**+**GA4** (β)

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.18 (t, *J* = 10.0 Hz, 1H), 3.44 (dd, *J* = 10.0, 3.6 Hz, 1H), 3.56–3.66 (m, 3H), 3.73 (t, *J* = 8.0 Hz, 1H), 3.86–3.91 (m, 2H), 4.30 (t, *J* = 11.6 Hz, 2H), 4.39 (d, *J* = 11.6 Hz, 1H), 4.47–4.56 (m, 4H), 4.59–4.68 (m, 2H), 4.73–4.90 (m, 5H), 4.98 (d, *J* = 2.4 Hz, 2H), 5.62 (d, *J* = 3.2 Hz, 1H), 6.95–7.30 (m, 35H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 63.8, 66.8, 70.3, 70.7, 71.9, 73.2, 74.8, 75.2, 75.3, 75.7, 78.4, 78.9, 79.9, 80.8, 81.2, 95.4, 103.3, 127.2, 127.4, 127.5, 127.6, 127.7, 127.9, 128.0, 128.1, 128.2, 128.3, 128.3(5), 128.4(4), 128.7, 135.3, 137.1, 137.6, 137.9, 138.3, 138.5, 170.2.

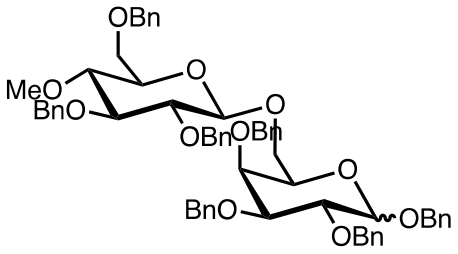
(2*S*,3*S*,4*S*,5*R*,6*R*)-3,4,5-Trihydroxy-6-(((3*R*,4*S*,5*R*)-2,4,5-trihydroxytetrahydro-2*H*-pyran-3-yl)oxy)tetrahydro-2*H*-pyran-2-carboxylic acid



G7 GlcA-β(1,2)-Xyl

HRMS (ESI) *m/z* calcd for $C_{11}H_{18}O_{11}Na$ $[M+Na]^+$: 349.0741, found: 349.0734.

(3*R*,4*S*,5*S*,6*R*)-2,3,4,5-Tetrakis(benzyloxy)-6-((((2*R*,3*R*,4*S*,5*R*,6*R*)-3,4-bis(benzyloxy)-6-((benzyloxy)methyl)-5-methoxytetrahydro-2*H*-pyran-2-yl)oxy)methyl)tetrahydro-2*H*-pyran



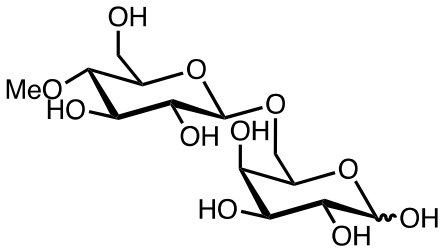
G8'

Glycosylation of **GD3**+**GA1** (β)

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.32 (d, *J* = 6.0 Hz, 2H), 3.42–3.52 (m, 5H), 3.68–3.71 (m, 1H), 3.80–3.89 (m, 2H), 4.01–4.07 (m, 3H), 4.15 (dd, *J* = 7.2, 3.2 Hz, 1H), 4.29 (d, *J* = 12.0 Hz, 1H), 4.38–4.43 (m, 2H), 4.46–4.53 (m, 4H), 4.58–4.65 (m, 2H), 4.67–4.78 (m, 4H), 4.86–4.94 (m, 3H), 5.14 (s, 1H), 7.20–7.35 (m, 35H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 60.5, 68.4, 69.0, 70.3, 71.8, 72.0, 73.0, 73.3, 73.6, 75.4, 75.7, 79.2, 79.7, 80.7, 81.3, 81.8, 82.7, 88.3, 97.7, 105.0, 127.4(7), 127.5(2), 127.5(9), 127.6(3), 127.6(6), 127.7(4), 127.7(9), 127.8(4), 127.8(7), 127.9(3), 128.0, 128.2, 128.2(6), 128.3(2), 128.3(4), 128.4, 137.6, 137.7, 137.8, 138.0, 138.1.

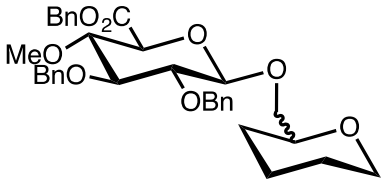
(3*R*,4*S*,5*R*,6*R*)-6-((((2*R*,3*R*,4*R*,5*S*,6*R*)-3,4-Dihydroxy-6-(hydroxymethyl)-5-methoxytetrahydro-2*H*-pyran-2-yl)oxy)methyl)tetrahydro-2*H*-pyran-2,3,4,5-tetraol



G8 GlcA-β(1,6)-Gal

HRMS (ESI) *m/z* calcd for $C_{13}H_{24}O_{11}Na$ $[M+Na]^+$: 379.1211, found: 379.1205.

Benzyl(2*S*,3*S*,4*S*,5*R*,6*R*)-4,5-bis(benzyloxy)-3-methoxy-6-((tetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylate



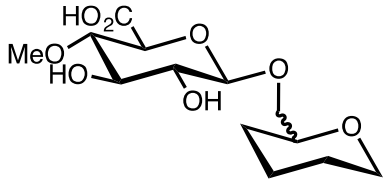
G10'

Glycosylation of **GD1**+**ROH** (tetrahydropyran-2-methanol) (β)

^{1}H NMR ($CDCl_3$, 400 MHz) δ 1.49–1.84 (m, 6H), 3.35 (s, 3H), 3.59–3.43(m, 5H), 3.79–3.91 (m, 2H), 3.97–4.00 (m, 1H), 4.46 (dd, *J* = 13.2, 7.6 Hz, 1H), 4.66–4.76 (m, 2H), 4.85 (dd, *J* = 10.8, 2.0 Hz, 1H), 4.96 (dd, *J* = 10.8, 4.0 Hz, 1H), 5.20–5.30 (m, 3H), 7.29–7.40 (m, 15H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 23.21, 25.9, 28.1, 28.3, 60.6, 67.2, 68.2, 68.4, 73.4, 73.7, 74.4, 74.6, 74.8, 75.6, 76.2, 81.0, 81.3(8), 81.4(4), 83.7, 103.9, 104.4, 127.6, 127.9, 128.2, 128.3, 128.4, 128.5, 128.6, 129.0, 135.2, 138.4, 168.4, 168.5.

(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-Dihydroxy-3-methoxy-6-((tetrahydro-2*H*-pyran-2-yl)methoxy) tetrahydro-2*H*-pyran-2-carboxylic acid



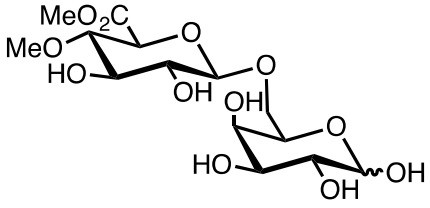
G10 4-Me-GlcA-β-Pyran

HRMS (ESI) *m/z* calcd for $C_{13}H_{22}O_8Na$ [M+Na]$^+$: 329.1207, found: 329.1198.

Preparation of G9 (Fig. S7)

To a stirred solution of the **G1** (1.5 mg) in 3 mL of toluene/MeOH (1:2), $TMSCHN_2$ (1.1–1.5 mmol) was added dropwise until yellow color persisted. The mixture was stirred for 30 min at RT and concentrated to give the corresponding methyl ester **G9** as white solid (1.6 mg, 95% yield).

Methyl(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-dihydroxy-3-methoxy-6-(((2*R*,3*R*,4*S*,5*R*)-3,4,5,6-tetra hydroxytetrahydro-2*H*-pyran-2-yl)methoxy)tetrahydro-2*H*-pyran-2-carboxylate

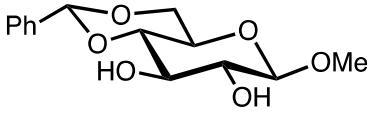


G9

HRMS (ESI) *m/z* calcd for $C_{14}H_{24}O_{12}Na$ [M+Na]$^+$: 407.1165, found: 407.1173.

Preparation of G11 (Fig. S8)

(2*R*,4a*R*,6*R*,7*R*,8*R*,8a*S*)-6-Methoxy-2-phenylhexahydropyrano[3,2-*d*][1,3]dioxine-7, 8-diol



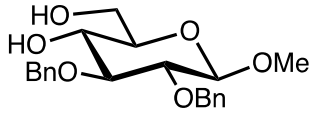
2-OMe

A mixture of commercially purchased 1-OMe-Glc (β) (776 mg, 4.0 mmol), benzaldehyde dimethyl acetal (1.8 mL, 12.0 mmol), and $TsOH·H_2O$ (189 mg, 1.0 mmol, 0.25 equiv.) was heated at 50 °C for 3 h. The solution was neutralized with $NaHCO_3$, filtration and wash with MeOH. The filtrate was concentrated *in vacuo* and the residue was purified by flash column chromatography (EtOAc) and recrystallized from EtOAc/hexane (1:2) afforded an analytical sample of acetal **2-OMe** as a white solid (761 mg, 2.7 mmol, 68% yield).

^1H NMR ($CDCl_3$, 400 MHz) δ 2.56 (s, 1H), 2.70 (s, 1H), 3.45–3.57 (m, 3H), 3.59 (s, 3H), 3.77–3.86 (m, 2H), 4.33–4.39 (m, 2H), 5.55 (s, 1H), 7.37–7.41 (m, 3H), 7.49–7.51 (m, 2H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.5, 66.4, 68.7, 73.2, 74.5, 80.6, 101.9, 104.1, 126.3, 128.4, 129.3.

(2*R*,3*R*,4*S*,5*R*,6*R*)-4,5-Bis(benzyloxy)-2-(hydroxymethyl)-6-methoxytetrahydro-2*H*-pyran-3-ol



3-OMe

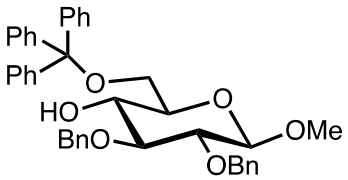
To a stirred suspension of acetal **2-OMe** (676 mg, 2.4 mmol) in dry DMF (12 mL) was added NaH 60% in mineral oil (240 mg, 6.0 mmol, 2.5 equiv.) in 2 portions at 0 °C, and stirred for 1 h, followed by treated with benzyl bromide (BnBr: 720 *μ*L, 6.0 mmol), stirred for 8 h at room temperature, and MeOH (1.0 equiv.) was added slowly until no gas was formed to quench the reaction. After extracted with EtOAc/H_2O = 1:1 (2 times), organic layer was concentrated *in vacuo* to remove solvents to give a crude oil mixture. To the CH_2Cl_2/MeOH solution of the yielded oil mixture was added $TsOH·H_2O$ (10 mol%), and then the mixture was stirred at room temperature for overnight. The solution was neutralized with $NaHCO_3$, and organic solvent was concentrated *in vacuo* to afford a crude viscous liquid. Column chromatography (hexane/EtOAc = 1:1) yielded dibenzyl **3-OMe** as a white solid

(664 mg, 1.8 mmol, 74% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.03 (t, *J* = 6.0 Hz, 1H), 2.70 (d, *J* = 2.4 Hz, 1H), 3.32–3.37 (m, 1H), 3.39–3.47 (m, 2H), 3.54 (dd, *J* = 9.2, 2.0 Hz, 1H), 3.74–3.80 (m, 1H), 3.87–3.92 (m, 1H), 4.37 (d, *J* = 7.6 Hz, 1H), 4.69 (dd, *J* = 14.4, 11.2 Hz, 2H), 4.95 (dd, *J* = 17.6, 12.8 Hz, 2H), 7.29–7.39 (m, 10H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.3, 62.5, 70.3, 74.6, 74.8, 75.2, 81.9, 83.8, 104.9, 127.7, 127.9, 128.1, 128.4, 128.6, 138.3, 138.4.

(2*R*,3*R*,4*S*,5*R*,6*R*)-4,5-Bis(benzyloxy)-6-methoxy-2-((trityloxy)methyl)tetrahydro-2*H*-pyran-3-ol



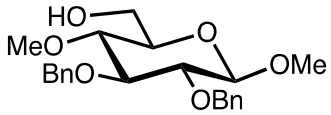
4-OMe

Triphenylmethyl chloride (1.1 g, 4.0 mmol, 2.5 equiv.) and *N*,*N*-dimethyl-4-aminopyridine (DMAP: 20.0 mg, 0.16 mmol) were added to a stirred solution of dibenzyl **3-OMe** (600 mg, 1.6 mmol) in dry pyridine (10 mL) and the reaction mixture heated at 60 °C for overnight. The reaction mixture was quenched with MeOH (5 mL) and concentrated *in vacuo*. The resulting syrup was purified by short column chromatography (hexane/EtOAc = 1:1) to give the trityl ether **4-OMe** (523 mg, 0.85 mmol, 53% yield) as a viscous oil liquid.

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.46 (s, 1H), 3.35–3.47 (m, 5H), 3.60–3.66 (m, 4H), 4.34 (d, *J* = 7.6 Hz, 1H), 4.73 (t, *J* = 10.8 Hz, 2H), 4.92 (t, *J* = 10.8 Hz, 2H), 7.20–7.38 (m, 20H), 7.42–7.48 (m, 5H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 56.8, 64.0, 71.7, 73.9, 74.7, 75.4, 81.9, 84.1, 86.8, 104.6, 127.0, 127.6, 127.7(6), 127.8(3), 127.9(6), 128.0(4), 128.3, 128.5, 128.6, 138.5, 138.6, 143.7.

((2*R*,3*R*,4*S*,5*R*,6*R*)-4,5-Bis(benzyloxy)-3,6-dimethoxytetrahydro-2*H*-pyran-2-yl)methanol



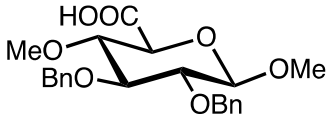
5-OMe

To a stirred solution of trityl ether **4-OMe** (493 mg, 0.8 mmol) in DMF (8 mL) was added 60% NaH dispersion in mineral oil (48.0 mg, 1.2 mmol, 1.5 equiv.) at 0 °C, after 30 min, iodomethane (MeI: 75 *μ*L, 1.2 mmol) was added and the reaction mixture was stirred for another 3 h at room temperature before 1.0 equiv. MeOH was added to stop the reaction. The reaction mixture was extracted with H_2O/EtOAc/hexane = 2:1:1 (10 mL) for 2 times to remove DMF, dried over Na_2SO_4. After filtration, the mixture was concentrated *in vacuo*. The yielded crude product was dissolved in MeOH/CH_2Cl_2 (30 mL) to afford a yellow solution which was treated with TsOH·H_2O (10 mol%) and stirred at RT, after 6 h, $NaHCO_3$ was added to neutralize the reaction. The yellow solution was concentrated *in vacuo*, followed by a flash column chromatography (hexane/EtOAc = 3:1) to yield alcohol **5-OMe** as a white solid (168 mg, 0.43 mmol, 54%).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 2.03 (t, *J* = 6.4 Hz, 1H), 3.28–3.31 (m, 2H), 3.35 (t, *J* = 8.4 Hz, 1H), 3.56 (s, 3H), 3.57 (s, 3H), 2.03 (t, *J* = 6.4 Hz, 1H), 3.74 (dd, *J* = 9.2, 7.2 Hz, 1H), 3.90 (dd, *J* = 12.0, 3.6 Hz, 1H), 4.34 (d, *J* = 8.0 Hz, 1H), 4.70 (d, *J* = 11.2 Hz, 1H), 4.79 (d, *J* = 11.2 Hz, 1H), 4.89 (d, *J* = 11.2 Hz, 2H), 7.27–7.35 (m, 10H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.2, 60.8, 61.9, 74.8, 75.0, 75.5, 79.5, 82.1, 84.2, 104.7, 127.6, 127.9, 128.0, 128.3, 138.4, 138.5

(2*S*,3*S*,4*S*,5*R*,6*R*)-4,5-Bis(benzyloxy)-3,6-dimethoxytetrahydro-2*H*-pyran-2-carboxylic acid



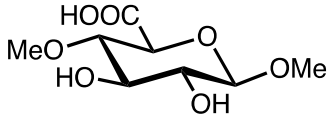
6-OMe

To a 10 mL CH_2Cl_2 solution of alcohol **5-OMe** (116 mg, 0.30 mmol) and buffer (Na_2HPO_4/NaH_2PO_4, PH=7) was added iodobenzene diacetate (193 mg, 0.60 mmol, 2.0 equiv.) at 0 °C, followed by addition of 2-azaadamantane *N*-oxyl (AZADO, 4.0 mg, 0.03 mmol, 0.1 equiv.). The mixture was stirred at the same temperature. The reaction was monitored by TLC, after 2 h, **5-OMe** was consumed, the reaction mixture was extracted by CH_2Cl_2 and water for 3 times, the organic layer was dried over Na_2SO_4, solvent was removed in *vacuo* and the residue was purified by a silica gel column chromatography (hexane/EtOAc = 5:1) to yield benzyl ether **6-OMe** as an amorphous solid (64.3 mg, 0.16 mmol, 53% yield).

^{1}H NMR ($CDCl_3$, 400 MHz) δ 3.38–3.56 (m, 9H), 3.75 (s, 1H), 4.30 (d, *J* = 5.6 Hz, 1H), 4.57 (d, *J* = 11.2 Hz, 1H), 4.75–4.80 (m, 4H), 7.22–7.23 (m, 10H).

^{13}C NMR ($CDCl_3$, 100 MHz) δ 57.8, 60.4, 74.6, 75.4, 81.8, 82.2, 83.6, 104.5, 127.4, 127.7, 128.2, 138.4, 138.5, 174.2.

(2*S*,3*S*,4*R*,5*R*,6*R*)-4,5-Dihydroxy-3,6-dimethoxytetrahydro-2*H*-pyran-2-carboxylic acid



G11

A 20 mL Schlenk tube was charged with **6-OMe** (40.2 mg, 0.10 mmol) in MeOH/EtOAc = 1:1 solution (5 mL) under N_2, then added pre-activated (water-removed) $Pd(OH)_2/C$ 20.0 mg, H_2 gas was later charged and replace the N_2 by air pump vacuum/H_2 exchange, the reaction mixture was stirred at room temperature for overnight, the completion of the reaction was monitored by LC-MS. The mixture was subjected to filtration by passing through a packed Celite® cake,

to remove $Pd(OH)_2/C$, the residue was obtained after removing the solvent *in vacuo*, followed by reverse phase TLC (MeOH), afford the corresponding product **G11** as an off-white solid (22.2 mg, 0.10 mmol, quant.).

^1H NMR (CD_3OD, 400 MHz) δ 3.13–3.21 (m, 1H), 3.24–3.25 (m, 2H), 3.40 (t, *J* = 9.2 Hz, 1H), 3.44 (s, 3H), 3.45 (s, 3H), 3.69 (d, *J* = 10.0 Hz, 1H), 4.14 (d, *J* = 8.0 Hz, 1H).

^{13}C NMR (CD_3OD 100 MHz) δ 57.6, 60.8, 74.8, 75.8, 77.3, 83.0, 105.5 (carbon signal of C=O is missing for its low concentration in CD_3OD).

^{13}C NMR (D_2O 100 MHz) δ 57.6 (the standard peak based on that observed in CD_3OD), 60.3, 72.9, 73.9, 75.1, 81.7, 103.4, 171.4.

HRMS (ESI) *m/z* calcd for $C_8H_{14}O_7Na$ $[M+Na]^+$: 245.0632 found: 245.0628.

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874 **Table S2**. AMOR activity results for synthetic AMOR and derivatives.
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Compound	Concentration (μM)	Responsive Pollen Tubes (%)	S.D.	S.E.	P value (Scheffé test) Comparison with 4-Me-GlcA-β(1,6)-Gal (G1)
4-Me-GlcA-β(1,6)-Gal **G1**	1.35	80.0	10.0	5.780	
4-Me-GlcA-α(1,6)-Gal **G2**	1.35	33.3	5.68	3.286	0.0054475 (**P<0.01)
4-Me-GlcA-β(1,6)-Glc **G3**	1.35	56.7	15.2	8.829	0.4897411 (insignificant)
4-Me-GlcA-β(1,3)-Gal **G4**	1.35	40.0	10.0	5.78	0.0241134 (*P<0.05)
4-Me-GlcA-β(1,2)-Xyl **G5**	1.35	26.7	11.5	6.674	0.0011994 (**P<0.01)
GlcA-β(1,6)-Gal **G6**	1.35	3.3	5.8	3.337	7.87E-06 (**P<0.01)
GlcA-β(1,2)-Xyl **G7**	1.35	6.7	5.8	3.337	6.28E-05 (**P<0.01)
4-Me-Glc-β(1,6)-Gal **G8**	1.35	13.33	11.5	6.674	4.05E-06 (**P<0.01)
4,6-Me-GlcA-β(1,6)-Gal **G9**	1.35	0	0	0	0 (**P<0.01)
4-Me-GlcA-β(1,6)-Prya n **G10**	1.35	83.3	11.5	6.674	0.9999993 (insignificant)
4-Me-GlcA-O-Me **G11**	1.35	23.3	5.8	3.337	0.0005656 (**P<0.01)

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