Tandem regio- and diastereo-selective synthesis of halogenated C-vinyl glycosides from unactivated arylacetylenes

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General information: 1H and 13C NMR spectra were recorded on 400 and 500 MHz spectrometers with TMS as the internal standard. Chemical shifts are expressed in parts per million (δ ppm). Silica gel coated aluminium plates were used for TLC. The products were 1
purified by column chromatography on silica gel (60-120/100-200 mesh) using petroleum ether–ethyl acetate as the eluent to obtain the pure products. Exact Mass of all products were analysed by using HRMS having QTOF analyser. Reagents used were mostly purchased from Sigma Aldrich.

**Representative procedure for glycosylation/halogenation with aryl acetylenes (I):**

Triacetyl-\(\beta\)-acet-D-glucal (272 mg, 1 mmol) in dichloroethane (10 mL) were placed in a dry, nitrogen -flushed, 100 mL round-bottom flask equipped with a magnetic stirring bar. The solution was cooled to -25 °C and Phenylacetylene (120 µL, 1.1 mmol) was added via syringe, followed by iron (III) bromide (0.33 mmol, 96 mg). The reaction solution gradually turned dark purple and was allowed to stir for another 1 hour. The completion of the reaction was monitored through TLC. The reaction mixture was quenched with water, extracted with dichloromethane (3 × 15 mL). The organic layer was separated and dried over anhydrous MgSO\(_4\). Product 3a (334 mg, \(E\):\(E\)\(_\beta\) = 11.47:1, 85% yield) was isolated by flash column chromatography using petroleum ether/EtOAc as eluent.
**Fig 1:** Product distribution obtained during the reaction of phenyl acetylene and glucal triacetate in presence of FeBr₃ at different temperatures. **A.** Reaction operated at rt. **B.** Reaction operated at -25 °C.

**Spectral analysis**

Prepared by the representative procedure 1 using tri-O-acetyl-D-glucal (1 mmol, 272 mg) and phenyl acetylene (1.1 mmol, 0.120 mL) to yield 3a in 85% (334 mg) yield. **¹H NMR** (400 MHz, Chloroform-d) δ 7.47-7.32 (m, 5H), 6.37 (d, J = 9.5 Hz, 1H ), 5.81 (ddd, J = 10.6, 6.4, 5.1 Hz, 2H), 5.17 (dd, J = 7.3, 1.1, 1H), 4.64 (dd, J = 9.6, 1.6 Hz, 1H), 4.18 (ddd, J = 15.3, 12.0, 4.5 Hz, 3H), 4.0 (ddd, J = 7.3, 5.8, 3.2 Hz, 1H), 2.10 (s, 3H ), 2.09 (s, 3H). **¹³C NMR** (101 MHz, CDCl₃) δ 170.86, 170.38, 137.63, 130.67, 129.89, 129.36, 128.81 (2C), 128.42 (2C), 127.10, 124.77, 70.23, 70.00, 64.45, 62.89, 21.09, 20.87. HRMS (ESI⁺) m/z calcd. for C₁₈H₁₉BrNaO₅ (M+Na)⁺ 417.0314, found 417.0305
Prepared by the representative procedure 1 using tri-\(\text{O}\)-acetyl-\(\text{D}\)-glucal (0.5 mmol, 136 mg) and 1-ethynyl-4-methylbenzene (0.55 mmol, 64 \(\mu\)L) to yield 3b (74%, 150 mg). \(^1\)H NMR (400 MHz, Chloroform-d) \(\delta\) 7.32 (d, \(J = 8.1\) Hz, 2H), 7.17 (d, \(J = 17.9\) Hz, 2H), 6.33 (d, \(J = 9.5\) Hz, 1H), 5.80 (ddd, \(J = 10.7, 6.2, 5.2\) , 2H), 5.16 (dd, \(J = 7.2, 3.1\) Hz, 1H), 4.64 (d, \(J = 9.6, 1H\)), 4.18 (ddd, \(J = 15.3, 12.0, 4.5\) Hz, 2H), 4.0 (ddd, \(J = 7.3, 5.8, 3.3\) Hz, 1H) 2.36 (s, 3H) 2.10 (s, 3H), 2.09 (s, 3H). \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 170.91, 170.43, 139.50, 134.78, 130.80, 129.49, 129.07 (2C), 128.74 (2C), 127.45, 124.63, 70.27, 69.99, 64.50, 62.93, 21.33, 21.09, 20.87. HRMS (ESI\(^+\)) m/z calcd for C\(_{19}\)H\(_{21}\)BrO\(_5\) (M+H)\(^+\) 409.0645, found 409.0647.

Prepared by the representative procedure 1 using tri-\(\text{O}\)-acetyl-\(\text{D}\)-glucal (0.5 mmol, 136 mg) and 1-ethynyl-4-pentylbenzene (0.55 mmol, 94\(\mu\)L) to yield 3c (68%, 157 mg). \(^1\)H NMR (400 MHz, Chloroform-d) \(\delta\) 7.34 (d, \(J = 8.2\) Hz, 2H), 7.17 (d, \(J = 8.2\) Hz, 2H), 6.34 (d, \(J = 9.5\) Hz, 1H), 5.88 – 5.76 (m, 2H), 5.24 – 5.14 (m, 1H), 4.66 (d, \(J = 9.6\) Hz, 1H), 4.23 (dd, \(J = 12.0, 5.7\) Hz, 1H), 4.14 (dd, \(J = 12.0, 3.2\) Hz, 1H), 4.00 (ddd, \(J = 7.3, 5.7, 3.2\) Hz, 1H), 2.60 (t, \(J = 7.3\)), 2.10 (s, 3H), 2.09 (s, 3H), 1.69 – 1.54 (m, 2H), 1.37 – 1.26 (m, 4H), 0.89 (t, \(J = 6.9\) Hz, 4H). \(^{13}\)C NMR (101 MHz, CDCl\(_3\)) \(\delta\) 170.89, 170.41, 144.51, 134.90, 130.79, 129.40, 128.76(2C), 128.40 (2C), 127.59, 124.69, 70.33, 69.92, 64.51, 62.96, 35.71, 31.48, 30.96, 22.53, 21.08, 20.87, 14.04. HRMS (ESI\(^+\)) m/z calcd for C\(_{23}\)H\(_{28}\)BrNaO\(_5\) (M+Na\(^+\)) 487.1091, found 487.1080.

Prepared by the representative procedure 1 using tri-\(\text{O}\)-acetyl-\(\text{D}\)-glucal (0.5 mmol, 136 mg) and 1-(4-ethynylphenoxy)benzene (0.55 mmol, 98 \(\mu\)L) to yield 3d (75%, 182 mg). \(^1\)H NMR
(400 MHz, Chloroform-d) δ  7.42–7.35 (m, 4H), 7.19–7.12 (m, 1H), 7.06–7.04 (m, 2H), 6.97–6.95 (m, 2H), 6.34 (d, J = 9.6 Hz, 1H), 5.82 (dt, J = 16.9, 7.4 Hz, 1H), 5.18 (d, J = 7.3 Hz, 1H), 4.66 (dd, J = 9.6, 1.2 Hz, 1H), 4.22 (dd, J = 12.0, 5.7 Hz, 1H), 4.14 (dd, J = 12.0, 3.2 Hz, 1H), 4.00 (ddd, J = 8.9, 5.8, 3.2 Hz, 1H), 2.10 (s, 3H), 2.08 (s, 3H).

13C NMR (101 MHz, CDCl3) δ 170.89, 170.41, 158.53, 156.06, 132.02, 130.70, 130.56 (2 × C), 129.98 (2 × C), 129.63, 127.09, 124.81, 124.17, 119.79 (2 × C), 117.76 (2C), 70.23, 70.01, 64.48, 62.90, 21.10, 20.88. HRMS (ESI+) m/z calc'd for C24H23BrNaO6 (M+Na)+ 509.0570, found 509.0559.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-ethyl-4-pentylbenzene (0.55 mmol, 94 μL) to yield 3e (65%, 150 mg).

1H NMR (400 MHz, Chloroform-d) δ  7.36 (d, J = 8.2 Hz, 2H), 7.17 (d, J = 8.2 Hz, 2H), 6.33 (d, J = 9.6 Hz, 1H), 6.03 (ddd, J = 10.1, 5.3, 2.0 Hz, 1H), 5.94 (dd, J = 10.2, 3.3 Hz, 1H), 5.09 (d, J = 5.1 Hz, 1H), 4.72 (ddd, J = 9.6, 3.0, 2.2 Hz, 1H), 4.23–4.15 (m, 3H), 2.60 (t, J = 7.6 Hz, 2H), 2.09 (s, 3H), 2.06 (s, 3H), 1.64–1.56 (m, 2H), 1.37–1.28 (m, 4H), 0.90 (t, J = 6.9 Hz, 3H).

13C NMR (101 MHz, CDCl3) δ 170.75, 170.46, 144.55, 134.90, 133.26, 128.80 (2 × C), 128.68, 128.40 (2 × C), 128.13, 122.42, 70.73, 68.87, 63.28, 62.77, 35.70, 31.45, 30.94, 22.51, 20.86, 20.84, 14.00. HRMS (ESI+) m/z calc'd for C23H29BrO5 (M+H)+ 465.1271, found 465.1264.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and phenyl acetylene (0.55 mmol, 62 μL) to yield 3f (82%, 160 mg).

1H NMR (400 MHz, Chloroform-d) δ  7.45 (dd, J = 7.8, 1.7 Hz, 2H), 7.36 (dd, J = 7.1 Hz, 5.4, 3H), 6.37 (d, J = 9.5 Hz, 1H), 6.03 (ddd, J = 10.1, 5.3, 2.0, 1H), 5.93 (dd, J = 10.2, 3.3 Hz, 1H), 5.09 (d, J = 5.23, 1.5 Hz, 1H), 4.76–4.62 (m, 1H), 4.31–4.12 (m, 3H), 2.09 (s, 3H), 2.06 (s, 3H).

13C NMR (101 MHz, CDCl3) δ 170.78, 170.48, 137.59, 133.08, 129.38, 129.15, 128.86 (2 × C), 128.42 (2 × C), 127.64, 122.53, 70.64, 68.87, 63.23, 62.75, 20.88, 20.86. HRMS (ESI+) m/z calc'd for C18H20BrO5 (M+H)+ 395.0489, found 395.0478.
Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-ethynyl-4-methylbenzene (0.55 mmol, 65 µL) to yield 3g (72%, 146 mg). 1H NMR (400 MHz, Chloroform-d) δ 7.35 (d, J = 8.1 Hz, 2H), 7.17 (d, J = 7.9 Hz, 2H), 6.33 (d, J = 9.5 Hz, 1H), 6.02 (ddd, J = 10.1, 5.3, 2.0, 1H), 5.92 (dd, J = 10.3, 3.3 Hz, 1H), 5.09 (d, J = 5.2 Hz, 1H), 4.71 (ddd, J = 9.5, 3.0, 2.2 Hz, 1H), 4.28–4.13 (m, 3H), 2.36 (s, 3H), 2.09 (s, 3H). 13C NMR (101 MHz, CDCl3) δ 170.78, 170.48, 137.59, 133.08, 129.38, 129.15, 128.86 (2 X C), 128.42 (2 X C), 127.64, 122.53, 70.64, 68.87, 63.23, 62.75, 20.88, 20.86. HRMS (ESI+) m/z calcld for C19H21BrO5 (M+H)+ 409.0645, found 409.0639.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-(4-ethynylphenoxy)benzene (0.55 mmol, 98 µL) to yield 3h (70%, 170 mg). 1H NMR (400 MHz, Chloroform-d) δ 7.46–7.41 (m, 2H), 7.40–7.33 (m, 2H), 7.18–7.13 (m, 1H), 7.04 (dt, J = 9.0, 1.8 Hz, 2H), 6.98–6.94 (m, 2H), 6.34 (d, J = 9.6 Hz, 1H), 6.04 (ddd, J = 10.1, 5.3, 2.0 Hz, 1H), 5.94 (dd, J = 10.2, 3.3 Hz, 1H), 5.09 (dd, J = 5.3, 1.4 Hz, 1H), 4.72 (ddd, J = 9.6, 3.0, 2.2 Hz, 1H), 4.25–4.16 (m, 2H), 4.14 (dd, J = 12.0, 3.2 Hz, 1H), 2.08 (s, 3H), 2.07 (s, 3H). 13C NMR (101 MHz, CDCl3) δ 169.93, 169.64, 157.68, 155.24, 132.28, 131.14, 129.77 (2 X C), 129.11 (2 X C), 128.03, 126.82, 123.29, 121.71, 118.87 (2 X C), 116.96 (2 X C), 69.80, 68.05, 62.39, 61.90, 20.05, 20.02. HRMS (ESI+) m/z calcld for C24H24BrO6 (M+H)+ 487.0751, found 487.0742.

Prepared by the representative procedure 1 using 3,4 Di-O-acetyl-L-rhamnal (0.5 mmol, 107 mg) and phenyl acetylene (0.55 mmol, 62 µL) to yield 3i (78%, 131 mg). 1H NMR (400 MHz, Chloroform-d) δ 7.46–7.41 (m, 2H), 7.40–7.33 (m, 3H), 6.36 (d, J = 9.6 Hz, 1H), 5.79 (d, J = 1.1 Hz, 2H), 4.93–4.86 (m, 1H), 4.56 (d, J = 9.6 Hz, 1H), 4.00–3.88 (m, 1H), 2.10.
(s, 3H, 1.21 (d, J = 6.4 Hz, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 170.66, 137.72, 130.99, 130.69, 129.21, 128.82 (2 X C), 128.33 (2 X C), 126.52, 124.45, 69.35, 69.27, 68.55, 21.18, 17.52. HRMS (ESI$^+$) m/z calcd for C$_{16}$H$_{18}$BrO$_3$ (M+H)$^+$ 337.0434, found 337.0421.

Prepared by the representative procedure 1 using of 3,4 Di-O-acetyl-L-rhamnal (0.5 mmol, 131 mg) and 1-ethynyl-4-methylbenzene (0.55 mmol, 64 µL) to yield 3j (72%, 126 mg). $^1$H NMR (400 MHz, Chloroform-d) $\delta$ 7.33 (d, J = 8.1 Hz, 1H), 7.17 (d, J = 7.9 Hz, 1H), 6.33 (d, J = 9.6 Hz, 1H), 5.79 (bs, 2H), 4.90 (dd, J = 6.0, 2.1 Hz, 1H), 4.57 (d, J = 9.6 Hz, 1H), 3.93 (dq, J = 12.6, 6.3 Hz, 1H), 2.36 (s, 2H), 2.10 (s, 2H), 1.21 (d, J = 6.4 Hz, 1H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 170.71, 139.35, 134.92, 131.17, 130.34, 129.01 (2 X C), 128.77 (2 X C), 126.87, 124.35, 69.40, 69.33, 68.60, 21.32, 21.22, 17.55. HRMS (ESI$^+$) m/z calcd for C$_{17}$H$_{19}$BrO$_3$ (M+H)$^+$ 350.0518, found 350.0523.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-glucal (1 mmol, 272 mg) and phenyl acetylene (1.1 mmol, 120 µL) to yield 4a 87% (304 mg). $^1$H NMR (400 MHz, Chloroform-d) $\delta$ 7.47 (dd, J = 6.6, 3.2 Hz, 1H), 7.39 (dd, J = 5.0, 1.9 Hz, 2H), 6.13 (d, J = 9.7 Hz, 1H), 5.81 (dt, J = 11.5, 1.7 Hz, 1H), 5.18 (dd, J = 7.2, 1.2 Hz, 1H), 4.70 (d, J = 9.8 Hz, 1H), 4.23 (dd, J = 12.0, 5.8 Hz, 1H), 4.15 (dd, J = 12.0, 3.3 Hz, 1H), 4.01 (ddd, J = 12.0, 5.9, 3.2 Hz, 1H), 2.10 (s, 3H), 2.09 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) $\delta$ 170.90, 170.43, 137.30, 136.08, 130.99, 129.51, 128.69 (2 X C), 128.44 (2 X C), 125.66, 124.73, 69.99, 69.58, 64.50, 62.93, 21.10, 20.89. HRMS (ESI$^+$) m/z calcd for C$_{18}$H$_{19}$ClNaO$_5$ (M+Na)$^+$ 373.0813, found 373.0814.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-glucal (0.5 mmol, 136 mg) and 1-ethynyl-4-methylbenzene (0.55 mmol, 62 µL) to yield 4b (75%, 136 mg). $^1$H NMR (400 MHz, Chloroform-d) $\delta$ 7.36 (d, J = 8.1 Hz 2H), 7.19 (d, J = 7.9 Hz, 2H), 6.09 (d, J = 7
9.7 Hz, 1H), 5.92–5.75 (m, 1H), 5.18 (d, J = 7.3 Hz, 1H), 4.71 (d, J = 9.9 Hz, 1H), 4.23 (dd, J = 12.0, 5.8 Hz 1H), 4.15 (dd, J = 12.0, 3.3 Hz, 1H), 4.01 (ddd, J = 6.9, 6.0, 3.3 Hz, 1H), 2.37 (s, 3H), 2.10 (s, 3H), 2.09 (s, 3H). 

13C NMR (101 MHz, CDCl3) δ 170.93, 170.45, 139.65, 137.53, 133.24, 131.13, 129.10 (2 X C), 128.65 (2 X C), 125.20, 124.59, 69.99, 69.63, 64.54, 62.97, 21.35, 21.11, 20.89. HRMS (ESI+) m/z calcd for C19H21ClNaO5 (M+Na)⁺ 387.0975, found 387.0970

Prepared by the representative procedure 1 using of tri-O-acetyl-D-glucal (0.5 mmol, 136 mg) and 1-ethynyl-4-pentylbenzene (0.55 mmol, 94 µL) to yield 4C (72%, 151 mg). 

1H NMR (400 MHz, Chloroform-d) δ 7.38 (d, J = 8.1 Hz, 2H), 7.19 (d, J = 8.0 Hz, 2H), 6.09 (d, J = 9.8 Hz, 1H), 5.83 (bs, 1H), 5.19 (d, J = 7.2, Hz, 1H), 4.72 (d, J = 9.8 Hz, 1H), 4.19 (ddd, J = 15.2, 12.0, 4.5 Hz, 3H), 4.01 (dd, J = 6.4, 3.3 Hz, 1H), 2.61 (t, J = 7.58 Hz, 2H), 2.10 (s, 3H), 2.09(s,3H), 1.62 (m, 2H), 1.32 (m, 4H), 0.90 (t, J = 6.7 Hz, 3H). 

13C NMR (101 MHz, CDCl3) δ 170.87, 170.40, 144.65, 137.61, 133.39, 131.14, 128.61, 128.41, 125.17, 125.12, 124.74, 124.65, 70.00, 69.90, 64.61, 63.00, 35.72, 31.47, 30.95, 22.51, 20.89, 20.82, 14.05. HRMS (ESI+) m/z calcd for C23H30ClO5 (M+H)+ 421.1776, found 421.1764.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-glucal (0.5 mmol, 136 mg) and 1-ethynyl-4-phenyl-benzene (0.55 mmol, 90 µL) to yield 4d (79%, 168 mg). 

1H NMR (400 MHz, Chloroform-d) δ 7.70–7.51 (m, 6H), 7.49–7.43 (m, 2H), 7.39 (d, J = 7.3 Hz, 1H), 6.16 (d, J = 9.8 Hz, 1H), 5.93 – 5.78 (m, 2H), 5.24 – 5.14 (m, 1H), 4.77 (dd, J = 9.8, 1.4 Hz, 1H), 4.22 (ddd, J = 15.3, 12.0, 4.5 Hz, 2H), 4.03 (ddd, J = 7.2, 5.8, 3.3 Hz, 1H), 2.11 (s, 3H), 2.10 (s, 3H). 

13C NMR (101 MHz, CDCl3) δ 170.93, 170.45, 142.38, 140.14, 137.04, 133.90, 131.14, 128.27, 128.01, 127.87, 127.63, 124.83, 124.78, 70.02, 69.63, 64.55, 62.99, 21.12, 20.89. HRMS (ESI+) m/z calcd for C24H23ClNaO5 (M+Na)⁺ 449.1126, found 449.1127
Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-ethynyl-4-Fluorobenzene (0.55 mmol, 66 µL) to yield 4e (80%, 147 mg). \[ \text{H NMR (400 MHz, Chloroform-d) } \delta \ 7.56 - 7.40 (m, 2H), 7.17 - 6.98 (m, 2H), 6.13 (d, J = 9.7 Hz, 1H), 5.91 - 5.77 (m, 2H), 5.19 (dd, J = 7.3, 3.5, 2.1 Hz, 1H), 4.69 - 4.59 (m, 1H), 4.23 (dd, J = 12.0, 5.8 Hz, 1H), 4.16 (dd, J = 12.0, 3.2 Hz, 1H), 4.01 (ddd, J = 7.3, 5.8, 3.3 Hz, 1H), 2.11 (s, 3H), 2.10 (s, 3H). \]

\[ \text{C NMR (101 MHz, CDCl}_3\text{) } \delta 170.87, 170.40, 163.14 (d, C-F Coupling), 136.51, 132.12, 130.81, 130.79, 125.96, 124.92, 115.61, 115.44, 70.04, 69.47, 64.49, 62.91, 21.09, 20.88. \]

HRMS (ESI\(^+\)) m/z calcd for C\(_{18}\)H\(_{19}\)ClFO\(_5\) (M+H)\(^+\) 369.0900, found 369.0890

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and phenylacetylene (0.55 mmol, 56 µL) to yield 4f (80% (140 mg)). \[ \text{H NMR (400 MHz, Chloroform-d) } \delta \ 7.53 - 7.48 (m, 2H), 7.41 - 7.35 (m, 3H), 6.13 (d, J = 9.8 Hz, 1H), 6.07-6.00 (m, 1H), 5.95 (dd, J = 10.2, 3.3 Hz, 1H), 5.11 (d, J = 5.2 Hz, 1H), 4.83-4.70 (m, 1H), 4.29-4.15 (m, 2H), 2.09 (s, 3H), 2.07 (s, 3H). \]

\[ \text{C NMR (101 MHz, CDCl}_3\text{) } \delta 168.38, 168.08, 135.41, 133.60, 130.95, 127.11, 126.32 (2 X C), 126.03 (2 X C), 122.48, 120.09, 67.57, 66.42, 60.86, 60.36, 18.48, 18.44. \]

HRMS (ESI\(^+\)) m/z calcd for C\(_{24}\)H\(_{23}\)ClNaO\(_5\) (M+Na)\(^+\) 449.1126, found 449.1123

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-ethynyl-4-methylbenzene (0.55 mmol, 64 µL) to yield 4g (74%, 134 mg). \[ \text{H NMR (400 MHz, Chloroform-d) } \delta \ 7.40 (d, J = 8.1, Hz 2H), 7.19 (d, J = 7.9 Hz, 2H ), 6.09 (d, J = 9.8 Hz, 1H), 6.03 (dd, J =10.1, 5.2, 2.0 Hz, 1H), 5.94 (dd, J =10.2, 3.3 Hz, 1H), 5.10 (d, J = 5.2 Hz, 1H), 4.77 (ddd, J = 9.8, 3.2, 2.1 Hz, 1H), 4.29-4.17 (m, 1H), 2.37 (s, 3H), 2.37 (s, 3H), 2.08 (s, 3H), 2.07 (s, 3H). \]

\[ \text{C NMR (101 MHz, CDCl}_3\text{) } \delta 170.80, 170.50, 139.67, 138.04, 133.49, 133.18, 129.07 (2 X C), 128.66 (2 X C), 124.44, 122.41, 70.05, 68.83, 63.31, \]
62.79, 21.34, 20.91, 20.86. HRMS (ESI⁺) m/z calcd for C₁₀H₂₂ClO₅ (M+H)⁺ 365.1150, found 365.1143.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-ethynyl-4-Fluorobenzene (0.55 mmol, 66 µL) to yield 4h (78%, 143 mg). ¹H NMR (400 MHz, Chloroform-d) δ 7.55–7.50 (m, 1H), 7.12–7.05 (m, 1H), 6.12 (d, J = 9.8 Hz, 1H), 6.05 (ddd, J = 10.1, 5.3, 2.0 Hz, 1H), 5.95 (dd, J = 10.2, 3.3 Hz, 1H), 5.11 (d, J = 5.1 Hz, 1H), 4.71 (ddd, J = 9.8, 3.1, 2.1 Hz, 1H). ¹³C NMR (101 MHz, CDCl₃) δ 170.77, 170.48, 163.16 (d, C-F coupling), 137.07, 133.19, 132.09, 132.06, 130.88, 130.81, 125.21, 122.68, 115.59, 115.42, 69.87, 68.92, 63.23, 62.75, 20.90, 20.85. HRMS (ESI⁺) m/z calcd for C₁₈H₁₉ClO₅ (M+H)⁺ 369.0900, found 369.0908.

Prepared by the representative procedure 1 using of tri-O-acetyl-D-galactal (0.5 mmol, 136 mg) and 1-ethynyl-4-phenyl-benzene (0.55 mmol, 98 µL) to yield 4i (75%, 159 mg). ¹H NMR (400 MHz, Chloroform-d) δ 7.64–7.56 (m, 6H), 7.50–7.42 (m, 2H), 7.41–7.37 (m, 2H), 6.15 (d, J = 9.8 Hz, 1H), 6.06 (ddd, J = 10.1, 5.2, 1.9 Hz, 1H), 5.98 (dd, J = 10.2, 3.3 Hz, 1H), 5.12 (d, J = 5.2 Hz, 1H), 4.83 (ddd, J = 9.8, 3.0, 2.0 Hz, 1H), 4.33–4.18 (m, 3H), 2.09 (s, 3H), 2.07 (s, 3H). ¹³C NMR (101 MHz, CDCl₃) δ 170.84, 170.54, 142.40, 140.14, 137.78, 134.87, 133.42, 129.27 (2 X C), 128.94 (2 X C), 127.11 (2 X C), 125.03, 122.56, 70.03, 68.90, 63.31, 62.83, 20.93, 20.90. HRMS (ESI⁺) m/z calcd for C₂₄H₂₄ClO₅ (M+H)⁺ 427.1307, found 427.1309.

Prepared by the representative procedure 1 using 3,4 Di-O-acetyl-L-rhamnal (0.5 mmol, 107 mg) and phenyl acetylene (0.55 mmol, 56 µL) to yield 4j (80%, 116 mg). ¹H NMR (400 MHz, Chloroform-d) δ 7.51–7.47 (m, 2H), 7.41–7.37 (m, 2H), 6.12 (d, J = 9.8 Hz, 1H),
5.84–5.77 (m, 1H), 4.95–4.86 (m, 1H), 4.63 (dd, J = 9.7, 1.7 Hz, 1H), 3.95 (d, J = 6.3 Hz, 1H), 2.10 (s, 3H), 1.22 (d, J = 6.4 Hz, 3H). \( ^{13} \text{C NMR} \) (101 MHz, CDCl\(_3\)) δ 170.71, 136.72, 136.24, 131.37, 129.39, 128.71 (2 X C), 128.37 (2 X C), 126.52, 124.40, 69.39, 68.63, 68.59, 21.22, 17.54. HRMS (ESI\(^+\)) m/z calcd for C\(_{16}\)H\(_{18}\)ClO\(_3\) (M+H\(^+\)) 293.0939, found 293.0934.

Prepared by the representative procedure 1 using 3,4-Di-O-acetyl-L-rhamnal (0.5 mmol, 107 mg) and 1-ethyl-4-methylbenzene (0.55 mmol, 64 µL) to yield 4k (72%, 110 mg). \( ^{1} \text{H NMR} \) (400 MHz, Chloroform-d) δ 7.38 (d, J = 8.1 Hz, 2H), 7.19 (d, J = 7.9 Hz, 2H), 6.08 (d, J = 9.8 Hz, 2H), 4.91 (dd, J = 5.9, 1.7 Hz, 1H), 4.64 (dd, J = 9.7, 1.6 Hz, 1H), 3.95 (d, J = 6.3 Hz, 1H), 3.95 (p, J = 6.3 Hz, 1H), 2.37 (s, 2H), 2.11 (s, 3H), 1.22 (d, J = 6.4 Hz, 3H). \( ^{13} \text{C NMR} \) (101 MHz, CDCl\(_3\)) δ 170.77, 139.51, 136.95, 133.38, 131.53, 129.03, 128.62, 126.04, 124.23, 69.39, 68.67, 68.60, 21.36, 21.24, 17.53. HRMS (ESI\(^+\)) m/z calcd for C\(_{17}\)H\(_{20}\)ClO\(_3\) (M+H\(^+\)) 307.1095, found 307.1099.

Typical procedure for preparation of iodo substituted vinyl glycosides (2): Tri-O-acetyl D-glucal (0.3 mmol, 82 mg) and dichloromethane (4 mL) were placed in a dry 50 mL round-bottomed flask equipped with a magnetic stirring bar. The solution was cooled to -30 °C and phenylacetylene (36 µL, 0.33 mmol) was added via syringe, followed by addition of Iodine (0.16 mmol, 45 mg). The reaction solution was stirred for 1 hr. The reaction was quenched with hypo and extracted with dichloromethane (3 × 15 mL). The organic layer was separated and dried over anhydrous MgSO\(_4\). Product 5a was obtained in 62% (82 mg).

\( ^{1} \text{H NMR} \) (400 MHz, Chloroform-d) δ 7.32–7.22 (m, 1H), 6.55 (dd, J = 9.2, 2.8 Hz, 1H), 5.72 (dd, J = 10.26, 9.05 Hz, 2H), 5.10–5.04 (m, 1H), 4.52 (d, J = 9.1 Hz, 1H), 4.23–4.02 (m, 2H), 3.96–3.86 (m, 1H), 2.03 (s, 3H), 2.02 (s, 3H). \( ^{13} \text{C NMR} \) (101 MHz, CDCl\(_3\)) δ 170.38, 170.22, 140.72, 138.35, 130.45, 128.39, 128.37 (2 X C), 128.21 (2 X C), 124.45, 70.57, 69.94, 64.42, 62.86, 21.07, 20.82. HRMS (ESI\(^+\)) m/z calcd for C\(_{18}\)H\(_{20}\)IO\(_5\) (M+H\(^+\)) 443.0350, found 443.0342.
Prepared by general procedure 2 using Tri-O-acetyl-d-glucal (0.3 mmol, 82 mg) and P-methyl 1-ethynyl-4-methylbenzene (0.33 mmol, 38 µL) to yield 5b (57%, 78 mg). $^1$H NMR (400 MHz, Chloroform-d) δ 7.19–7.16 (m, 2H), 7.06 (d, $J = 7.9$ Hz, 2H), 6.52 (d, $J = 9.1$ Hz, 1H), 5.76–5.65 (m, 2H), 5.09–5.04 (m, 1H), 4.52 (ddd, $J = 9.2$, 1.8 Hz, 1H), 4.09 (ddd, $J = 15.4$, 12.0, 4.6 Hz, 1H), 3.91 (dt, $J = 6.5$, 3.5 Hz, 1H), 2.27 (s, 3H), 2.03 (s, 3H), 2.02 (s, 3H).

$^{13}$C NMR (101 MHz, CDCl$_3$) δ 170.80, 170.35, 138.93, 138.13, 138.08, 130.58, 129.02 (2X C), 128.30 (2X C), 124.52, 102.21, 70.69, 70.08, 64.49, 62.91, 21.25, 21.03, 20.81. HRMS (ESI$^+$) m/z calcd for C$_{19}$H$_{22}$I$_2$O$_5$ (M+H)$^+$ 457.0506, found 457.0513

Prepared by the representative procedure 1 using of 2-acetoxy-tri-O-acetyl-d-galucal (0.5 mmol, 165 mg) and phenylacetylene (0.55 mmol, 56 µL) to yield 6a (51%, 78 mg). $^1$H NMR (400 MHz, Chloroform-d) δ 7.57–7.48 (m, 2H), 7.37–7.28 (m, 3H), 6.89 (dd, $J = 10.5$, 2.5 Hz, 1H), 6.15 (dd, $J = 10.5$, 2.3 Hz, 1H), 6.02 (d, $J = 9.9$ Hz, 1H), 4.72 (dd, $J = 9.7$, 4.3 Hz, 2H), 4.26 (dd, $J = 11.8$, 5.6 Hz, 1H), 4.17 (dd, $J = 11.8$, 4.1 Hz, 1H), 1.96 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 193.06 170.51, 146.36, 141.12, 135.81, 129.71, 128.94 (2C), 128.29 (2C), 127.40, 121.31, 75.44, 69.21, 64.29, 20.69. HRMS (ESI$^+$) m/z calcd for C$_{16}$H$_{15}$ClNaO$_4$ (M+Na)$^+$ 329.0551, found 329.0556

Prepared by the representative procedure 1 using of 2-Acetoxy-tri-O-acetyl-d-galucal (0.5 mmol, 165 mg) and 1-ethynyl-4-methylbenzene (0.55 mmol, 64 µL) to yield 6b (46%, 73 mg). $^1$H NMR (400 MHz, Chloroform-d) δ 7.47 (d, $J = 8.0$ Hz, 2H), 7.19 (d, $J = 7.9$ Hz, 2H), 6.96 (dd, $J = 10.5$, 2.4 Hz, 1H), 6.21 (d, $J = 10.5$ Hz, 1H), 6.05 (d, $J = 9.9$ Hz, 1H), 4.79 (d, $J = 9.9$ Hz, 2H), 4.32 (dd, $J = 11.8$, 5.6 Hz, 1H), 4.24 (dd, $J = 11.8$, 4.1 Hz, 1H), 2.37 (s, 3H), 2.04 (s, 3H). $^{13}$C NMR (101 MHz, CDCl$_3$) δ 193.24, 170.61, 146.38, 141.45, 139.91, 132.88,
128.94 (2C), 128.84 (2C), 127.39, 120.65, 75.45, 69.12, 64.29, 21.34, 20.73. HRMS (ESI+) m/z calcd for C_{17}H_{17}ClNaO_4 (M+Na)^+ 343.0708, found 343.0702.

Prepared by the representative procedure 1 using of 2-Acetoxy-tri-O-acetyl-D-galucal (0.5 mmol, 165 mg) and 1-ethynyl-4-Fluorobenzene (0.55 mmol, 66 µL) to yield 6c (52%, 84 mg). \(^1\)H NMR (400 MHz, Chloroform-d) δ 7.60 (dd, \(J = 8.5, 5.4\) Hz, 2H), 7.09 (t, \(J = 8.7\) Hz, 2H), 6.98 (dd, \(J = 10.6, 2.3\) Hz, 1H), 6.24 (dd, \(J = 10.5, 2.0\) Hz, 1H), 6.09 (d, \(J = 9.9\) Hz, 1H), 4.34 (dd, \(J = 11.9, 5.7\) Hz, 1H), 4.24 (dd, \(J = 11.8, 4.0\) Hz, 1H), 2.05 (s, 3H).

\(^{13}\)C NMR (101 MHz, CDCl_3) δ 193.03, 170.58, 163.35 (d, C–F coupling), 146.54, 140.03, 131.13, 131.06, 128.33, 127.39, 121.45, 115.50, 115.33, 75.41, 69.15, 64.24, 20.76. HRMS (ESI+) m/z calcd for C_{16}H_{14}ClNaO_4 (M+Na)^+ 347.0462, found 347.0454.

Prepared by the representative procedure 1 using of 2-Acetoxy-tri-O-acetyl-D-galucal (0.5 mmol, 165 mg) and 1-ethynyl-4-phenyl-benzene (0.55 mmol, 98 µL) to yield 6d (52%, 99 mg). \(^1\)H NMR (400 MHz, Chloroform-d) δ 7.63 (dt, \(J = 7.2, 6.2\) Hz, 7H), 7.46 (t, \(J = 7.5\) Hz, 2H), 7.38 (t, \(J = 7.3\) Hz, 1H), 6.97 (dd, \(J = 10.5, 2.4\) Hz, 1H), 6.30 – 6.20 (m, 1H), 6.24 (dd, \(J = 10.5, 2.2\) Hz, 1H), 6.12 (d, \(J = 9.9\) Hz, 1H), 4.86 (d, \(J = 9.9\) Hz, 1H), 4.80 (dt, \(J = 6.5, 3.3\) Hz, 1H), 4.35 (dd, \(J = 11.8, 5.6\) Hz, 1H), 4.27 (dd, \(J = 11.8, 4.1\) Hz, 1H), 2.02 (s, 3H). \(^{13}\)C NMR (101 MHz, CDCl_3) δ 193.21, 170.65, 146.51, 142.61, 141.02, 140.12, 134.60, 129.46 (2C), 128.95 (2 x C), 127.87, 127.43, 126.15 (2 x C), 126.99 (2C), 121.31, 75.49, 69.21, 64.40, 20.77. HRMS (ESI+) m/z calcd for C_{22}H_{20}ClO_4 (M+H)^+ 383.1045, found 383.1052.

**General procedure for Pd-catalyzed coupling between bromo substituted alkenyl glycoside 3a and Arylboronic Acids (3):**

To a solution of Compound 3a (0.3 mmol) in mixed solvent (PEG-400 0.5 mL and H_2O 1.5 mL) were added arylboronic acid (0.7 mmol), palladium acetate (0.012 mmol) and potassium phosphate (0.6 mmol). The reaction mixture was stirred at 40 °C for 24 h. After cooling to room temperature, the mixture was diluted with water and the combined aqueous phases were extracted three times with ethyl acetate. The organic layers were combined, dried with Na_2SO_4 and concentrated to yield the crude product, which was further purified by silica gel chromatography using petroleum ether and ethyl acetate as eluent to provide the
desired product.

Prepared by the general procedure 3 using compound 3a (0.3 mmol, 118 mg), and \( p \)-methoxy phenylboronic acid (0.7 mmol, 106 mg), to yield 7a (64%, 80 mg).\( ^1\)H NMR (400 MHz, Chloroform-d) \( \delta \) 7.43–7.31 (m, 2H), 7.29–7.20 (m, 3H), 7.18 (d, \( J = 8.8 \) Hz, 2H), 6.82 (d, \( J = 8.8 \) Hz, 2H), 6.08 (d, \( J = 9.3 \) Hz, 1H), 5.83 (m, 2H), 5.20–5.13 (m, 1H), 4.73 (d, \( J = 9.3 \) Hz, 1H), 4.26–4.06 (m, 3H), 3.80 (s, 3H), 2.10 (s, 3H), 2.08 (s, 3H), \( ^{13}\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) 170.92, 170.76, 159.48, 145.48, 138.95, 134.16, 132.88, 129.70 (2 x C), 120.85 (2 x C), 128.30 (2 x C), 127.74, 123.47, 122.67, 115.26, 113.55 (2 x C), 70.07, 64.74, 63.09, 55.30, 21.13, 20.87. HRMS (ESI\(^+\)) m/z calcld for C\(_{25}\)H\(_{26}\)NaO\(_6\) (M+Na\(^+\)) 445.1622, found 445.1625.

Prepared by the general procedure 3 using compound 3a (0.3 mmol, 118 mg), and \( m \)-nitrophenylboronic acid (0.7 mmol, 117 mg), to yield 7b (52%, 68 mg).\( ^1\)H NMR (400 MHz, Chloroform-d) \( \delta \) 8.26–8.11 (m, 1H), 7.69–7.48 (m, 1H), 7.48–7.30 (m, 4H), 7.26–7.15 (m, 2H), 6.26 (d, \( J = 9.2 \) Hz, 1H), 5.86 (bs, 2H), 5.20–5.14 (m, 1H), 4.80 (d, \( J = 9.2 \) Hz, 1H), 4.27–4.07 (m, 2H), 2.11 (s, 1H), 2.09 (s, 1H), \( ^{13}\)C NMR (101 MHz, CDCl\(_3\)) \( \delta \) 170.86, 170.46, 148.38, 143.77, 143.36, 137.39, 133.72, 131.56, 129.55 (2 x C), 129.21, 128.81 (2 x C), 128.52, 127.26, 124.25, 122.67, 122.18, 70.30, 69.73, 64.51, 62.93, 21.10, 20.85. HRMS (ESI\(^+\)) m/z calcld for C\(_{24}\)H\(_{27}\)N\(_2\)O\(_7\) (M+ NH\(_4\)^\(^+\)) 445.1813, found 445.1809.

Prepared by the general procedure 3 using compound 3a (0.3 mmol, 118 mg), and \( m \)-nitrophenylboronic acid (0.7 mmol, 114 mg), to yield 7c 54% (70 mg).\( ^1\)H NMR (400 MHz, Chloroform-d) \( \delta \) 7.88 (d, \( J = 8.3 \) Hz, 2H), 7.37 (dd, \( J = 22.2, 7.8 \) Hz, 5H), 7.26–7.19 (m, 2H), 6.26 (d, \( J = 9.2 \) Hz, 1H), 5.86 (bs, 2H), 5.17 (d, \( J = 6.1 \) Hz, 1H), 4.79 (d, \( J = 9.0 \) Hz,
Typical procedure for Pd-Catalyzed Heck Coupling (4). A mixture of alkenylbromide 3a (0.3 mmol, 118 mg), p-nitrostyrene (0.3 mmol, 45 µL), PEG-2000 (1 g), TEA (0.3 mmol, 30 µL), and Pd(OAc)$_2$ (0.03 mmol, 6.7 mg) were placed in a 10-mL round-bottomed flask and heated at 80°C. After 8h, the reaction mixture was cooled, extracted with cold diethyl ether (15 mL), and purified by column chromatography to yield 8a (57%, 79 mg).
$^1$H NMR of compound 3a

$^{13}$C NMR of compound 3a
DEPT of compound 3a

$^1$H NMR of compound 3b
$^{13}$C NMR of compound 3b

DEPT of compound 3b
$^1$H NMR of compound 3C

$^{13}$C NMR of compound 3C
DEPT of compound 3C

\[ \text{H NMR of compound 3d} \]
$^{13}$C NMR of compound 3d

DEPT of compound 3d
$^1$H NMR of compound 3e

$^{13}$C NMR of compound 3e
DEPT of compound 3e

$^1$H NMR of compound 3f
$^{13}$C NMR of compound 3f

DEPT of compound 3f
$^1$H NMR of compound 3g

$^{13}$C NMR of compound 3g
DEPT of compound 3g

\[ \text{1H NMR of compound 3h} \]
$^{13}$C NMR of compound 3h

DEPT of compound 3h
$^1$H NMR of compound 3i

$^{13}$C NMR of compound 3i
DEPT of compound 3i

$^1$H NMR of compound 3j
$^{13}$C NMR of compound 3j

DEPT of compound 3j
HSQC of compound 3j

NOESY of compound 3j
$^1$H NMR of compound 4a

$^{13}$C NMR of compound 4a
DEPT of compound 4a
$^1$H-$^1$H COSY of compound 4a

HMBC of compound 4a
HSQC of compound 4a

NOESY of compound 4a
$^1$H NMR of compound 4b

$^{13}$C NMR of compound 4b
DEPT of compound 4b

^1^H NMR of compound 4c
$^{13}$C NMR of compound 4c

DEPT of compound 4c
$^1$H NMR of compound 4d

$^{13}$C NMR of compound 4d
DEPT of compound 4d

$^1$H NMR of compound 4e
$^{13}$C NMR of compound 4e

DEPT of compound 4e
$^{1}\text{H NMR of compound 4f}$

$^{13}\text{C NMR of compound 4f}$
DEPT of compound 4f

$^1$H NMR of compound 4g
$^{13}$C NMR of compound 4g

DEPT of compound 4g
$^1$H NMR of compound 4h

$^{13}$C NMR of compound 4h
DEPT of compound 4h
COSY of compound 4h

COSY (exp) of compound 4h
NOESY of compound 4h

NOESY (exp) of compound 4h
$^1$H NMR of compound 4i

$^{13}$C NMR of compound 4i
DEPT of compound 4i

\[\text{\textsuperscript{1}H NMR of compound 4j}\]
$^{13}$C NMR of compound 4j

DEPT of compound 4j
$^1$H NMR of compound 4k

$^{13}$C NMR of compound 4k
DEPT of compound 4k

$^1$H NMR of compound 5a
$^{13}$C NMR of compound 5a

DEPT of compound 5a
$^1$H NMR of compound 5b

$^{13}$C NMR of compound 5b
DEPT of compound 5b

\[ \text{H NMR of compound 6a} \]
$^{13}$C NMR of compound 6a

DEPT of compound 6a
$^1$H NMR of compound 6b

$^{13}$C NMR of compound 6b
DEPT of compound 6b

$^1$H NMR of compound 6c
$^{13}$C NMR of compound 6c
$^1$H NMR of compound 6d

$^{13}$C NMR of compound 6d
DEPT of compound 6d

$^1$H NMR of compound 7a
$^{13}$C NMR of compound 7a

DEPT of compound 7a
$^1$H NMR of compound 7b

$^{13}$C NMR of compound 7b
DEPT of compound 7b

1H-1H COSY of compound 7b
HMBC of compound 7b

NOESY of compound 7b
$^1$H NMR of compound 7c

$^{13}$C NMR of compound 7c
DEPT of compound 7c

$^1$H NMR of compound 8a
\(^{13}\)C NMR of compound 8a

DEPT of compound 8a