

Supplementary Information

Synthesis of C-arylglycosides via Ru(II)-catalyzed [2 + 2 + 2] cycloaddition

Yoshihiko Yamamoto,*¹ Saigoku Tomoaki,¹ Takashige Ohgai,² Hisao Nishiyama,¹ and Kenji Itoh²

¹*Department of Applied Chemistry,* ²*Department of Molecular Design and Engineering, Graduate School of Engineering, Nagoya University, Chikusa, Nagoya 464-8603, Japan*

Experimental Section

General Considerations. Flash chromatography was performed with a silica gel column (Merck Silica gel 60) eluted with mixed solvents [hexane / ethyl acetate]. ¹H and ¹³C NMR spectra were obtained for samples in CDCl₃ solution at 25 °C. ¹H NMR chemical shifts are reported in terms of chemical shift (δ, ppm) relative to the singlet at 7.26 ppm for chloroform. Splitting patterns are designated as follows: s, singlet; d, doublet; t, triplet; q, quartet; quint, quintet; m, multiplet. Coupling constants are reported in Hz. ¹³C NMR spectra were fully decoupled and are reported in terms of chemical shift (δ, ppm) relative to the triplet at δ = 77.0 ppm for CDCl₃. Melting points were obtained in capillary tubes and are uncorrected. 1,2-Dichloroethane was distilled from CaH₂, and degassed before use. Cp*RuCl(cod) was obtained according to the literature procedures.

Typical experimental procedure. Synthesis of 4aa: To a solution of Cp*RuCl(cod) (5.7 mg, 0.015 mmol) in dry degassed DCE (1 mL) was added a solution of **3a** (67.4 mg, 0.32 mmol) and **2a** (143.0 mg, 0.6 mmol) in DCE (4 mL) over 5 h via syringe pump at room temperature. The reaction mixture was concentrated in vacuo and the residue was purified by silica gel column flush chromatography (eluent, hexane:AcOEt = 6:1) to

afford **4aa** (132.8 mg, 93%) as colorless solids: mp. 106.2-107.2 °C; $[\alpha]_D^{25} = -27.8^\circ$ ($c = 0.05$, CHCl_3); IR (CHCl_3) 1734, 1247 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3 , 25 °C): δ 2.06 (s, 3 H), 2.08 (s, 3 H), 3.58 (s, 4 H), 3.73 (s, 3 H), 3.74 (s, 3 H), 3.84 (ddd, $J = 6.6, 6.0, 3.0$ Hz, 1 H), 4.08 (dd, $J = 12.0, 3.0$ Hz, 1 H), 4.26 (dd, $J = 12.0, 6.0$ Hz, 2 H), 5.25-5.30 (m, 2 H), 5.96 (ddd, $J = 10.2, 2.4, 1.8$ Hz, 1 H), 6.14 (ddd, $J = 10.2, 3.0, 1.5$ Hz, 1 H), 7.18-7.19 (m, 2 H), 7.23 (s, 1 H); ^{13}C NMR (75 MHz, CDCl_3 , 25 °C): δ 20.73, 20.99, 40.23, 40.41, 52.86, 60.24, 62.70, 64.86, 69.22, 73.40, 123.53, 123.97, 124.57, 126.61, 131.43, 137.57, 139.77, 140.06, 170.08, 170.41, 171.60; MS (FAB): m/z (%): 445 (14) [$\text{M}^+ - \text{H}$], 385 (35) [$\text{M}^+ - \text{H} - \text{HOAc}$], 327 (100) [$\text{M}^+ - \text{H} - 2\text{OAc}$]; EA calcd (%) for $\text{C}_{23}\text{H}_{26}\text{O}_9$ (446.45): C 61.88, H 5.87; found: C 61.96, H 5.86.

4ba: mp. 134.5-135.4 °C; $[\alpha]_D^{25} = -39.2^\circ$ ($c = 0.05$, CHCl_3); IR (CHCl_3) 1737, 1235 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3 , 25 °C): δ 2.05 (s, 3 H), 2.07 (s, 3 H), 2.40 (s, 3 H), 3.79 (ddd, $J = 6.3, 6.0, 3.0$ Hz, 1 H), 4.06 (dd, $J = 12.0, 3.0$ Hz, 1 H), 4.25 (dd, $J = 12.0, 6.0$ Hz, 2 H), 4.61 (s, 4 H), 5.23-5.39 (m, 2 H), 5.97 (ddd, $J = 10.2, 2.4, 1.5$ Hz, 1 H), 6.11 (ddd, $J = 10.2, 2.7, 1.2$ Hz, 1 H), 7.17 (d, $J = 7.8$ Hz, 1 H), 7.21 (s, 1 H), 7.28 (d, $J = 7.8$ Hz, 1 H), 7.31 (d, $J = 8.4$ Hz, 2 H), 7.76 (d, $J = 8.4$ Hz, 2 H); ^{13}C NMR (75 MHz, CDCl_3 , 25 °C): δ 20.87, 21.11, 21.57, 53.51, 53.61, 62.69, 64.82, 69.60, 73.15, 121.96, 122.63, 124.95, 127.41, 127.48, 129.70, 131.15, 133.58, 136.09, 136.48, 138.80, 143.58, 170.18, 170.52; MS (FAB): m/z (%): 484 (100) [$\text{M}^+ - \text{H}$], 366 (25) [$\text{M}^+ - \text{H} - 2\text{OAc}$]; EA calcd (%) for $\text{C}_{25}\text{H}_{27}\text{NO}_7\text{S}$ (485.88): C 61.84, H 5.60, N 2.88; found: C 61.71, H 5.60, N 2.82.

4ca: mp. 53.3-54.1 °C; $[\alpha]_D^{25} = -12.7^\circ$ ($c = 0.53$, CHCl_3); IR (CHCl_3) 1737, 1238 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3 , 25 °C): δ 2.07 (s, 3 H), 2.09 (s, 3 H), 3.85 (ddd, $J = 6.9, 6.0, 3.0$ Hz, 1 H), 4.09 (dd, $J = 12.0, 3.0$ Hz, 1 H), 4.28 (dd, $J = 12.0, 6.0$ Hz, 2 H), 5.11 (s, 4 H), 5.27-5.34 (m, 2 H), 5.99 (ddd, $J = 10.5, 3.0, 2.1$ Hz, 1 H), 6.17 (ddd, $J = 10.5, 3.0, 1.5$ Hz, 1 H), 7.23 (d, $J = 7.5$ Hz, 1 H), 7.29 (s, 1 H), 7.31 (dd, $J = 7.5, 1.5$ Hz, 1 H); ^{13}C NMR (75 MHz, CDCl_3 , 25 °C): δ 20.87, 21.13, 62.79, 64.94, 69.42, 73.34, 73.40, 73.46, 120.40, 120.91, 124.91, 127.10, 131.37, 138.14, 139.17, 139.53, 170.22, 170.56; MS (FAB): m/z (%): 331 (100) [$\text{M}^+ - \text{H}$], 273 (51) [$\text{M}^+ - \text{OAc}$], 213 (79) [$\text{M}^+ - \text{H} - 2\text{OAc}$]; EA calcd (%) for $\text{C}_{18}\text{H}_{20}\text{O}_6$ (332.35): C 65.05, H 6.07; found: C 65.00, H

6.07.

4da: mp. 121.6-122.0 °C; $[\alpha]_D^{25} = -94.9^\circ$ ($c = 0.05$, CHCl₃); IR (CHCl₃) 1739, 1676, 1234 cm⁻¹; ¹H NMR (300 MHz, CDCl₃, 25 °C): δ 2.11 (s, 3 H), 2.15 (s, 3 H), 3.88 (ddd, $J = 6.9, 6.0, 3.0$ Hz, 1 H), 4.17 (dd, $J = 12.0, 3.0$ Hz, 1 H), 4.31 (dd, $J = 12.0, 6.9$ Hz, 2 H), 5.28-5.33 (m, 1 H), 5.46-5.49 (m, 1 H), 6.07 (ddd, $J = 10.5, 3.0, 2.1$ Hz, 1 H), 6.29 (ddd, $J = 10.5, 3.0, 1.8$ Hz, 1 H), 7.81 (d, $J = 3.3$ Hz, 1 H), 7.83 (d, $J = 3.3$ Hz, 1 H), 7.87 (ddd, $J = 7.8, 2.0, 0.5$ Hz, 1 H), 8.31-8.37 (m, 4 H); ¹³C NMR (75 MHz, CDCl₃, 25 °C): δ 20.84, 21.06, 62.82, 64.71, 70.19, 72.73, 125.71, 125.77, 127.08, 127.09, 127.57, 130.17, 132.73, 132.87, 133.25, 133.29, 133.48, 134.02, 134.05, 145.78, 170.15, 170.60, 182.46, 182.59; MS (FAB): m/z (%): 421 (66) [MH⁺], 361 (66) [M⁺ - OAc], 301 (100) [M⁺ - H - 2OAc]; EA calcd (%) for C₂₄H₂₀O₇ (420.41): C 68.57, H 4.80; found: C 68.33, H 5.04.

4ea: oil; $[\alpha]_D^{25} = -30.4^\circ$ ($c = 1.00$, CHCl₃); IR (CHCl₃) 1733, 1259 cm⁻¹; ¹H NMR (300 MHz, CDCl₃, 25 °C): δ 1.19 (t, $J = 6.9$ Hz, 3 H), 1.22 (t, $J = 7.5$ Hz, 3 H), 2.03 (s, 3 H), 2.05 (s, 3 H), 2.05-2.15 (m, 2 H), 2.43 (t, $J = 7.5$ Hz, 2 H), 3.53 (t, $J = 7.5$ Hz, 1 H), 3.75-3.81 (m, 1 H), 4.03 (dd, $J = 12.0, 3.0$ Hz, 1 H), 4.03 (dd, $J = 12.0, 6.0$ Hz, 1 H), 4.06 (q, $J = 7.2$ Hz, 2 H), 4.12 (s, 4 H), 4.14 (q, $J = 7.2$ Hz, 2 H), 4.22 (dd, $J = 12.0, 6.0$ Hz, 1 H), 5.24-5.30 (m, 2 H), 5.94 (d, $J = 10.5$ Hz, 1 H), 6.12 (dd, $J = 10.5, 1.2$ Hz, 1 H), 7.15 (d, $J = 8.4$ Hz, 1 H), 7.20 (s, 1 H), 7.21 (d, $J = 8.4$ Hz, 1 H); ¹³C NMR (75 MHz, CDCl₃, 25 °C): δ 14.21, 14.38, 20.83, 21.08, 25.90, 30.73, 54.91, 55.05, 60.39, 60.53, 62.80, 63.11, 64.92, 68.96, 73.63, 121.84, 122.21, 124.83, 126.62, 131.32, 137.32, 139.21, 139.41, 170.18, 170.55, 171.85, 172.78; MS (FAB): m/z (%): 518 (100) [MH⁺], 444 (25) [M⁺ - CO₂Et]; EA calcd (%) for C₂₇H₃₅NO₉ (517.57): C 62.66, H 6.82, N 2.71; found: C 62.76, H 7.00, N 2.43.

4fa: mp. 52.3-53.0 °C; $[\alpha]_D^{25} = 35.6^\circ$ ($c = 1.07$, CHCl₃); IR (CHCl₃) 1735, 1240 cm⁻¹; ¹H NMR (300 MHz, CDCl₃, 25 °C): δ 2.06 (s, 3 H), 2.08 (s, 3 H), 2.07 (s, 3 H), 2.09 (s, 3 H), 3.60 (s, 2 H), 3.70 (d, $J = 2.7$ Hz, 2 H), 3.73 (s, 3 H), 3.75 (s, 3 H), 3.81-3.89 (m, 2 H), 4.08 (dt, $J = 12.3, 2.7$ Hz, 2 H), 4.27 (dd, $J = 12.0, 6.6$ Hz, 1 H), 4.30 (dd, $J = 12.0, 5.7$ Hz, 1 H), 5.22-5.33 (m, 4 H), 5.98 (ddd, $J = 10.2, 2.4, 1.8$ Hz, 1 H), 6.04 (ddd, $J = 10.5, 3.3, 1.8$ Hz, 1 H), 6.15 (ddd, $J = 10.5, 2.6, 1.5$ Hz, 1 H), 7.14 (s, 1 H), 7.24 (s, 1 H); ¹³C NMR (75 MHz, CDCl₃, 25 °C): δ 20.80, 20.84, 20.99, 21.09,

39.20, 40.40, 52.97, 52.99, 60.12, 62.45, 62.63, 64.76, 64.80, 69.56, 70.02, 71.64, 73.30, 123.50, 124.59, 124.79, 126.15, 131.06, 131.44, 134.43, 137.92, 139.79, 141.23, 170.19, 170.25, 170.57, 171.58, 171.75; MS (EI): m/z (%): 657 (35) [M⁺ - H], 599 (45) [M⁺ - H - OAc], 539 (100) [M⁺ - H - 2OAc], 479 (92) [M⁺ - 2H - 3OAc]; EA calcd (%) for C₃₃H₃₈O₁₄ (658.65): C 60.18, H 5.82; found: C 60.10, H 5.90.

4ab: mp. 97.0-98.0 °C; $[\alpha]_D^{25} = -176.1^\circ$ ($c = 1.02$, CHCl₃); IR (CHCl₃) 1733, 1247 cm⁻¹; ¹H NMR (300 MHz, CDCl₃, 25 °C): δ 2.01 (s, 3 H), 2.11 (s, 3 H), 3.59 (s, 4 H), 3.74 (s, 3 H), 3.75 (s, 3 H), 3.93 (ddd, $J = 6.9, 6.0, 2.7$ Hz, 1 H), 4.15 (dd, $J = 11.5, 5.7$ Hz, 1 H), 4.21 (dd, $J = 11.5, 6.0$ Hz, 1 H), 5.10 (dd, $J = 5.1, 2.4$ Hz, 1 H), 5.33-5.37 (m, 1 H), 6.17 (ddd, $J = 10.2, 5.4, 2.4$ Hz, 1 H), 6.37 (ddd, $J = 10.2, 3.6, 0.6$ Hz, 1 H), 7.18 (br s, 2 H), 7.21 (br s, 1 H); ¹³C NMR (75 MHz, CDCl₃, 25 °C): δ 20.81, 21.00, 40.33, 40.52, 53.02, 60.36, 62.70, 63.75, 68.21, 73.63, 123.20, 123.53, 124.07, 126.55, 123.26, 137.10, 139.84, 140.15, 170.31, 170.37, 171.73; MS (FAB): m/z (%): 447 (75) [MH⁺], 387 (53) [M⁺ - OAc], 327 (100) [M⁺ - H - 2OAc]; EA calcd (%) for C₂₃H₂₆O₉ (446.45): C 61.88, H 5.87; found: C 61.84, H 5.90.

4ac: mp. 62.0-63.2 °C; $[\alpha]_D^{25} = -53.1^\circ$ ($c = 0.05$, CHCl₃); IR (CHCl₃) 1750, 1231 cm⁻¹; ¹H NMR (300 MHz, CDCl₃, 25 °C): δ 1.80 (s, 3 H), 2.00 (s, 3 H), 2.05 (s, 3 H), 2.08 (s, 3 H), 3.57 (s, 4 H), 3.73 (s, 3 H), 3.74 (s, 3 H), 3.81 (ddd, $J = 9.9, 4.5, 2.1$ Hz, 1 H), 4.13 (dd, $J = 12.0, 2.1$ Hz, 1 H), 4.27 (dd, $J = 12.0, 4.8$ Hz, 1 H), 4.36 (d, $J = 9.9$ Hz, 1 H), 5.11 (t, $J = 9.9$ Hz, 1 H), 5.21 (t, $J = 9.3$ Hz, 1 H), 5.31 (t, $J = 9.3$ Hz, 1 H), 7.13-7.19 (m, 3 H), 6.37 (ddd, $J = 10.2, 3.6, 0.6$ Hz, 1 H), 7.18 (br s, 2 H), 7.21 (br s, 1 H); ¹³C NMR (75 MHz, CDCl₃, 25 °C): δ 20.52, 20.74, 20.77, 20.89, 40.40, 40.46, 60.42, 62.40, 68.58, 72.58, 74.31, 76.15, 80.25, 122.96, 124.12, 126.05, 134.98, 140.15, 140.67, 168.73, 169.33, 170.21, 170.58, 171.69, 171.73; MS (FAB): m/z (%): 565 (55) [MH⁺], 505 (42) [M⁺ - OAc], 473 (100) [M⁺ - H - OAc]; EA calcd (%) for C₂₇H₃₂O₁₃ (564.54): C 57.44, H 5.71; found: C 57.40, H 5.78.

4ad: mp. 106.2-107.2 °C; $[\alpha]_D^{25} = -74.4^\circ$ ($c = 1.10$, CHCl₃); IR (KBr) 3247, 1734 cm⁻¹; ¹H NMR (300 MHz, CDCl₃, 25 °C): δ 2.47 (br s, 2 H), 3.40 (dt, $J = 7.8, 4.8$ Hz, 1 H), 3.57 (s, 4 H), 3.71 (s, 1 H), 3.73 (s, 1 H), 3.74 (s, 6 H), 4.23 (dd, $J = 8.4, 2.1$ Hz, 1 H), 5.20 (s, 1 H), 6.01 (s, 2 H), 7.16 (d, $J = 8.1$ Hz, 1 H), 7.16 (d, $J = 8.1$ Hz, 1 H), 7.20 (s, $J = 8.1$ Hz, 1 H), 7.21 (s, 1 H); ¹³C NMR (75 MHz, CDCl₃, 25 °C): δ 40.33, 40.50,

53.04, 60.36, 62.83, 64.08, 72.39, 73.90, 123.88, 124.07, 127.02, 128.76, 129.86, 137.98, 139.74, 140.04, 171.83; MS (FAB): m/z (%): 361 (100) [M^+ - H], 303 (71) [M^+ - CO_2Me]; EA calcd (%) for $C_{19}H_{22}O_7$ (362.57): C 62.97, H 6.12; found: C 62.96, H 6.13.

4ae: oil; $[\alpha]_D^{25} = -201.9^\circ$ ($c = 1.00$, $CHCl_3$); IR (neat) 3431, 1728 cm^{-1} ; 1H NMR (300 MHz, $CDCl_3$, 25 $^\circ C$): δ 1.90 (br s, 2 H), 3.54-3.60 (m, 1 H), 3.59 (s, 2 H), 3.60 (s, 2 H), 3.74 (s, 6 H), 3.73 (s, 1 H), 3.74 (s, 6 H), 3.80 (d, $J = 12.0$ Hz, 1 H), 3.99 (d, $J = 5.4$ Hz, 1 H), 4.53 (d, $J = 7.8$ Hz, 1 H), 4.87 (s, 1 H), 5.92 (dd, $J = 10.2, 3.0$ Hz, 1 H), 6.20-6.26 (m, 1 H), 7.20 (s, 2 H), 7.29 (s, 1 H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 $^\circ C$): δ 40.32, 40.54, 52.97, 60.34, 61.65, 64.52, 73.42, 75.03, 122.28, 123.94, 125.17, 128.15, 128.76, 137.11, 139.20, 139.95, 171.79; MS (FAB): m/z (%): 361 (33) [M^+ - H], 345 (71) [M^+ - OH]; EA calcd (%) for $C_{19}H_{22}O_7$ (362.57): C 62.97, H 6.12; found: C 62.97, H 6.11.

4af: oil; $[\alpha]_D^{25} = +5.2^\circ$ ($c = 1.05$, $CHCl_3$); IR ($CHCl_3$) 1706, 1362 cm^{-1} ; 1H NMR (300 MHz, $CDCl_3$, 25 $^\circ C$): δ 1.90 (ddd, $J = 13.2, 10.8, 6.0$ Hz, 1 H), 2.33 (ddd, $J = 13.2, 5.4, 1.2$ Hz, 1 H), 3.56 (s, 4 H), 3.58 (dd, $J = 9.9, 5.4$ Hz, 1 H), 3.74 (s, 6 H), 3.67 (dd, $J = 9.9, 4.5$ Hz, 1 H), 4.14-4.17 (m, 1 H), 4.28 (ddd, $J = 5.3, 4.8, 2.4$ Hz, 1 H), 4.56 (s, 2 H), 4.60 (s, 2 H), 5.09 (dd, $J = 10.8, 5.1$ Hz, 1 H), 7.13-7.14 (m, 3 H), 7.21 (s, 1 H), 7.29-7.38 (m, 10 H); ^{13}C NMR (75 MHz, $CDCl_3$, 25 $^\circ C$): δ 40.26, 40.45, 41.19, 52.87, 60.37, 70.90, 71.04, 73.32, 80.32, 81.47, 83.65, 121.74, 123.78, 125.00, 127.38, 127.45, 127.48, 128.16, 128.20, 137.89, 137.99, 139.05, 139.84, 140.34, 171.73, 171.76; MS (EI): m/z (%): 361 (9) [M^+], 439 (100) [M^+ - CH_2Ph], 439 (100) [M^+ - H - CH_2Ph - CO_2Me]; EA calcd (%) for $C_{32}H_{34}O_7$ (530.61): C 72.43, H 6.46; found: C 72.44, H 6.45.