Reactivity and Selectivity of 1,3-Diyn-6-enes in Electrophilic Transition Metal-Catalyzed Reactions

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Materials and Methods

^1H and ^{13}C NMR spectra were recorded on a Varian Mercury plus 300 or a Bruker AC-300 spectrometer. Tetramethylsilane (TMS) served as an internal standard ($\delta = 0$) for ^1H NMR and CDCl_3 was used as an internal standard ($\delta = 77.23$) for ^{13}C NMR. Flasks were oven-dried overnight and cooled under a stream of nitrogen. Compounds were purchased from Aldrich or Strem. THF was distilled from sodium/benzophenone and dichloromethane was distilled from CaH_2 . Flash chromatography was performed using silica gel 60 Å (32-63 mesh) from Sorbent Technologies. Reactions were monitored by thin layer chromatography (TLC) using 0.25 mm E. Merck pre-coated silica gel 60 (particle size 0.040–0.063 mm).

Representative procedures for the synthesis of diynes¹

Alkyne–Bromoalkyne Coupling: Copper(I) chloride (0.2 equiv) was added to a stirred solution of *n*-BuNH₂ (1.2 mL) and distilled water (2.8 mL) at 0 °C, which resulted in a deep blue solution. A few crystals of $\text{NH}_2\text{OH}\cdot\text{HCl}$ were added to get a colorless solution which is indicative of the presence of the required Cu(I) salt. At the same temperature was added diethyl 2-allyl-2-(prop-2-ynyl)malonate (318 mg, 1.34 mmol) by a syringe as a solution in CH_2Cl_2 upon which was a yellow suspension formed. Then a freshly prepared 3-bromo-1-phenylprop-2-yn-1-ol (1.1 equiv) was slowly added under a flow of N_2 in order to prevent the solution from turning to green or blue ($\text{NH}_2\text{OH}\cdot\text{HCl}$ can be added as necessary throughout the reaction). The reaction mixture was allowed to warm up to room temperature. After stirring for 10–20 minutes, the brownish orange colored solution was extracted twice with CH_2Cl_2 , dried over magnesium sulfate, and concentrated under vacuum. Purification by flash chromatography on silica gel (hexane/ethyl ether) afforded the product (452 mg, 92%).

Acetylation: To a solution of the corresponding product alcohol (452 mg, 1.23 mmol) in CH_2Cl_2 was added acetic anhydride (1.2 equiv), Et_3N (2.0 equiv), and *N,N*-dimethylaminopyridine (0.05 equiv). The reaction mixture was stirred for 2 hours and quenched with aqueous NH_4Cl . This solution was extracted twice with CH_2Cl_2 , dried over magnesium sulfate, and concentrated under vacuum. Purification by flash chromatography on silica gel (hexanes/ethyl ether) afforded the product **13b** (495 mg, 98%).

¹ (a) Marino, J. P.; Nguyen, H. N. *J. Org. Chem.* **2002**, 67, 6841. (b) Kim, S.; Kim, S.; Lee, T.; Ko, H.; Kim, D. *Org. Lett.* **2004**, 6, 3601, and references cited therein.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 7.50-7.46 (m, 2H), 7.40-7.36 (m, 3H), 6.47 (s, 1H), 5.61 (ddt, *J* = 17.1, 10.0, 7.4 Hz, 1H), 5.22-5.11 (m, 2H), 4.20 (q, *J* = 7.2 Hz, 4H), 2.91 (s, 2H), 2.79 (d, *J* = 7.4 Hz, 2H), 2.09 (s, 3H), 1.25 (t, *J* = 7.2 Hz, 6H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.63, 169.47(2), 136.39, 131.63, 129.27, 128.88(2), 127.84(2), 120.25, 77.03, 72.60, 71.76, 67.25, 65.87, 61.96(2), 56.80, 36.81, 23.69, 21.05, 14.18(2); **IR (neat):** $\nu_{\max}$ = 2983, 2260, 1733, 1218 cm⁻¹; **HRMS *m/z* (ESI):** calc. for C₂₄H₂₆O₆Na [M⁺+Na] 433.1627, found 433.1606.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 5.60 (ddt, *J* = 16.8, 9.8, 7.5 Hz, 1H), 5.45 (q, *J* = 6.5 Hz, 1H), 5.23-5.12 (m, 2H), 4.21 (q, *J* = 7.1 Hz, 4H), 2.89 (s, 2H), 2.78 (d, *J* = 7.5 Hz, 2H), 2.07 (s, 3H), 1.49 (d, *J* = 6.5 Hz, 3H), 1.26 (t, *J* = 7.1 Hz, 6H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.86, 169.58(2), 131.70, 120.29, 76.25, 74.56, 69.55, 67.30, 62.00(2), 60.57, 56.86, 36.84, 23.69, 21.24, 21.11, 14.24(2); **IR (neat):** $\nu_{\max}$ = 2985, 2261, 1736, 1224 cm⁻¹; **HRMS *m/z* (ESI):** calc. for C₁₉H₂₄O₆Na [M⁺+Na] 371.1471, found 371.1462.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 5.88 (ddt, *J* = 17.2, 10.3, 5.8 Hz, 1H), 5.48 (q, *J* = 6.8 Hz, 1H), 5.31 (ddt, *J* = 17.2, 1.6, 1.6 Hz, 1H), 5.25-5.20 (m, 1H), 4.22 (s, 2H), 4.06 (dt, *J* = 5.8, 1.6 Hz, 2H), 2.07 (s, 3H), 1.51 (d, *J* = 6.8 Hz, 3H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.81, 133.83, 118.32, 77.17, 76.40, 70.93, 70.27, 68.97, 60.47, 57.66, 21.12, 21.05; **HRMS *m/z* (ESI):** calc. for C₁₂H₁₄O₃Na [M⁺+Na] 229.0841, found 229.0848.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 7.72 (d, *J* = 8.2 Hz, 2H), 7.33 (d, *J* = 8.2 Hz, 2H), 5.71 (ddt, *J* = 17.0, 10.5, 6.5 Hz, 1H), 5.42 (q, *J* = 6.8 Hz, 1H), 5.31-5.23 (m, 2H), 4.14 (s, 2H), 3.78 (d, *J* = 6.5 Hz, 2H), 2.44 (s, 3H), 2.08 (s, 3H), 1.47 (d, *J* = 6.8 Hz, 3H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.74, 143.98, 135.69, 131.88, 129.81(2), 127.90(2), 120.46, 76.48, 73.22, 69.52, 68.62, 60.32, 49.61, 36.65, 21.70, 21.18, 21.06; **IR (neat):** $\nu_{\max}$ = 2924, 1744, 1226, 1164 cm⁻¹; **HRMS *m/z* (ESI):** calc. for C₁₉H₂₁NO₄SNa [M⁺+Na] 382.1089, found 382.1100.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 5.61 (ddt, J = 17.2, 9.9, 7.2 Hz, 2H), 5.21-5.11 (m, 4H), 4.21 (q, J = 7.2 Hz, 8H), 2.86 (s, 4H), 2.78 (d, J = 7.2 Hz, 4H), 1.26 (t, J = 7.2 Hz, 12H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.66(4), 131.81(2), 120.14(2), 72.67(2), 68.04(2), 61.92(4), 56.93(2), 36.85(2), 23.65(2), 14.22(4); **IR** (neat): $\nu_{\max}$ = 2983, 2261, 1735, 1215 cm⁻¹; **HRMS m/z (ESI)**: calc. for C₂₆H₃₄O₈Na [M⁺+Na] 497.2151, found 497.2153.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 5.89 (ddt, J = 17.3, 10.4, 5.8 Hz, 2H), 5.32 (ddt, J = 17.3, 1.6, 1.4 Hz, 2H), 5.23 (ddt, J = 10.4, 1.6, 1.4 Hz, 2H), 4.23 (s, 4H), 4.06 (dt, J = 5.8, 1.4 Hz, 4H); **¹³C NMR (75 MHz, CDCl₃)** δ 133.86(2), 118.33(2), 75.53(2), 70.97(2), 70.55(2), 57.72(2); **IR** (neat): $\nu_{\max}$ = 2851, 2137, 1348, 1086 cm⁻¹; **HRMS m/z (EI)**: calc. for C₁₂H₁₄O₂ [M⁺] 190.0994, found 190.0997.

Colorless oil: **¹H NMR (300 MHz, CDCl₃)** δ 5.32 (t, J = 7.0 Hz, 2H), 4.20 (s, 4H), 4.05 (d, J = 7.0 Hz, 4H), 1.76 (s, 6H), 1.71 (s, 6H); **¹³C NMR (75 MHz, CDCl₃)** δ 138.90(2), 120.20(2), 75.78(2), 70.40(2), 66.34(2), 57.43(2), 25.99(2), 18.24(2); **IR** (neat): $\nu_{\max}$ = 2933, 2241, 1349, 1070 cm⁻¹; **HRMS m/z (ESI)**: calc. for C₁₆H₂₂O₂Na [M⁺+Na] 269.1517, found 269.1519.

White solid: **¹H NMR (300 MHz, CDCl₃)** δ 7.70 (d, J = 8.2 Hz, 4H), 7.29 (d, J = 8.2 Hz, 4H), 5.69 (ddt, J = 17.3, 9.8, 6.5 Hz, 2H), 5.28-5.22 (m, 4H), 4.11 (s, 4H), 3.75 (d, J = 6.5 Hz, 4H), 2.42 (s, 6H); **¹³C NMR (75 MHz, CDCl₃)** δ 144.03(2), 135.83(2), 131.83(2), 129.76(4), 127.82(4), 120.37(2), 71.93(2), 69.40(2), 49.55(2), 36.60(2), 21.72(2); **IR**: $\nu_{\max}$ 2915, 1343, 1163 cm⁻¹; **HRMS m/z (ESI)**: calc. for C₂₆H₂₈N₂O₄S₂Na [M⁺+Na] 519.1388, found 519.1384.

Colorless oil: ^1H NMR (300 MHz, CDCl_3) δ 8.28 (dt, $J = 8.8, 2.0$ Hz, 2H), 8.17 (dt, $J = 8.8, 2.0$ Hz, 2H), 5.61 (ddt, $J = 16.9, 10.0, 7.4$ Hz, 1H), 5.22-5.11 (m, 2H), 4.21 (q, $J = 7.2$ Hz, 4H), 2.90 (s, 2H), 2.78 (d, $J = 7.4$ Hz, 2H), 1.83 (s, 6H), 1.25 (t, $J = 7.2$ Hz, 6H); ^{13}C NMR (75 MHz, CDCl_3) δ 169.60(2), 162.91, 150.73, 136.29, 131.70, 130.95(2), 123.65(2), 120.29, 76.00, 74.08(2), 70.08, 67.30, 62.02(2), 56.87, 36.85, 28.98(2), 23.76, 14.23(2); IR (neat): $\nu_{\text{max}} = 2985, 2256, 1733, 1278$ cm^{-1} ; HRMS m/z (ESI): calc. for $\text{C}_{25}\text{H}_{27}\text{NO}_8\text{Na}$ [$\text{M}^+ + \text{Na}$] 492.1634, found 492.1049.

Colorless oil: ^1H NMR (300 MHz, CDCl_3) δ 8.29 (dt, $J = 8.9, 2.1$ Hz, 2H), 8.18 (dt, $J = 8.9, 2.1$ Hz, 2H), 5.88 (ddt, $J = 17.0, 10.5, 5.8$ Hz, 1H), 5.31 (ddt, $J = 17.0, 1.6, 1.2$ Hz, 1H), 5.22 (ddt, $J = 10.5, 1.6, 1.2$ Hz, 1H), 4.23 (s, 2H), 4.06 (dt, $J = 5.8, 1.2$ Hz, 2H), 1.85 (s, 6H); ^{13}C NMR (75 MHz, CDCl_3) δ 162.92, 150.75, 136.16, 133.84, 130.95(2), 123.67(2), 118.32, 78.58, 77.44, 73.91, 70.99, 70.23, 69.55, 57.73, 28.91(2); HRMS m/z (EI): calc. for $\text{C}_{18}\text{H}_{17}\text{NO}_5$ [M^+] 327.1107, found 327.1093.

Colorless oil: ^1H NMR (300 MHz, CDCl_3) δ 5.78 (ddt, $J = 16.8, 10.1, 6.7$ Hz, 2H), 5.39 (t, $J = 6.7$ Hz, 2H), 5.10-4.99 (m, 4H), 2.20 (dt, $J = 7.9, 6.7$ Hz, 4H), 2.08 (s, 6H), 1.92-1.84 (m, 4H); ^{13}C NMR (75 MHz, CDCl_3) δ 169.91(2), 136.76(2), 116.08(2), 77.03(2), 69.61(2), 63.73(2), 33.78(2), 29.26(2), 21.04(2); IR (neat): $\nu_{\text{max}} = 2937, 2166, 1747, 1227$ cm^{-1} ; HRMS m/z (ESI): calc. for $\text{C}_{18}\text{H}_{22}\text{O}_4\text{Na}$ [$\text{M}^+ + \text{Na}$] 325.1416, found 325.1422.

Colorless oil: ^1H NMR (300 MHz, CDCl_3) δ 5.85-5.71 (m, 1H), 5.68-5.54 (m, 1H), 5.39 (t, $J = 6.5$ Hz, 1H), 5.22-4.99 (m, 4H), 4.21 (q, $J = 7.2$ Hz, 4H), 2.89 (s, 2H), 2.78 (d, $J = 7.4$ Hz, 2H), 2.19 (q, $J = 6.8$ Hz, 2H), 2.08 (s, 3H), 1.90-1.82 (m, 2H), 1.26 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 169.89, 169.58(2), 136.85, 131.71, 120.28, 115.93, 76.22, 73.60, 70.34, 67.32, 63.78, 62.01(2), 56.87, 36.85, 33.90, 29.27, 23.70, 21.06, 14.23(2); IR (neat): $\nu_{\text{max}} = 2983, 2260, 1737, 1218$ cm^{-1} ; HRMS m/z (EI): calc. for $\text{C}_{22}\text{H}_{28}\text{O}_6$ [M^+] 388.1886, found 388.1868.

Colorless oil: ^1H NMR (300 MHz, CDCl_3) δ 5.78 (ddt, J = 16.9, 10.1, 6.7 Hz, 1H), 5.46 (q, J = 6.9 Hz, 1H), 5.39 (t, J = 6.9 Hz, 1H), 5.10-4.99 (m, 2H), 2.20 (td, J = 7.3, 6.7 Hz, 2H), 2.08 (s, 3H), 2.07 (s, 3H), 1.91-1.83 (m, 2H), 1.50 (d, J = 6.9 Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 169.86, 169.84, 136.74, 116.04, 77.95, 77.08, 69.55, 68.78, 63.69, 60.45, 33.75, 29.22, 33.75, 29.22, 21.08, 21.06, 21.01; HRMS m/z (ESI): calc. for $\text{C}_{15}\text{H}_{18}\text{O}_4\text{Na}$ [$\text{M}^+ + \text{Na}$] 285.1103, found 285.1097.

Colorless oil: ^1H NMR (300 MHz, CDCl_3) δ 5.76 (ddt, J = 16.9, 10.1, 6.6 Hz, 1H), 5.48 (q, J = 6.8 Hz, 1H), 5.14-5.03 (m, 2H), 4.53 (t, J = 6.8 Hz, 1H), 2.33-2.25 (m, 2H), 2.14-2.06 (m, 2H), 2.08 (s, 3H), 1.51 (d, J = 6.8 Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 169.83, 136.01, 116.70, 79.64, 77.75, 70.88, 68.70, 60.48, 38.40, 35.51, 31.44, 21.07(2); IR (neat): ν_{max} = 2938, 2163, 1746, 1228 cm^{-1} ; HRMS m/z (ESI): calc. for $\text{C}_{13}\text{H}_{15}\text{BrO}_2\text{Na}$ [$\text{M}^+ + \text{Na}$] 305.0153, found 305.0158.

General procedures for PtCl_2 -catalyzed reactions

PtCl_2 (5 mol %) was added to a solution of the diyne in toluene (0.03 M), and CO was bubbled through the solution. The mixture was warmed to 80 $^\circ\text{C}$ and stirred until the reaction was complete (2~15 hrs). The mixture was cooled to room temperature and the solvent was evaporated under vacuum. Purification by flash chromatography on silica gel (hexanes/ethyl ether) afforded the product.

Colorless oil (88% yield, Crude $Z:E$ = 2.5:1, after column $Z:E$ = 1:3.3): ^1H NMR (300 MHz, CDCl_3) E -isomer δ 5.63 (q, J = 7.2 Hz, 1H), 4.15 (q, J = 7.1 Hz, 4H), 2.83 (d, J = 13.8 Hz, 1H), 2.63-2.52 (m, 3H), 2.14 (s, 3H), 1.81 (d, J = 7.2 Hz, 3H), 1.80-1.72 (m, 1H), 1.27-1.20 (m, 6H), 1.01-0.93 (m, 1H), 0.67 (dd, J = 5.4, 5.4 Hz, 1H); Z -isomer δ 5.65 (q, J = 7.2 Hz, 1H), 4.15 (q, J = 7.1 Hz, 4H), 2.80 (d, J = 13.8 Hz, 1H), 2.63-2.52 (m, 3H), 2.19 (s, 3H), 1.60 (d, J = 7.2 Hz, 3H), 1.80-1.72 (m, 1H), 1.27-1.20 (m, 6H), 1.01-0.93 (m, 1H), 0.62 (dd, J = 5.4, 5.4 Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3) E -isomer δ 172.51, 171.23, 169.34, 131.14, 123.10, 98.25, 70.27, 62.15, 61.99, 59.71, 39.99, 35.73, 28.47, 21.08, 19.20, 18.92, 14.19(2), 13.60; Z -isomer δ 172.51, 171.23, 169.34, 130.86, 122.80, 98.25, 69.89, 62.15, 61.99, 59.71, 39.94, 35.73, 28.24, 20.84, 18.92, 18.71, 14.19(2), 11.78; IR (neat): ν_{max} = 2921, 2219, 1731, 1445, 1367, 1250 cm^{-1} ; HRMS m/z (EI): calc. for $\text{C}_{19}\text{H}_{24}\text{O}_6$ [M^+] 348.1573, found

348.1580.

Colorless oil (92% yield, *Z:E*=6.5:1): **¹H NMR (300 MHz, CDCl₃)** *Z*- isomer δ 7.42-7.22 (m, 5H), 6.39 (s, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 4.16 (q, *J* = 7.1 Hz, 2H), 2.84 (d, *J* = 13.6 Hz, 1H), 2.64-2.57 (m, 3H), 2.24 (s, 3H), 1.85-1.78 (m, 1H), 1.25 (t, *J* = 7.1 Hz, 3H), 1.23 (t, *J* = 7.1 Hz, 3H), 1.02 (dd, *J*=8.4, 5.8 Hz, 1H), 0.68 (dd, *J* = 5.8, 5.8 Hz, 1H); **¹³C NMR (75 MHz, CDCl₃)** *Z*- isomer δ 172.41, 171.11, 167.97, 133.79, 129.91, 128.97(2), 128.67(2), 128.40, 128.25, 125.01, 94.90, 73.53, 62.08, 61.93, 59.63, 39.83, 35.66, 28.48, 21.19, 19.09, 18.84, 14.13; **IR (neat):** ν_{max} = 2982, 2214, 1730, 1196 cm⁻¹; **HRMS *m/z* (EI):** calc. for C₂₄H₂₆O₆[M⁺] 410.1729, found 410.1718.

Colorless oil (87% yield, *Z:E*=2.7:1 after column *Z:E* =1.1:1): **¹H NMR (300 MHz, CDCl₃)** *Z*- isomer δ 5.69 (q, *J* = 7.2 Hz, 1H), 3.86 (d, *J* = 8.1 Hz, 1H), 3.79 (m, 2H), 3.69 (d, *J* = 8.1 Hz, 1H), 2.20 (s, 3H), 1.97-1.89 (m, 1H), 1.61 (d, *J* = 7.2 Hz, 3H), 1.11-1.05 (m, 1H), 0.94 (dd, *J* = 4.9, 4.9 Hz, 1H); *E*- isomer δ 5.67 (q, *J* = 7.2 Hz, 1H), 3.90 (d, *J* = 8.1 Hz, 1H), 3.81(m, 2H), 3.72 (d, *J* = 8.1 Hz, 1H), 2.15 (s, 3H), 1.97-1.89 (m, 1H), 1.83 (d, *J* = 7.2 Hz, 3H), 1.11-1.05 (m, 1H), 0.98 (dd, *J* = 4.9, 4.9 Hz, 1H); **¹³C NMR (75 MHz, CDCl₃)** *Z*-isomer δ 168.30, 130.64, 123.24, 88.96, 73.88, 71.66, 69.46, 27.75, 20.73, 18.64, 15.85, 11.72; *E*-isomer δ 169.22, 130.91, 123.51, 88.96, 73.88, 71.66, 69.46, 27.99, 20.97, 18.85, 16.06, 13.54; **IR (neat):** ν_{max} = 2932, 2869, 2215, 1714, 1587, 1202, 1086, 911 cm⁻¹; **HRMS *m/z* (EI):** calc. for C₁₂H₁₄O₃ [M⁺] 206.0943, found 206.0946.

Colorless oil (82% yield, *Z:E*=4.7:1): **¹H NMR (300 MHz, CDCl₃)** *Z*- isomer δ 7.66 (d, *J* = 8.0 Hz, 2H), 7.34 (d, *J* = 8.0 Hz, 2H), 5.65 (q, *J* = 7.2 Hz, 1H), 3.64 (d, *J* = 9.2 Hz, 1H), 3.52 (d, *J* = 9.2 Hz, 1H), 3.09 (dd, *J* = 9.2, 3.8 Hz, 1H), 3.02 (d, *J* = 9.2 Hz, 1H), 2.45 (s, 3H), 2.16 (s, 3H), 1.80-1.74 (m, 1H), 1.58 (d, *J* = 7.2 Hz, 3H), 1.11-1.02 (m, 2H); **¹³C NMR (75 MHz, CDCl₃)** *Z*- isomer δ 168.26, 143.95, 133.22, 130.30, 129.92(2), 127.72(2), 123.79, 88.60, 74.04, 52.24, 49.42, 26.19, 21.66, 20.69, 17.58, 16.79, 11.71; **IR (neat):** ν_{max} = 2933, 2216, 1761, 1167 cm⁻¹; **HRMS *m/z* (ESI):** calc. for C₁₉H₂₁NO₄Na [M⁺+Na] 382.1089, found 382.1093.

Colorless oil (98% yield): **¹H NMR (300 MHz, CDCl₃)** δ 8.35-8.28 (m, 4H), 4.17 (q, *J* = 7.1 Hz, 2H), 4.14 (q, *J* = 7.1 Hz, 2H), 2.82 (d, *J* = 13.5 Hz, 1H), 2.61-2.55 (m, 3H), 1.98 (s, 3H), 1.80-1.74 (m, 1H), 1.71 (s, 3H), 1.24 (t, *J* = 7.1 Hz, 3H), 1.21 (t, *J* = 7.1 Hz, 3H), 1.00-0.95 (m, 1H), 0.65 (dd, *J* = 5.4, 5.4 Hz, 1H); **¹³C NMR (75 MHz, CDCl₃)** δ 172.45,

171.20, 162.59, 150.96, 135.17, 132.53, 131.40(2), 125.88, 123.79(2), 97.19, 70.91, 62.08, 61.93, 59.64, 40.02, 35.67, 28.37, 20.80, 19.14, 18.91, 17.80, 14.13(2); **IR (neat):** ν_{max} = 2983, 2218, 1732, 1531, 1259, 1115 cm⁻¹; **HRMS *m/z* (ESI):** calc. for C₂₅H₂₇NO₈Na [M⁺+Na] 492.1634, found 492.1620.

Colorless oil (90% yield): **¹H NMR (300 MHz, CDCl₃)** δ 8.35-8.28 (m, 4H), 3.89 (d, *J* = 7.8 Hz, 1H), 3.81-3.80 (m, 2H), 3.71 (dd, *J* = 7.8, 0.3 Hz, 1H), 1.99 (s, 3H), 1.95-1.90 (m, 1H), 1.73 (s, 3H), 1.09 (dd, *J* = 8.1, 4.8 Hz, 1H), 0.96 (dd, *J* = 4.8, 4.8 Hz, 1H); **¹³C NMR (75 MHz, CDCl₃)** δ 162.61, 151.02, 135.09, 133.18, 131.41(2), 125.75, 123.84, 93.80, 72.35, 71.81, 69.52, 27.98, 20.85,

18.92, 17.86, 16.10; **IR (neat):** ν_{max} = 2860, 2220, 1742, 1530, 1267, 1116 cm⁻¹; **HRMS *m/z* (EI):** calc. for C₁₈H₁₇NO₅ [M⁺] 327.1107, found 327.1093.

Colorless oil (96% yield): **¹H NMR (300 MHz, CDCl₃)** δ 4.17 (q, *J* = 7.2 Hz, 4H), 4.14 (q, *J* = 7.2 Hz, 4H), 2.75 (d, *J* = 13.6 Hz, 2H), 2.54-2.48 (m, 6H), 1.64-1.58 (m, 2H), 1.23 (t, *J* = 7.2 Hz, 6H), 1.22 (t, *J* = 7.2 Hz, 6H), 0.82 (dd, *J* = 8.5, 5.5 Hz, 2H), 0.51 (dd, *J* = 5.5, 5.1 Hz, 2H); **¹³C NMR (75 MHz, CDCl₃)** δ 172.62(2), 171.42(2), 80.60(2), 62.02(2), 61.86(2), 59.63(2), 40.61(2), 35.76(2), 27.51(2), 18.66(2), 18.43(2), 14.20(2), 14.17(2); **IR (neat):** ν_{max} =

2982, 2080, 1729, 1249 cm⁻¹; **HRMS *m/z* (ESI):** calc. for C₂₆H₃₄O₈ Na [M⁺+Na] 497.2151, found 497.2142.

Colorless oil (6.3% yield): **¹H NMR (300 MHz, CDCl₃)** δ 3.83 (d, *J* = 7.8 Hz, 2H), 3.79-3.78 (m, 4H), 3.66 (d, *J* = 7.8 Hz, 2H), 1.82-1.77 (m, 2H), 0.97 (dd, *J* = 8.0, 4.8 Hz, 2H), 0.85 (dd, *J* = 4.8, 4.8 Hz, 2H); **¹³C NMR (75 MHz, CDCl₃)** δ 78.72(2), 72.27(2),

69.62(2), 27.20(2), 18.68(2), 15.62(2); **IR (neat):** $\nu_{\max}$ = 2924, 2854, 2230, 1017 cm^{-1} ; **HRMS m/z (EI):** calc. for $\text{C}_{12}\text{H}_{14}\text{O}_2$ [M^+] 190.0994, found 190.0997.

Colorless oil (25% yield, 1:1 mixture of diastereomers): **^1H NMR (300 MHz, CDCl_3)** major δ 3.99 (dd, J = 4.1, 1.6 Hz, 2H), 3.94-3.80 (m, 6H), 1.56-1.54 (m, 2H), 1.11 (s, 12H); **minor** δ 4.02 (dd, J = 4.1, 1.6 Hz, 2H), 3.94-3.80 (m, 6H), 1.56-1.54 (m, 2H), 1.20 (s, 12H); **^{13}C NMR (75 MHz, CDCl_3)** major δ 79.25(2), 71.78(2), 68.54(2), 38.47(2), 29.68(2), 25.43(2), 24.57(2), 13.25(2); **minor** δ 79.32(2), 71.84(2), 68.54(2), 38.57(2), 29.92(2), 25.62(2), 24.66(2), 13.29(2); **IR (neat):** $\nu_{\max}$ = 2921, 2865, 2233, 1081 cm^{-1} ; **HRMS m/z (EI):** calc. for $\text{C}_{16}\text{H}_{22}\text{O}_2$ [M^+] 246.1620, found 246.1624.

Colorless oil (23% yield, 1.1:1 mixture of diastereomers): **^1H NMR (300 MHz, CDCl_3)** major δ 6.19 (d, J = 6.0 Hz, 2H), 5.27 (d, J = 6.0 Hz, 2H), 4.07 (dd, J = 10.5, 1.2 Hz, 2H), 3.72 (dd, J = 10.5, 2.0 Hz, 2H), 1.26-1.22 (m, 2H), 0.85-0.71 (m, 4H); **minor** δ 6.18 (d, J = 6.0 Hz, 2H), 5.24 (d, J = 6.0 Hz, 2H), 4.10 (dd, J = 10.5, 1.2 Hz, 2H), 3.79 (dd, J = 10.5, 2.0 Hz, 2H), 1.37-1.32 (m, 2H), 0.85-0.71 (m, 4H); **^{13}C NMR (75 MHz, CDCl_3)** major δ 141.77(2), 108.91(2), 62.59(2), 22.76(2), 19.98(2), 17.14(2); **minor** δ 141.59(2), 109.28(2), 62.65(2), 22.92(2), 19.92(2), 17.00(2); **IR (neat):** $\nu_{\max}$ = 2865, 1639, 1232, 1018 cm^{-1} ; **HRMS m/z (EI):** calc. for $\text{C}_{12}\text{H}_{14}\text{O}_2$ [M^+] 190.0994, found 190.0994.

White solid (63% yield, 1.3:1 mixture of diastereomers): **^1H NMR (300 MHz, CDCl_3)** major δ 7.62 (d, J = 8.5 Hz, 4H), 7.30 (d, J = 8.5 Hz, 4H), 6.35 (d, J = 8.2 Hz, 2H), 5.29 (d, J = 8.2 Hz, 2H), 3.81 (d, J = 11.6 Hz, 2H), 2.88 (dd, J = 11.6, 2.6 Hz, 2H), 2.42 (s, 6H), 1.22-1.16 (m, 2H), 0.58 (dd, J = 9.0, 4.8 Hz, 2H), 0.40 (dd, J = 5.2, 4.8 Hz, 2H); **minor** δ 7.62 (d, J = 8.5 Hz, 4H), 7.30 (d, J = 8.5 Hz, 4H), 6.33 (d, J = 8.2 Hz, 2H), 5.20 (d, J = 8.2 Hz, 2H), 3.87 (d, J = 11.6 Hz, 2H), 2.96 (dd, J = 11.6, 2.6 Hz, 2H), 2.42 (s, 6H), 1.22-1.16 (m, 2H), 0.48 (dd, J = 9.0, 4.8 Hz, 2H), 0.31 (dd, J = 5.2, 4.8 Hz, 2H); **^{13}C NMR (75 MHz, CDCl_3)** major δ 143.98(2), 135.11(2), 129.99(4), 127.23(4), 121.86(2), 114.25(2), 41.05(2), 29.91(2), 23.76(2), 21.75(2), 17.61(2); **minor** δ 143.98(2), 135.11(2), 129.99(4), 127.23(4), 121.74(2), 114.64(2), 41.14(2), 24.13(2), 21.75(2), 21.28(2), 17.16(2); **HRMS m/z (ESI):** calc. for $\text{C}_{26}\text{H}_{28}\text{N}_2\text{O}_4\text{S}_2\text{Na}$ [$\text{M}^+ + \text{Na}$] 519.1388, found 519.1375.

Colorless oil (80% yield): **¹H NMR (300 MHz, CDCl₃) (mixture of stereoisomers)** δ 5.88-5.73 (m, 1H), 5.64-5.71 (m, 1H), 5.43-5.30 (m, 1H), 5.09-4.97 (m, 2H), 2.36-2.29 (m, 1H), 2.19-2.09 (m, 3H), 2.18, 2.13, 2.08, 2.07 (s, 6H), 2.02-1.89 (m, 1H), 1.82-1.72 (m, 2H), 1.25-1.01 (m, 4H); **¹³C NMR (75 MHz, CDCl₃) (mixture of stereoisomers)** δ 171.40, 171.26, 171.18, 169.15, 168.45, 137.77, 137.62, 130.74, 130.19, 127.50, 127.34, 115.57, 115.47, 96.89, 91.40, 80.30, 79.47, 73.33, 73.11, 71.16, 33.11, 32.60, 29.81, 28.37, 28.22, 27.42, 26.48, 26.38, 25.73, 24.82, 21.77, 21.55, 21.38, 21.32, 21.08, 20.87, 15.34, 15.17; **IR (neat):** ν_{max} = 2920, 2221, 1763, 1739, 1371, 1238 cm⁻¹; **HRMS m/z (EI):** calc. for C₁₈H₂₂O₄ [M⁺] 302.1518, found 302.1531.

Colorless oil (67% yield): **¹H NMR (300 MHz, CDCl₃)** δ 5.89-5.59 (m, 1H), 5.59 (t, *J* = 7.7 Hz, 1H), 5.09-4.97 (m, 2H), 4.16 (q, *J* = 7.2 Hz, 2H), 4.15 (q, *J* = 7.2 Hz, 2H), 2.83 (d, *J* = 13.8 Hz, 1H), 2.61-2.54 (m, 3H), 2.37-2.27 (m, 1H), 2.31 (d, *J* = 13.8 Hz, 1H), 2.21-2.09 (m, 2H), 2.14 (s, 3H), 1.87-1.74 (m, 1H), 1.24 (t, *J* = 7.2 Hz, 3H), 1.23 (t, *J* = 7.2 Hz, 3H), 1.00-0.93 (m, 1H), 0.66 (dd, *J* = 5.3, 5.3 Hz, 1H); **IR (neat):** ν_{max} = 2981, 2220, 1732, 1250, 1199 cm⁻¹; **HRMS m/z (EI):** calc. for C₂₂H₂₈O₆ [M⁺] 388.1886, found 388.1868.

Colorless oil (33% yield, *Z:E* = 3.5:1): **¹H NMR (300 MHz, CDCl₃)** δ 5.86-5.74 (m, 1H), 5.78 (q, *J* = 7.2 Hz, 1H), 5.78 (t, *J* = 7.2 Hz, 1H), 5.10-4.98 (m, 2H), 2.42-2.13 (m, 4H), 2.19 (s, 3H), 2.15 (s, 3H), 1.85 (d, *J* = 7.2 Hz, 3H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.10, 168.16, 137.38, 130.46, 129.68, 129.56, 125.84, 115.78, 88.39, 81.00, 32.54, 25.84, 20.95, 20.79, 13.70; **IR (neat):** ν_{max} = 2920, 2033, 1765, 1188 cm⁻¹; **HRMS m/z (EI):** calc. for C₁₅H₁₈O₄ [M⁺] 262.1205, found 262.1215.

Colorless oil (57% yield, *Z:E* = 2.2:1): **¹H NMR (300 MHz, CDCl₃)** δ 5.64 (q, *J* = 7.2 Hz, 1H), 5.41 (dd, *J* = 8.3, 8.3 Hz, 1H), 2.22-2.12 (m, 2H), 2.14 (s, 3H), 2.08 (s, 3H), 2.02-1.91 (m, 1H), 1.84-1.74 (m, 2H), 1.81 (d, *J* = 7.2 Hz, 3H), 1.22 (dd, *J* = 5.3, 5.3 Hz, 1H), 1.06 (dd, *J* = 8.3, 5.3 Hz, 1H); **¹³C NMR (75 MHz, CDCl₃)** δ 171.22, 169.29, 131.10, 123.20, 97.00, 79.39, 71.03, 28.36, 26.43, 24.83, 21.79, 21.33, 21.06, 15.36, 13.54; **IR (neat):** ν_{max} = 2921, 2219, 1761, 1738, 1237 cm⁻¹; **HRMS m/z (ESI):** calc. for C₁₅H₁₈O₄Na [M⁺+Na] 285.1103, found 285.1109.

Colorless oil (50% yield): **¹H NMR (300 MHz, CDCl₃)** δ 5.68 (q, *J* = 7.2 Hz, 1H), 4.55 (dd, *J* = 9.7, 8.0 Hz, 1H), 2.32-2.19 (m, 2H), 2.14 (s, 3H), 2.03-1.95 (m, 2H), 1.85 (d, *J* = 7.2 Hz, 3H), 1.69-1.62 (m, 1H), 1.18-1.08 (m, 2H); **¹³C NMR (75 MHz, CDCl₃)** δ 169.31, 131.01, 123.72, 96.09, 72.04, 55.77, 32.50, 32.45, 26.73, 24.91, 21.07, 17.66, 13.69; **IR (neat):** ν_{max} = 2937, 2212, 1743, 1218 cm⁻¹;

HRMS *m/z* (ESI): calc. for C₁₃H₁₅BrO₂Na [*M*⁺+Na] 305.0153, found 305.0158.

NMR spectra of **13a**

NMR spectra of **13b**

NMR spectra of **13c**

NMR spectra of **13d**

NMR spectra of **13e**

NMR spectra of **13f**

NMR spectra of **14a**
(mixture of *Z/E*-isomers)

NMR spectra of **14b**
(mixture of *Z/E*- isomers)

NMR spectra of **14c**

(mixture of *Z/E*- isomers- **crude**; Purification attempt has led to a change of *Z/E* ratio and the hydrolysis of acetate)

NMR spectra of **14d**

(mixture of *Z/E*- isomers- **crude**; Purification attempt has led to a change of *Z/E* ratio and the hydrolysis of acetate)

NMR spectra of **14e**

NMR spectra of **14f**

NMR spectra of **15a**

NMR spectra of **15b**

NMR spectra of **15c**

NMR spectra of **15d**

NMR spectra of **16a**

NMR spectra of **16b**

NMR spectra of **16c**
(mixture of diastereomers)

NMR spectra of **17b**
(mixture of diastereomers)

NMR spectra of **18a**

NMR spectra of **18b**

NMR spectra of **18c**

NMR spectra of **18d**

NMR spectra of **19a**
(mixture of stereoisomers)

NMR spectra of **19b**
(mixture of *Z/E*- isomers)

NMR spectra of **19c**
(mixture of *Z/E*- isomers)

NMR spectra of **19c'**
(mixture of stereoisomers)

NMR spectra of **19d**
(mixture of stereoisomers)