Lewis Base Activation of Lewis Acids. Vinylogous Aldol Reactions

Scott E. Denmark* and Gregory L. Beutner

*Roger Adams Laboratory, Department of Chemistry, University of Illinois
Urbana, Illinois 61801***SUPPORTING INFORMATION****General Experimental**

All reactions were performed in oven-dried (140 °C) or flame-dried glassware under an atmosphere of dry N₂. The following reaction solvents were distilled from the indicated drying agents: dichloromethane (P₂O₅), benzene (Fisher ACS grade), hexanes (Fisher ACS grade), pentane (Fisher, ACS grade), acetonitrile (Fisher, ACS grade), tetrahydrofuran (Na, benzophenone) and diethyl ether (Na, benzophenone). Solvents for chromatography and filtration were technical grade and distilled from the indicated drying agents: hexane (CaCl₂), ethyl acetate (K₂CO₃), dichloromethane (CaCl₂). Column chromatography was performed using EM Science 230-400-mesh silica gel. Benzaldehyde (**1a**), (*E*)-cinnamaldehyde (**1b**), hydrocinnamaldehyde (**1c**) and 2,2,6-Trimethyl-1,3-dioxin-4-one (Lancaster) were freshly distilled before use. 1-(*tert*-butyldimethylsilyloxy)-1-methoxyethene (**1**) (Aldrich), methyl [(1-Methoxy-2-methyl-1-propenyl)oxy]trimethylsilane (**12**) and *tert*-butyl dimethylsilyl chloride (TBSCl, Aldrich), ethyl 3,3-dimethyl acrylate (Aldrich), methyl tiglate (Lancaster), ethyl crotonate (Aldrich) and (*E*)-2-pentenoic acid (Lancaster) were used without further purification. Silicon tetrachloride (Gelest) was heated at reflux for 24 h and then distilled prior to use. HMPA was distilled and then stored over 3Å molecular sieves prior to use. Diisopropylamine, diisopropylethylamine (DIPEA) and pyridine were freshly distilled from CaH₂ prior to use. All reaction temperatures correspond to bath temperatures unless otherwise noted. Internal temperatures were measured by Teflon-coated thermocouples during optimization studies.

¹H NMR, ¹³C NMR and low temperature spectra were recorded on a Varian Unity 400 (400 MHz, ¹H; 100 MHz, ¹³C), Unity 500 (500 MHz, ¹H; 126 MHz, ¹³C) spectrometers. Spectra were referenced to residual chloroform (7.26 ppm, ¹H, 77.23 ppm, ¹³C). Chemical shifts are reported in ppm, multiplicities are indicated by s (singlet), d (doublet), t (triplet), q (quartet), p (pentet) h (hextet) m (multiplet) and br (broad). Coupling constants, *J*, are reported in Hertz. Mass spectroscopy was performed by the University of Illinois Mass Spectrometer Center. EI

and CI mass spectra were performed on a 70-VSE spectrometer. Data are reported in the form of (m/z). Infrared spectra (IR) were recorded on a Mattson Galaxy 5020 spectrophotometer in NaCl cells. Peaks are reported in cm^{-1} with indicated relative intensities: s (strong, 67-100%); m (medium, 34-66%); w (weak, 0-33%). Elemental analyses were performed by the University of Illinois Microanalytical Service Laboratory. Melting points (mp) were determined on a Thomas-Hoover capillary melting point apparatus in sealed tubes and are corrected. Kugelrohr distillations were performed on a Büchi GKR-50 Kugelrohr and temperatures reported are air bath temperatures. Analytical thin-layer chromatography was performed on Merck silica gel plates with QF-254 indicator. Visualization was accomplished with UV(254), potassium permanganate (KMnO_4) and p-anisaldehyde.

Optical rotation data was obtained on a JASCO DIP-360 digital polarimeter and are reported as follows: concentration ($c = \text{g}/100 \text{ mL}$), and solvent. Chiral stationary phase, supercritical fluid chromatography (CSP-SFC) was performed on a Berger Instruments packed-column SFC with built-in photometric detector (220 nm) using Daicel Chiralpak OD, OJ, AD, AS, OB columns and a Regis Whelk-O1 column. All retention times (t_R) are reported in min.

Ozonolyses were performed with a Welsbach Model T-816 Ozonator set at 55 W / 90 V with a 1 slpm flow rate.

Literature Preparations.

(*R,R*)-*N,N'*-Bis[4,5-dihydro-3,5-dimethyl-4-(3H-dinaphtho[2,1-d:1',2'-f][1,3,2]-2-oxo-diazaphosphepino)]-*N,N'*-dimethyl-1,5-pentanediamine ((*R,R*)-**5**)¹ and (*E*)-[(1-methoxy)-propenyloxy]-*tert*-butyldimethylsilane (**10**)² were prepared according to established procedures.

Experimental Procedures.

General Procedure 1. Enolization of Alkenoates to Silyl Dienol Ethers.

Preparation of (Z)-tert-Butyl-(1-ethoxy-1,3-butadienyloxy)dimethylsilane ((Z)-3a)

To a flame-dried, 100 mL, 3-neck round-bottom flask was added 1.54 mL of diisopropylamine (11 mmol, 1.1 equiv) and 11 mL of THF. The solution was cooled to 0 °C in an ice-water bath and then 7.1 mL of *n*-BuLi (1.55 M in hexane, 11 mmol, 1.1 equiv) was added slowly over 5 min. The resulting solution was stirred for 30 min prior to cooling to –78 °C in a dry ice/isopropanol bath. To this solution was added 2.1 mL of HMPA (12 mmol, 1.2 equiv). The solution was stirred for 30 min at –78 °C and a white precipitate formed. Then, 1.24 mL of ethyl crotonate (10 mmol, 1.0 equiv.) was added slowly over 5 min. The resulting solution was stirred for 30 min at –78 °C prior to slow addition of 1.65 g of TBSCl (11.6 mmol, 1.2 equiv) in 6 mL of THF via cannula. The dry ice/isopropanol bath was then removed and the solution was allowed to stir for 1 h at room temperature. The yellow solution was diluted with cold pentane (50 mL) and washed with cold H₂O (3 x 50 mL). The organic layer was dried over Na₂SO₄ (10 g), filtered through a pad of Celite and the filtrate was concentrated *in vacuo*. The residue was purified by short path distillation to yield 1.63 g (71 %, 86/14 *Z/E*) of **3a** as a colorless oil.

Data for (Z)-**3a**:

bp: 70 °C (1 mm Hg)

¹H NMR: (500 MHz, CDCl₃)

6.53 (dt, *J* = 17.1, 10.5, 1 H, HC(3)), 4.81 (dd, *J* = 17.5, 1.9, 1 H, HC(4)), 4.57 (dd, *J* = 10.7, 1.5, 1 H, HC(4)), 4.43 (d, *J* = 10.5, 1 H, HC(2)), 3.79 (q, *J* = 7.1, 2 H, HC(5)), 1.30 (t, *J* = 7.1, 3 H, H₃C(6)), 0.95 (s, 9 H, H₃C(9)), 0.19 (s, 6 H, H₃C(7))

NOE ^1H NMR: (500 MHz, CDCl_3)

Irradiation at 3.79 ppm (HC(5)) enhanced signal at 4.43 ppm (HC(2)) in major isomer

^{13}C NMR: (100 MHz, CDCl_3)

157.73 (C(1)), 132.58 (C(3)), 106.26 (C(4)), 80.52 (C(5)), 63.26 (C(2)), 25.69 (C(9)), 25.52 (C(6)), 14.35 (C(8)), -4.15 (C(7))

IR: (neat)

3085 (w), 2958 (m), 2933 (m), 2888 (m), 2859 (m), 1648 (s), 1602 (w), 1473 (w), 1425 (m), 1369 (m), 1334 (m), 1255 (m), 1214 (s), 1176 (m), 1079 (m), 1025 (m)

MS: (CI, 70 eV)

229 (M^+ , 27), 205 (26), 187 (36), 171 (36), 147 (30), 115 (52), 75 (100)

HRMS: calcd for $\text{C}_{12}\text{H}_{24}\text{O}_2\text{Si}$: 229.1623, found: 229.1249

***tert*-Butyl-(1-methoxy-2-methyl-1,3-butadienyloxy)dimethylsilane ((*Z*)-**3b**)**

Following General Procedure 1, 1.54 mL of diisopropylamine (11 mmol, 1.1 equiv) was combined with 7.1 mL of *n*-BuLi (1.55 M in hexane, 11 mmol, 1.1 equiv), 2.1 mL of HMPA (12 mmol, 1.2 equiv), 1.2 mL of methyl tiglate (10 mmol, 1.0 equiv.) and 1.65 g of TBSCl (11.6 mmol, 1.2 equiv) to yield, after short path distillation, 1.48 g (65 %, 58:42 *Z/E*) of **3b**³ as a colorless oil.

Data for (Z)-3b:bp: 66 °C (1 mm Hg)¹H NMR: (500 MHz, CDCl₃)6.76 (dd, *J* = 17.6, 11.0, 1 H, HC(3)), 4.85 (dd, *J* = 17.6, 1.5, 1 H, HC(4)), 4.78 (dd, *J* = 10.5, 1.5, 1 H, HC(4)), 3.58 (s, 3 H H₃C(5)), 1.63 (s, 3 H, H₃C(6)), 0.97 (s, 9 H, H₃C(9)), 0.18 (s, 6 H, H₃C(7))¹³C NMR: (100 MHz, CDCl₃)

153.20 (C(1)), 134.54 (C(3)), 107.55 (C(4)), 97.43 (C(2)), 57.83 (C(5)), 25.62 (C(9)), 18.15 (C(6)), 10.65 (C(8)), -4.49 (C(7))

IR: (neat)

3089 (w), 2958 (s), 2935 (s), 2896 (m), 2859 (s), 1658 (s), 1463 (m), 1440 (m), 1290 (s), 1255 (s), 1209 (s), 1170 (s), 1124 (s), 1043 (m)

MS: (CI, 70 eV)229 (M⁺, 6), 213 (4), 187 (100), 173 (12)HRMS: calcd for C₁₂H₂₄O₂Si: 229.1264, found: 229.1259**(Z)-tert-Butyl-(1-ethoxy-3-methyl-1,3-butadienyloxy)dimethylsilane ((Z)-3c)** **3c**

Following General Procedure 1, 1.54 mL of diisopropylamine (11 mmol, 1.1 equiv) was combined with 7.1 mL of *n*-BuLi (1.55 M in hexane, 11 mmol, 1.1 equiv), 2.1 mL of HMPA (12 mmol, 1.2 equiv), 1.39 mL of ethyl senecioate (10 mmol, 1.0 equiv.) and 1.65 g of TBSCl (11.6 mmol, 1.2 equiv) to yield, after short path distillation, 1.65 g (68 %, >99/1 *Z/E*) of **3c** as a colorless oil.

Data for (Z)-3c:bp: 68 °C (1 mm Hg)¹H NMR: (400 MHz, CDCl₃)4.77 (d, *J* = 2.4, 1 H, HC(4)), 4.51 (d, *J* = 2.4, 1 H, HC(4)), 4.2 (s, 1 H, HC(2)), 3.78 (q, *J* = 6.8, 2 H, H₂C(5)), 1.95 (s, 3 H, H₃C(7)), 1.29 (t, *J* = 7.08, 3 H, H₃C(6)), 0.94 (s, 9 H, H₃C(10)), 0.20 (s, 6 H, H₃C(8))¹³C NMR: (100 MHz, CDCl₃)

156.62 (C(1)), 140.50 (C(3)), 107.02 (C(4)), 80.39 (C(4)), 63.42 (C(2)), 25.85 (C(10)), 23.96 (C(6)), 18.14 (C(7)), 14.37 (C(9)), -3.70 (C(8))

IR: (neat)

3079 (w), 2960 (m), 2931 (s), 2859 (m), 1650 (s), 1606 (w), 1473 (m), 1452 (m), 1349 (m), 1375 (m), 1275 (m), 1195 (s), 1087 (s), 1031 (m)

MS: (CI, 70 eV)243 (M⁺, 41), 201 (73), 185 (46), 147 (38), 127 (29), 103 (70), 75 (100)HRMS: calcd for C₁₃H₂₆O₂Si: 243.1780, found: 243.1403**(1Z,3Z)-[1-(*tert*-Butyloxy)-1,3-pentadienyloxy]-*tert*-butyldimethylsilane ((1Z,3Z)-3d)**

Following General Procedure 1, 1.54 mL of diisopropylamine (11 mmol, 1.1 equiv) was combined with 7.1 mL of *n*-BuLi (1.55 M in hexane, 11 mmol, 1.1 equiv), 2.1 mL of HMPA (12 mmol, 1.2 equiv), 1.55 g of *tert*-butyl 2-pentenoate (10 mmol, 1.0 equiv.) and 1.65 g of TBSCl (11.6 mmol, 1.2 equiv) to yield, after short path distillation, 1.41 g (52 %, 89% 1Z,3Z) of **3d** as a colorless oil.

Data for (1Z,3Z)-3d:

bp: 68 °C (1 mm Hg)

¹H NMR: (500 MHz, CDCl₃)

6.12 (dt, *J* = 1.7, 10.7, 1 H, HC(3)), 5.14 (dq, *J* = 10.2, 6.3, 1 H, HC(4)), 4.87 (d, *J* = 10.8, 1 H, HC(2)), 1.65 (dd, *J* = 6.8, 1.5, 3 H, H₃C(5)), 1.37 (s, 9 H, H₃C(7)), 0.95 (s, 9 H, H₃C(10)), 0.17 (s, 6 H, H₃C(8))

NOE ¹H NMR: (500 MHz, CDCl₃)

Irradiation at 4.87 ppm (HC(2)) enhanced signal at 1.65 ppm (HC(5)) in major isomer

¹³C NMR: (100 MHz, CDCl₃)

153.22 (C(1)), 124.73 (C(3)), 118.08 (C(4)), 88.38 (C(6)), 79.39 (C(2)), 29.09 (C(5)), 28.50 (C(7)), 18.06 (C(10)), 13.25 (C(9)), -4.13 (C(8))

IR: (neat)

2977 (s), 2958 (s), 2931 (s), 2859 (s), 1648 (s), 1610 (s), 1473 (m), 1367 (m), 1319 (m), 1299 (m), 1253 (s), 1201 (m), 1132 (s), 1062 (m)

MS: (EI, 70 eV)

270 (M, 6), 231 (5), 214 (100), 198 (42), 156 (38), 82 (98)

HRMS: calcd for C₁₅H₃₀O₂Si: 270.2015, found: 270.2020

***tert*-Butyl-(2,2-dimethyl-6-methylene-6*H*-[1,3]dioxin-4-yloxy)dimethylsilane (6)**

Following General Procedure 1, 1.54 mL of diisopropylamine (11 mmol, 1.1 equiv) was combined with 7.1 mL of *n*-BuLi (1.55 M in hexane, 11 mmol, 1.1 equiv), 2.1 mL of HMPA (12 mmol, 1.2 equiv), 1.3 mL of dioxanone (10 mmol, 1.0 equiv.) and 1.65 g of TBSCl (11.6 mmol, 1.2 equiv) to yield, after short path distillation, 1.52 g (59 %) of **6** as a colorless oil.

Data for 6:bp: 78 °C (1 mm Hg)¹H NMR: (400 MHz, CDCl₃)4.65 (s, 1 H, HC(2)), 4.05 (s, 1 H, HC(4)), 3.86 (s, 1 H, HC(4)), 1.54 (s, 6 H, HC(6)), 0.93 (s, 9 H, H₃C(9)), 0.20 (s, 6 H, H₃C(7))¹³C NMR: (100 MHz, CDCl₃)

153.54 (C(1)), 151.94 (C(3)), 102.45 (C(5)), 84.67 (C(4)), 76.64 (C(2)), 25.49 (C(9)), 24.50 (C(6)), 18.01 (C(8)), -4.28 (C(7))

IR: (neat)

2996 (m), 2958 (m), 2933 (m), 2888 (w), 2861 (m), 1668 (s), 1633 (m), 1473 (w), 1386 (m), 1375 (m), 1344 (s), 1294 (m), 1261 (s), 1224 (s), 1205 (s), 1126 (m), 1031 (m)

MS: (CI, 70 eV)257 (M⁺, 100), 215 (21), 173 (22), 143 (24), 85 (29)HRMS: calcd for C₁₃H₂₄O₃Si: 257.1573, found: 257.1575**General Procedure 2. Addition of Silyl Dienol Ethers to Conjugated Aldehydes.****Preparation of (2*E*,5*R*) 5-Hydroxy-5-phenyl-2-pentenoic Acid Ethyl Ester ((2*E*,5*R*)-4aa)**

A flame-dried, 25 mL, 2-neck flask containing a solution of 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) and 102 μ L of benzaldehyde **1a** (1.0 mmol, 1.0 equiv) in CH₂Cl₂ (5 mL) was cooled to -78 °C under nitrogen. To the resulting solution was added 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv). Then 272 mg of **3a** (1.2 mmol, 1.2 equiv) was added dropwise over 5 min to the reaction mixture. The solution was allowed to stir at -78 °C (bath temperature) for 3 h whereupon the cold reaction mixture was poured into a rapidly stirring 1/1 sat. aq. KF/1.0

M KH_2PO_4 solution (20 mL). This biphasic mixture was stirred vigorously for 1 h before filtration through Celite. The aqueous layer was washed with CH_2Cl_2 (3 x 25 mL). The combined organic extracts were washed with brine (50 mL), dried over Na_2SO_4 (2 g), filtered and the filtrate was concentrated *in vacuo*. The residue was purified by column chromatography (silica gel, hexanes/EtOAc, 4/1) to yield 196 mg (89 %) of (2*E*,5*R*)-**4aa**⁴ as a colorless oil.

Data for (2*E*,5*R*)-**4aa**:

¹H NMR: (400 MHz, CDCl_3)

7.4-7.25 (m, 5 H, HC(7,8,9)), 6.95 (dt, $J = 15.6, 7.1$, 1 H, HC(3)), 5.87 (d, $J = 15.6$, 1 H, HC(2)), 4.81 (m, 1 H, HC(5)), 4.16 (q, $J = 7.1$, 2 H, $\text{H}_2\text{C}(10)$), 2.64 (m, 2 H, $\text{H}_2\text{C}(4)$), 2.2 (bs, 1 H, OH), 1.26 (t, $J = 7.1$, 3 H, $\text{H}_3\text{C}(11)$)

¹³C NMR: (100 MHz, CDCl_3)

166.29 (C(1)), 144.67 (C(3)), 142.97 (C(6)), 128.60 (C(8)), 127.89 (C(9)), 125.69 (C(7)), 124.0 (C(2)), 73.06 (C(5)), 60.29 (C(10)), 41.83 (C(4)), 14.21 (C(11))

IR: (neat)

3440 (m), 3029 (w), 2983 (m), 2939 (w), 2904 (w), 1712 (s), 1654 (s), 1494 (m), 1454 (m), 1369 (m), 1315 (s), 1278 (s), 1199 (s), 1160 (s), 1043 (s)

MS: (EI, 70 eV)

221 (M^+ , 3), 203 (32), 175 (3), 129 (11), 114 (100), 107 (87), 86 (37)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} +22.86$ ($c = 1.0$, EtOH), lit. $[\alpha]_{\text{D}}^{24} +10.4$ ($c=1.13$, EtOH) for (5*R*)-**4aa**⁴

TLC: R_f 0.26 (hexanes/EtOAc, 4/1) [UV(254)/ KMnO_4]

SFC: t_R (*R*)-**4aa**, 3.25 (98.8%); t_R (*S*)-**4aa**, 4.17 (1.2%) (Chiralpak AD, 125 psi, 40 °C, 10.0% CH_3OH in CO_2 , 3.0 mL/min, 220 nm)

Analysis: $\text{C}_{13}\text{H}_{16}\text{O}_3$ (220.26)

Calcd: C, 70.89; H, 7.32%

Found: C, 70.64; H, 7.28%

(2*E*,5*R*,6*E*)-5-Hydroxy-7-phenyl-2,6-heptadienoic Acid Ethyl Ester ((2*E*,5*R*,6*E*)-4ab)

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 126 μ L of cinnamaldehyde **1b** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl_4 (1.1 mmol, 1.1 equiv) and 272 mg of **3a** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 4/1), 207 mg (84 %) of (2*E*,5*R*,6*E*)-**4ab** as a colorless oil.

Data for (2*E*,5*R*,6*E*)-4ab:

^1H NMR: (400 MHz, CDCl_3)

7.4-7.2 (m, 5 H, HC(9,10,11)), 7.0 (dt, $J = 15.6, 7.3$, 1 H, HC(3)), 6.62 (d, $J = 16.1$, 1 H, HC(7)), 6.23 (dd, $J = 15.9, 6.6$, 1 H, HC(6)), 5.94 (dt, $J = 15.6, 1.5$, 1 H, HC(2)), 4.45 (q, $J = 6.1$, 1 H, HC(5)), 4.18 (q, $J = 7.1$, 2 H, $\text{H}_2\text{C}(12)$), 2.55 (t, $J = 7.1$, 2 H, $\text{H}_2\text{C}(4)$), 1.28 (t, $J = 7.08$, 3 H, $\text{H}_3\text{C}(13)$)

^{13}C NMR: (100 MHz, CDCl_3)

166.24 (C(1)), 144.17 (C(3)), 136.24 (C(8)), 131.13 (C(7)), 130.87 (C(6)), 128.61 (C(9)), 127.92 (C(11)), 126.54 (C(10)), 124.24 (C(2)), 71.53 (C(5)), 60.33 (C(12)), 40.12 (C(4)), 14.23 (C(13))

IR: (neat)

3430 (m), 3027 (w), 2983 (m), 2937 (w), 2904 (w), 1716 (s), 1654 (m), 1494 (w), 1448 (w), 1369 (m), 1317 (m), 1272 (m), 1201 (m), 1164 (m), 1041 (m)

MS: (EI, 70 eV)

245 (M^+ , 3), 229 (100), 183 (11), 155 (17), 133 (31), 115 (11)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} -17.86$ ($c = 1.0$, EtOH)

TLC: R_f 0.25 (hexanes/EtOAc, 4/1) [UV(254)/ KMnO_4]

SFC: t_R (*R*)-**4ab**, 4.15 (98.3%); t_R (*S*)-**4ab**, 4.41 (1.7%) (Chiralpak AD, 125 psi, 40 $^\circ\text{C}$, 10.0% CH_3OH in CO_2 , 3.0 mL/min, 220 nm)

Analysis: C₁₅H₁₈O₃ (246.30)

Calcd: C, 73.15; H, 7.37%

Found: C, 72.91; H, 7.38%

General Procedure 3. Preparation of (2*E*,5*S*)-5-Hydroxy-7-phenyl-2-heptenoic Acid Ethyl Ester ((2*E*,5*S*)-4ac)

A flame-dried, 25 mL, 2-neck flask containing a solution of 42 mg of bis-phosphoramidate (*R,R*)-**5** (0.05 mmol, 0.05 equiv), 8 μ L of *i*-Pr₂EtN (0.05 mmol, 0.05 equiv) and 132 μ L of hydrocinnamaldehyde **1c** (1.0 mmol, 1.0 equiv) in CH₂Cl₂ (5 mL) was cooled to -78°C under nitrogen. To the resulting solution was added 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv). Then 272 mg of **3a** (1.2 mmol, 1.2 equiv) was added dropwise over 5 min to the reaction mixture. The solution was allowed to stir at -78°C (bath temperature) for 24 h whereupon the cold reaction mixture was poured into a rapidly stirring 1/1 sat. aq. KF/1.0 M KH₂PO₄ solution (20 mL). This biphasic mixture was stirred vigorously for 1 h before filtration through Celite. The aqueous layer was washed with CH₂Cl₂ (3 x 25 mL). The combined organic extracts were washed with brine (50 mL), dried over Na₂SO₄ (2 g), filtered and the filtrate was concentrated *in vacuo*. The residue was purified by column chromatography (silica gel, hexanes/EtOAc, 4/1) to yield 167 mg (68 %) of (2*E*,5*S*)-**4ac**⁵ as a colorless oil.

Data for (2*E*,5*S*)-**4ac**:

¹H NMR: (500 MHz, CDCl₃)

7.3-7.18 (m, 5 H, HC(9,10,11)), 6.96 (dt, *J* = 15.6, 7.7, 1 H, HC(3)), 5.9 (dt, *J* = 15.6, 1.5, 1 H, HC(2)), 4.19 (q, *J* = 7.3, 2 H, H₂C(12)), 3.78 (m, 1 H, HC(5)), 2.80-2.69 (m, 2 H, H₂C(4)), 2.42-2.35 (m, 2 H, H₂C(7)), 1.81 (m, 2 H, H₂C(6)), 1.28 (t, *J* = 7.1, 3 H, H₃C(13))

¹³C NMR: (125 MHz, CDCl₃)
166.27 (C(1)), 144.27 (C(3)), 141.58 (C(8)), 128.49 (C(9)), 128.41 (C(10)),
125.99 (C(11)), 124.13 (C(2)), 69.79 (C(5)), 60.31 (C(12)), 40.31 (C(4)), 38.64
(C(7)), 31.92 (C(6)), 14.20 (C(13))

IR: (neat)
3442 (m), 3025 (w), 2981 (w), 2935 (m), 2863 (w), 1718 (s), 1654 (m), 1496 (m),
1454 (m), 1369 (m), 1319 (m), 1270 (s), 1211 (m), 1176 (s), 1045 (s)

MS: (EI, 70 eV)
249 (M⁺, 1), 230 (15), 203 (5), 156 (7), 135 (7), 114 (80), 91 (100)

Opt. Rot.: [α]_D²⁴ -12.77 (c = 1.0, EtOH)

TLC: *R_f* 0.21 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: *t_R* (*R*)-**4ac**, 7.95 (4.7%); *t_R* (*S*)-**4ac**, 8.29 (95.3%) (Chiralpak AD, 125 psi, 40 °C,
7.0% CH₃OH in CO₂, 2.0 mL/min, 220 nm)

Analysis: C₁₅H₂₀O₃ (248.32)

Calcd:	C, 72.55;	H, 8.12%
Found:	C, 72.44;	H, 8.23%

(2*E*,5*R*)-5-Hydroxy-2-methyl-5-phenyl-2-pentenoic Acid Methyl Ester ((2*E*,5*R*)-4ba**)**

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 102 μ L of benzaldehyde **1a** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 272 mg of **3b** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 4/1), 205 mg (93 %) of (2*E*,5*R*)-**4ba** as a colorless oil.

Data for (2*E*,5*R*)-4ba:¹H NMR: (500 MHz, CDCl₃)

7.4-7.28 (m, 5 H, HC(7,8,9)), 6.83 (t, *J* = 7.5, 1 H, HC(3)), 4.83 (dd, *J* = 7.7, 5.2, 1 H, HC(5)), 3.72 (s, 3 H, H₃C(10)), 2.71-2.56 (m, 2 H, H₂C(4)), 2.0 (s, 1 H, OH), 1.79 (s, 3 H, H₃C(11))

¹³C NMR: (125 MHz, CDCl₃)

168.37 (C(1)), 143.17 (C(6)), 137.68 (C(3)), 129.95 (C(8)), 128.60 (C(9)), 127.88 (C(7)), 125.71 (C(2)), 73.46 (C(5)), 51.76 (C(10)), 38.43 (C(4)), 12.58 (C(11))

IR: (neat)

3453 (m), 3029 (w), 2950 (m), 1710 (s), 1648 (m), 1436 (s), 1278 (s), 1195 (s), 1124 (s), 1083 (s), 1051 (s)

MS: (EI, 70 eV)

221 (M⁺, 15), 203 (100), 171 (20), 143 (6), 114 (30)

Opt. Rot.: [α]_D²⁴ +2.51 (c = 1.0, EtOH)TLC: *R_f* 0.22 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: *t_R* (*S*)-4ba, 4.17 (0.5%); *t_R* (*R*)-4ba, 5.33 (99.5%) (Chiralpak AD, 125 psi, 40 °C, 7.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

Analysis: C₁₃H₁₆O₃ (220.20)

Calcd: C, 70.89; H, 7.32%

Found: C, 70.74; H, 7.36%

(2*E*,5*R*,6*E*)-5-Hydroxy-2-methyl-7-phenyl-2,6-heptadienoic Acid Methyl Ester ((2*E*,5*R*,6*E*)-4bb**)**

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 126 μ L of cinnamaldehyde **1b** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl_4 (1.1 mmol, 1.1 equiv) and 272 mg of **3b** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 4/1), 216 mg (88 %) of (2*E*,5*R*,6*E*)-**4bb** as a colorless oil.

Data for (2*E*,5*R*,6*E*)-4bb**:**

^1H NMR: (500 MHz, CDCl_3)

7.4-7.2 (m, 5 H, HC(9,10,11)), 6.85 (t, $J = 7.5$, 1 H, HC(3)), 6.63 (d, $J = 15.9$, 1 H, HC(7)), 6.24 (dd, $J = 16.1$, 6.6, 1 H, HC(6)), 4.45 (q, $J = 6.0$, 1 H, HC(5)), 3.73 (s, 3 H, $\text{H}_3\text{C}(12)$), 2.53 (m, 2 H, $\text{H}_2\text{C}(4)$), 1.88 (s, 3 H, $\text{H}_3\text{C}(13)$), 1.82 (s, 1 H OH)

^{13}C NMR: (125 MHz, CDCl_3)

168.37 (C(1)), 137.28 (C(3)), 136.36 (C(8)), 131.16 (C(7)), 130.99 (C(6)), 130.04 (C(9)), 128.63 (C(11)), 127.88 (C(10)), 126.55 (C(2)), 71.93 (C(5)), 51.29 (C(12)), 36.65 (C(13)), 12.75 (C(13))

IR: (neat)

3423 (m), 3025 (w), 2950 (m), 1710 (s), 1648 (m), 1494 (w), 1436 (m), 1282 (m), 1195 (m), 1128 (m), 1097 (m), 1081 (m), 1037 (m)

MS: (EI, 70 eV)

245 (M^+ , 4), 229 (73), 197 (17), 169 (26), 133 (100), 115 (18)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} -36.88$ ($c = 1.0$, EtOH)

TLC: R_f 0.24 (hexanes/EtOAc, 4/1) [UV(254)/ KMnO_4]

SFC: t_R (*S*)-**4bb**, 3.78 (0.4%); t_R (*R*)-**4bb**, 4.62 (99.6%) (Chiralpak AD, 125 psi, 40 $^\circ\text{C}$, 10.0% CH_3OH in CO_2 , 3.0 mL/min, 220 nm)

Analysis: C₁₅H₁₈O₃ (246.30)
Calcd: C, 73.15; H, 7.37%
Found: C, 73.28; H, 7.24%

(2*E*,5*R*)-5-Hydroxy-3-methyl-5-phenyl-2-pentenoic Acid Ethyl Ester ((2*E*,5*R*)-4ca)

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (R,R)-5 (0.01 mmol, 0.01 equiv) was combined with 102 μ L of benzaldehyde **1a** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 290 mg of **3c** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 4/1), 214 mg (91 %) of (2*E*,5*R*)-**4ca**⁶ as a colorless oil.

Data for (2*E*,5*R*)-4ca:

¹H NMR: (500 MHz, CDCl₃)

7.37-7.26 (m, 5 H, HC(7,8,9)), 5.77 (s, 1 H, HC(2)), 4.90 (dd, *J* = 8.8, 4.6, 1 H, HC(5)), 4.15 (q, *J* = 7.0, 2 H, H₂C(10)), 2.57 (dd, *J* = 13.9, 8.8, 1 H, HC(4)), 2.51 (dd, *J* = 13.7, 4.4, 1 H, HC(4)), 2.22 (s, 3 H, H₃C(12)), 2.04 (s, 1 H, OH), 1.27 (t, *J* = 7.1, 3 H, H₃C(11))

NOE ¹H NMR: (500 MHz, CDCl₃)

Irradiation at 5.77 ppm (HC(2)) enhanced signal at 2.57 ppm (HC(4)) in major isomer

¹³C NMR: (125 MHz, CDCl₃)

166.44 (C(1)), 155.63 (C(3)), 143.69 (C(6)), 128.59 (C(8)), 127.85 (C(9)), 125.67 (C(7)), 118.55 (C(2)), 72.09 (C(5)), 59.64 (C(10)), 50.70 (C(4)), 18.94 (C(12)), 14.23 (C(11))

IR: (neat)

3451 (m), 3029 (w), 2981 (m), 2940 (m), 2906 (m), 1710 (s), 1648 (s), 1452 (m), 1369 (m), 1226 (s), 1151 (s), 1058 (s)

MS: (EI, 70 eV)

235 (M^+ , 7), 217 (100), 189 (7), 171 (15), 128 (80), 107 (37), 100 (27), 83 (30)

Opt. Rot.: $[\alpha]_D^{24} +19.61$ ($c = 1.0$, EtOH)

TLC: R_f 0.36 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: t_R (*R*)-**4ca**, 4.04 (96.1%); t_R (*S*)-**4ca**, 7.92 (3.9%) (Chiralpak AD, 125 psi, 40 °C, 7.5% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

Analysis: C₁₄H₁₈O₃ (234.29)

Calcd: C, 71.77; H, 7.74%

Found: C, 71.65; H, 7.98%

(2*E*,5*R*,6*E*)-5-Hydroxy-3-methyl-7-phenyl-2,6-heptadienoic Acid Ethyl Ester ((2*E*,5*R*,6*E*)-4cb**)**

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 126 μ L of cinnamaldehyde **1b** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 290 mg of **3c** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 4/1), 253 mg (97%, 97/3 2*E*/2*Z*) of (2*E*,5*R*,6*E*)-**4cb** as a colorless oil.

Data for (2*E*,5*R*,6*E*)-4cb**:**

¹H NMR: (500 MHz, CDCl₃)

7.39-7.25 (m, 5 H, HC(9,10,11)), 6.63 (d, $J = 15.8$, 1 H, HC(7)), 6.22 (dd, $J = 16.0$, 6.5, 1 H, HC(6)), 5.79 (s, 1 H, HC(2)), 4.53 (q, $J = 6.7$, 1 H, HC(5)), 4.15 (q,

$J = 7.2$, 2 H, H₂C(12)), 2.45 (d, $J = 6.7$, 2 H, H₂C(4)), 2.25 (s, 3 H, H₃C(14)), 1.80 (s, 1 H, OH), 1.28 (t, $J = 7.2$, 3 H, H₃C(13))

NOE ¹H NMR: (500 MHz, CDCl₃)

Irradiation at 5.79 ppm (HC(2)) enhanced signal at 2.45 ppm (HC(4)) in major isomer

¹³C NMR: (125 MHz, CDCl₃)

166.67 (C(1)), 155.57 (C(3)), 136.60 (C(8)). 131.37 (C(7)), 130.99 (C(6)), 128.85 (C(9)), 128.09 (C(11)), 126.77 (C(10)), 118.86 (C(2)), 70.77 (C(5)), 59.89 (C(12)), 49.01 (C(4)), 19.28 (C(14)), 14.47 (C(13))

IR: (neat)

3440 (m), 3025 (m), 2981 (m), 2939 (w), 2906 (w), 1712 (s), 1646 (m), 1494 (w), 1448 (m), 1382 (m), 1369 (m), 1295 (m), 1224 (s), 1149 (s), 1099 (m), 1058 (m)

MS: (EI, 70 eV)

260 (M, 1), 243 (2), 213 (2), 185 (2), 157 (5), 133 (100), 115 (18), 103 (21), 91 (13), 72 (24)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} -9.94$ (c = 1.0, EtOH)

TLC: R_f 0.32 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: t_R (*R*)-**4cb**, 4.10 (94.0%); t_R (*S*)-**4cb**, 7.35 (6.0%) (Chiralpak AD, 125 psi, 40 °C, 12.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

Analysis: C₁₆H₂₀O₃ (260.33)

Calcd: C, 73.82; H, 7.74%

Found: C, 73.55; H, 7.83%

(2*E*,5*S*)-5-Hydroxy-3-methyl-7-phenyl-2-Heptenoic Acid Ethyl Ester ((2*E*,5*S*)-4cc)

Following General Procedure 3, 42 mg of bis-phosphoramidate (*R,R*)-**5** (0.05 mmol, 0.05 equiv) was combined with 8 μ L of *i*-Pr₂EtN (0.05 mmol, 0.05 equiv), 126 μ L of hydrocinnamaldehyde **1c** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 290 mg of **3c** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 9/1), 190 mg (73 %) of (2*E*,5*S*)-**4cc** as a colorless oil.

Data for (2*E*,5*S*)-**4cc**:

¹H NMR: (500 MHz, CDCl₃)

7.31-7.18 (m, 5 H, HC(9,10,11)), 5.74 (s, 1 H, HC(2)), 4.15 (q, *J* = 7.2, 2 H H₂C(12)), 3.84 (pent, *J* = 6.5, 1 H, HC(5)), 2.83 (dt, *J* = 13.7, 7.9, 1 H, HC(7)), 2.70 (dt, *J* = 13.8, 8.3, 1 H, HC(7)), 2.33 (dd, *J* = 13.5, 4.0, 1 H, HC(4)), 2.27 (dd, *J* = 13.5, 8.6, 1 H, HC(4)), 2.17 (s, 3 H, H₃C(14)), 1.79 (q, *J* = 7.72, 2 H, H₂C(6)), 1.65 (s, 1 H, OH), 1.28 (t, *J* = 7.1, 3 H, H₃C(13))

NOE ¹H NMR: (500 MHz, CDCl₃)

Irradiation at 5.74 ppm (HC(2)) enhanced signal at 2.27 ppm (HC(4)) in major isomer

¹³C NMR: (125 MHz, CDCl₃)

166.41 (C(1)), 156.06 (C(3)), 141.69 (C(8)), 128.46 (C(9)), 128.40 (C(10)), 125.95 (C(11)), 118.32 (C(2)), 68.62 (C(5)), 59.65 (C(12)), 49.04 (C(4)), 38.86 (C(7)), 31.96 (C(6)), 18.92 (C(14)), 14.23 (C(13))

IR: (neat)

3450 (m), 3025 (w), 2981 (m), 2939 (m), 2863 (m), 1712 (s), 1644 (s), 1496 (m), 1454 (m), 1369 (m), 1280 (m), 1226 (s), 1149 (s), 1068 (m)

MS: (EI, 70 eV)

263 (M⁺, 1), 244 (8), 217 (16), 171 (3), 128 (100), 117 (13), 100 (30), 91 (48), 82 (21)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} -5.85$ ($c = 1.0$, EtOH)

TLC: R_f 0.51 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: t_R (*R*)-**4cc**, 3.52 (97.5%); t_R (*S*)-**4cc**, 4.18 (2.5%) (Chiralpak AD, 125 psi, 40 °C, 12.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

Analysis: C₁₆H₂₂O₃ (262.34)

Calcd: C, 73.25; H, 8.45%

Found: C, 73.16; H, 8.22%

(2*E*,4*R*,5*R*)-5-Hydroxy-4-methyl-5-phenyl-2-pentenoic Acid *tert*-Butyl Ester ((2*E*,4*R*,5*R*)-4da**)**

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 102 μ L of benzaldehyde **1a** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 324 mg of **3d** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 4/1), 242 mg (92 %) of (2*E*,4*R*,5*R*)-**4da** as a colorless oil.

Data for (2*E*,4*R*,5*R*)-**4da**:

¹H NMR: (400 MHz, CDCl₃)

7.37-7.29 (m, 5 H, HC(7,8,9)), 6.91 (dd, $J = 15.6, 8.3$, 1 H, HC(3)), 5.84 (dd, $J = 15.9, 0.7$, 1 H, HC(2)), 4.47 (d, $J = 7.6$, 1 H, HC(5)), 2.62 (m, 1 H, HC(4)), 2.65 (s, 1 H, OH), 1.48 (s, 9 H, H₃C(11)), 0.89 (d, $J = 6.8$, 3 H, H₃C(12))

¹³C NMR: (100 MHz, CDCl₃)

165.74 (C(1)), 149.76 (C(3)), 142.17 (C(6)), 128.45 (C(8)), 127.95 (C(9)), 126.66 (C(7)), 124.11 (C(2)), 80.27 (C(10)), 77.94 (C(5)), 44.28 (C(4)), 28.12 (C(11)), 16.17 (C(12))

IR: (neat)

3442 (m), 2977 (s), 2933 (m), 1710 (s), 1650 (m), 1454 (m), 1367 (m), 1313 (m), 1253 (m), 1157 (s), 1035 (m)

MS: (EI, 70 eV)

263 (M^+ , 29), 189 (100), 143 (37), 100(39)

Opt. Rot.: $[\alpha]_D^{24} +65.37$ ($c = 1.0$, EtOH)

TLC: R_f 0.45 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: t_R (2*S*,3*R*)-**4da**, 6.20 (94.5%); t_R (2*R*,3*S*)-**4da**, 7.05 (5.5%) (Chiralpak AD, 125 psi, 40 °C, 3.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

Analysis: C₁₆H₂₂O₃ (262.16)

Calcd: C, 73.25; H, 8.45%

Found: C, 73.42; H, 8.70%

(2*E*,4*R*,5*S*)-5-Hydroxy-4-methyl-7-phenyl-2,6-Heptadienoic Acid *tert*-Butyl Ester
((2*E*,4*R*,5*S*)-4db**)**

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 126 μ L of cinnamaldehyde **1b** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 324 mg of **3d** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 9/1), 205 mg (71 %) of (2*E*,4*R*,5*S*)-**4db** as a colorless oil.

Data for (2*E*,4*R*,5*S*)-**4db**:

mp: 62-66 °C (hexanes, EtOAc)

¹H NMR: (400 MHz, CDCl₃)

7.39-7.23 (m, 5 H, HC(9,10,11)), 6.90 (dd, $J = 16.1, 8.0$, 1 H, HC(3)), 6.61 (d, $J = 15.9$, 1 H, HC(7)), 6.19 (dd, $J = 15.9, 7.1$, 1 H, HC(6)), 5.85 (dd, $J = 15.6, 1.0$, 1

H, HC(2)), 4.16 (t, $J = 6.8$, 1 H, HC(5)), 2.52 (m, 1 H, HC(4)), 1.78 (s, 1 H, OH), 1.48 (s, 9 H, H₃C(13)), 1.09 (d, $J = 6.8$, 3 H, H₃C(14))

¹³C NMR: (100 MHz, CDCl₃)

165.81 (C(1)), 148.75 (C(3)), 136.28 (C(8)), 132.36 (C(7)), 129.65 (C(6)), 128.58 (C(9)), 127.68 (C(11)), 126.59 (C(10)), 124.14 (C(2)), 80.33 (C(12)), 76.17 (C(5)), 42.91 (C(4)), 28.12 (C(13)), 15.66 (C(14))

IR: (CHCl₃)

3605 (w), 3027 (m), 3013 (m), 2981 (m), 1705 (s), 1651 (m), 1494 (m), 1455 (m), 1369 (m), 1301 (m), 1158 (s)

MS: (CI, 70 eV)

289 (M⁺, 1), 271 (33), 215 (100), 197 (9), 169 (10), 133 (21), 100 (3)

Opt. Rot.: [α]_D²⁴ +5.78 (c = 1.0, EtOH)

TLC: R_f 0.58 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: t_R (2*R*,3*S*)-**4db**, 8.29 (8.8%); t_R (2*S*,3*R*)-**4db**, 9.15 (91.2%) (Chiralpak OJ, 125 psi, 40 °C, 4.0% CH₃OH in CO₂, 2.0 mL/min, 220 nm)

Analysis: C₁₈H₂₄O₃ (288.38)

Calcd: C, 74.97; H, 8.39%

Found: C, 75.11; H, 8.59%

((5*R*)-6-(2-Hydroxy-2-phenylethyl)-2,2-dimethyl-[1,3]-dioxin-4-one ((5*R*)-7a**))**

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-**5** (0.01 mmol, 0.01 equiv) was combined with 102 μ L of benzaldehyde **1a** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 307 mg of **6** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 6/4), 228 mg (92 %) of (*5R*)-**7a**⁷ as a white, crystalline solid.

Data for (5*R*)-7a:

- mp: 70-72 °C (hexanes, EtOAc)
- ¹H NMR: (400 MHz, CDCl₃)
 7.4-7.28 (m, 5 H, HC(7,8,9)), 5.27 (s, 1 H, HC(2)), 4.98 (m, 1 H, HC(5)), 2.7 (dd, *J* = 14.6, 8.2, 1 H, HC(4)), 2.55 (dd, *J* = 14.6, 4.8, 1 H, HC(4)), 2.1 (d, *J* = 4.0, 1 H, OH), 1.65 (s, 3 H, H₃C(11)), 1.63 (s, 3 H, H₃C(11))
- ¹³C NMR: (100 MHz, CDCl₃)
 168.19 (C(3)), 161.2 (C(1)), 142.65 (C(6)), 128.74 (C(8)), 128.33 (C(9)), 125.69 (C(7)), 106.66 (C(10)), 95.38 (C(2)), 71.22 (C(5)), 43.16 (C(4)), 25.39 (C(11)), 24.70 (C(11))
- MS: (CI, methane, 70 eV)
 249 (M⁺, 29), 191 (28), 173 (32), 147 (22), 131 (100), 105 (25), 85 (21)
- Opt. Rot.: [α]_D²⁴ +35.1 (c = 1.0, CHCl₃), lit. [α]_D²⁴ +35.9 (c = 1.0, CHCl₃) for (5*R*)-7a⁷
- TLC: *R*_f 0.35 (hexanes/EtOAc, 6/4) [UV(254)/KMnO₄]
- SFC: *t*_R (*S*)-7a, 3.29 (12.8%); *t*_R (*R*)-7a, 3.53 (87.2%) (Chiralpak AD, 125 psi, 40 °C, 10.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

(5*R*)-6-(2-Hydroxy-4-phenyl 3-butenyl)-2,2-dimethyl-[1,3]-dioxin-4-one ((5*R*)-7b)

Following General Procedure 2, 8.4 mg of bis-phosphoramidate (*R,R*)-5 (0.01 mmol, 0.01 equiv) was combined with 126 μL of cinnamaldehyde **1b** (1.0 mmol, 1.0 equiv), 123 μL of SiCl₄ (1.1 mmol, 1.1 equiv) and 290 mg of **6** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 6/4), 241 mg (88 %) of (5*R*)-7b⁷ as a white, crystalline solid.

Data for (5*R*)-7b:mp: 81-82 °C (hexanes, EtOAc)¹H NMR: (400 MHz, CDCl₃)7.37-7.25 (m, 5 H, HC(9,10,11)), 6.63 (d, *J* = 16.1, 1 H, HC(7)), 6.21 (dd, *J* = 15.8, 6.9, 1 H, HC(6)), 5.36 (s, 1 H, HC(2)), 4.6 (q, *J* = 6.9, 1 H, HC(5)), 2.55 (m, 2 H, H₂C(4)), 1.95 (s, 1 H, OH), 1.69 (s, 3 H, H₃C(13)), 1.68 (s, 3 H, H₃C(13))¹³C NMR: (100 MHz, CDCl₃)

168.19 (C(3)), 161.03 (C(1)), 135.96 (C(8)), 131.62 (C(7)), 130.13 (C(6)), 128.72 (C(9)), 128.17 (C(11)), 126.55 (C(10)), 106.72 (C(12)), 95.43 (C(2)), 69.83 (C(5)), 41.50 (C(4)), 25.34 (C(13)), 24.84 (C(13))

MS: (EI, 70 eV)275 (M⁺, 2), 216 (45), 188 (60), 172 (23), 157 (18), 131 (44), 115 (32), 104 (100), 84 (41)Opt. Rot.: [α]_D²⁴ +14.43 (c = 1.0, EtOH), [α]_D²⁴ +6.79 (c = 1.0, CHCl₃), lit [α]_D²⁴ +6.2 (c = 1.0, CHCl₃) for (5*R*)-7b⁷TLC: *R*_f 0.28 (hexanes/EtOAc, 6/4) [UV(254)/KMnO₄]SFC: *t*_R (S)-7b, 6.56 (11.1%); *t*_R (R)-7b, 7.9 (88.9%) (Chiralpak AD, 125 psi, 40 °C, 8.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)**((5*S*)-6-(2-Hydroxy-4-phenylbutyl)-2,2-dimethyl-[1,3]-dioxin-4-one ((5*S*)-7c)**

Following General Procedure 3, 42 mg of bis-phosphoramidate (*R,R*)-5 (0.05 mmol, 0.05 equiv) was combined with 8 μL of *i*-Pr₂EtN (0.05 mmol, 0.05 equiv), 126 μL of hydrocinnamaldehyde **1c** (1.0 mmol, 1.0 equiv), 123 μL of SiCl₄ (1.1 mmol, 1.1 equiv) and 272

mg of **6** (1.2 mmol, 1.2 equiv) to yield, after column chromatography (silica gel, hexanes/EtOAc, 6/4), 230 mg (83 %) of (5*S*)-**7c**⁷ as a white, crystalline solid.

Data for (5*S*)-**7c**:

mp: 59-60 °C (hexanes, EtOAc)

¹H NMR: (500 MHz, CDCl₃)

7.3-7.18 (m, 5 H, HC(9,10,11)), 5.31 (s, 1 H, HC(2)), 3.92 (pent, *J* = 6.2, 1 H, HC(5)), 2.81 (m, 1 H, HC(4)), 2.70 (m, 1 H, HC(4)), 2.42 (dd, *J* = 14.4, 4.3, 1 H, HC(6)), 2.36 (dd, *J* = 14.6, 8.1, 1 H, HC(6)), 1.82 (m, 2 H, H₂C(7)), 1.68 (s, 3 H, H₃C(12)), 1.66 (s, 3 H, H₃C(12))

¹³C NMR: (125 MHz, CDCl₃)

168.95 (C(3)), 161.0 (C(1)), 141.27 (C(8)), 128.55 (C(9)), 128.37 (C(10)), 126.11 (C(11)), 106.63 (C(11)), 95.14 (C(2)), 68.32 (C(5)), 41.73 (C(4)), 38.89 (C(7)), 31.77 (C(6)), 25.16 (C(12)), 24.84 (C(12))

MS: (EI, 70 eV)

277 (M⁺, 3), 218 (28), 200 (31), 172 (7), 158 (16), 130 (24), 117 (44), 104 (22), 91 (100), 69 (26)

Opt. Rot.: [α]_D²⁴ +10.17 (c = 1.0, EtOH), [α]_D²⁴ +3.4 (c = 1.0, CHCl₃), lit. [α]_D²⁴ +2.5 (c = 1.0, CHCl₃) for (5*S*)-**7c**⁷

TLC: *R_f* 0.27 (hexanes/EtOAc, 6/4) [UV(254)/KMnO₄]

SFC: *t_R* (*R*)-**7c**, 4.80 (5.4%); *t_R* (*S*)-**7c**, 5.18 (94.6%) (Chiralpak AD, 125 psi, 40 °C, 8.0% CH₃OH in CO₂, 3.0 mL/min, 220 nm)

(3S)-3-Hydroxy-2,2-dimethyl-3-phenylpropanoic Acid Methyl Ester ((3S)-13) **13**

Following General Procedure 3, 42 mg of bis-phosphoramidate (*R,R*)-**5** (0.05 mmol, 0.05 equiv) was combined with 8 μ L of *i*-Pr₂EtN (0.05 mmol, 0.05 equiv), 102 μ L of benzaldehyde **1a** (1.0 mmol, 1.0 equiv), 123 μ L of SiCl₄ (1.1 mmol, 1.1 equiv) and 208 mg of **12** (1.2 mmol, 1.2 equiv) to yield, after Kugelrohr distillation, 180 mg (87 %) of (3S)-**13**⁸ as a white, crystalline solid.

Data for (3S)-13:

mp: 62-64 °C

bp: 175 °C (0.1 mm Hg, ABT)

¹H NMR: (400 MHz, CDCl₃)

7.32-7.26 (m, 5 H, HC(5,6,7)), 4.90 (s, 1 H, HC(3)), 3.72 (s, 3 H, H₃C(8)), 3.05 (s, 1 H, OH), 1.14 (s, 3 H, H₃C(9)), 1.11 (s, 3 H, H₃C(9))

¹³C NMR: (100 MHz, CDCl₃)

178.21 (C(1)), 139.89 (C(4)), 127.77 (C(6)), 127.75 (C(5)), 127.63 (C(7)), 78.69 (C(3)), 52.11 (C(8)), 47.67 (C(2)), 23.06 (C(9)), 19.0 (C(9))

Opt. Rot.: [α]_D²⁴ +1.94 (c = 2.4, MeOH), lit. [α]_D²⁴ +5.7 (c = 2.49, MeOH) for (3S)-**13**⁸

TLC: *R_f* 0.36 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

SFC: *t_R* (3*R*)-**13**, 3.69 (91.1%); *t_R* (3*S*)-**13**, 4.25 (8.9%) (Chiralpak OB, 125 psi, 40 °C, 2.0% CH₃OH in CO₂, 2.0 mL/min, 220 nm)

Representative Procedure 4. Preparation of (3*R*)-1-Phenylpropane-1,3-diol ((3*R*)-14**) from (2*E*,5*R*)-5-Hydroxy-5-phenyl-2-pentenoic Acid Ethyl Ester ((2*E*,5*R*)-**4aa**)**

A 25 mL, 1-neck flask containing a solution of 94 mg (2*E*,5*R*)-5-hydroxy-5-phenyl-2-pentenoic acid ethyl ester (2*E*,5*R*)-**4aa** (0.42 mmol) in 5 mL of pentane was cooled to -78°C and a solution of ozone in oxygen was passed through it using a gas dispersion tube for 1 h. The solution was sparged with N_2 (to remove residual ozone) and then 2.89 mL of a solution of LiAlH_4 in THF (0.58 M, 1.68 mmol, 4 equiv) was added slowly at -78°C . The flask was then fitted with a reflux condenser and was heated at 65°C for 1 h. The mixture was cooled to room temperature and 5 mL of sat. aq. sodium potassium tartrate solution was added and the mixture was stirred to break up the resulting precipitate. The organic layer was separated and the aqueous layer was washed with Et_2O (3 x 10 mL). The combined organic extracts were washed with brine (25 mL), then were dried over Na_2SO_4 (5 g), filtered and the filtrate was concentrated *in vacuo*. The residue was purified by column chromatography (silica gel, EtOAc / hexanes, 2/1) to yield 41 mg (64%) of (3*R*)-**14**⁹ as a colorless oil.

Data for (3*R*)-14**:**

$^1\text{H NMR}$: (400 MHz, CDCl_3)

7.36-7.25 (m, 5 H, HC(5,6,7)), 4.96 (dd, $J = 8.5, 3.9$, 1 H, HC(3)), 3.86 (t, $J = 5.6$, 2 H, $\text{H}_2\text{C}(1)$), 2.55 (s, 1 H, OH), 2.1-1.85 (m, 2 H, $\text{H}_2\text{C}(2)$)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} +60.8$ ($c = 1.0$, CHCl_3), lit. $[\alpha]_{\text{D}}^{24} -63.0$ ($c=0.958$, CHCl_3) for (3*S*)-**14**⁹

TLC: R_f 0.28 (EtOAc /hexanes, 2/1) [p-anisaldehyde]

(5*R*)-5-Hydroxy-7-phenylheptanoic Acid Ethyl Ester ((5*R*)-15**) from (2*E*,5*R*,6*E*)-5-Hydroxy-7-phenyl-2,6-heptadienoic Acid Ethyl Ester ((2*E*,5*R*,6*E*)-**4ab**)**

A 50 mL, 1-neck flask containing a suspension of 246 mg of (2*E*,5*R*,6*E*)-5-hydroxy-7-phenyl-2,6-heptadienoic acid ethyl ester ((2*E*,5*R*,6*E*)-**4ab**) (1.0 mmol) and 7.0 mg of 10% Pd-C in 25 mL of EtOAc was stirred for 3 h at 23 °C under 1 atm of H₂. After briefly evacuating the flask and venting with N₂, the suspension was then filtered through Celite and the filtrate was concentrated *in vacuo*. The residue was purified by column chromatography (silica gel, hexanes/EtOAc, 4/1) to yield 206 mg (82 %) of (5*R*)-**15** as a colorless oil.

Data for (5*R*)-**15**:

¹H NMR: (400 MHz, CDCl₃)

7.30-7.16 (m, 5 H, HC(9,10,11)), 4.12 (q, *J* = 7.1, 2 H, H₂C(12)), 3.61 (m, 1 H, HC(5)), 2.77 (m, 1 H, HC(7)), 2.68 (m, 1 H, HC(7)), 2.32 (dt, *J* = 1.2, 7.56, 2 H, H₂C(2)), 1.79-1.67 (m, 4 H, 2 x H₂C(4,6)), 1.50 (m, 2 H, H₂C(3)), 1.24 (t, *J* = 7.1, 3 H, H₃C(13))

¹³C NMR: (100 MHz, CDCl₃)

173.78 (C(1)), 142.01 (C(8)), 128.37 (C(9)), 128.35 (C(10)), 125.29 (C(11)), 70.65 (C(5)), 60.34 (C(12)), 39.63 (C(7)), 36.83 (C(4)), 34.05 (C(2)), 31.99 (C(6)), 20.84 (C(3)), 14.21 (C(13))

IR: (neat)

3451 (w), 2980 (w), 2866 (w), 1733 (s), 1495 (w), 1454 (m), 1373 (m), 1238 (m), 1180 (m), 1094 (m), 1031 (m)

MS: (EI, 70 eV)

251 (M⁺, 1), 232 (35), 204 (7), 186 (70), 117 (35), 104 (40), 91 (100), 71 (19)

Opt. Rot.: [α]_D²⁴ -5.94 (c = 1.0, EtOH)

TLC: *R_f* 0.19 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

Analysis: C₁₅H₂₂O₃ (250.33)

Calcd: C, 71.97; H, 8.86%

Found: C, 71.91; H, 8.91%

(5*R*)-5-Hydroxy-7-phenylheptanoic Acid Ethyl Ester (5*R*)-15 from (2*E*,5*S*)-5-Hydroxy-7-phenyl-2-heptenoic Acid Ethyl Ester (2*E*,5*S*)-4ac

A 50 mL, 1-neck flask containing a suspension of 50 mg of (2*E*,5*S*)-5-Hydroxy-7-phenyl-2-heptenoic acid ethyl ester (2*E*,5*S*)-**4ac** (0.2 mmol) and 1.4 mg of 10% Pd-C in 5 mL of EtOAc was stirred for 3 h at 23 °C under 1 atm of H₂. After briefly evacuating the flask and venting with N₂, the suspension was then filtered through Celite and the filtrate was concentrated *in vacuo*. The residue was purified by column chromatography (silica gel, hexanes/EtOAc, 4/1) to yield 31 mg (61 %) of (5*R*)-**15** as a colorless oil.

Data for (5*R*)-15:

¹H NMR: (400 MHz, CDCl₃)

7.30-7.16 (m, 5 H, HC(9,10,11)), 4.12 (q, *J* = 7.1, 2 H, H₂C(12)), 3.61 (m, 1 H, HC(5)), 2.77 (m, 1 H, HC(7)), 2.68 (m, 1 H, HC(7)), 2.32 (dt, *J* = 1.2, 7.56, 2 H, H₂C(2)), 1.79-1.67 (m, 4 H, 2 x H₂C(4,6)), 1.50 (m, 2 H, H₂C(3)), 1.24 (t, *J* = 7.1, 3 H, H₃C(13))

Opt. Rot.: [α]_D²⁴ -6.09 (c = 1.0, EtOH)

(5*S*)-5-Phenylpentane-1,3-diol ((5*S*)-16**) from (2*E*,5*S*)-5-Hydroxy-7-phenyl-2-heptenoic Acid Ethyl Ester ((2*E*,5*S*)-**4ac**)**

Following General Procedure 4, a solution of 93 mg of (2*E*,5*S*)-5-hydroxy-7-phenyl-2-heptenoic acid ethyl ester (2*E*,5*S*)-**4ac** (0.37 mmol) in 5 mL of pentane was treated with a solution of ozone in oxygen followed by reduction with 2.55 mL of a solution of LiAlH₄ in THF (0.58 M, 1.48 mmol, 4 equiv) to yield, after column chromatography (silica gel, EtOAc/hexanes, 2/1), 42 mg (63%) of (5*S*)-**16**¹⁰ as a colorless oil.

Data for (3*S*)-16**:**

¹H NMR: (400 MHz, CDCl₃)

7.30-7.18 (m, 5 H, HC(7,8,9)), 3.89 (m, 2 H, H₂C(1)), 3.82 (m, 1 H, HC(3)), 2.81-2.65 (m, 2 H, H₂C(5)), 2.60 (s, 1 H, OH), 1.85-1.70 (m, 4 H, 2 x H₂C(2,4))

¹³C NMR: (100 MHz, CDCl₃)

141.88 (C(6)), 128.43 (C(7)), 128.39 (C(8)), 125.87 (C(9)), 71.53 (C(3)), 61.72 (C(1)), 39.30 (C(5)), 38.25 (C(2)), 31.84 (C(4))

Opt. Rot.: [α]_D²⁴ -10.2 (c = 1.32, EtOH), lit. [α]_D²⁴ -7.21 (c=1.52, EtOH) for (3*S*)-**16**¹⁰

TLC: *R_f* 0.26 (EtOAc/hexanes, 2/1) [p-anisaldehyde]

(3*R*)-1-Phenylpropane-1,3-diol ((3*R*)-14**) from (2*E*,5*R*)-5-Hydroxy-2-methyl-5-phenyl-2-pentenoic Acid Methyl Ester ((2*E*,5*R*)-**4ba**)**

Following General Procedure 4, a solution of 95 mg of (2*E*,5*R*)-5-Hydroxy-2-methyl-5-phenyl-2-pentenoic acid methyl ester (2*E*,5*R*)-**4ba** (0.43 mmol) in 5 mL of pentane was treated

with a solution of ozone in oxygen followed by reduction with 2.96 mL of a solution of LiAlH_4 in THF (0.58 M, 1.72 mmol, 4 equiv) to yield, after column chromatography (silica gel, EtOAc/hexanes, 2/1), 47 mg (71%) of (3*R*)-**14**⁹ as a colorless oil.

Data for (3*R*)-14**:**

¹H NMR: (400 MHz, CDCl_3)

7.36-7.25 (m, 5 H, HC(5,6,7)), 4.96 (dd, $J = 8.5, 3.9$, 1 H, HC(3)), 3.86 (t, $J = 5.6$, 2 H, $\text{H}_2\text{C}(1)$), 2.55 (s, 1 H, OH), 2.1-1.85 (m, 2 H, $\text{H}_2\text{C}(2)$)

Opt. Rot.: $[\alpha]_{\text{D}}^{24} +57.1$ ($c = 0.978$, CHCl_3), lit. $[\alpha]_{\text{D}}^{24} -63.0$ ($c=0.958$, CHCl_3) for (3*S*)-**14**⁹

(4*R*)-4-(Acetyloxy)-4-phenyl-2-butanone ((4*R*)-17**) from (2*E*,5*R*)-5-Hydroxy-3-methyl-5-phenyl-2-pentenoic Acid Ethyl Ester ((2*E*,5*R*)-**4ca**)**

To a 25 mL, 1-neck flask containing a solution of 53 mg of (2*E*,5*R*)-5-Hydroxy-3-methyl-5-phenyl-2-pentenoic acid ethyl ester (2*E*,5*R*)-**4ca** (0.23 mmol) in 0.5 mL of acetic anhydride (5.3 mmol, 23 equiv) was slowly added 0.5 mL of pyridine (6.2 mmol, 27 equiv). The solution was allowed to stir at room temperature for 90 min before the addition of 10 mL of Et_2O . The cloudy solution was then washed with 0.1 M HCl (20 mL) followed by washing with brine (20 mL). The organic layer was then separated and dried over Na_2SO_4 (5 g), filtered and the filtrate was concentrated *in vacuo*. The residue was then transferred to a 25 mL, 1-neck flask and dissolved in a mixture of 2 mL CH_2Cl_2 , 2 mL CH_3CN and 2 mL H_2O . To this solution was added 1 mg of $\text{RuCl}_3 \cdot \text{H}_2\text{O}$ (0.0046 mmol, 0.02 equiv) and 206 mg of NaIO_4 (0.96 mmol, 4.2 equiv). The biphasic mixture was stirred at room temperature for 2 h prior to addition of 10 mL of 0.1 M HCl. The solution was then extracted with CH_2Cl_2 (2 x 10 mL). The combined organic layers were washed with brine (10 mL), dried over Na_2SO_4 (5 g), filtered and the filtrate was

concentrated *in vacuo*. The residue was purified by column chromatography (silica gel, hexanes/EtOAc, 4/1) to yield 28 mg (55%) of (4*R*)-**17**¹¹ as a colorless oil.

Data for (4*R*)-**17**:

¹H NMR: (400 MHz, CDCl₃)

7.34-7.29 (m, 5 H, HC(6,7,8)), 6.18 (dd, *J* = 8.5, 4.9, 1 H, HC(4)), 3.11 (dd, *J* = 16.6, 8.8, 1 H, HC(3)), 2.82 (dd, *J* = 16.6, 4.9, 1 H, HC(3)), 2.14 (s, 3 H, H₃C(1)), 2.03 (s, 3 H, H₃C(10))

¹³C NMR: (100 MHz, CDCl₃)

204.61 (C(2)), 169.77 (C(9)), 139.62 (C(5)), 128.58 (C(7)), 128.21 (C(6)), 126.39 (C(8)), 71.54 (C(4)), 49.80 (C(3)), 30.40 (C(10)), 21.03 (C(1))

Opt. Rot.: [α]_D²⁴ +60.0 (c = 0.71, CHCl₃), lit. [α]_D²⁴ +64.6 (c=0.71, CHCl₃) for (3*R*)-**17**¹¹

TLC: *R*_f 0.35 (hexanes/EtOAc, 4/1) [UV(254)/KMnO₄]

(2*R*,3*R*)-2-Methyl-1-phenylpropane-1,3-diol ((2*R*,3*R*)-18**) from (2*E*,4*R*,5*R*)-5-Hydroxy-4-methyl-5-phenyl-2-pentenoic Acid *tert*-Butyl Ester ((2*E*,4*R*,5*R*)-**4da**)**

Following General Procedure 4, a solution of 95 mg of (2*E*,4*R*,5*R*)-5-hydroxy-4-methyl-5-phenyl-2-pentenoic acid *tert*-butyl ester (2*E*,4*R*,5*R*)-**4da** (0.36 mmol) in 5 mL of pentane was treated with a solution of ozone in oxygen followed by reduction with 2.48 mL a solution of LiAlH₄ in THF (0.58 M, 1.44 mmol, 4 equiv) to yield, after column chromatography (silica gel, EtOAc/hexanes, 2/1), 26 mg (44%) of (2*R*,3*R*)-**18**⁹ as a colorless oil.

Data for (2*R*,3*R*)-**18**:

¹H NMR: (400 MHz, CDCl₃)

7.37-7.26 (m, 5 H, HC(5,6,7)), 4.50 (d, *J* = 8.5, 1 H, HC(3)), 3.70 (m, 2 H, H₂C(1)), 3.19 (s, 2 H, OH), 2.03 (m, 1 H, H₂C(2)), 0.67 (d, *J* = 7.1, 3 H, H₃C(8))

¹³C NMR: (100 MHz, CDCl₃)
 143.29 (C(4)), 128.39 (C(6)), 127.80 (C(5)), 126.66 (C(7)), 80.83 (C(3)), 67.92 (C(1)), 41.51 (C(2)), 13.75 (C(8))

Opt. Rot.: [_D²⁴ +35.17 (c = 0.34, CHCl₃), lit. [_D²⁴ -46.8 (c=0.35, CHCl₃) for (2*S*,3*S*)-**18**⁹

TLC: *R*_f 0.47 (EtOAc/hexanes, 2/1) [p-anisaldehyde]

(2*E*)-2-Pentenoic Acid *tert*-Butyl Ester ((2*E*)-19**)**

A 250 mL Parr flask containing a solution of 22.7 mL of *trans*-2-pentenoic acid (0.225 mol) and 2.25 mL of conc. sulfuric acid (0.04 mol, 0.17 equiv) in 10 mL of Et₂O was cooled to -78 °C before condensation of ~30 mL of isobutylene (0.34 mmol, 1.5 equiv) into the solution. The flask was then placed in a sealed Parr shaker and it was shaken for 24 h. The flask was vented and the excess isobutylene was removed by sparging the solution with an N₂ stream. The solution was diluted with 50 mL of Et₂O, washed with sat. aq. NaHCO₃ solution (50 mL), brine (50 mL), dried over K₂CO₃ (10 g), filtered and the filtrate was concentrated by distillation of the remaining Et₂O at atmospheric pressure. The residue was then purified by short path distillation to yield 8.94 g (25%) of (2*E*)-**19**¹² as a colorless oil.

Data for (2*E*)-**19**:

bp: 72 °C (32 mm Hg)

¹H NMR: (400 MHz, CDCl₃)
 6.90 (dt, *J* = 15.1, 6.3, 1 H, HC(3)), 5.74 (dt, *J* = 15.1, 1.7, 1 H, HC(2)), 2.18 (dpent, *J* = 1.4, 7.6, 2 H, H₂C(4)), 1.47 (s, 9 H, H₃C(7)), 1.04 (t, *J* = 7.6, 3 H, H₃C(5))

¹³C NMR: (100 MHz, CDCl₃)
 166.26 (C(1)), 149.38 (C(3)), 122.03 (C(2)), 79.95 (C(6)), 28.12 (C(4)), 25.10 (C(7)), 12.19 (C(5))

References:

1. Denmark, S. E.; Wynn T. *J. Am Chem. Soc.* **2001**, *123*, 6199.
2. Denmark, S. E., Wynn, T., Beutner, G. L. *J. Am. Chem. Soc.* **2002**, *124*, 13405.
3. Hertler, W. R.; Reddy, G. S.; Sogah, D. Y. *J. Org. Chem.* **1988**, *53*, 3532.
4. Hunter, T. J.; O'Doherty, G. A. *Org. Lett.* **2001**, *3*, 1049.
5. Sumida, S.; Ohga, M.; Mitani, J.; Nokami, J. *J. Am. Chem. Soc.* **2000**, *122*, 1310.
6. Dugger, R. W.; Heathcock, C. H. *J. Org. Chem.* **1980**, *45*, 1181.
7. Singer, R. A.; Carriera, E. M. *J. Am. Chem. Soc.* **1995**, *117*, 12360.
8. Kobayashi, S.; Ishitani, H.; Yamashita, Y.; Ueno, M.; Shimizu, H. *Tetrahedron* **2001**, *57*, 861.
9. Masamune, S.; Sato, T.; Kim, B.; Wollman, T.A. *J. Am. Chem. Soc.* **1986**, *108*, 8279.
10. Nunez, M. T.; Martin, V. S. *J. Org. Chem.* **1990**, *55*, 1928.
11. Nair, M. S.; Joly, S. *Tetrahedron: Asymmetry* **2000**, *11*, 2049.
12. Hine, J.; Kanagasabapathy, V. M. *J. Org. Chem.* **1982**, *47*, 2745.