Supporting Information

Dynamic Kinetic Resolution of α,β-Unsaturated Lactones Via Asymmetric Copper-Catalyzed Conjugate Reduction: Application to the Total Synthesis of Eupomatilone-3

Matthew P. Rainka, Jacqueline E. Milne and Stephen L. Buchwald

I. General Considerations.

Unless otherwise noted, THF and toluene were purchased from J.T. Baker in CYCLE-TAINER® solvent-delivery kegs and vigorously purged with argon for 2 h. The solvents were further purified by passing them under argon pressure through two packed columns of neutral alumina (for THF) or through neutral alumina and copper (II) oxide (for toluene).\(^1\) Starting materials for substrate synthesis were purchased from commercial sources and used as is. PMHS (polymethylhydrosiloxane) and \(t\)-BuOH were purchased from Aldrich and used as is. SYNPHOS was purchased from Strem Chemicals, Inc.

Yields refer to isolated yields of compounds of greater than 95% purity as estimated by capillary GC and \(^1\)H NMR. Yields reported in this section refer to a single experiment, while those reported in the tables are the average of two or more runs.

All new compounds were characterized by \(^1\)H NMR, \(^{13}\)C NMR, and IR spectroscopy, in addition to elemental analysis (Atlantic Microlabs, Inc) or HRMS. Nuclear Magnetic Resonance spectra were recorded on a Varian Mercury 300 of Varian 500 instrument. Infrared spectra were recorded on a Perkin-Elmer Model 2000 FTIR instrument. All \(^1\)H NMR experiments are reported in \(\delta\) units, parts per million (ppm) downfield from tetramethylsilane. All \(^{13}\)C NMR spectra are reported in ppm relative to residual solvent, and all were obtained with \(^1\)H decouling. Melting points (uncorrected) were obtained on a Mel-Temp capillary melting point apparatus. Optical rotations were taken on a Jasco Model-1010 Polarimeter at 21 °C. Gas Chromatographic analyses were performed on a Hewlett-Packard 6890 gas chromatography instrument with an FID detector using 25m x 0.20 mm capillary column with cross-linked methyl siloxane as a stationary phase. Chiral High Performance Liquid Chromatography analyses were performed on a Hewlett-Packard 1100 system with an HP 1100 Diode Array Detector, using the columns and wavelengths mentioned in sections II and IV.

Part II. Total Synthesis of Eupomatilone-3

A flame-dried 5 mL screw cap vial equipped with a Teflon-coated magnetic stir bar was charged with Pd(OAc)$_2$ (1 mg, 0.005 mmol) and SPhos (8.2 mg, .02 mmol), then sealed with a Teflon centered screw cap. The flask was then evacuated, backfilled with argon, and this process was repeated one additional time. THF (1 mL) was then added to the flask via syringe and the resulting solution was allowed to stir at room temperature for 5 minutes. Separately, a flame-dried 15 mL Schlenk flask equipped with a Teflon-coated magnetic stir bar was charged with aryl bromide 4 (145 mg, 0.5 mmol), 3,4,5-trimethoxy benzeneboronic acid (159 mg, 0.75 mmol), and tripotassium phosphate (212 mg, 1.0 mmol). The flask was then capped with a rubber septum, evacuated, backfilled with argon, and this process was repeated one additional time. THF (1 mL) was then added to the Schlenk flask while under argon via syringe. Then 5 µL of the catalyst solution generated in the vial; as described above, was added to the Schlenk flask via syringe, followed by an additional 0.5 mL of THF that was added to the Schlenk flask to wash down the sides of the flask. The septum was then replaced with a Teflon screw cap and the flask was sealed and placed in a 80 °C oil bath for 20 h. Upon complete conversion of the starting aryl bromide (as assessed by both TLC and GC) the reaction mixture was allowed to cool to room temperature, then filtered through a small plug of silica gel eluting with EtOAc. This was then concentrated to dryness with the aid of a rotary evaporator. The resulting residue was purified by flash chromatography on silica gel eluting with 3:1 to 2:1 EtOAc : Hexane to give 173 mg (92%) of the title compound as a white solid. M.p. : 145-146 °C. $^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.02 (s, 1H), 6.44 (s, 2H), 6.06 (s, 2H), 3.90 (s, 3H), 3.84 (s, 6H), 3.83 (s, 3H), 3.55 (s, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 168.1, 152.5, 148.2, 141.0, 140.0, 137.0, 132.0, 125.9, 106.8, 104.2, 102.0, 60.8, 60.0, 56.0, 52.0; IR (cm$^{-1}$): 1728, 1612, 1583, 1434, 1326, 1281, 1240, 1126, 1086, 1044; Anal. Calcd. for C$_{19}$H$_{20}$O$_8$: C, 60.63; H, 5.36. Found: C, 60.61; H, 5.33.

A flame-dried 25 mL round bottom flask equipped with a Teflon-coated magnetic stir bar was charged with 5 (850 mg, 2.26 mmol) and THF (5 mL). Then, 11.3 mL of a solution of BH$_3$•THF in THF (1M) (10 mmol) was carefully added dropwise to the stirring solution. When addition was complete, the flask was equipped with a reflux condenser
and then placed in a 80 °C oil bath and allowed to stir for 14 h. The reaction mixture was allowed to cool to room temperature, then carefully quenched with water. This mixture was then extracted with EtOAc. The combined organic layers were dried over MgSO₄, filtered, then concentrated with the aid of a rotary evaporator. The resulting residue was then purified by flash chromatography on silica gel eluting with 1:1 to 2:1 EtOAc:Hexane to give 724 mg (92%) of the title compound as a white solid. M.p.: 106-108 °C. 

1H NMR (300 MHz, CDCl₃) δ: 6.74 (s, 1H), 6.43 (s, 2H), 5.95 (s, 2H), 4.30 (s, 2H), 3.86 (s, 3H), 3.80 (s, 9H), 2.09 (s, 1H); 13C NMR (75 MHz, CDCl₃) δ: 152.9, 148.6, 141.0, 136.9, 136.4, 133.6, 131.5, 127.4, 107.3, 102.9, 101.3, 62.9, 60.9, 60.1, 56.1; IR (cm⁻¹): 3481, 1584, 1507, 1457, 1410, 1238, 1126, 1059; Anal. Calcd. for C₁₈H₂₀O₇: C, 62.06; H, 5.79. Found: C, 62.06; H, 5.82.

A 100 mL round bottom flask equipped with a Teflon-coated magnetic stir bar was charged with 13 (660 mg, 1.9 mmol) and CH₂Cl₂ (28 mL). To the stirring solution was added MnO₂ (1.65 g, 19 mmol) in one portion. This suspension was allowed to stir at room temperature for 2 h (at which time complete conversion of the starting material was confirmed by TLC and 1H NMR). The reaction mixture was filtered through a plug of celite, eluting with CH₂Cl₂. The solution was then concentrated to dryness with the aid of a rotary evaporator, then used in the next reaction without further purification.

A flame-dried 100 mL round bottom flask equipped with a Teflon-coated magnetic stir bar was charged with 13 (660 mg, 1.9 mmol) and CH₂Cl₂ (28 mL). To the stirring solution was added MnO₂ (1.65 g, 19 mmol) in one portion. This suspension was allowed to stir at room temperature for 2 h (at which time complete conversion of the starting material was confirmed by TLC and 1H NMR). The reaction mixture was filtered through a plug of celite, eluting with CH₂Cl₂. The solution was then concentrated to dryness with the aid of a rotary evaporator, then used in the next reaction without further purification.

5-{7-Methoxy-6-[(3,4,5-trimethoxy-phenyl)-benzo[1,3]dioxole-5-carbaldehyde

A flame-dried 100 mL round bottom flask equipped with a Teflon-coated magnetic stir bar was charged with 13 (660 mg, 1.9 mmol) and CH₂Cl₂ (28 mL). To the stirring solution was added MnO₂ (1.65 g, 19 mmol) in one portion. This suspension was allowed to stir at room temperature for 2 h (at which time complete conversion of the starting material was confirmed by TLC and 1H NMR). The reaction mixture was filtered through a plug of celite, eluting with CH₂Cl₂. The solution was then concentrated to dryness with the aid of a rotary evaporator, then used in the next reaction without further purification.
with saturated aqueous ammonium chloride and allowed to warm to room temperature. The reaction mixture was then extracted three times with EtOAc. The combined organic layers were then washed with brine, dried over MgSO₄, filtered, and concentrated to dryness with the aid of a rotary evaporator. The resulting residue was then purified by flash chromatography on silica gel eluting with 2:1 to 1:1 Hexane:EtOAc to give 600mg (76%) of the title compound as a white solid. M.p. : 166-168 °C. ¹H NMR (300 MHz, CDCl₃) δ: 6.52 (d, J=2Hz, 1H), 6.39 (d, J=2Hz, 1H), 6.23 (s, 1H), 5.97 (dd, J=2Hz, 4Hz, 2H), 5.87 (m, 1H), 5.56 (m, 1H), 3.87 (s, 3H), 3.83 (s, 3H), 3.82 (s, 3H), 3.81 (s, 3H), 1.83 (m, 3H); ¹³C NMR (75 MHz, CDCl₃) δ: 173.5, 168.5, 153.7, 153.3, 153.1, 151.7, 143.3, 131.0, 130.7, 127.6, 117.2, 107.8, 107.7, 104.7, 83.5, 79.0, 61.5, 61.1, 56.4, 14.6; IR (cm⁻¹): 2940, 2252, 1760, 1583, 1477, 1411, 1237, 1127; Anal. Calcd. for C₂₂H₂₂O₈: C, 63.76; H, 5.35. Found: C, 63.66; H, 5.33.

An oven-dried screw cap test tube equipped with a Teflon-coated magnetic stir bar was charged with copper (II) chloride dihydrate (2.1 mg, 0.013 mmol), (S)-BIPHEP (7.3 mg, 0.013 mmol), and sodium tert-butoxide (29 mg, 0.30 mmol). The tube was then sealed with a Teflon-centered screw cap, then evacuated, backfilled with argon, and the cycle was repeated. THF (2 mL) was then added to the tube and the mixture was allowed to stir at room temperature for 5 minutes. PMHS (90 µL, 1.5 mmol) was then added dropwise and allowed to stir for 5 minutes. Following this, 10 was added as a solution in THF / CH₂Cl₂ / t-BuOH (1.75 mL / 1.25 mL / 375 µL) and allowed to stir at room temperature for 24 h, at which point TLC indicated complete conversion of the starting material. At this point, an equal volume of 3N HCl was carefully added to the reaction and allowed to stir for 15 minutes. This was then extracted 3 times with EtOAc. The combined organics were dried over MgSO₄, filtered, and concentrated to dryness with the aid of a rotary evaporator. The resulting residue was then purified by flash chromatography on silica gel eluting with 1:6 to 1:1 EtOAc:Hexane to give 89 mg (85%) of the title compound a white solid. M.p.: 52-54 °C. Chiral HPLC analysis (Daicel Chiralpak® AD column (0.46cm x 25 cm), 1 mL/min, 50% i-PrOH/ Hexane, 254 nm, 210 nm, 225 nm, retention times: 9.29 min (major), 20.3 min (minor)) showed 92% ee. ¹H NMR (300 MHz, CDCl₃) δ: 6.73 (s, 1H), 6.41 (d, J=2Hz, 1H), 6.30 (d, J=2Hz, 1H), 6.00 (s, 2H), 5.37 (d, J=6Hz, 1H), 3.91 (s, 3H), 3.85 (s, 3H), 3.84 (s, 3H), 3.82 (s, 3H), 2.68 (dd, J=8Hz, 17Hz, 1H), 2.26 (m, 2H), 0.74 (d, J=7Hz, 3H); ¹³C NMR (75 MHz, CDCl₃) δ: 176.5, 153.5, 153.2, 148.9, 141.1, 137.4, 136.5, 131.3, 129.1, 126.5, 107.7, 106.4, 101.6, 101.0, 82.1, 61.1, 60.2, 56.3, 56.2, 37.9, 34.4, 15.7; IR (cm⁻¹): 2360, 1780,
1583, 1479, 1410, 1238, 1165, 1058; Anal. Calcd. for C_{22}H_{24}O_8: C, 63.45; H, 5.81. Found: C, 63.32; H, 5.45. α_D (589 nm, 2.2 g/100 mL CHCl_3) = -10.9°.

A flame-dried 25 mL round bottom flask equipped with a Teflon-coated magnetic stir bar was brought into a drybox and charged with sodium hexamethyldisilazide (66 mg, 0.36 mmol). The flask was sealed with a rubber septum and then removed from the drybox. A balloon filled with argon was inserted through the septum, then THF (2 mL) was added. The flask was then cooled to −78 °C. 12 (75 mg, 0.18 mmol) was then added slowly as a solution in THF (10 mL) over 30 minutes, and then allowed to stir for an additional 4 h. Iodomethane (224 µL, 3.6 mmol) was added dropwise, then allowed to stir for 1 h. The reaction was then allowed to gradually warm to −20 °C. The reaction was then quenched with water (3 mL) and allowed to warm to room temperature. The reaction mixture was then extracted three times with EtOAc. The combined organic layers were then dried over MgSO_4, filtered, and concentrated to dryness with the aid of a rotary evaporator. The resulting residue was then purified by flash chromatography on silica gel eluting with 5:1 to 1:1 Hexane:EtOAc to give 66 mg (85%) of the title compound as a colorless oil. Chiral HPLC analysis (Daicel Chiralpak® AD column (0.46cmØ x 25 cm), 1 mL/ min, 50% i-PrOH/ Hexane, 254 nm, 210 nm, 225 nm, retention times: 5.9 min (major), 7.9 min (minor)) showed 93% ee. 1H NMR (300 MHz, CDCl_3) δ: 6.54 (s, 1H), 6.41 (d, J=2Hz, 1H), 6.32 (d, J=2Hz, 1H), 5.99 (s, 2H), 5.48 (d, J=7.3Hz, 1H), 5.89 (s, 3H), 3.84 (s, 3H), 3.83 (s, 3H), 3.82 (s, 3H), 2.38 (quintet, J=7.3Hz, 1H), 2.04 (sextet, J=7.3Hz, 1H), 1.16 (d, J=7.3Hz, 3H), 0.77 (d, J=7.3Hz, 3H); 13C NMR (75 MHz, CDCl_3) δ: 179.6, 153.4, 153.1, 149.0, 141.1, 137.3, 136.6, 131.2, 129.2, 127.5, 108.2, 106.7, 101.5, 100.8, 79.9, 61.0, 60.1, 56.3, 41.9, 41.7, 35.2, 15.3, 14.8; IR (cm⁻¹): 1772, 1583, 1507, 1479, 1410, 1238, 1127, 1086; Anal. Calcd. for C_{23}H_{26}O_8: C, 64.18; H, 6.09. Found: C, 64.35; H, 6.23. α_D (589 nm, 2.1 g/100 mL CHCl_3) = -27.4°.

**Part III. Synthesis of unsaturated lactones**

**General procedure for the synthesis of α,β-unsaturated lactones:**

All unsaturated lactones examined were prepared following the procedure described by Knochel.ⁱ³
$^1$H NMR (300 MHz, CDCl$_3$) δ: 7.39 (m, 3H), 7.25 (m, 2H), 5.93 (m, 1H), 5.71 (m, 1H), 1.91 (m, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ: 173.6, 168.7, 134.4, 129.6, 129.2, 126.9, 116.4, 86.7, 14.2; IR (cm$^{-1}$): 2360, 1761, 1646, 1456, 1290, 1147, 1023, 978; Anal. Calcd. for C$_{11}$H$_{10}$O$_2$: C, 75.84; H, 5.79. Found: C, 75.76; H, 5.91.

5-Biphenyl-2-yl-4-methyl-5H-furan-2-one

$^1$H NMR (300 MHz, CDCl$_3$) δ: 7.39 (m, 8H), 7.11 (m, 1H), 5.91 (m, 1H), 5.87 (m, 1H), 1.81 (m, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ: 173.6, 168.7, 143.3, 139.7, 131.3, 130.7, 129.6, 129.3, 128.6, 128.3, 127.8, 126.7, 117.1, 83.3, 14.4; IR (cm$^{-1}$): 1762, 1646, 1481, 1437, 1290, 1149, 1021, 974; Anal. Calcd. for C$_{17}$H$_{14}$O$_2$: C, 81.58; H, 5.64. Found: C, 81.32; H, 5.44.

5-(2,4-Dimethoxy-phenyl)-4-methyl-5H-furan-2-one

$^1$H NMR (300 MHz, CDCl$_3$) δ: 6.94 (m, 1H), 6.46 (m, 2H), 6.16 (s, 1H), 5.86 (m, 1H), 3.82 (s, 3H), 3.80 (s, 3H), 1.91 (m, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ: 174.1, 169.7, 161.7, 158.6, 128.2, 116.3, 114.8, 105.1, 98.8, 81.1, 55.7, 55.6, 14.2; IR (cm$^{-1}$): 2941, 1758, 1612, 1508, 1303, 1210, 1159, 1031; Anal. Calcd. for C$_{13}$H$_{14}$O$_4$: C, 66.66; H, 6.02. Found: C, 66.32; H, 5.84.

4-Methyl-5-o-tolyl-5H-furan-2-one

$^1$H NMR (300 MHz, CDCl$_3$) δ: 7.36 (m, 3H), 7.25 (m, 2H), 5.93 (m, 1H), 5.71 (m, 1H), 1.91 (m, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) δ: 173.6, 168.7, 134.4, 129.6, 129.2, 126.9, 116.4, 86.7, 14.2; IR (cm$^{-1}$): 2360, 1761, 1646, 1456, 1290, 1147, 1023, 978; Anal. Calcd. for C$_{11}$H$_{10}$O$_2$: C, 75.84; H, 5.79. Found: C, 75.76; H, 5.91.
$^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.24 (m, 3H), 7.01 (m, 1H), 6.02 (m, 1H), 5.96 (m, 1H), 2.43 (s, 3H), 1.94 (m, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 173.6, 168.8, 136.8, 132.3, 131.3, 129.4, 126.8, 126.6, 117.2, 83.6, 19.4, 14.3; IR (cm$^{-1}$): 2980, 1761, 1289, 1173, 1029; Anal. Calcd. for C$_{12}$H$_{12}$O$_2$: C, 76.57; H, 6.43.  Found: C, 76.63; H, 6.38.

4-Methyl-5-(2-trifluoromethyl-phenyl)-5H-furan-2-one

$^{1}$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.74 (d, $J=7$Hz, 1H), 7.54 (ddd, $J=7$Hz, 2H), 7.21 (d, $J=7$Hz, 1H), 6.18 (m, 1H), 6.02 (m, 1H), 1.89 (m, 3H); $^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$: -57.3; $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 173.2, 168.6, 133.2, 132.9, 129.7, 127.7, 126.3, 126.2, 117.4, 81.2, 81.1, 14.2; IR (cm$^{-1}$): 1767, 1315, 1285, 1161, 1114, 1028; Anal. Calcd. for C$_{12}$H$_{9}$F$_3$O$_2$: C, 59.51; H, 3.75.  Found: C, 59.74; H, 3.74

Part IV. Asymmetric reduction of unsaturated lactones

**General Procedure:**

An oven-dried screw cap test tube equipped with a Teflon-coated magnetic stir bar was charged with copper(II) chloride dihydrate (5 mol%), (R)-SYNPHOS (5 mol%), and sodium tert-butoxide (1.2 equiv). The tube was then sealed with a Teflon centered screw cap. Next, the tube was evacuated, backfilled with argon, and this process was repeated. THF (2.5 mL) was then added to the tube via syringe and the mixture was allowed to stir at room temperature for 5 minutes. To this mixture was then added PMHS (6 equiv) dropwise, and then the mixture was allowed to stir for an additional 5 minutes. The unsaturated lactone (0.3 mmol) was then added to the reaction as a solution in THF (2 mL), CH$_2$Cl$_2$ (1.5 mL) and r-BuOH (450 µL). The reaction was allowed to stir at room temperature until complete conversion of the starting material was obtained (as judged by TLC or GC). The reaction was then carefully quenched with an equal volume of 3N HCl, and allowed to stir for 15-30 minutes. The mixture was then extracted three times with EtOAc. The combined organic layers were then dried over MgSO$_4$, filtered, and concentrated to dryness with the aid of a rotary evaporator. The crude residue was purified by flash chromatography on silica gel to give the desired compound.

4-Methyl-5-phenyl-dihydro-furan-2-one

The general procedure was employed using 52 mg (0.3 mmol) of 8a. Purification via flash chromatography on silica gel eluting with 1:9 EtOAc:Hexane gave 50 mg (95%) of
the title compound as a colorless oil. Chiral HPLC analysis (Daicel Chiralpak® OJ column (0.46cm x 25 cm), 1.2 mL/min, 2% i-PrOH/Hexane, 254 nm, 210 nm, 225 nm, retention times: 25.9 min (minor), 30.1 min (major)) showed 68% ee. 

$^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.33 (m, 3H), 7.21 (m, 2H), 5.56 (d, $J=6$Hz, 1H), 2.79 (m, 2H), 2.30 (dd, $J=4$Hz, 17Hz, 1H), 0.65 (d, $J=7$Hz, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 177.0, 136.2, 128.6, 128.2, 125.5, 84.2, 37.2, 35.1, 15.3; IR (cm$^{-1}$): 1780, 1456, 1157, 913, 749; Anal. Calcd. for C$_{11}$H$_{12}$O$_2$: C, 74.98; H, 6.86. Found: C, 75.22; H, 6.94. $\alpha_D$ (589 nm, 1.3g/100 mL CHCl$_3$) = 16.9°.

5-Biphenyl-2-yf 4-methyl-dihydro-furan-2-one

The general procedure was employed using 75 mg (0.3 mmol) of 9a. Purification via flash chromatography on silica gel eluting with 1:9 EtOAc:Hexane gave 69 mg (91%) of the title compound as a colorless oil. Chiral HPLC analysis (Daicel Chiralpak® OJ column (0.46cm x 25 cm), 1 mL/min, 8% i-PrOH/Hexane, 254 nm, 210 nm, 225 nm, retention times: 17.4 min (major), 20.8 min (minor) showed 79% ee. 

$^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.53 (m, 1H), 7.40 (m, 5H), 7.25 (m, 2H), 7.2 (m, 1H), 5.67 (d, $J=6$Hz, 1H), 2.67 (dd, $J=8$Hz, 17Hz, 1H), 2.21 (m, 2H), 0.64 (d, $J=7$Hz, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 176.6, 140.5, 140.2, 133.7, 130.0, 128.8, 128.6, 127.8, 127.7, 127.6, 125.8, 82.2, 37.9, 33.9, 15.7; IR (cm$^{-1}$): 1783, 1479, 1306, 1213, 1164, 987, 756; Anal. Calcd. for C$_{17}$H$_{16}$O$_2$: C, 80.93; H, 6.39. Found: C, 81.21; H, 6.45. $\alpha_D$ (589 nm, 5.2g/100 mL CHCl$_3$) = 28.9°.

5-(2.4-Dimethoxy-phenyl)-4-methyl-dihydro-furan-2-one

The general procedure was employed using 70 mg (0.3 mmol) of 10a. Purification via flash chromatography on silica gel eluting with 1:3 EtOAc:Hexane gave 60 mg (85%) of the title compound as a colorless oil. Chiral HPLC analysis (Daicel Chiralpak® OD column (0.46cm x 25 cm), 1 mL/min, 10% i-PrOH/Hexane, 254 nm, 210 nm, 225 nm, retention times: 9.66 min (minor), 26.0 min (major) showed 87% ee. 

$^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.21 (d, $J=8$Hz, 1H), 6.49 (dd, $J=2$Hz, 8Hz, 1H), 6.46 (d, $J=2$Hz, 1H), 5.75 (d, $J=6$Hz, 1H), 3.81 (s, 3H), 3.80 (s, 3H), 2.97 (m, 1H), 2.82 (dd, $J=8$Hz, 17Hz, 1H), 2.31 (dd, $J=4$Hz, 17Hz, 1H), 0.67 (d, $J=7$Hz, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 177.3, 160.7, 157.0, 127.1, 117.2, 103.9, 98.4, 81.2, 55.5, 55.4, 37.4, 33.6, 15.3; IR (cm$^{-1}$): 1780, 1456, 1157, 913, 749; Anal. Calcd. for C$_{17}$H$_{16}$O$_2$: C, 80.93; H, 6.39. Found: C, 81.21; H, 6.45. $\alpha_D$ (589 nm, 5.2g/100 mL CHCl$_3$) = 28.9°.
1): 1780, 1616, 1590, 1287, 1210, 1160, 1033, 987; Anal. Calcd. for C$_{13}$H$_{16}$O$_4$: C, 66.09; H, 6.83. Found: C, 66.39; H, 6.87. $\alpha_D$ (589 nm, 3.9 g/100 mL CHCl$_3$) = 30.5°.

The general procedure was employed using 56 mg (0.3 mmol) of 11a. Purification via flash chromatography on silica gel eluting with 1:4 EtOAc:Hexane gave 52 mg (91%) of the title compound as a colorless oil. Chiral HPLC analysis (Daicel Chiralpak® OJ column (0.46 cm x 25 cm), 1 mL/min, 10% i-PrOH/Hexane, 254 nm, 210 nm, 225 nm, retention times: 12.7 min (major), 13.9 min (minor) showed 80% ee. $^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.4 (m, 1H), 7.23 (m, 3H), 5.76 (d, $J$=6Hz, 1H), 2.95 (m, 2H), 2.33 (m, 4H), 0.64 (d, $J$=7Hz, 3H); $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 176.7, 134.4, 133.7, 130.4, 128.0, 126.2, 125.3, 82.1, 33.2, 19.3, 15.6; IR (cm$^{-1}$): 1783, 1462, 1305, 1212, 1163, 987, 912, 750; Anal. Calcd. for C$_{12}$H$_{14}$O$_2$: C, 75.76; H, 7.42. Found: C, 75.46; H, 7.23. $\alpha_D$ (589 nm, 2.1 g/100 mL CHCl$_3$) = 37.2°.

The general procedure was employed using 69 mg (0.3 mmol) of 12a. Purification via flash chromatography on silica gel eluting with 1:4 EtOAc:Hexane gave 69 mg (93%) of the title compound as a colorless oil. Chiral HPLC analysis (Daicel Chiralpak® AD column (0.46 cm x 25 cm), 1 mL/min, 10% i-PrOH/Hexane, 254 nm, 210 nm, 225 nm, retention times: 5.63 min (minor), 6.46 min (major) showed 78% ee. $^1$H NMR (300 MHz, CDCl$_3$) $\delta$: 7.68 (m, 3H), 7.47 (m, 1H), 5.97 (d, $J$=6Hz, 1H), 3.00 (m, 2H), 2.38 (m, 1H), 0.66 (d, $J$=7Hz, 3H); $^{19}$F NMR (282 MHz, CDCl$_3$) $\delta$: -59.5; $^{13}$C NMR (75 MHz, CDCl$_3$) $\delta$: 176.5, 136.2, 132.9, 128.7, 127.5, 126.3, 126.2, 117.4, 81.2, 37.5, 35.4, 14.2; IR (cm$^{-1}$): 1791, 1457, 1315, 1273, 1162, 1037, 990, 771; Anal. Calcd. for C$_{12}$H$_{11}$F$_3$O$_2$: C, 59.02; H, 4.54. Found: C, 59.32; H, 4.67. $\alpha_D$ (589 nm, 2.8 g/100 mL CHCl$_3$) = 24.9°.