Stereoselective Synthesis of Z- α -Aryl- α,β -unsaturated Esters

Neelakandha S. Mani,^{*} Christopher M. Mapes, Jiejun Wu, Xiaohu Deng, and Todd K. Jones

Johnson & Johnson Pharmaceuticals Research and Development, L.L.C., 3210 Merryfield Row, San Diego, CA 92121
(USA)

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General: All reactions were conducted under a slight positive pressure of nitrogen. Dichloromethane, toluene, acetonitrile, THF, diethyl ether were dried by passing through activated alumina cylinders under argon. Standard syringe techniques were used in all reactions. Flash chromatography was performed using EM Science silica gel 60 (230-400 mesh). All glassware was oven dried and cooled under nitrogen to room temperature before use. Melting points were determined using an electrothermal apparatus and are uncorrected. IR spectra were recorded on a FTIR spectrophotometer. ^1H NMR and ^{13}C NMR spectra were recorded using a 400 MHz spectrometer (^1H at 400 MHz and ^{13}C at 100 MHz) and unless otherwise mentioned, CDCl_3 was used as the solvent with TMS as internal standard.

General procedures for the preparation of α -hydroxy esters (6)

Method A: Alkylation of mandelic acid methyl ester (entries 1,3,4,5,7,and 8)

To a solution of mandelic acid methyl ester (12 mmol) in 30 mL of dry tetrahydrofuran at $-78\text{ }^\circ\text{C}$, under nitrogen, was added LiHMDS (1M solution in THF, 26.4 mL). After the addition, the reaction mixture was allowed to warm up to $0\text{ }^\circ\text{C}$ (1 h) and then re-cooled to $-78\text{ }^\circ\text{C}$. A solution of the alkyl bromide (12.5 mmol) in 5 mL of dry THF was then added. The cooling bath was removed, and the reaction allowed to slowly warm up to room temperature (3-4 h). The reaction was quenched with aqueous ammonium chloride (10 mL), diluted with ethyl acetate (150 mL) and transferred to a separatory funnel. The organic layer was washed with water, brine, and dried over Na_2SO_4 . After filtration, the solvents were evaporated and the residue purified by flash column silica gel chromatography using hexanes/ethyl acetate as eluent.

Method B: Addition of Grignard reagent to α -ketoesters (entry 2 and compound 7)

To a solution of methyl benzoylformate (6.1mmol) in 20 mL of dry diethyl ether at -78°C , under nitrogen, was added 2-methoxybenzylmagnesiumchloride (0.25M solution in THF, 25.6 mL, 1.05 eq.) dropwise. After the addition, the cooling bath was removed, and the reaction was stirred for 10-12 h while allowing to slowly warm up to room temperature. The reaction was quenched with aqueous ammonium chloride (20 mL). 50 mL of ethyl acetate was then added and the mixture transferred to a separatory funnel. The layers were separated and the organic layer was washed with water, brine, and dried over Na_2SO_4 . After filtration, the solvents were evaporated and the product is purified by recrystallization using 10% hexanes/ethyl acetate.

2-Hydroxy-2,3-diphenylpropionic acid methyl ester (entry 1)

$\text{C}_{16}\text{H}_{16}\text{O}_3$
Exact Mass: 256.1099
Mol. Wt.: 256.2964

Obtained according to method A in 67% yield as a white crystalline solid. Mp $86-87^{\circ}\text{C}$; IR (film): 3317, 2947, 2834, 1716, 1494, 1447, 1432, 1255, 1212, 1202, 1183, 1113, 1099, 1023, 969, 946, 745, 728, 695, 690 cm^{-1} ; ^1H NMR (CDCl_3 , 400 MHz) δ 3.20 (d, $J = 13.6\text{ Hz}$, 1H), 3.59 (s, 1H), 3.59 (d, $J = 13.5\text{ Hz}$, 1H), 3.73 (s, 3H), 7.20-7.28 (m, 5H), 7.30-7.31 (m, 1H), 7.36-7.38 (m, 2H), 7.67-7.69 (m, 2H); ^{13}C NMR (CDCl_3 , 100 MHz) δ 45.9, 53.1, 78.8, 125.7, 127.0, 127.9, 128.1, 128.3, 130.4, 135.6, 141.4, 174.7; HRMS (EI): m/z calcd $\text{C}_{16}\text{H}_{16}\text{NaO}_3$ $[\text{M}+\text{H}]^+$ 279.0992, found 279.0985.

2-Hydroxy-3-(2-methoxyphenyl)-2-phenylpropionic acid methyl ester (entry 2)

$\text{C}_{17}\text{H}_{18}\text{O}_4$
Exact Mass: 286.1205
Mol. Wt.: 286.3224

Obtained according to method B using 2-methoxybenzylmagnesium chloride as the Grignard reagent in 79% yield as a white crystalline solid (recrystallized from 10% EtOAc/Hexanes). Mp 115-116 °C; IR (neat): 3328, 2982, 2833, 1724, 1494, 1447, 1272, 1242, 1173, 1125, 1101, 1021, 968, 938, 780, 752, 694 cm^{-1} ; ^1H NMR (CDCl_3 , 400 MHz) δ 3.34 (d, $J = 13.9$ Hz, 1H), 3.70 (s, 3H), 3.74 (d, $J = 13.9$ Hz, 1H), 3.81 (s, 3H), 4.13 (s, 1H), 6.83-6.87 (m, 2H), 7.08-7.10 (m, 1H), 7.19-7.22 (m, 1H), 7.27-7.30 (m, 1H), 7.33-7.36 (m, 2H), 7.65-7.67 (m, 2H); ^{13}C NMR (CDCl_3 , 100 MHz) δ 40.2, 52.8, 55.4, 79.0, 110.4, 120.7, 124.0, 125.7, 127.6, 128.0, 128.3, 132.5, 141.8, 157.6, 174.6; HRMS (EI): m/z calcd for $\text{C}_{17}\text{H}_{18}\text{NaO}_4 [\text{M}+\text{H}]^+$ 309.1097, found 309.1090.

3-Biphenyl-4-yl-2-hydroxy-2-phenylpropionic acid methyl ester (entry 3)

$\text{C}_{22}\text{H}_{20}\text{O}_3$
Exact Mass: 332.1412
Mol. Wt.: 332.3924
C, 79.50; H, 6.06; O, 14.44

Obtained according to method A in 75% yield as a white crystalline solid. Mp 135-136 °C; IR (film): 3525, 3031, 1721, 1487, 1447, 1251, 1209, 1117, 1072, 1040, 843, 780, 760, 730, 692, 650 cm^{-1} ; ^1H NMR δ : 3.24 (d, $J = 13.2$, 1H), 3.61 (d, $J = 13.2$ Hz, 1H), 3.64 (s, 1H), 3.76 (s, 3H), 7.2-7.7 (m, 9H); ^{13}C NMR δ : 45.5, 53.0, 78.8, 125.6, 126.7, 126.9, 127.1, 127.9, 128.3, 128.7, 130.8, 134.7, 139.7, 140.8, 141.4, 174.7; HRMS (EI): m/z calcd for $\text{C}_{22}\text{H}_{19}\text{O}_2 [\text{M}-\text{H}_2\text{O}]^+$ 315.1385, found 315.1372.

2-Hydroxy-2-phenylbutyric acid methyl ester (entry 4)

$\text{C}_{11}\text{H}_{14}\text{O}_3$
Exact Mass: 194.0943
Mol. Wt.: 194.2271
C, 68.02; H, 7.27; O, 24.71

Obtained according to method A in 72% yield as a colorless oil. IR (film): 3514, 2968, 1726, 1446, 1239, 1194, 1145, 1066, 1007, 768, 731, 698 cm^{-1} ; ^1H NMR δ 0.91 (3H, t, J = 7.2 Hz), 2.01 (1H, m), 2.20 (m, 1H), 3.76 (3H, s), 3.77 (1H, s), 7.26-7.36 (3H, m), 7.58 (2H, m); ^{13}C NMR δ : 7.9, 32.6, 53.1, 78.7, 125.5, 127.6, 128.1, 141.7, and 175.7; HRMS (EI): m/z calcd for $\text{C}_{11}\text{H}_{14}\text{O}_3\text{Na}$ $[\text{M}+\text{Na}]^+$ 217.0841, found 217.0838.

2-Hydroxy-4-methyl-2-phenylpentanoic acid methyl ester (entry 5)

$\text{C}_{13}\text{H}_{18}\text{O}_3$
Exact Mass: 222.1256
Mol. Wt.: 222.2802
C, 70.24; H, 8.16; O, 21.59

Obtained according to method A in 71% yield as a colorless oil. IR (film): 3510, 2955, 1724, 1446, 1243, 1149, 1071, 769, 730, 698 cm^{-1} ; ^1H NMR δ : 0.89 dd, J = 4.4, 6.4 Hz, 6H), 1.83 (m, 1H), 1.97 (dd, J = 5.2, 14.0 Hz, 1H), 2.11 (dd, J = 7.2, 14.0 Hz, 1H), 3.77 (s, 3H), 4.77 (s, 1H), 7.25-7.35 (m, 3H), 7.60 (m, 2H); ^{13}C NMR δ : 23.0, 24.3, 24.6, 47.9, 53.0, 78.2, 125.4, 127.5, 128.1, 142.6, 176.3; HRMS (EI): m/z calcd for $\text{C}_{13}\text{H}_{18}\text{O}_3\text{Na}$ $[\text{M}+\text{Na}]^+$ 245.1154, found 245.1149.

2-Hydroxy-2-phenylsuccinic acid dimethyl ester (entry 6)

$\text{C}_{12}\text{H}_{14}\text{O}_5$
Exact Mass: 238.0841
Mol. Wt.: 238.2366

Obtained by the procedure detailed in reference 1 in 43% yield as a, clear, colorless oil. All analytical information matches with that reported in reference 2. HRMS (EI): m/z calcd for $\text{C}_{12}\text{H}_{15}\text{O}_5^+$ 239.0914 found 239.0905.

1 Rondestvedt, C.S.; Filbey, A.H.; *J. Org. Chem.* **1954**, 19, 119-128.

- 2 Blay, G.; Fernandez, I.; Formentin, B.M.; Pedro, J.R.; Ruiz, R.; *Tetrahedron*, **2001**, 57, 1075-1081.

2-(3-chlorophenyl)-2-hydroxypent-4-ynoic acid methyl ester (entry 7)

$C_{12}H_{11}ClO_3$
 Exact Mass: 238.0397
 Mol. Wt.: 238.6666
 C, 60.39; H, 4.65; Cl, 14.85; O, 20.11

Obtained according to method A in 80% yield as a pale yellow oil. IR (film): 3504, 3296, 2955, 1734, 1594, 1573, 1476, 1421, 1280, 1258, 1222, 1186, 1120, 1080, 1052, 998, 957, 888, 793, 774, 752, 712, 684, 651 cm^{-1} ; 1H NMR δ : 2.06 (t, $J = 2.8$ Hz, 1H), 2.80 (dd, $J = 2.6, 16.5$ Hz, 1H), 3.12 (dd, $J = 2.6, 16.5$ Hz), 3.84 (s, 3H), 7.29 (m, 2H), 7.3-7.6 (m, 1H), 7.61 (m, 1H); ^{13}C NMR δ : 31.0, 53.7, 71.4, 76.6, 78.4, 123.7, 125.8, 128.4, 129.6, 134.4, 141.7, 173.3; HRMS (EI): m/z calcd for $C_{12}H_{12}ClO_3$ $[M+H]^+$, 239.0397, found 239.0402.

2-Hydroxy-2-phenylpent-4-enoic acid methyl ester (entry 8)

$C_{12}H_{14}O_3$
 Exact Mass: 206.0943
 Mol. Wt.: 206.2378

Obtained according to method A in 78% yield as a colorless oil. IR (film): 3507, 2954, 1728, 1640, 1493, 1437, 1229, 1143, 1093, 1070, 1032, 920, 732, 697 cm^{-1} ; 1H NMR δ : 2.75 (1H, dd, $J = 6.4, 14.0$ Hz), 2.96 (1H, dd, $J = 7.6, 14.0$ Hz), 3.73 (1H, s), 3.76 (3H, s), 5.14 (m, 2H), 5.78 (1H, m), 7.33 (3H, m), 7.60 (2H, m); ^{13}C NMR δ : 44.1, 53.1, 78.1, 119.3, 125.5, 127.8, 128.2, 132.3, 141.2, 175.0; HRMS (EI): m/z calcd for $C_{12}H_{14}O_3$ $[M+Na]^+$ 229.0841, found 229.0834.

2-Hydroxy-2,3-diphenylpropionic acid isopropyl ester (entry 9)

$C_{18}H_{20}O_3$
 Exact Mass: 284.1412
 Mol. Wt.: 284.3496

To a solution of 2-Hydroxy-2,3-diphenyl-propionic acid methyl ester (3.9 mmol) in 16 mL of THF/methanol (3:1) was added LiOH (11.7 mmol, 3 eq.) dissolved in 4 mL of water. The reaction was aged at room temperature for 24 hours. After removing all solvents by evaporation under reduced pressure, the residue was taken up in 20 mL of 1N HCl. The resultant mixture was transferred to a separatory funnel and extracted with EtOAc (3 X 15 mL). All organic layers were combined, washed with brine and dried over $MgSO_4$. After filtration, the solvents were evaporated under reduced pressure to yield 2-Hydroxy-2,3-diphenyl-propionic acid in 100% yield as a white solid. Mp 165-166 °C; IR (neat): 3424, 1715, 1493, 1454, 1262, 1189, 1099, 1075, 792, 692 cm^{-1} ; 1H NMR ($CDCl_3$, 400 MHz) δ 3.18 (d, J = 13.6 Hz, 1H), 3.56 (d, J = 13.6 Hz, 1H), 7.14-7.22 (m, 5H), 7.24-7.27 (m, 1H), 7.31-7.34 (m, 2H), 7.64-7.66 (m, 2H); ^{13}C NMR ($MEOD_6$, 100 MHz) δ 46.7, 79.9, 126.9, 127.5, 128.6, 128.7, 129.1, 131.9, 137.8, 143.9, 177.2; HRMS (EI): m/z calcd for $C_{15}H_{13}O_3^-$ 241.0859, found 241.0867.

To a solution of 2-Hydroxy-2,3-diphenyl-propionic acid (1.03 mmol) in 19 mL of isopropanol was added 1.0 mL of 12 N HCl. The reaction mixture was then refluxed for 48 hours. After cooling to room temperature, the solvents were evaporated under reduced pressure and the residue purified by flash column silica gel chromatography using hexanes/ethyl acetate as eluent to yield the isopropyl ester as a white solid, (0.25 g, 85%). Mp 50-51 °C; IR (neat): 3498, 2981, 1720, 1601, 1495, 1453, 1375, 1261, 1210,

1179, 1101, 1069, 1032, 911, 842, 773, 730, 655 cm^{-1} ; ^1H NMR (CDCl_3 , 400 MHz) δ 1.15 (d, $J = 6.3$ Hz, 3H), 1.26 (d, $J = 6.3$ Hz, 3H), 3.21 (d, $J = 13.7$ Hz, 1H), 3.54 (d, $J = 13.7$ Hz, 1H), 3.70 (s, 1H), 4.98 (septuplet, $J = 6.3$ Hz, 1H), 7.22-7.32 (m, 6H), 7.35-7.38 (m, 2H), 7.68-7.70 (m, 2H); ^{13}C NMR (CDCl_3 , 100 MHz) δ 21.5, 21.7, 45.8, 70.6, 78.5, 125.6, 126.8, 127.7, 127.9, 128.1, 130.6, 135.9, 141.9, 173.8; HRMS (EI): m/z calcd for $\text{C}_{18}\text{H}_{20}\text{NaO}_3$ $[\text{M}+\text{Na}]^+$ 307.1305, found 307.1314.

2-Hydroxy-2-methyl-3-phenylpropionic acid ethyl ester (compound 8)

Prepared by method B using benzylmagnesium chloride as the Grignard reagent. Colorless oil, yield 80%; IR (film): 3521, 2981, 1728, 1495, 1452, 1264, 1200, 1156, 1106, 1019, 959, 768, 744, 701, 613; ^1H NMR δ : 1.24 (t, $J = 7.2$ Hz, 3H), 1.48 (s, 3H), 2.89 (d, $J = 13.6$ Hz, 1H), 3.05 (d, $J = 13.6$ Hz, 1H), 3.09 (s, 1H), 4.15 (q, 2H), 7.17-7.28 (m, 5H); ^{13}C NMR δ : 14.1, 25.8, 46.3, 61.7, 75.0, 126.8, 128.1, 130.0, 135.9, 176.0; HRMS (EI): m/z calcd for $\text{C}_{12}\text{H}_{17}\text{O}_3$ $[\text{M}+\text{H}]^+$, 209.1174, found 209.1168.

General procedure for the dehydration of α -hydroxy esters (entries 1-9)

To a solution of the hydroxyl ester (1.0 mmol.) in anhydrous CH_2Cl_2 (10 mL) cooled to 0 $^\circ\text{C}$ using an ice bath was added triflic anhydride (0.31 g, 1.1 mmol). After 10 min, anhydrous pyridine (0.4 mL, 5.0 mmol) was added drop wise. The reaction mixture was stirred for 10-12 h while allowing to slowly warm up to room temperature. The reaction was then quenched by the addition of water (20 mL) and the mixture transferred to a separatory funnel. The layers were separated and the aqueous layer was extracted with CH_2Cl_2 (2 x 30 mL). All organic layers were combined, washed with brine, dried over

MgSO₄, filtered, and evaporated under reduced pressure. The crude unsaturated ester thus obtained was purified by flash column silica gel chromatography (eluting with a gradient of 10-25% EtOAc / hexanes).

(Z)-2,3-Diphenylacrylic acid methyl ester (entry 1)

C₁₆H₁₄O₂
 Exact Mass: 238.10
 Mol. Wt.: 238.28
 C, 80.65; H, 5.92; O, 13.43

Colorless oil, yield 88%, *Z/E* = 40/1. IR (film): 2921, 1724, 1433, 1264, 1250, 1211, 1195, 1172, 1037, 1007, 751, 734, 694 cm⁻¹; ¹H NMR (CDCl₃, 400 MHz) δ 3.79 (s, 3H), 7.05 (s, 1H), 7.29-7.40 (m, 8H), 7.46-7.47 (m, 2H); ¹³C NMR (CDCl₃, 100 MHz) δ 52.3, 126.4, 128.1, 128.3, 128.5, 128.7, 131.5, 134.8, 135.6, 136.8, 170.1; HRMS (EI): *m/z* calcd for C₁₆H₁₅O₂ [M+H]⁺ 239.1067, found 239.1072.

(Z)-3-(2-Methoxyphenyl)-2-phenylacrylic acid methyl ester (entry 2)

C₁₇H₁₆O₃
 Exact Mass: 268.11
 Mol. Wt.: 268.31
 C, 76.10; H, 6.01; O, 17.89

White crystalline solid, yield 94%, *Z/E* = 20/1. Mp 50-51 °C; IR (film): 2948, 2920, 2839, 1722, 1596, 1578, 1494, 1486, 1462, 1433, 1359, 1308, 1275, 1248, 1207, 1194, 1172, 1111, 1077, 1051, 1025, 1007, 971, 847, 779, 751, 736, 694, 668 cm⁻¹; ¹H NMR (CDCl₃, 400 MHz) δ 3.73 (s, 3H), 3.84 (s, 3H), 6.89-6.94 (m, 2H), 7.27 (s, 1H), 7.29-7.33 (m, 3H), 7.35-7.39 (m, 3H), 7.45-7.47 (m, 3H); ¹³C NMR (CDCl₃, 100 MHz) δ 51.9,

55.4, 110.5, 120.4, 125.1, 126.8, 128.1, 128.3, 128.5, 128.6, 129.8, 134.7, 137.4; HRMS

(EI): m/z calcd for $C_{17}H_{17}O_3$ $[M+H]^+$ 269.1172 found 269.1180.

(Z)-3-Biphenyl-4-yl-2-phenylacrylic acid methyl ester (entry 3)

$C_{22}H_{18}O_2$
Exact Mass: 314.1307
Mol. Wt.: 314.3771

White crystalline solid, yield 86%, $Z/E = 40/1$. Mp 115-116 °C; IR (film): 3029, 1724, 1598, 1486, 1434, 1361, 1218, 1198, 1171, 1004, 892, 836, 763, 695 cm^{-1} ; 1H NMR δ : 3.81 (s, 3H), 7.06 (s, 1H), 7.23-7.61 (m, 14H); ^{13}C NMR δ : 52.2, 126.3, 126.9, 127.1, 127.5, 128.3, 128.6, 128.7, 128.8, 128.9, 131.0, 134.5, 134.6, 136.8, 140.3, 141.0, 170.1; HRMS (EI): m/z calcd for $C_{22}H_{19}O_2$ $[M+H]^+$ 315.1381, found 315.1371.

(Z)-2-Phenylbut-2-enoic acid methyl ester (entry 4)

$C_{11}H_{12}O_2$
Exact Mass: 176.0837
Mol. Wt.: 176.2118
C, 74.98; H, 6.86; O, 18.16

Colorless oil, yield 90%, $Z/E = 40/1$. IR (film): 2950, 1718, 1494, 1434, 1352, 1202, 1114, 1005, 753, 696 cm^{-1} ; 1H NMR δ : 2.03 (d, $J = 7.2$ Hz, 3H), 3.79 (s, 3H), 6.25 (q, $J = 7.2$ Hz, 1H), 7.29 (m, 5H); ^{13}C NMR δ : 15.9, 51.5, 127.2, 127.4, 128.1, 135.3, 135.4, 138.1, 168.4. HRMS (EI): m/z calcd for $C_{11}H_{13}O_2$ $[M+H]^+$ 177.0912, found 177.0905.

(Z)-4-Methyl-2-phenylpent-2-enoic acid methyl ester (entry 5)

$C_{13}H_{16}O_2$
 Exact Mass: 204.1150
 Mol. Wt.: 204.2649
 C, 76.44; H, 7.90; O, 15.67

Colorless oil, yield 93%, $Z/E = 40/1$. IR (film): 2952, 1720, 1615, 1495, 1435, 1331, 1200, 1171, 1093, 1028, 990, 868, 812, 775, 699 cm^{-1} ; 1H NMR δ : 1.08 (d, $J = 6.6$ Hz, 6H), 2.95 (m, 1H), 3.79 (s, 3H), 5.95 (d, $J = 10.0$ Hz), 7.27 (m, 5H); ^{13}C NMR δ : 22.6, 29.4, 51.6, 127.1, 127.4, 128.2, 132.3, 137.8, 146.4, 168.7; HRMS (EI): m/z calcd for $C_{13}H_{17}O_2$ $[M+H]^+$ 205.1225, found 205.1228.

(Z)-2-Phenylbut-2-enedioic acid dimethyl ester (entry 6)

$C_{12}H_{12}O_4$
 Exact Mass: 220.07
 Mol. Wt.: 220.22
 C, 65.45; H, 5.49; O, 29.06

Pale tan oil, yield, 92% yield, $Z/E = 99/1$. IR (neat): 2951, 2836, 1719, 1625, 1577, 1497, 1450, 1434, 1357, 1291, 1197, 1169, 1024, 1003, 887, 835, 773, 753, 687, 668, 633 cm^{-1} ; 1H NMR ($CDCl_3$, 400 MHz) δ 3.78 (s, 3H), 3.94 (s, 3H), 6.31 (s, 1H), 7.37-7.42 (m, 3H), 7.46-7.48 (m, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 52.0, 52.7, 116.9, 126.7, 128.9, 130.6, 133.1, 148.9, 165.4, 168.3; HRMS (EI): m/z calcd for $C_{12}H_{13}O_4$ $[M+H]^+$ 221.0808, found 221.0812.

(Z)-2-(3-Chlorophenyl)-pent-2-en-4-ynoic acid methyl ester (entry 7)

$C_{12}H_9ClO_2$
 Exact Mass: 220.0291
 Mol. Wt.: 220.6514
 C, 65.32; H, 4.11; Cl, 16.07; O, 14.50

Pale yellow oil, yield 91%, $Z/E = 8/1$. IR (film): 3289, 2951, 2100, 1725, 1592, 1563, 1475, 1435, 1345, 1207, 1178, 1099, 1048, 784, 690, 638 cm^{-1} ; ^1H NMR δ : 3.48 (d, $J = 2.4$ Hz, 1H), 3.88 (s, 3H), 6.17 (d, $J = 2.4$ Hz, 1H), 7.26-7.37 (m, 4H); ^{13}C NMR δ : 52.3, 79.6, 87.2, 114.6, 125.2, 127.1, 129.1, 129.7, 134.5, 137.0, 144.2, 166.4; HRMS (EI): m/z calcd for $\text{C}_{12}\text{H}_{10}\text{ClO}_2$ $[\text{M}+\text{H}]^+$ 221.0291, found 221.0293.

(Z)-2-Phenylpenta-2,4-dienoic acid methyl ester (entry 8)

$\text{C}_{12}\text{H}_{12}\text{O}_2$
Exact Mass: 188.0837
Mol. Wt.: 188.2225

Pale yellow oil, yield 81%, $Z/E = 10/1$. IR (film): 2951, 1714, 1484, 1493, 1434, 1345, 1243, 1202, 1171, 1003, 918, 763, 695 cm^{-1} ; ^1H NMR δ : 3.83 (s, 3H), 5.43 (dd, $J = 1.4$, 10.4 Hz, 1H), 5.52 (ddd, $J = 1.4$, 2.1, 16.7 Hz, 1H), 6.66 (d, $J = 11.2$ Hz, 1H), 7.01 (m, 1H), 7.29-7.35 (m, 5H); ^{13}C NMR δ : 51.8, 123.8, 127.4, 127.9, 128.3, 133.5, 133.7, 137.1, 137.4, 168.0; HRMS (EI): m/z calcd for $\text{C}_{12}\text{H}_{13}\text{O}_2$ $[\text{M}+\text{H}]^+$ 189.0912, found 189.0910.

(Z)-2,3-Diphenylacrylic acid isopropyl ester (entry 9)

$\text{C}_{18}\text{H}_{18}\text{O}_2$
Exact Mass: 266.13
Mol. Wt.: 266.33
C, 81.17; H, 6.81; O, 12.01

Colorless oil, yield 86%, $Z/E = 70/1$. IR (film): 2980, 1715, 1495, 1449, 1373, 1215, 1184, 1103, 1078, 1030, 1001, 985, 914, 858, 826, 753, 719, 692, 668, 649 cm^{-1} ; ^1H NMR (CDCl_3 , 400 MHz) δ 1.18 (d, $J = 6.3$ Hz, 6H), 5.19 (septuplet, $J = 6.3$ Hz, 1H), 7.02 (s, 1H), 7.27-7.40 (m, 8H), 7.46-7.78 (m, 2H); ^{13}C NMR (CDCl_3 , 100 MHz) δ 21.4,

68.9, 126.3, 128.1, 128.2, 128.3, 128.6, 130.6, 135.7, 135.8, 136.9, 169.1; HRMS (EI): m/z calcd for $C_{18}H_{19}O_2$ $[M+H]^+$ 267.1380 found 267.1373.

(*E*)-2-Methyl-3-phenylacrylic acid ethyl ester (9**) and 2-Benzylacrylic acid ethyl ester (**10**)**

Colorless oil, mixture of isomers **9** (71%) and **10** (29%), $Z/E = 1/45$ (**8**). IR (film): 1705, 1633, 1493, 1446, 1390, 1366, 1296, 1249, 1200, 1110, 1029, 930, 764, 700 cm^{-1} ; 1H NMR δ : 1.24 (t, $J = 7.2$ Hz, 3H), 1.35 (t, $J = 7.2$ Hz, 3H), 2.11 (d, $J = 1.4$ Hz), 3.63 (s, 2H), 4.17 (q, $J = 7.2$ Hz, 2H), 4.28 (q, $J = 7.2$ Hz, 2H), 5.44 (d, $J = 1.4$ Hz, 1H), 6.22 (d, $J = 1.2$ Hz, 1H); 7.18-7.40 (m, 5H), 7.69 (q, $J = 1.3$ Hz, 1H); HRMS (EI): m/z calcd for $C_{12}H_{15}O_2$ $[M+H]^+$ 191.1068, found 191.1073.

¹H NMR time-course experiments

1. Using triflic anhydride and *d*⁵pyridine.

In an NMR tube, a solution of hydroxyester **3** (38 mg, 0.1958 mmol) in 0.4 mL of CD₂Cl₂ was taken. To this mixture, *d*⁵-Pyridine (80 μL, 0.98 mmol) was added and the NMR tube was cooled to 0 °C in an ice bath. Triflic anhydride (60.7 mg, 0.215 mmol) in 0.1 mL of CD₂Cl₂ was added quickly to this cold solution. The tube was then quickly transferred the NMR spectrometer (where it was allowed to slowly warm to room temperature) and time-course experiment started. ¹H NMR spectra were taken in every 20 min intervals for 13 h (overnight). As can be seen from representative NMRs at select intervals shown below, the reaction appeared to be slow, requiring 10-14 h for completion.

MS Spectrum Graph

Peak#: 1 Ret Time: Averaged 0.292-0.942 (Scan#: 36-114)
BG Mode: None
Mass Peaks: 751 Base Peak: 261.05 (380372) Polarity: Pos Segment: 1 - Event 1

MS Spectrum Graph

Peak#:1 Ret Time:Averaged 0.292-0.817(Scan#:36-99)

BG Mode:None

Mass Peaks:751 Base Peak:256.10(515262) Polarity:Pos Segment1 - Event1

2. Using triflic acid

The NMR time course experiments were carried out in a similar fashion as outlined in the first experiment. Only trace amount (10 mol %) of triflic acid were used as the dehydrating agent.

Time-Course Experiment with trace acid added