Palladium-Catalyzed Oxidative Alkoxylation of α -Alkenyl β - Diketones to form Functionalized Furans

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Supporting Information

Experimental procedures and analytical and spectroscopic data for new compounds, and copies of NMR spectra for 3-(benzoyl)-2,5-dimethylfuran (25 pages).

General Methods. Reactions were performed under an atmosphere of nitrogen unless otherwise stated. NMR spectra were obtained on a Varian spectrometer operating at 400 MHz for ^1H NMR and 100 MHz for ^{13}C NMR in CDCl_3 unless otherwise noted. IR spectra were obtained on a Bomen MB-100 FT IR spectrometer. Gas chromatography was performed on a HP 5890 gas chromatograph equipped with a 25 m polydimethylsiloxane capillary column. Flash column chromatography was performed employing 200-400 mesh silica gel (EM). Elemental analyses were performed by Complete Analysis Laboratories (Parsippany, NJ). Thin layer chromatography (TLC) was performed on SiO_2 plates eluting with a 5:1 mixture of hexanes–EtOAc unless noted otherwise. Diethyl ether was distilled from sodium/benzophenone under nitrogen. 1,4-Dioxane (Aldrich, anhydrous), DMF (Aldrich, anhydrous), and $\text{PdCl}_2(\text{CH}_3\text{CN})_2$ (Strem) were used as received.

β -Diketone

1-Phenyl-1,3-octanedione.¹ A suspension of acetophenone (5.93 g, 49.4 mmol), methyl hexanoate (6.43 g, 49.4 mmol), and NaNH_2 (3.85 g, 98.7 mmol) was refluxed overnight, cooled to room temperature, and quenched with 1 N HCl. The reaction mixture was extracted with ether (2×100 mL), washed with brine, dried (MgSO_4), concentrated, and chromatographed (hexanes:ether = 50:1) to give 1-phenyl-1,3-octanedione (3.33 g, 31 %) as a yellow oil. ^1H NMR (enol): δ 16.22 (s, 1 H), 7.90-7.87 (m, 2 H), 7.54-7.49 (m, 1 H), 7.47-7.42 (m, 2 H), 6.17 (s, 1 H), 2.42 (t, J = 7.6 Hz, 2 H), 1.73-1.65 (m, 2 H), 1.39-1.31 (m 4 H), 0.92 (t, J = 7.2 Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (enol): δ 197.3, 183.8, 135.4, 132.5, 128.9, 127.3, 96.4, 39.5, 31.8, 25.9, 22.8, 14.3.

1-(4-Methoxyphenyl)-1,3-butanedione.² 1-(4-Methoxyphenyl)-butane-1,3-dione was synthesized in 46 % yield as a white solid from ethyl acetate and 4-methoxyacetophenone using a procedure similar to that used to synthesize 1-phenyl-octane-1,3-dione. ¹H NMR (enol): δ 16.30 (s, 1 H), 7.85 (d, J = 8.8 Hz, 2 H), 6.93 (d, J = 8.8 Hz, 2 H), 6.01 (s, 1 H), 3.85 (s, 3 H), 2.16 (s, 3 H). ¹³C{¹H} NMR (enol): δ 191.9, 184.4, 163.4, 129.4, 127.9, 114.2, 96.1, 55.7, 25.6.

6-Methoxy-1-phenyl-1,3-hexanedione. 6-Methoxy-1-phenyl-1,3-hexanedione was synthesized in 34 % as a yellow oil from methyl 4-methoxybutyrate and acetophenone using a procedure similar to that used to synthesize 1-phenyl-1,3-octanedione. ¹H NMR (enol): δ 16.12 (s, 1 H), 7.89-7.85 (m, 2 H), 7.52-7.47 (m, 1 H), 7.46-7.40 (m, 2 H), 6.18 (s, 1 H), 3.43 (t, J = 6.4 Hz, 2 H), 3.33 (s, 3 H), 2.52 (t, J = 7.6 Hz, 2 H), 1.98-1.92 (m, 2 H). ¹³C{¹H} NMR (enol): δ 197.0, 183.2, 135.2, 132.5, 128.9, 127.2, 96.5, 71.9, 58.8, 36.1, 25.9. IR (neat, cm⁻¹): 2926, 2871, 1602, 1573, 1456, 1268, 1116, 767. HRMS Calcd (found) for C₁₃H₁₆O₃ (M⁺): 220.1099 (220.1095).

1-(4-Trifluoromethylphenyl)-1,3-butanedione. 1-(4-Trifluoromethylphenyl)-1,3-butanedione was synthesized in 61 % as a yellow oil from ethyl acetate and 4'-trifluoromethylacetophenone using a procedure similar to that used to synthesize 1-phenyl-1,3-octanedione. ¹H NMR (enol): δ 16.00 (s, 1 H), 7.96 (d, J = 8.0 Hz, 2 H), 7.69 (d, J = 8.4 Hz, 2 H), 6.19 (s, 1 H), 2.23 (s, 3 H), ¹³C{¹H} NMR (enol): δ 195.5, 181.2, 138.4, 133.9 (q, J = 32.6 Hz), 127.6, 125.9 (q, J = 3.8 Hz), 124.0 (q, J = 270.8 Hz), 97.7, 26.4. IR (neat, cm⁻¹): 3106, 1600, 1559, 1324, 1170, 1135, 1067, 859, 787. HRMS Calcd (found) for C₁₁H₉F₃O₂ (M⁺): 230.0555 (230.0550).

1-(2-Thiophenyl)-1,3-butanedione. 1-(2-Thiophenyl)-1,3-butanedione was synthesized in 51 % yield as a red oil from acetone and methyl thiophene-2-carboxylate employing a

reported procedure.³ Enol:keto = 4.0:1.0. ¹H NMR: δ 15.67 (s, 0.80×1 H, enol), 7.76-7.65 (m, 1.2×1 H), 7.59-7.57 (m, 0.8×1 H), 7.15-7.09 (m, 1 H), 6.02 (s, 0.80×1 H, enol), 4.00 (s, 0.2×2 H, keto), 2.29 (s, 0.2×3 H, keto), 2.11 (s, 0.8×3 H, enol). ¹³C{¹H} NMR (enol + keto): δ 187.5, 186.4, 182.1, 179.0, 141.9, 135.4, 134.0, 132.6, 132.3, 130.5, 128.7, 128.5, 96.7, 55.6, 30.7, 24.1.

α -Alkenyl β -diketones

4-Allyl-2,6-dimethyl-3,5-heptanedione (2). A solution of 2,6-dimethyl-3,5-heptanedione (2.27 g, 14.5 mmol) in DMF (15 mL) was added to a suspension of NaH (0.35 g, 14.5 mmol) in DMF (40 mL) at 0 °C and resulting mixture was stirred for 10 minutes and treated with a solution of allyl bromide (1.76 g, 14.5 mmol) in DMF (15 mL). The resulting mixture was warmed to room temperature slowly and stirred overnight. The resulting mixture was quenched with water, extracted with ether/hexane (v/v = 1/2), dried (MgSO₄), concentrated, and chromatographed (hexanes–ether = 25:1) to give 4-allyl-2,6-dimethyl-3,5-heptanedione (1.52 g, 52 %) as a yellow oil. TLC: R_f = 0.55. Enol:keto = 1:4.5; ¹H NMR: δ 17.47 (s, 0.18×1 H, enol), 5.94-5.84 (m, 0.18×1 H, enol), 5.73-5.62 (m, 0.82×1 H, keto), 5.01-4.94 (m, 2 H), 4.00 (t, J = 7.2 Hz, 0.82×1 H, keto), 3.04-3.00 (m, 0.18×2 H, enol), 2.84-2.68 (m, 2 H), 2.60-2.53 (m, 0.82×2 H, keto), 1.11-1.04 (m, 12 H). ¹³C{¹H} NMR (enol + keto): δ 209.7, 199.5, 137.6, 135.1, 117.6, 115.2, 103.9, 63.8, 40.5, 33.0, 32.7, 29.9, 19.8, 18.7, 18.5. IR (neat, cm⁻¹): 3080, 2971, 2933, 2874, 1726, 1697, 1639, 1467, 1383, 1360, 1092, 1035, 997, 918. Anal. Calcd (found) for C₁₂H₂₀O₂: C, 73.43 (73.28); H, 10.27 (10.35).

The remaining α -alkenyl β -diketones were synthesized employing a procedure analogous to that used to synthesized **2**.

4-Allyl-3,5-heptanedione (4) (Table 2, entry 1).⁴ Yellow oil, 46%. Enol:keto = 1:1.4. ¹H NMR: δ 16.88 (s, 0.42×1 H, enol), 5.87-5.78 (m, 0.42×1 H, enol), 5.71-5.61 (m, 0.58×1 H, keto), 5.09-4.94 (m, 2 H), 3.73 (t, $J = 7.6$ Hz, 0.58×1 H, keto), 2.97 (td, $J = 2.0, 5.6$ Hz, 0.42×2 H, enol), 2.58-2.35 (m, 5.16 H), 1.10 (t, $J = 7.6$ Hz, 0.42×6 H, enol), 1.00 (t, $J = 7.6$ Hz, 0.58×6 H, keto). ¹³C{¹H} NMR (enol + keto): δ 206.6, 195.0, 136.8, 134.7, 117.7, 115.2, 105.9, 66.7, 35.8, 32.8, 30.3, 28.8, 9.8, 7.8.

2-Allyl-1,3-diphenyl-1,3-propanedione (Table 2, entry 2).⁵ Yellow Solid, 69 %. ¹H NMR (keto): δ 7.96 (d, $J = 7.2$ Hz, 4 H), 7.57 (t, $J = 7.2$ Hz, 2 H), 7.45 (t, $J = 7.6$ Hz, 4 H), 5.93-5.83 (m, 1 H), 5.30 (t, $J = 7.2$ Hz, 1 H), 5.02-5.13 (m, 2 H), 2.86-2.90 (m, 2 H). ¹³C{¹H} NMR (keto): δ 195.9, 136.3, 135.4, 133.9, 129.2, 128.9, 117.6, 57.1, 33.9

2-Allyl-1-phenyl-1,3-butanedione (Table 2, entry 3).⁶ Yellow oil, 75 %. Enol:keto = 1:6.3. ¹H NMR: δ 17.04 (s, 0.14×1 H, enol), 7.97-7.94 (m, 0.86×2 H, keto), 7.59-7.51 (m, 0.86×1 H, keto), 7.50-7.33 (m, 2.42 H), 5.96-5.86 (m, 0.14×1 H, enol), 5.78-5.67 (m, 0.86×1 H, keto), 5.17-4.53 (m, 2 H), 4.53 (t, $J = 7.2$ Hz, 0.86×1 H, keto), 3.00 (td, $J = 2.0, 4.4$ Hz, 0.14×2 H, enol), 2.77-2.64 (m, 0.86×2 H, keto), 2.02 (s, 0.14×3 H, enol), 2.11 (s, 0.86×3 H, keto). ¹³C{¹H} NMR (enol + keto): δ 203.7, 200.0, 196.0, 183.5, 137.4, 136.6, 136.3, 134.6, 134.0, 130.5, 129.1, 128.9, 128.3, 127.7, 117.6, 116.0, 106.9, 62.8, 33.2, 32.1, 28.4, 25.1.

2-Allyl-1-phenyl-1,3-octanedione (Table 2, entry 4). Colorless oil, 82%. TLC: $R_f = 0.47$. ¹H NMR (keto): δ 8.07-8.04 (m, 2 H), 7.68- 7.64 (m, 1 H), 7.58-7.53 (m, 2 H), 5.88-5.77 (m, 1 H), 5.18-5.07 (m, 2 H), 4.64 (t, $J = 7.2$ Hz, 1 H), 2.81 (br t, $J = 7.2$ Hz, 2 H), 2.61-2.48 (m, 2 H), 1.62-1.54 (m, 2 H), 1.33-1.19 (m, 4 H), 0.89 (t, $J = 6.8$ Hz, 3 H). ¹³C{¹H} NMR (keto): δ 205.8, 196.1, 136.7, 134.9, 133.9, 129.1, 128.9, 117.6, 62.4, 41.2, 33.3, 31.3, 23.3, 22.6, 14.1. IR

(neat, cm^{-1}): 3078, 2956, 2930, 2871, 1722, 1714, 1680, 1596, 1448, 1337, 1267, 1203, 1000, 919. Anal. Calcd (found) for $\text{C}_{17}\text{H}_{22}\text{O}_2$: C, 79.03 (79.10); H, 8.58 (8.46).

2-Allyl-6-methoxy-1-phenyl-1,3-hexanedione (Table 2, entry 5). Yellow oil, 61%. TLC: R_f = 0.28. ^1H NMR (keto): δ 7.97-7.95 (m, 2 H), 7.59-7.55 (m, 1 H), 7.49-7.44 (m, 2 H), 5.79-5.68 (m, 1 H), 5.09-4.98 (m, 2 H), 4.56 (t, J = 7.2 Hz, 1 H), 3.27-3.24 (m, 2 H), 3.18 (s, 3 H), 2.72 (t, J = 7.2 Hz, 2 H), 2.57-2.49 (m, 2 H), 1.78 (pentet, J = 6.4 Hz, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (keto): δ 205.4, 196.0, 136.8, 134.9, 133.9, 129.1, 129.0, 117.6, 71.6, 62.4, 58.7, 37.9, 33.3, 23.7. IR (neat, cm^{-1}): 3076, 2977, 2927, 2873, 2828, 2810, 1719, 1676, 1596, 1579, 1447, 1340, 1252, 1203, 1118, 1000, 920. Anal. Calcd (found) for $\text{C}_{16}\text{H}_{20}\text{O}_3$: C, 73.82 (73.69); H, 7.74 (7.65).

2-Allyl-1-(4-methoxyphenyl)-1,3-butanedione (Table 2, entry 6). Colorless oil, 84%. TLC: R_f = 0.27. ^1H NMR (keto): δ 7.96 (br d, J = 9.2 Hz, 2 H), 6.92 (br d, J = 9.2 Hz, 2 H), 5.78-5.68 (m, 1 H), 5.10-4.98 (m, 2 H), 4.47 (t, J = 7.2 Hz, 1 H), 3.85 (s, 3 H), 2.73-2.68 (m, 2 H), 2.11 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (keto): δ 204.2, 194.3, 164.4, 134.8, 131.5, 129.7, 117.6, 114.3, 62.8, 55.8, 33.3, 28.2. IR (neat, cm^{-1}): 3078, 3006, 2977, 2842, 1723, 1714, 1667, 1600, 1512, 1422, 1262, 1173, 1028, 922, 846. Anal. Calcd (found) for $\text{C}_{14}\text{H}_{16}\text{O}_3$: C, 72.39 (72.26); H, 6.94 (6.86).

2-Allyl-1-(4-trifluoromethylphenyl)-1,3-butanedione (Table 2, entry 7). Yellow oil, 39%. TLC: R_f = 0.38. Enol:keto = 1:3.7. ^1H NMR: δ 16.89 (s, 0.2×1 H, enol), 8.08-8.05 (m, 0.8×2 H, keto), 7.73-7.63 (m, 1.2×2 H), 5.97-5.88 (m, 0.2×1 H, enol), 5.78-5.68 (m, 0.8×1 H, keto), 5.20-5.00 (m, 2 H), 4.54 (t, J = 7.2 Hz, 0.8×1 H, enol), 2.98 (td, J = 2.4, 4.4 Hz, 0.2×1 H, enol), 2.80-2.67 (m, 0.8×2 H, keto), 2.23 (s, 0.2×3 H, enol), 2.15 (s, 0.8×3 H, keto). $^{13}\text{C}\{^1\text{H}\}$ NMR (enol + keto): δ 203.4, 200.7, 195.2, 181.7, 139.7, 139.3, 137.1, 135.2 (q, J =

32.6 Hz), 134.3, 132.3 (q, $J = 32.6$ Hz), 129.3, 128.2, 126.2 (q, $J = 3.4$ Hz), 125.5 (q, $J = 3.5$ Hz), 124.0 (q, $J = 270.7$ Hz), 123.7 (q, $J = 271.2$ Hz), 118.1, 116.4, 107.3, 63.3, 33.2, 32.0, 28.4, 25.2. IR (neat, cm^{-1}): 3081, 2981, 2921, 1722, 1714, 1681, 1410, 1325, 1170, 1131, 1114, 1017, 923. Anal. Calcd (found) for $\text{C}_{14}\text{H}_{13}\text{F}_3\text{O}_2$: C, 62.22 (61.97); H, 4.85 (4.77).

2-Allyl-1-(2-furyl)-1,3-butanedione (Table 2, entry 8). Colorless oil, 64%. TLC: $R_f = 0.22$. ^1H NMR (keto): δ 7.57-7.56 (m, 1 H), 7.24-7.23 (m, 1 H), 6.52-6.50 (m, 1 H), 5.73-5.63 (m, 1 H), 5.05-4.94 (m, 2 H), 4.28 (t, $J = 7.2$ Hz, 1 H), 2.68-2.58 (m, 2 H), 2.13 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (keto): δ 203.2, 184.4, 152.4, 147.5, 134.5, 119.1, 117.8, 113.1, 62.8, 32.7, 29.1. IR (neat, cm^{-1}): 3132, 3079, 2980, 1719, 1668, 1465, 1393, 1358, 1162, 1031, 996, 919, 768. Anal. Calcd (found) for $\text{C}_{11}\text{H}_{12}\text{O}_3$: C, 68.74 (68.49); H, 6.29 (6.25).

2-Allyl-1-(2-thiophenyl)-1,3-butanedione (Table 2, entry 9). Yellow oil, 77%. TLC: $R_f = 0.21$. ^1H NMR (keto): δ 7.78 (dd, $J = 4.0, 0.8$ Hz, 1 H), 7.69 (dd, $J = 1.2, 5.2$ Hz, 1 H), 7.13 (t, $J = 4.0$ Hz, 1 H), 5.77-5.66 (m, 1 H), 5.11-4.98 (m, 2 H), 4.33 (t, $J = 7.6$ Hz, 1 H), 2.77-2.65 (m 2 H), 2.15 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (keto): δ 203.3, 188.4, 144.0, 135.6, 134.4, 133.8, 128.8, 117.9, 64.3, 33.3, 28.2. IR (neat, cm^{-1}): 3081, 2980, 2919, 1714, 1659, 1650, 1415, 1357, 1246, 1066, 922, 853, 729. HRMS Calcd (found) for $\text{C}_{11}\text{H}_{12}\text{O}_2\text{S}$ (M^+): 208.0558 (208.0557).

4-(3-Butenyl)-3,5-heptanedione (Table 2, entry 10). Yellow oil, 20%. TLC: $R_f = 0.46$. enol:keto = 1:3.7. ^1H NMR: δ 16.89 (s, 0.21×1 H, enol), 5.86 (m, 1 H), 5.07 (m, 2 H), 3.67 (t, $J = 6.8$ Hz, 0.79×1 H, keto), 2.55-2.37 (m, 4 H), 2.14-1.90 (m, 4 H), 1.14 (t, $J = 7.2$ Hz, 0.21×6 H, enol), 1.02 (t, $J = 7.2$ Hz, 0.79×6 H, keto). $^{13}\text{C}\{^1\text{H}\}$ NMR (enol + keto): δ 207.1, 194.7, 137.8, 137.4, 116.2, 115.6, 108.5, 66.5, 35.6, 35.5, 32.0, 28.7, 27.7, 26.2, 10.0, 7.8. IR (neat, cm^{-1}): 3077, 2977, 2939, 2882, 1726, 1698, 1459, 1377, 1349, 1103, 994, 915. Anal. Calcd (found) for $\text{C}_{11}\text{H}_{18}\text{O}_2$: C, 72.49 (72.32); H, 9.95 (10.06).

4-(3-Butenyl)-2,6-dimethyl-3,5-heptanedione (Table 2, entry 11). Colorless oil, 15%. TLC: R_f = 0.57. ^1H NMR (keto): δ 5.74-5.64 (m, 1 H), 4.99-4.95 (m, 2 H), 3.90 (t, J = 6.8 Hz, 1 H), 2.69 (heptet, J = 6.8 Hz, 2 H), 1.98-1.84 (m, 4 H), 1.04 (d, J = 6.8 Hz, 6 H), 1.01 (d, J = 6.8 Hz, 6 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (keto): δ 210.3, 137.5, 116.3, 63.4, 40.4, 32.3, 27.7, 18.9, 18.6. IR (neat, cm^{-1}): 3077, 2971, 2933, 2874, 1725, 1696, 1467, 1383, 1349, 1037, 1002, 914. Anal. Calcd (found) for $\text{C}_{13}\text{H}_{22}\text{O}_2$: C, 74.24 (74.09); H, 10.54 (10.61).

4-(4-Pentenyl)-3,5-heptanedione (Table 2, entry 12). Colorless oil, 15%. TLC: R_f = 0.40. Enol:keto = 1:3.0. ^1H NMR: δ 16.84 (s, 0.25×1 H, enol), 5.85-5.68 (m, 1 H), 5.05-4.92 (m, 2 H), 3.63 (t, J = 7.2 Hz, 0.75×1 H, keto), 2.54-2.37 (m, 4 H), 2.21-2.17 (m, 0.25×2 H, enol), 2.21-2.00 (m, 2 H), 1.85-1.79 (m, 0.75×2 H, keto), 1.13 (t, J = 7.2 Hz, 0.25×6 H, enol), 1.01 (t, J = 7.2 Hz, 0.75×6 H, keto). $^{13}\text{C}\{^1\text{H}\}$ NMR (enol + keto): δ 207.2, 194.5, 138.2, 138.0, 115.3, 109.1, 67.3, 35.5, 33.9, 33.7, 30.6, 28.6, 28.2, 27.1, 26.1, 9.9, 7.8. IR (neat, cm^{-1}): 3076, 2977, 2938, 1726, 1698, 1459, 1410, 1349, 1104, 1020, 989, 912. Anal. Calcd (found) for $\text{C}_{12}\text{H}_{20}\text{O}_2$: C, 73.43 (73.50); H, 10.27 (10.22).

Furans

2-Ethyl-5-methyl-3-(propionyl)furan (5) (Table 2, entry 1). Colorless oil. TLC: R_f = 0.54. ^1H NMR: δ 6.18 (s, 1 H), 2.98 (q, J = 7.6 Hz, 2 H), 2.70 (q, J = 7.6 Hz, 2 H), 2.23 (s, 3 H), 1.22 (t, J = 7.6 Hz, 3 H), 1.14 (t, J = 7.6 Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 197.6, 162.1, 150.1, 120.9, 106.0, 34.7, 21.9, 13.6, 12.5, 8.3. IR (neat, cm^{-1}): 2977, 2938, 2879, 1678, 1566, 1461, 1394, 1241, 1212, 1178, 1016, 920. Anal. Calcd (found) for $\text{C}_{10}\text{H}_{14}\text{O}_2$: C, 72.26 (72.58); H, 8.49 (8.38).

3-Benzoyl-5-methyl-2-phenylfuran (Table 2, entry 2).⁷ ^1H NMR: δ 7.83-7.80 (m, 2

H), 7.67-7.63 (m, 2 H), 7.48-7.44 (m 1 H), 7.36-7.32 (m, 2 H), 7.29-7.20 (m, 3 H), 6.27 (br s, 1 H), 2.37 (d, $J = 0.8$ Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 192.3, 154.8, 151.5, 138.5, 132.9, 130.3, 130.0, 128.9, 128.53, 128.52, 127.6, 122.0, 110.1, 13.7.

3-Benzoyl-2,5-dimethylfuran (Table 2, entry 3). Colorless oil. TLC: $R_f = 0.50$. ^1H NMR: δ 7.79-7.77 (m, 2 H), 7.56-7.52 (m, 1 H), 7.47-7.43 (m, 2 H), 6.16 (br s, 1 H), 2.48 (s, 3 H), 2.28 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 191.8, 158.3, 150.1, 139.7, 132.3, 129.2, 128.6, 121.5, 107.8, 14.5, 13.5. IR (neat, cm^{-1}): 3059, 2921, 1649, 1567, 1446, 1393, 1364, 1285, 1233, 1218, 901, 725. Anal. Calcd (found) for $\text{C}_{13}\text{H}_{12}\text{O}_2$: C, 77.98 (77.84); H, 6.04 (5.99).

3-Benzoyl-5-methyl-2-pentylfuran (Table 2, entry 4). Colorless oil. TLC: $R_f = 0.61$. ^1H NMR: δ 7.80-7.77 (m, 2 H), 7.55-7.51 (m, 1 H), 7.46-7.42 (m 2 H), 6.13 (d, $J = 1.2$ Hz, 1 H), 2.85 (t, $J = 7.6$ Hz, 2 H), 2.28 (d, $J = 0.8$ Hz, 3 H), 1.73-1.64 (m, 2 H), 1.38-1.25 (m, 4 H), 0.87 (t, $J = 6.8$ Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 191.8, 162.4, 150.0, 139.8, 132.2, 129.2, 128.5, 121.1, 107.8, 31.8, 28.2, 22.7, 14.3, 13.6. IR (neat, cm^{-1}): 2956, 2928, 2859, 1650, 1563, 1446, 1383, 1220, 903, 725. HRMS Calcd (found) for $\text{C}_{17}\text{H}_{20}\text{O}_2$ (M^+): 256.1463 (256.1470).

3-Benzoyl-2-(3-methoxypropyl)-5-methylfuran (Table 2, entry 5). Colorless oil. TLC: $R_f = 0.38$. ^1H NMR: δ 7.79-7.76 (m, 2 H), 7.54-7.50 (m, 1 H), 7.46-7.41 (m, 2 H), 6.14 (s, 1 H), 3.38 (t, $J = 6.8$ Hz, 2 H), 3.30 (s, 3 H), 2.93 (t, $J = 7.2$ Hz, 2 H), 2.27 (s, 3 H), 1.95 (pentet, $J = 7.2$ Hz, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 191.6, 161.4, 150.2, 139.6, 132.3, 129.2, 128.5, 121.3, 107.8, 72.2, 58.8, 28.4, 25.0, 13.6. IR (neat, cm^{-1}): 2923, 2871, 1650, 1562, 1446, 1384, 1220, 1118, 903. Anal. Calcd (found) for $\text{C}_{16}\text{H}_{18}\text{O}_3$: C, 74.39 (74.24); H, 7.02 (6.92).

3-(4-Methoxybenzoyl)-2,5-dimethylfuran (Table 2, entry 6). Colorless oil. TLC: $R_f = 0.36$. ^1H NMR: δ 7.80 (br d, $J = 9.2$ Hz, 2 H), 6.92 (br d, $J = 8.8$ Hz, 2 H), 6.15 (s, 1 H), 3.85

(s, 3 H), 2.45 (s, 3 H), 2.26 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 190.4, 163.1, 157.4, 149.9, 132.2, 131.6, 121.6, 113.8, 107.8, 55.7, 14.3, 13.5. IR (neat, cm^{-1}): 3002, 2954, 2921, 2838, 1644, 1601, 1573, 1257, 1230, 1171, 1030, 905, 844. Anal. Calcd (found) for $\text{C}_{14}\text{H}_{14}\text{O}_3$: C, 73.03 (73.04); H, 6.13 (5.94).

3-(4-Trifluoromethylbenzoyl)-2,5-dimethylfuran (Table 2, entry 7). Colorless oil. TLC: R_f = 0.38. ^1H NMR: δ 7.86 (br d, J = 8.0 Hz, 2 H), 7.72 (br d, J = 8.4 Hz, 2 H), 6.11 (s, 1 H), 2.50 (s, 3 H), 2.27 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 190.5, 159.2, 150.5, 142.8, 133.7 (q, J = 32.4 Hz), 129.4, 125.6 (q, J = 3.6 Hz) 124.1 (q, J = 271.0 Hz), 121.1, 107.5, 14.6, 13.5. IR (neat, cm^{-1}): 2925, 1658, 1650, 1567, 1410, 1326, 1235, 1168, 1131, 1066, 1017, 907, 856, 776. HRMS Calcd (found) for $\text{C}_{14}\text{H}_{11}\text{F}_3\text{O}_2$ (M^+): 268.0711 (268.0717).

3-(2-Furyl)-2,5-dimethylfuran (Table 2, entry 8). Yellow solid. mp 67 - 68 °C. TLC: R_f = 0.43. ^1H NMR: δ 7.59-7.58 (m, 1 H), 7.23-7.21 (m, 1H), 6.56 (br s, 1 H), 6.52 (dd, J = 1.6, 3.6 Hz, 1 H), 2.55 (s, 3 H), 2.27 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 177.3, 159.4, 154.0, 150.2, 146.1, 120.1, 118.1, 112.4, 106.8, 14.6, 13.5. IR (neat, cm^{-1}): 3136, 2956, 2928, 1633, 1556, 1469, 1384, 1298, 1237, 1011, 848, 789. Anal. Calcd (found) for $\text{C}_{11}\text{H}_{10}\text{O}_3$: C, 69.46 (69.13); H, 5.30 (5.09).

3-(2-Thiophenyl)-2,5-dimethyl-furan (Table 2, entry 9). Yellow oil. TLC: R_f = 0.47. ^1H NMR: δ 7.71 (dd, J = 1.2, 4.8 Hz, 1 H), 7.63 (dd, J = 1.2, 4.8 Hz, 1 H), 7.12 (t, J = 4.8 Hz, 1 H), 6.36 (s, 1 H), 2.52 (s, 3 H), 2.29 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 182.5, 158.2, 150.3, 145.4, 133.2, 132.9, 128.1, 121.0, 107.1, 14.3, 13.6. IR (neat, cm^{-1}): 3100, 2950, 2920, 1629, 1561, 1394, 1233, 1048, 1008, 887, 825, 773. HRMS Calcd (found) for $\text{C}_{11}\text{H}_{10}\text{O}_2\text{S}$ (M^+): 206.0402 (206.0403).

2,5-Diethyl-3-(propionyl)furan (Table 2, entry 10). Colorless oil. TLC: R_f = 0.65. ^1H NMR: δ 6.18 (t, J = 1.2 Hz, 1 H), 2.98 (q, J = 7.6 Hz, 2 H), 2.70 (q, J = 7.6 Hz, 2 H), 2.69 (dq, J = 1.2, 7.6 Hz, 2 H), 1.22 (t, J = 7.6 Hz, 3 H), 1.21 (t, J = 7.6 Hz, 3 H), 1.14 (t, J = 7.6 Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 197.7, 162.0, 155.8, 120.7, 104.4, 34.7, 22.0, 21.4, 12.4, 12.2, 8.3. IR (neat, cm^{-1}): 3111, 2974, 2937, 2879, 1677, 1565, 1460, 1397, 1213, 1062, 1006, 921, 803. Anal. Calcd (found) for $\text{C}_{11}\text{H}_{16}\text{O}_2$: C, 73.30 (73.12); H, 8.95 (9.02).

5-Ethyl-2-isopropanyl-3-(2-methylpropionyl)furan (Table 2, entry 11). Colorless oil. TLC: R_f = 0.76. ^1H NMR: δ 6.16 (t, J = 1.2 Hz, 1 H), 3.73 (septet, J = 7.2 Hz, 1 H), 3.05 (septet, J = 7.2 Hz, 1 H), 2.61 (dq, J = 1.2, 7.6 Hz, 2 H), 1.23 (d, J = 6.8 Hz, 6 H), 1.22 (t, J = 7.6 Hz, 3 H), 1.14 (d, J = 6.8 Hz, 6 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 201.4, 166.1, 155.5, 118.9, 104.4, 38.6, 27.8, 21.4, 21.0, 19.0, 12.2. IR (neat, cm^{-1}): 2971, 2934, 2874, 1673, 1556, 1468, 1382, 1218, 1071, 952, 859. Anal. Calcd (found) for $\text{C}_{13}\text{H}_{20}\text{O}_2$: C, 74.96 (74.87); H, 9.68 (9.59).

2-Ethyl-5-propanyl-3-(propionyl)furan (Table 2, entry 12). Colorless oil. TLC: R_f = 0.61. ^1H NMR: δ 6.18 (br s, 1 H), 2.97 (q, J = 7.6 Hz, 2 H), 2.70 (q, J = 7.6 Hz, 2 H), 2.54 (t, J = 7.6 Hz, 2 H), 1.64 (sextet, J = 7.6 Hz, 2 H), 1.21 (t, J = 7.6 Hz, 3 H), 1.13 (t, J = 7.6 Hz, 3 H), 0.95 (t, J = 7.6 Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 197.7, 162.0, 154.4, 120.7, 105.2, 34.7, 30.0, 22.0, 21.5, 14.0, 12.4, 8.24. IR (neat, cm^{-1}): 2969, 2936, 2875, 1677, 1565, 1396, 1378, 1210, 1007, 923, 794. Anal. Calcd (found) for $\text{C}_{12}\text{H}_{18}\text{O}_2$: C, 74.19 (73.98); H, 9.34 (9.42).

Determination of furan regiochemistry.

The regiochemistry of 3-(benzoyl)-2,5-dimethylfuran (Table 2, entry 3) was established by NMR spectroscopy. The resonances corresponding to H(2'), H(3'), H(4'), H(5'), H(6'), H(4),

and C(8) were assigned directly from ^1H and ^{13}C NMR spectra (Figure S1 and S2). The remaining chemical shifts were assigned from the HMQC (Figure S3) and HMBC NMR spectra (Figure S4-S6). Incorporation of the acyl carbonyl group into the furan ring was established by the presence of cross-peak between the carbonyl carbon atom at δ 191.8 and the ortho phenyl protons at δ 7.78 and the absence of a cross peak between the carbonyl carbon and either of the two methyl resonances at δ 2.28 and 2.48 in the HMBC spectrum. The regiochemistries of the remaining furans were established in a similar manner.

Figure S1. ^1H NMR spectrum for 3-(benzoyl)-2,5-dimethyl-furan in CDCl_3 .

Figure S2. ^{13}C NMR spectrum for 3-(benzoyl)-2,5-dimethyl-furan in CDCl_3 .

Figure S 3. HMQC NMR sepctrum for 3-(benzoyl)-2,5-dimethyl-furan in CDCl_3 .

Figure S 4. HMBC NMR spectrum for 3-(benzoyl)-2,5-dimethyl-furan in CDCl₃.

Figure S 5. HMBC NMR spectrum for 3-(benzoyl)-2,5-dimethyl-furan in CDCl₃.

Figure S 6. HMBC NMR spectrum for 3-(benzoyl)-2,5-dimethyl-furan in CDCl₃.

Figure S7. ¹H NMR spectrum for 3-(benzoyl)-5-methyl-2-pentylfuran (Table 2, entry 4).

Figure S8. ^{13}C NMR spectrum for 3-(benzoyl)-5-methyl-2-pentylfuran (Table 2, entry 4).

Figure S9. ^1H NMR spectrum for 3-(4-trifluoromethylbenzoyl)-2,5-dimethylfuran (Table 2, entry 7).

Figure S11. ^1H NMR spectrum for 3-(2-thiophenyl)-2,5-dimethyl-furan (Table 2, entry 9).

Figure S12. ^{13}C NMR spectrum for 3-(2-thiophenyl)-2,5-dimethyl-furan (Table 2, entry 9).

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