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Synthesis of Acyl Pyrroles via Palladium-Catalyzed Carbonylative Amination of Aryl and Alkenyl Iodides

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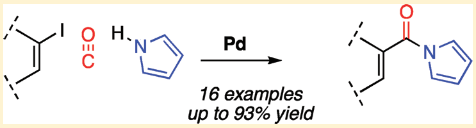
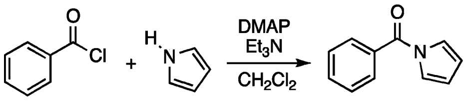
Ⓢ *Supporting Information*

ABSTRACT: A palladium-catalyzed synthesis of acyl pyrroles from aryl and alkenyl iodides is reported. This carbonylative amination requires only atmospheric (balloon) pressure of carbon monoxide and proceeds with $Pd(PPh_3)_4$ and Pd-NHC catalysts. Aryl and heteroaryl iodides give the corresponding acyl pyrroles in good to excellent yields, while alkenyl iodides provide the corresponding acyl pyrroles in low to moderate yields.



Ketones are perhaps the most versatile functional group, and their preparation is a central issue in synthetic organic chemistry. The addition of organometallic reagents to *N*-methoxy-*N*-methylamides, commonly known as Weinreb amides,[1−5] is a standard method for the synthesis of ketones from carboxylic acid derivates. Morpholine amides[6−8] and acyl triazoles[9] have also proven to be effective acylating agents in the synthesis of ketones, but their use is much less frequent. In general, these amides are prepared by condensation of carboxylic acid derivatives with the corresponding amine. Recently, Buchwald[10,11] reported a protocol for the synthesis of Weinreb amides from aryl halides through a palladium-catalyzed carbonylative amination reaction employing a xantphos/Pd_2dba_3 catalyst system.[12] Other reports of palladium-catalyzed carbonylative amidation leading to Weinreb amides have also appeared.[13,14] This method is attractive since it incorporates a C1 unit in the form of carbon monoxide. It is worth noting that morpholine amides can also be prepared using this method.[15]

In 2002, Evans demonstrated that the reaction of acyl pyrroles with organometallic reagents results in the formation of remarkably stable aminals that could even survive purification by silica gel chromatography.[16] These intermediates could be induced to undergo elimination of the pyrrole moiety to generate ketones in good yields. Thus, *N*-acyl pyrroles can be viewed as alternative reagents to Weinreb amides. In addition, *N*-acyl pyrroles have found use as monodentate electrophiles in asymmetric conjugate addition reactions.[17−19] *N*-Acyl pyrroles can be synthesized by the reaction of an acyl chloride with pyrrole[20,21] (eq 1). An alternative protocol involves the synthesis of the pyrrole moiety by condensation of an amide with 2,5-dimethoxytetrahydrofuran[22] (eq 2).



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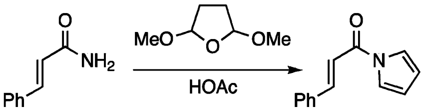
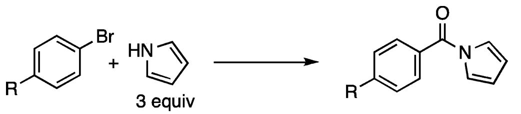


(2)

We became intrigued by the possibility of preparing acyl pyrroles by palladium-catalyzed carbonylative coupling of aryl halides with pyrrole[23] in a manner analogous to the synthesis of Weinreb amides reported by Buchwald. Our work was motivated in part by the lower cost of pyrrole compared to that of *N*-methoxy-*N*-methylamine.[24] At the outset, we were aware that the nature of the nitrogen atom of pyrrole is markedly different from that of an alkylamine and that this would have implications on the mechanism of the proposed carbonylative amination reaction and/or the efficiency of the transformation.[25,26] In this paper, we report that acyl pyrroles can be efficiently prepared from aryl iodides and pyrrole using simple catalytic systems and carbon monoxide at atmospheric pressure.

In our initial experiments we mimicked the conditions developed by Buchwald for the synthesis of Weinreb amides. Surprisingly, we found that subjecting bromobenzene to these reactions conditions provided benzoyl pyrrole in only 21% yield.[27] In contrast, the use of a simple catalyst system consisting of $Pd(OAc)_2$ and Ph_3P provided benzoyl pyrrole in 92% yield. Unfortunately, this reaction proved capricious and resulted in highly variable yields. The use of freshly prepared $Pd(PPh_3)_4$ and elevated carbon monoxide pressure[28] did not ameliorate the situation. During the course of this exploratory work we also noted that the use of electron poor aryl bromides resulted in diminished or no yield of the corresponding acyl pyrroles under these conditions (Table 1).

Table 1. Attempted Preparation of Acyl Pyrroles Using a Range of Aryl Bromides



CO (balloon)
$Pd(OAc)_2$ (10 mol%)
Ph_3P (40 mol%)
K_3PO_4 (4 equiv.)
THF, 60 °C

R	yield
H	92%
CO_2Me	35%
CHO	0%
NO_2	0%

Since oxidative addition of electron-poor aryl bromides to palladium(0) is expected to be facile, the results in Table 1 are somewhat surprising and suggest that downstream intermediates (i.e., arylpalladium(II) or benzoylpalladium(II) intermediates) may be subject to undesired decomposition. This unexpected trend prompted

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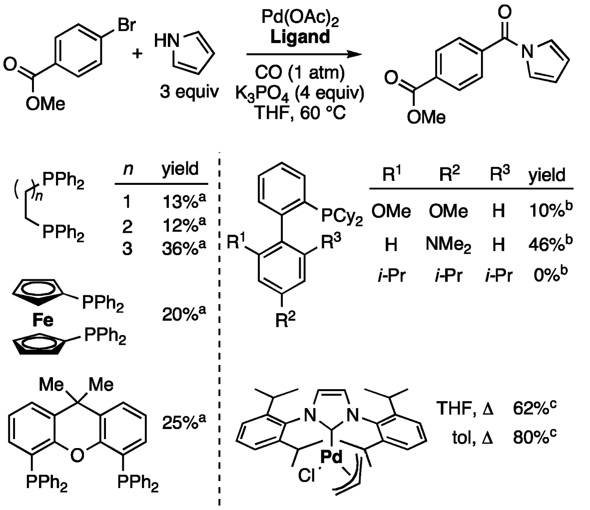
us to explore a range of ligands for this reaction with the aim of finding a general catalyst. As can be gleaned from Table 2, while a range of structurally distinct phosphine-based ligands can be utilized, the yields are uniformly poor (i.e., less than 50% isolated yield) for these reactions. Notably, the use of an NHC-ligated precatalyst resulted in a marked improvement in the yield, and the use of toluene at higher temperature provided the acyl pyrrole in a satisfactory 80% yield.

Table 2. Evaluation of Ligands for the Synthesis of Acyl Pyrroles Using an Activated Aryl Bromide



[a] Reactions conducted with 10 mol % of $Pd(OAc)_2$ and 10 mol % of ligand. [b] Reactions conducted with 10 mol % of $Pd(OAc)_2$ and 20 mol % of ligand. [c] Reactions conducted with 10 mol % of precatalyst.

Having determined that a Pd-NHC precatalyst system was suitable for the synthesis of acyl pyrroles using electron-poor substrates, we proceeded to evaluate other aryl bromides. We were dismayed to find that this catalyst provided generally poor yields with a variety of aryl bromides (not shown). In view of these results, we shifted our attention to the use of aryl iodides for the preparation of acyl pyrroles and evaluated the reaction conditions shown in Figure 1 based on our experience with aryl bromides. Although the carbonylative amination of aryl bromides proceeds with a catalyst system consisting of a 1:4 molar ratio of $Pd(OAc)_2$ and PPh_3, we elected to use freshly prepared $Pd(PPh_3)_4$ for this study for consistency across all reactions and also explored this catalyst system under elevated CO pressure.[28] In addition, we also evaluated the Pd-NHC precatalyst given its success in the synthesis of acyl pyrroles from activated aryl bromides.

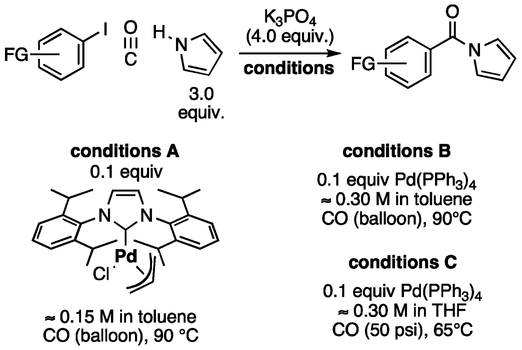
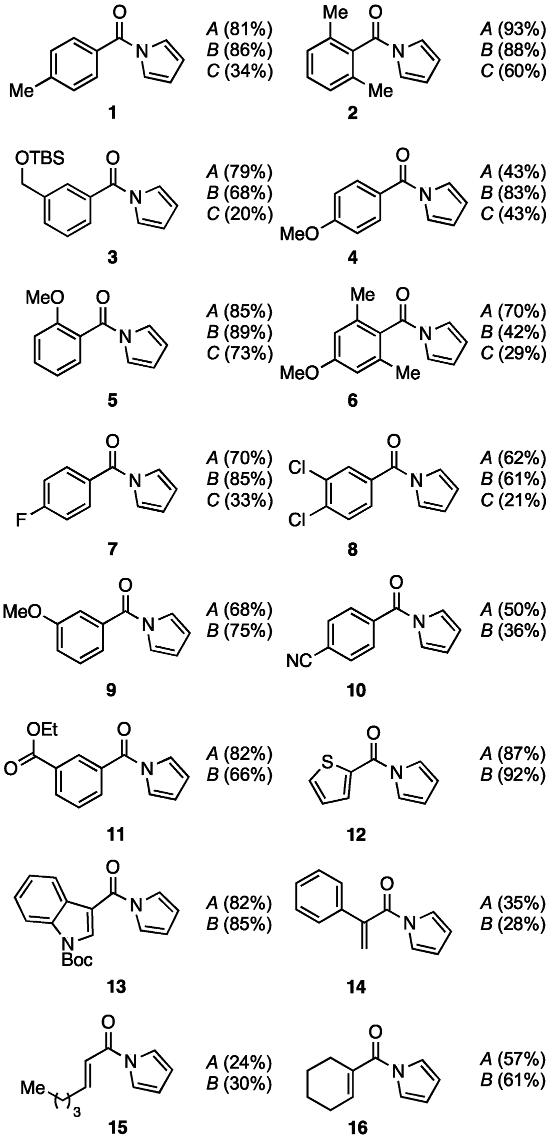


Figure 1. Reaction conditions for the synthesis of acyl pyrroles from aryl iodides via carbonylative amination.

Table 3. Scope of the Synthesis of Acyl Pyrroles from Aryl Iodides via Carbonylative Amination



As can be gleaned from Table 3, the synthesis of acyl pyrroles via carbonylative amination proceeds with a range of aryl iodides. In general, the reactions conducted at elevated pressure of CO were significantly lower yielding than those conducted at atmospheric pressure using a balloon of CO (entries 1−8). This method tolerates a range of electron-donating (entries 1−6) and electron-withdrawing (entries 7−11) substituents on the aryl ring. Heterocyclic iodides provide the desired acyl pyrroles in excellent yield (entries 12 and 13). In contrast, alkenyl iodides provide the desired product in low to moderate yields (entries 14−16). Sterically demanding aryl iodides work well (entries 2, 5, and 6), and the resulting di-*ortho*-substituted acyl pyrroles (entries 2 and 6) display restricted rotation of the amide function at room temperature as determined by NMR. Interestingly, neither catalyst system ($Pd(PPh_3)_4$ or Pd-NHC) was superior across all substrates. In general, however, good to excellent yields of the acyl pyrroles could be obtained with both catalysts, with the exception of alkenyl halides. In a couple of instances, a significant difference in yield could be observed between the two catalysts (entries 4, 6, 10, and 11), and thus, they appear to be somewhat complementary.

In conclusion, we have shown that acyl pyrroles can be prepared readily from aryl, heteroaryl and alkenyl iodides using simple catalyst systems and carbon monoxide at atmospheric pressure. This reaction tolerates a range of functional groups on the aryl ring and provides the acyl pyrroles in good to excellent yields in most cases.

EXPERIMENTAL SECTION

General Procedure for the Synthesis of Acyl Pyrroles via Carbonylative Amination. *Conditions A.* A 50 mL test tube equipped with a stir bar and sealed with a rubber septum was purged with argon and charged with potassium phosphate (0.741 g, 3.49 mmol, 4.0 equiv), (IPr)Pd(allyl)Cl (0.050 g, 0.10 equiv, 0.087 mmol), and 3 mL of toluene. The aryl iodide (1.0 equiv, 0.873 mmol), pyrrole (0.181 mL, 3.0 equiv, 2.61 mmol), and an additional 3 mL of toluene were added. The mixture was then purged with CO for 30 s. The vessel was placed in an oil bath heated to 90 °C for 19 h, and an atmosphere of CO was maintained using a balloon. Upon completion, the reaction was allowed to cool to room temperature, diluted with EtOAc, filtered through a plug of Celite, and concentrated. The crude product was purified by flash column chromatography, eluting with the indicated solvent mixture to afford the desired acyl pyrrole.

Conditions B. A 50 mL test tube equipped with a stir bar and sealed with a rubber septum was purged with argon and charged with potassium phosphate (0.741 g, 4.0 equiv, 3.49 mmol) and 3 mL of toluene. The aryl iodide (1.0 equiv, 0.873 mmol) and pyrrole (0.181 mL, 3.0 equiv, 2.61 mmol) were then added to the mixture. Pd(PPh$_3$)$_4$ (0.100 g, 0.10 equiv, 0.087 mmol) was added to the reaction mixture, and the vessel was then purged with CO for 30 s. The reaction vessel was placed in an oil bath heated to 90 °C for 19 h and a CO atmosphere was maintained using a balloon. Upon completion, the reaction was allowed to cool to room temperature, diluted with EtOAc, filtered through a plug of Celite, and concentrated. The crude product was purified by flash column chromatography, eluting with the indicated solvent mixture to afford the desired acyl pyrrole.

Conditions C. A 150 mL pressure tube[28] equipped with a stir bar and sealed with a rubber septum was purged with argon and charged with potassium phosphate (0.741 g, 4.0 equiv, 3.49 mmol) and 3 mL of toluene. The aryl iodide (1.0 equiv, 0.873 mmol) and pyrrole (0.181 mL, 3.0 equiv, 2.61 mmol) were added to the mixture. Pd(PPh$_3$)$_4$ (0.100 g, 0.1 equiv, 0.087 mmol) was added, and the reaction vessel was further purged with argon. The pressure reactor was assembled, pressurized with CO to 50 psi, vented thrice, and finally pressurized to 50 psi. The vessel was placed in an oil bath heated to 65 °C for 19 h. Upon completion, the reaction was allowed to cool to room temperature, diluted with EtOAc, filtered through a plug of Celite, and concentrated. The crude product was purified by flash column chromatography, eluting with the indicated solvent mixture to afford the desired acyl pyrrole.

4-Toluylpyrrole (Table 3, Entry 1). Isolated as an oil using a 10% solution of ethyl acetate in hexanes (method A 81%, method B 86%, method C 34%): ^{1}H NMR (300 MHz, CDCl$_3$) δ 7.68 (d, J = 8.1 Hz, 2H), 7.33 (m, 4H), 6.36 (t, J = 2.4 Hz, 2H) 2.47 (s, 2H); ^{13}C NMR (75 MHz, CDCl$_3$) δ 167.7, 143.0, 130.3, 129.7, 129.1, 121.3, 112.9, 21.6; IR ν = 1695, 1610, 1466, 1401, 1327, 1303, 1088, 882, 739 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{12}H_{12}NO$ ([M + H]$^+$) 186.0919, found 186.0921.

1-(2,6-Dimethylbenzoyl)pyrrole (Table 3, Entry 2). Isolated as pink needle crystals using a 5% solution of EtOAc in hexanes (method A 93%, method B 88%, method C 60%): mp 59 °C; ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.69 (br s, 1H), 7.29 (m, 1H), 7.12 (d, J = 7.2 Hz, 2H), 6.51 (br s, 1H), 6.41 (br s, 1H), 6.24 (br s, 1H), 2.23 (s, 6H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 168.6, 134.6, 134.5, 129.6, 127.4, 120.9, 118.3, 113.8, 113.6, 18.9; IR ν = 1708, 1595 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{13}H_{14}NO$ ([M + H]$^+$) 200.1075, found 200.1070.

(3-((tert-Butyldimethylsilyloxy)methyl)phenyl)(1H-pyrrol-1-yl)methanone (Table 3, Entry 3). Isolated as a clear oil using a 4% solution of ethyl acetate in hexanes (method A 79%, method B 68%, method C 20%): ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.73 (s, 1H), 7.64 (d, J = 7.7 Hz, H), 7.59 (d, J = 7.7 Hz) 7.49 (dd, J = 7.7, 7,7 Hz, 1H), 7.31 (m, 2H), 6.36 (m, 2H), 4.82 (s, 2H), 0.97 (s, 9H), 0.14 (s, 6H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 167.7, 142.0, 133.0, 129.7, 128.3, 128.0, 126.9, 121.2, 64.2, 25.8, 25.8, 18.3, −5.4; IR ν = 1699, 1558, 1507, 1466, 1330, 1303, 1157, 1086, 837, 778, 737 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{18}H_{25}NO_2Si$ ([M + H]$^+$) 316.1733, found 316.1725.

1-(4-Methoxybenzoyl)pyrrole (Table 3, Entry 4). Isolated as an oil using a 7% solution of ethyl acetate in hexanes (method A 43%, method B 83%, method C 43%): ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.79 (d, J = 8.9 Hz, 2H), 7.32 (t, J = 1.7 Hz, 2H), 7.01 (d, J = 8.9 Hz, 2H), 6.36 (t, J = 2.0 Hz, 2H), 3.91 (s, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 167.1, 162.9, 131.9, 125.1, 121.3, 113.7, 112.6, 76.6, 55.4; IR ν = 1687, 1603, 1511, 1465, 1328, 1299, 1257, 1172, 1089, 1074, 882, 741 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{12}H_{12}NO_2$ ([M + H]$^+$) 202.0868, found 202.0871.

1-(2-Methoxybenzoyl)-1H-pyrrole (Table 3, Entry 5). Isolated as an oil using 15% solution of ethyl acetate in hexanes (method A 85%, method B 89%, method C 73%): ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.51 (ddd, J = 1.6, 7.6, 8.4 Hz, 1H), 7.41 (d, J = 1.6, 8.4 Hz, 1H), 7.18 (br s, 2H), 7.07 (t, J = 7.6 Hz, 1H), 7.03 (d, J = 8.4 Hz, 1H), 6.31 (br s, 2H), 3.83 (s, 3H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 166.2, 156.6, 132.2, 129.1, 123.5, 120.5, 120.3, 112.9, 111.3, 55.6; IR ν = 1705, 1600, 1335 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{12}H_{11}NNaO_2$ ([M + Na]$^+$) 224.0687, found 224.0885.

1-(4-Methoxy-2,6-dimethylbenzoyl)-1H-pyrrole (Table 3, Entry 6). Isolated as a clear oil using 5% solution of ethyl acetate in hexanes (method A 70%, method B 42%, method C 29%): ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.67 (s, 1H), 6.64 (s, 2H), 6.54 (s, 1H), 6.39 (s, 1H), 6.23 (s, 1H), 3.84 (s, 1H), 2.20 (s, 1H); ^{13}C NMR (400 MHz, CDCl$_3$) δ 168.7, 160.2, 136.7, 127.2, 121.1, 118.3, 113.7, 113.3, 112.8, 55.1, 19.3; IR ν = 1733, 1698, 1602, 1466, 1325, 1302, 1148, 1087, 884, 742 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{14}H_{15}NO_2$ ([M + H]$^+$) 230.1181, found 230.1185.

1-(4-Fluorobenzoyl)-1H-pyrrole (Table 3, Entry 7). Isolated as a solid using a 2% solution of ethyl acetate in hexanes (method A 70%, method B 85%, method C 33%): mp 43 °C; ^{1}H NMR (300 MHz, CDCl$_3$) δ 7.77 (d, J = 8.6 Hz, 2H), 7.23 (m, 4H), 6.35 (t, J = 2.2 Hz, 2H); ^{13}C NMR (75 MHz, CDCl$_3$) δ 166.6 (d, J_{C-F} = 0.34 Hz), 163.4, 132.1 (d, J_{C-F} = 0.12 Hz), 121.2 Hz, 115.6 (d, J_{C-F} = 0.30 Hz), 113.1; ^{19}F NMR (282 MHz, CDCl$_3$) δ −104.4; IR ν = 1683, 1601, 1507, 1467, 1402, 1325, 1226, 1159, 1090, 1072, 882, 741 cm^{-1}; HRMS (ESI) *m/z* calcd for $C_{11}H_8FNO$ (M$^+$) 189.0590, found 189.0586.

1-(3,4-Dichlorobenzoyl)-1H-pyrrole (Table 3, Entry 8). Isolated as a white solid using a 2% solution of ethyl acetate in hexanes (method A 62%, method B 61%, method C 21%): mp 64 °C; ^{1}H NMR (300 MHz, CDCl$_3$) δ 7.88 (s, 1H), 7.61 (d, J = 1.8 Hz, 2H), 7.27 (m, 2H), 6.40 (t, J = 2.4 Hz, 2H); ^{13}C NMR (100 MHz, CDCl$_3$) δ 165.3, 137.0, 133.2, 132.9, 131.4, 130.6, 128.5, 121.1, 113.8; IR ν = 1675, 1469, 1410, 1339, 1100, 1040, 907, 773, 732 cm^{-1}; HRMS (EI) *m/z* calcd for $C_{11}H_7Cl_2NO$ ([M + H]$^+$) 239.9983, found 239.9983.

1-(3-Methoxybenzoyl)-1H-pyrrole (Table 3, Entry 9). Isolated as a clear oil using a 4% solution of ethyl acetate in hexanes (method A 68%, method B 75%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.43 (t, J = 7.8 Hz, 1H), 7.32 (m, 3H), 7.29 (m, 1H), 7.16 (m, 1H), 3.88 (s, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 159.4, 134.3, 129.4, 121.6, 121.2, 118.4, 114.2, 113.1, 55.4; IR ν = 1682, 1601, 1507, 1467, 1326, 1227, 1159, 1090, 1072, 882, 741 cm^{-1}; HRMS (ESI) m/z calcd for $C_{12}H_{12}NO_2$ ([M + H]$^+$) 202.0868, found 202.0870.

1-(4-Cyanobenzoyl)pyrrole (Table 3, Entry 10). Isolated as a solid using 15% solution of ethyl acetate in hexanes (method A 50%, method B 36%): mp 87 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.86 (m, 4H), 7.23 (m, 2H), 6.41 (dd, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.9, 137.2, 132.3, 129.8, 120.9, 117.6, 115.8, 114.1; IR ν = 2233, 1679, 1610 cm^{-1}; HRMS (ESI) m/z calcd for $C_{12}H_8N_2O$ ([M + Na]$^+$) 219.0534, found 219.0531.

Ethyl 3-(1H-Pyrrole-1-carbonyl)benzoate (Table 3, Entry 11). Isolated as a oil using 15% solution of ethyl acetate in hexanes (method A 82%, method B 66%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.43 (s, 1H), 8.30 (d, J = 8.0 Hz, 1H), 7.95 (d, J = 6.8 Hz, 1H), 7.63 (dd, J = 8.0, 6.8 Hz, 1H), 7.29 (br s, 2H), 6.40 (br s, 2H), 4.44 (q, J = 7.2 Hz, 2H), 1.43 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.7, 165.3, 133.5, 133.3, 132.9, 130.9, 130.2, 128.6, 121.1, 113.5, 61.4, 14.2; IR ν = 1726, 1701, 1606 cm^{-1}; HRMS (ESI) m/z calcd for $C_{14}H_{14}NO_3$ ([M + H]$^+$) 244.0974, found 244.0972.

(1H-Pyrrol-1-yl)(thiophene-2-yl)methanone (Table 3, Entry 12). Isolated as an oil using a 5% solution of ethyl acetate in hexanes (method A 87%, method B 92%): ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.77 (d, J = 3.6 Hz, 1H), 7.72 (d, J = 4.5 Hz, 1H), 7.48 (t, J = 1.8 Hz, 2H), 7.20 (t, J = 4.5 Hz, 1H), 6.40 (t, J = 1.8 Hz, 2H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 160.6, 135.8, 134.1, 133.4, 127.7, 121.0, 113.2; IR ν = 1672, 1459, 1419, 1357, 1321, 1063, 813 cm^{-1}; HRMS (ESI) m/z calcd for C_9H_7NOS ([M + H]$^+$) 177.0248, found 177.0241.

tert-butyl 3-(1H-Pyrrole-1-carbonyl)-1H-indole-1-carboxylate (Table 3, Entry 13). Isolated as a white crystalline solid using a 5% solution of ethyl acetate in hexanes (method A 82%, method B 85%): mp 83−85 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.23 (d, J = 8.0 Hz, 1H), 8.19 (s, 1H), 8.07 (d, J = 8.0 Hz, 1H), 7.51 (bs, 2H), 7.46 (t, J = 8.0 Hz, 1H), 7.39 (t, J = 8.0 Hz, 1H), 6.42 (bs, 2H), 1.75 (s, 9H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.2, 148.9, 135.1, 131.2, 128.2, 125.7, 124.1, 121.5, 120.6, 115.2, 113.6, 112.9, 85.5, 28.0; IR ν = 1743, 1677, 1459, 1366, 1285, 1232, 1152, 1116, 832, 756 cm^{-1}; HRMS (ESI) m/z calcd for $C_{18}H_{18}N_2O_3$ (M$^+$) 310.1317, found 310.1311.

2-Phenyl-1-(1H-pyrrol-1-yl)prop-2-en-1-one (Table 3, Entry 14). Isolated as a yellow oil using a 5% solution of ethyl acetate in hexanes (method A 35%, method B 28%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.46 (m, 2H), 7.40 (m, 3H), 7.30 (bs, 2H), 6.30 (m, 2 H), 6.08 (s, 1H), 5.71 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.4, 143.2, 135.3, 128.9, 128.8, 126.1, 120.4, 119.5, 113.4; IR ν = 1683, 1625, 1466, 1357, 1254, 1168, 829, 763 cm^{-1}; HRMS (ESI) m/z calcd for $C_{13}H_{11}NO$ (M$^+$) 197.0841, found 197.0845.

(E)-1-(1H-Pyrrol-1-yl)hept-2-en-1-one (Table 3, Entry 15). Isolated as a yellow oil using a 5% solution of ethyl acetate in hexanes (method 24%, method B 30%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.40 (bs, 2H), 7.29 (dt, J = 15.2 Hz, 7.2 Hz, 1H), 6.57 (d, J = 15.2, 1H), 6.34 (bs, 2H), 2.36 (q, J = 7.2 Hz, 2H), 1.54 (quintet, J = 7.2 Hz, 2H), 1.40 (sextet, J = 7.2 Hz, 2H), 0.96 (t, J = 7.2 Hz, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 162.8, 152.9, 119.2, 119.1, 113.0, 32.4, 30.0, 22.2, 13.7; IR ν = 1697, 1643, 1662, 1351, 1125, 736 cm^{-1}; HRMS (ESI) m/z calcd for $C_{11}H_{15}NO$ (M$^+$) 177.1154, found 177.1158.

Cyclohexenyl (1H-Pyrrol-1-yl)methanone (Table 1, Entry 16). Isolated as an oil using a 5% solution of ethyl acetate in hexanes (method A 57%, method B 61%): ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28 (t, J = 3.2 Hz, 2H), 6.42 (m, 1H), 6.31 (t, J = 3.2 Hz, 2H) 2.42 (m, 2H); 2.28 (m, 2H), 1.79−1.69 (m, 4H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 168.8, 138.3, 132.9, 120.7, 112.5, 25.4, 25.3, 21.9, 21.4; IR ν = 2952, 1693, 1618, 1461, 1401, 1353, 1314, 1078, 791 cm^{-1}; HRMS (ESI) m/z calcd for $C_{11}H_{13}NO$ (M$^+$) 175.0997, found 175.0992.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

^{1}H and ^{13}C NMR spectra for all new compounds. This material is free of charge via the Internet at http://pubs.acs.org.

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