Solvent free synthesis of 2-acylpyrroles and its derivatives catalysed by reuseable zinc oxide

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A highly efficient procedure for preparing 2-acylpyrroles and its derivatives is described. The products were obtained through regioselective Friedel–Crafts reactions of pyrroles and its derivatives with alkyl or aryl acid chlorides catalysed by zinc oxide under solvent-free conditions. This method has the advantages of green chemistry, operational simplicity, solvent-free conditions, and recoverable catalyst.

Keywords: zinc oxide, Friedel–Crafts reaction, pyrroles, solvent-free conditions, green chemistry

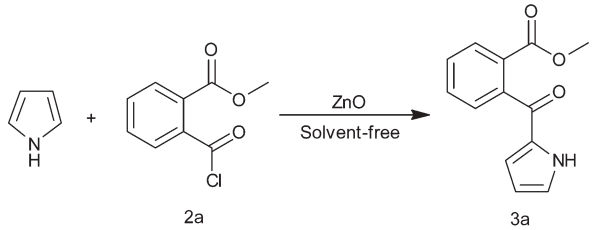
2-Aecylpyrroles are found in many natural products[1] and are also important synthons for the synthesis of several biologically active molecules, such as indanomycin, calcimycin and Zomax.[2–8] A number of methods have been used to synthesise the targeted products.[9–18] These included pyrroles and its derivatives reacted with acid chlorides,[11] Vilsmeier–Haack reagents,[12] seleno-esters,[13] thiol-esters,[14] nitrilium salts,[15] pyrrylmagnesium halide precursors,[16] N-acylbenzotriazoles[17] and carboxylic acids.[18] However, these methods suffer from disadvantages such as long reaction time, use of solvents, poor regioselectivity and low yield. Thus, there is a need to develop an environmentally benign protocol for the synthesis of 2-acylpyrroles.

In recent years, solvent-free reactions have gained attention because of their high efficiency, operational simplicity, economically viability and are environmentally benign.[19] Zinc oxide is an inexpensive, reuseable, nontoxic Lewis acid, which has been utilised for various organic reactions.[20–22] Here we report that zinc oxide as a reuseable catalyst for regioselective acylation of pyrroles and its derivatives under solvent-free conditions.

We initially selected pyrrole with methyl 2-(chlorocarbonyl)-benzoate (**2a**) as a model substrate for the optimisation of the reaction conditions (Scheme 1).

In order to elucidate the efficiency of the catalyst, different amounts of zinc oxide were examined for the acylation of pyrrole. Initially, **2a** (10 mmol), pyrrole (10 mmol) and zinc oxide (10 mol%) were stirred at room temperature for 2 min under solvent-free conditions; the mixture gave 2-(1*H*-pyrrol-2-ylcarbonyl)benzoate(**3a**) in 32% yield. As indicated in Table 1, on increasing the amounts of catalyst, there is significant increase of the product yield. However, for the amounts of catalyst beyond 25 mol%, there is no appreciable effect on the yield.

In order to study the effect of temperature, the Friedel–Crafts reaction was carried out at five different temperatures (0, 5, 10, 20, 30 °C). We chose 20 °C as the reaction temperature, because the reaction was easily handled under these conditions (Table 2).



Scheme 1

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Table 1 The amounts of catalyst optimisation for the acylation

Entry	ZnO/mol%	Yield/%[a]
1	10	32
2	15	54
3	20	65
4	25	82
5	50	83

[a]Isolated yield.

To determine the effect of solvent, reactions were run in various solvents (Table 3). The results show that a better yield was obtained in toluene compared to other solvents. However, the yield was maximum under solvent-free conditions.

In order to check the reusability of zinc oxide, the reaction between **2a** and pyrrole was repeated several times (Table 4) using the recovered zinc oxide catalyst. The catalyst was filtered off after each run and washed thoroughly with dichloromethane. It was then dried at 60 °C for 3h and used for the next catalytic cycle. The catalyst was found to be reuseable

Table 2 Influence of reaction temperature on ZnO catalysed Friedel–Crafts acylation of pyrrole

Entry	Temperature/°C	Time/min	Yield/%[a]
1	0	5	79
2	5	5	78
3	10	3	80
4	20	2	82
5	30	1	79

[a]Isolated yield.

Table 3 Acylation of pyrrole with **2a** under solvents or solvent-free conditions

Entry	Solvent	Time/min	Yield/%[a]
1	None	2	82
2	Acetonitrile	120	68
3	Dichloromethane	120	62
4	Chloroform	120	55
5	Toluene	120	73

[a]Isolated yield.

Table 4 The recycled ZnO for the acylation of pyrrole with **2a**

Entry	Recovery time/h	Yield/%[a]
1	0	82
2	1	80
3	2	79
4	3	79

[a]Isolated yield.

Table 5 Reaction time and yield of products

Product	R^1	R^2	Time/min	Yield/%[a]
3a	H	2-$(CH_3OOC)C_6H_4$-	2	82
3b	H	C_6H_5-	5	85
3c	H	4-$(Cl)C_6H_4$-	4	79
3d	H	4-$(ClCH_2)C_6H_4$-	3	82
3e	H	$C_6H_5CH_2$-	4	86
3f	H	$C_6H_5CH_2OOCCH_2CH_2$-	3	87
3g	H	CH_3-	3	77
3h	H	$ClCH_2$-	3	79
4a	CH_3-	2-$(CH_3OOC)C_6H_4$-	2	86
4b	CH_3-	C_6H_5-	2	84
4c	CH_3-	4-$(Cl)C_6H_4$-	2	85
4d	CH_3-	4-$(ClCH_2)C_6H_4$-	3	88
4e	CH_3-	$C_6H_5CH_2$-	3	81
4f	CH_3-	$ClCH_2$-	3	86
5a	$C_6H_5CH_2$-	2-$(CH_3OOC)C_6H_4$-	2	81
5b	$C_6H_5CH_2$-	C_6H_5-	3	80
5c	$C_6H_5CH_2$-	4-$(CH_3O)C_6H_4$-	5	83
5d	$C_6H_5CH_2$-	4-$(CH_3)C_6H_4$-	4	85
5e	$C_6H_5CH_2$-	3-$(Cl)C_6H_4$-	5	83
5f	$C_6H_5CH_2$-	$ClCH_2$-	3	82

[a]Isolated yield.

up to three catalytic cycles without any significant loss in catalytic activity.

To explore the substrate scope of this method, Friedel–Crafts acylations of pyrroles and its derivatives with various alkyl and aryl substituted acid chlorides are listed in Table 5. When pyrroles reacted with various alkyl and aryl substituted acid chlorides, the corresponding products were obtained in good yield. When its derivatives, such as 1-methyl-1*H*-pyrrole and 1-benzyl-1*H*-pyrrole, reacted with the corresponding acid chlorides, these also gave good yield (Scheme2).

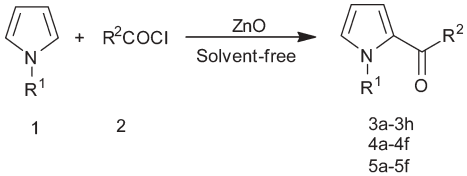
In summary, we have successfully developed a novel and simple method for the synthesis of 2-acylpyrroles using zinc oxide as catalyst under solvent-free conditions. The methods have several advantages including high yield of products, great regioselectivity, simple products isolated procedures, short reaction time and inexpensive catalyst.

Experimental

All reagents were purchased from commercial sources and used without further purification. Melting points were determined on a RY-1 hot stage microscope and are uncorrected. IR spectra were determined as KBr pellets on a Thermo Nicolet 6700 spectrophotometer. ^{1}H NMR and ^{13}C NMR spectra were recorded on a Bruker Avance DPX-300 MHz/500 MHz instrument in $CDCl_3$ or DMSO, chemical shifts (δ) were given in part per million (ppm) relative to TMS as an internal standard. Mass spectra (MS) were obtained from Agilent 1100LC/MS Spectrometry Services. The HRMS spectra were obtained on a Thermo Finnigan spectrometer, model MAT 95XP. All reactions were monitored by TLC on silica gel GF-254 glass plates (E.Merck) and viewed under UV light at 254 nm.

General procedure for the synthesis of 2-acylpyrroles and its derivatives (Scheme 2)

A mixture of acid chloride (10 mmol), pyrroles or its derivatives (10 mmol) and zinc oxide (2.5 mmol) were stirred at 20 °C for a certain period of time by TLC monitor. The solid mass was eluted with dichloromethane and then washed with an aqueous solution of sodium bicarbonate and dried over anhydrous sodium sulfate. Evaporation of the solvent followed by purification on silica gel or recrystallisation afforded the corresponding product **3a–h**, **4a–f** and **5a–f**. Structures of the new compounds **3a**, **3d**, **3f**, **4a**, **4d**, **5a**, **5c**, **5d** and **5e** were characterised by ^{1}H NMR, ^{13}C NMR, IR and HRMS. The other compounds were characterised by ^{1}H NMR, ^{13}C NMR and MS.



Scheme 2

2-(1H–Pyrrol-2-ylcarbonyl)benzoate (**3a**): White solid; m.p. 112–114 °C. IR (KBr) ν: 3287, 3117, 1722, 1623, 1544, 1437, 1406, 1388, 1291, 1133, 895, 777, 709 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.70 (s, 3H), 6.24–6.26 (m, 1H), 6.45 (s, 1H), 7.12 (s, 1H), 7.52–7.56 (m, 2H), 7.58–7.61 (m, 1H), 7.97–7.98 (m, 1H), 9.77 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 52.27, 111.02, 118.99, 125.40, 128.20, 129.72, 129.97, 130.02, 131.74, 132.13, 140.75, 167.01, 185.73; HRMS calcd for $C_{13}H_{11}NO_3Na[M+Na]^+$: 252.0637, found: 252.0635

Phenyl(1H-pyrrol-2-yl)methanone (**3b**): White solid; m.p. 76–77 °C, (lit.[23] m.p. 77–78 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.00–6.35 (m, 1H), 6.70–6.90 (m, 1H), 7.15 (s, 1H), 7.40–7.51 (m, 2H), 7.54–7.62 (m, 1H), 7.75–8.16 (m, 2H), 9.98 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 110.95, 119.45, 125.25, 128.30, 128.49, 128.89, 130.07, 131.08, 131.76, 138.30, 184.81; MS *m/z*: 170.1([M-H]$^-$, 100%).

(4-Chlorophenyl)(1H-pyrrol-2-yl)methanone (**3c**): White solid; m.p. 115–117 °C, (lit.[23] m.p. 116–117 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 6.35–6.36 (d, *J* = 2.49 Hz, 1H), 6.87 (s, 1H), 7.17 (s, 1H), 7.45–7.60 (m, 2H), 7.84–7.87 (d, *J* = 8.34 Hz, 1H), 8.04–8.07 (d, *J* = 8.37 Hz, 1H), 9.85 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 111.29, 119.60, 125.66, 128.65, 128.88, 130.37, 130.82, 131.57, 136.58, 138.24, 184.51; MS *m/z*: 206.0([M+H]$^+$, 100%).

[4-(Chloromethyl)phenyl](1H-pyrrol-2-yl)methanone (**3d**): White solid; m.p. 83–85 °C. IR (KBr) ν: 3281, 1702, 1623, 1540, 1425, 1400, 1318, 1292, 1262, 1142, 1052, 893, 856, 766, 715, 671 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.63–4.65 (d, *J* = 5.04 Hz, 2H), 6.36 (s, 1H), 6.90 (s, 1H), 7.18 (s, 1H), 7.50–7.53 (d, *J* = 7.98 Hz, 2H), 7.89–7.91 (d, *J* = 7.98 Hz, 1H), 8.10–8.13 (d, *J* = 8.1 Hz, 1H), 9.95 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 111.22, 119.84, 125.68, 128.46, 128.56, 129.43, 130.61, 138.23, 141.16, 142.99, 170.08, 184.21; HRMS calcd for $C_{12}H_{11}NOCl[M+H]^+$: 220.0529, found: 220.0531.

2-Phenyl-1-(1H-pyrrol-2-yl)ethanone (**3e**): White solid; m.p. 95–97 °C, (lit.[24] 94–96 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.05 (s, 2H), 6.28 (s, 1H), 7.00 (s, 1H), 7.23–7.31 (m, 5H), 9.72 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 44.89, 110.78, 117.19, 125.20, 126.79, 127.18, 128.55, 129.35, 129.35, 131.58, 135.09, 187.89; MS *m/z*: 208.1 ([M+Na]$^+$, 100%).

Benzyl 4-oxo-4-(1H-pyrrol-2-yl)butanoate (**3f**): White solid; m.p. 53–55 °C. IR (KBr) ν: 3283, 2926, 1735, 1643, 1547, 1409, 1353, 1217, 1160, 1110, 907, 835, 771, 752, 698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.73–2.84 (m, 2H), 3.16–3.21 (m, 2H), 5.15–5.18 (m, 2H), 6.28–6.31 (m, 1H), 6.99–7.06 (m, 2H), 7.33–7.37 (m, 5H), 9.85 (s, 1H);^{13}C NMR ($CDCl_3$, 75 MHz) δ 28.83, 32.38, 66.53, 110.69, 117.25, 124.94, 128.13, 128.22, 128.50, 128.63, 129.05, 131.33, 135.78, 176.13, 188.39; HRMS calcd for $C_{15}H_{15}NO_3Na[M+Na]^+$: 280.0950, found: 280.0953.

1-(1H-Pyrrol-2-yl)ethanone (**3g**): White solid; m.p. 90–91 °C, (lit.[25] 89–90 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 2.44 (s, 3H), 6.27–6.28 (d, *J* = 2.4 Hz, 1H), 6.92 (s, 1H), 7.04 (s, 1H), 9.54–9.62 (m, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 25.38, 104.70, 110.61, 116.70, 124.56, 187.98; MS *m/z*: 108.1([M-H]$^-$, 20%).

2-Chloro-1-(1H-pyrrol-2-yl)ethanone (**3h**): White solid; m.p. 115–117 °C, (lit.[26] 115–116 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.49 (s, 2H), 6.32–6.35 (m, 1H), 6.99–7.02 (m, 1H), 7.11–7.13 (m, 1H), 9.53 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 44.42, 111.29, 117.34, 125.98, 129.18, 181.35; MS *m/z*: 108.1([M-H]$^-$, 20%).

Methyl 2-(1-methyl-1H-pyrrole-2-carbonyl)benzoate (**4a**): White solid; m.p. 63–65 °C. IR (KBr) ν: 3107, 2951, 2840, 1726, 1637, 1527, 1463, 1406, 1384, 1328, 1271, 1192, 1128, 1086, 1058, 963, 919, 875, 826, 741, 717, 690, 651, 607 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.69 (s, 3H), 4.07 (s, 3H), 6.03–6.04 (m, 1H), 6.29–6.30 (m, 1H), 6.85–6.86 (m, 1H), 7.45–7.50 (m, 2H), 7.53–7.57 (m, 1H), 7.93–7.95 (m, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 37.04, 51.98, 108.07, 121.81, 127.90, 129.04, 129.29, 129.66, 131.02, 131.24, 131.54, 142.22, 166.60, 186.31; HRMS calcd for $C_{14}H_{14}NO_3$ [M+H]$^+$: 244.0974, found: 244.0976.

(1-Methyl-1H-pyrrol-2-yl)(phenyl)methanone (**4b**): White solid; m.p. 113–115 °C, (lit.[23] 114–115 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.03 (s, 3H), 6.13–6.16 (m, 1H), 6.72–6.74 (m, 1H), 6.90–6.91 (m, 1H), 7.40–7.46 (m, 2H), 7.49–7.78 (m, 1H), 7.79–7.81 (m, 2H); ^{13}C

NMR ($CDCl_3$, 75 MHz) δ 37.31, 108.08, 122.85, 128.00, 128.00, 129.14, 129.14, 131.34, 131.34, 131.46, 139.93, 186.18; MS *m/z*: 208.1([M+Na]$^+$, 100%).

(4-Chlorophenyl)(1-methyl-1H-pyrrol-2-yl)methanone (**4c**): White solid; m.p. 70–71 °C, (lit.[23] 69–71 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.03 (s, 3H), 6.15–6.17 (m, 1H), 6.70–6.71 (m, 1H), 6.93 (s, 1H), 7.41–7.44 (d, *J* = 8.28 Hz, 2H), 7.73–7.76 (d, *J* = 8.31 Hz, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 37.32, 108.29, 122.77, 128.33, 128.33, 130.22, 130.22, 130.55, 131.75, 137.63, 138.25, 188.30; MS *m/z*: 220.0([M+H]$^+$, 100%).

(4-(Chloromethyl)phenyl)(1-methyl-1H-pyrrol-2-yl)methanone (**4d**): Colourless oil. IR (KBr) ν: 3108, 2951, 2867, 1717, 1626, 1571, 1525, 1461, 1412, 1402, 1378, 1329, 1256, 1152, 1092, 1061, 918, 877, 850, 806, 743, 723, 679, 606 cm^{-1}; ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.03 (s, 3H), 4.63 (s, 2H), 6.15–6.17 (m, 1H), 6.72–6.73 (m, 1H), 6.92 (s, 1H), 7.45–7.48 (m, 2H), 7.78–7.80 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 37.32, 45.54, 108.19, 122.88, 128.16, 128.47, 129.54, 129.95, 130.35, 131.64, 139.85, 140.55, 185.37; HRMS calcd for $C_{13}H_{13}NOCl$ [M+H]$^+$: 234.0686, found: 234.0688.

1-(1-Methyl-1H-pyrrol-2-yl)-2-phenylethanone (**4e**): Colourless oil, (lit.[24] colourless oil). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.88 (s, 3H), 4.04–4.10 (m, 2H), 6.11–6.13 (m, 1H), 6.78 (s, 1H), 7.06–7.07 (m, 1H), 7.21–7.22 (m, 1H); 7.24–7.30 (m, 4H);^{13}C NMR ($CDCl_3$, 75 MHz) δ 37.55, 45.84, 107.96, 119.78, 126.54, 126.98, 128.13, 128.37, 129.09, 129.30, 131.35, 135.47, 188.17; MS *m/z*: 222.1([M+Na]$^+$, 100%).

2-Chloro-1-(1-methyl-1H-pyrrol-2-yl)ethanone (**4f**): White solid; m.p. 46–47 °C, (lit.[27] m.p. 47 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 3.96 (s, 3H), 4.49 (s, 2H), 6.16–6.18 (m, 1H), 6.89 (s, 1H), 6.98–7.00 (m, 1H);^{13}C NMR ($CDCl_3$, 75 MHz) δ 37.64, 45.67, 108.67, 119.88, 128.12, 132.27, 178.17; MS *m/z*: 180.1([M+H]$^+$, 8%).

Methyl 2-(1-benzyl-1H-pyrrole-2-carbonyl) benzoate (**5a**): White oil. IR (KBr) ν: 2950, 2921, 1721, 1630, 1457, 1397, 1323, 1331, 1263, 1122, 1078, 1030, 913, 871, 714 cm^{-1}; ^{1}H NMR (DMSO-d_6, 300 MHz) δ 3.38 (s, 3H), 5.70 (s, 2H), 6.18 (dd, *J* = 2.52 Hz, 4.05 Hz, 1H), 6.33(dd, *J* = 1.71 Hz, 4.05 Hz, 1H), 7.23–7.46 (m, 7H), 7.60–7.66 (m, 2H), 7.85–7.88 (m, 1H); ^{13}C NMR (DMSO-d_6, 75 MHz) δ 51.26, 51.98, 108.96, 122.58, 127.18, 128.13, 129.39, 129.43, 129.43, 129.61, 129.70, 129.70, 131.82, 131.82, 132.01, 132.01, 138.71, 141.51, 166.60, 185.05; HRMS calcd for $C_{20}H_{18}NO_3$ [M+H]$^+$: 320.1287, found: 320.1289.

(1-Benzyl-1H-pyrrol-2-yl)(phenyl)methanone (**5b**): Colourless oil, (lit.[11] colourless oil). ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.63 (s, 2H), 6.16–6.17 (m, 1H), 6.73–6.75 (m, 1H), 6.95–6.96 (m, 1H), 7.14–7.20 (m, 2H), 7.24–7.27 (m, 1H), 7.35–7.38 (m, 2H), 7.42–7.44 (m, 2H), 7.45–7.46 (m, 1H), 7.73–7.74 (m, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 52.22, 108.52, 123.32, 127.06, 127.33, 127.33, 127.83, 127.83, 128.47, 128.47, 129.06, 129.06, 130.01, 130.31, 131.22, 138.16, 139.82, 185.95; MS *m/z*: 180.1([M+H]$^+$, 8%).

(1-Benzyl-1H-pyrrol-2-yl)(4-methoxyphenyl)methanone (**5c**): White solid; m.p. 66–68C. IR (KBr) ν: 3106, 2969, 2930, 2840, 1624, 1601, 1506, 1457, 1406, 1390, 1340, 1303, 1256, 1172, 1142, 1088, 1022, 918, 877, 845, 742, 732, 647, 614 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 3.77 (s, 3H), 5.60 (s, 2H), 6.16–6.17 (m, 1H), 6.73–6.74 (m, 1H), 6.86–6.87 (m, 2H), 6.88–6.94 (m, 1H), 7.13–7.15 (m, 2H), 7.17–7.20 (m, 1H), 7.25–7.26 (m, 2H), 7.77 (s, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 52.02, 55.18, 108.29, 113.14, 113.14, 122.28, 127.01, 127.01, 127.26, 127.26, 128.42, 130.09, 130.09, 130.18, 131.33, 132.32, 139.30, 162.33, 184.91; HRMS calcd for $C_{19}H_{18}NO_2$ [M+H]$^+$: 292.1338, found: 292.1342.

(1-Benzyl-1H-pyrrol-2-yl)(p-tolyl)methanone (**5d**): Pale yellow oil. IR (KBr) ν: 3030, 2922, 1624, 1523, 1495, 1460, 1410, 1333, 1259, 1178, 1083, 915, 876, 744 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.38 (s, 3H), 5.64 (s, 2H), 6.17–6.19(dd, *J* = 2.6, 4 Hz, 1H), 6.75–6.76 (dd, *J* = 1.65, 4 Hz, 1H), 6.96–6.97 (m, 2H), 7.16 (d, *J* = 7.15 Hz, 3H), 7.21 (d, *J* = 7.8 Hz, 2H), 7.69 (d, *J* = 8.1 Hz, 2H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 21.44, 52.25, 108.45, 122.95, 127.15, 127.38, 127.38, 128.54, 128.54, 128.61, 129.38, 130.28, 130.46, 130.46, 137.17, 137.17, 138.30, 141.89, 185.92; HRMS calcd for $C_{19}H_{18}NO$ [M+H]$^+$: 276.1388, found: 276.1390.

(1-Benzyl-1H-pyrrol-2-yl)(3-chlorophenyl)methanone (**5e**): Pale yellow oil. IR (KBr) ν: 3064, 3031, 2926, 1627, 1566, 1524, 1464, 1410, 1333, 1253, 1143, 1084, 737 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 5.63 (s, 2H), 6.21(dd, *J* = 2.6, 4 Hz, 1H), 6.75(dd, *J* = 1.6, 4 Hz, 1H), 7.01 (m, 1H), 7.16 (d, *J* = 7.4 Hz, 2H), 7.22 (m, 1H), 7.27–7.36 (m, 3H), 7.43–7.46 (m, 1H), 7.62 (d, *J* = 7.7 Hz, 1H), 7.73 (s, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 52.40, 108.87, 123.69, 127.11, 127.18, 127.49, 127.60, 128.58, 129.08, 129.25, 129.53, 131.21, 131.34, 132.90, 134.10, 137.97, 141.50, 184.22; HRMS calcd for $C_{18}H_{15}NOCl$ [M+H]$^+$: 296.0843, found: 296.0842.

1-(1-Benzyl-1H-pyrrol-2-yl)-2-chloroethanone (**5f**): Pale yellow solid; m.p. 90–92 °C, (lit.[26] 89–91 °C). ^{1}H NMR ($CDCl_3$, 300 MHz) δ 4.79 (s, 2H), 5.56 (s, 2H), 6.25–6.27 (m, 1H), 7.07–7.09 (d, *J* = 6.93 Hz, 2H), 7.20–7.31 (m, 4H), 7..42–7.43 (m, 1H); ^{13}C NMR ($CDCl_3$, 75 MHz) δ 46.32, 51.39, 108.97, 121.24, 126.61, 126.89, 127.12, 127.12, 128.33, 128.33, 132.66, 138.54, 181.10; MS *m/z*: 234.1 ([M+H]$^+$, 100%).

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References

1 J.A. Joule, K. Mills and D.F. Smith, *Heterocyclic chemistry*, 3rd edn., Stanley Thornes: Cheltenham, 1998.
2 G.H. Posner, *Angew. Chem. Int. Ed. Engl.*, 1978, **17**, 487.
3 A. McKillop and D.W. Young, *Synthesis*, 1979, 401.
4 H. Firouzabadi, N. Iranpoor and S. Sobhani, *Tetrahedron Lett.*, 2002, **43**, 477.
5 H. Firouzabadi, N. Iranpoor, S. Sobhani and A. Sardarian, *Tetrahedron Lett.*, 2001, **42**, 4369.
6 H. Sharghi, K. Niknam and A.R. Massah, *J. Heterocycl. Chem.*, 1999, **36**, 601.
7 A. Shockravi, H. Sharghi, H. Valisadeh and M.M. Heravi, *Phosphorus. Sulfur. Silicon.*, 2002, **177**, 2555.
8 F. Kazemi, H. Sharghi and M.A. Nasseri, *Synthesis.*, 2004, 205.
9 M.H. Sarvari and H.J. Sharghi, *J. Org. Chem*., 2004, **69**, 6953.
10 J.S. Yadav, B.V.S. Reddy, G. Kondaji, R.R. Srinivasa and K.S. Praveen, *Tetrahedron Lett*., 2002, **43**, 8133.
11 J.E. Taylor, M.D. Jones, J.M.J. Williams and S.D. Bull, *Org Lett*., 2010, **24**, 5740.
12 C.F. Candy, R.A. Jones and P.H. Wright, *J. Chem. Soc*., 1970, 2563.
13 A.P. Kozikowski and A. Ames, *J. Am. Chem. Soc.*, 1980, **102**, 860.
14 K.C. Nicolaou, D.A. Claremon and D.P. Papahatjis, *Tetrahedron Lett*., 1981, **22**, 4647.
15 S.C. Eyley, R.G. Giles and H.Heaney, *Tetrahedron Lett*., 1985, **26**, 4649.
16 S.R. Cornforth and D.M. Huib, *J. Chem. Soc. Perkin. Trans., 1*, 1990, 1463.
17 A.R. Katritzky, K. Suzuki and S.K. Singh, *J. Org. Chem*., 2003, **68**, 5720.
18 C.J. Song, D.W. Knight and M.A. Whatton, *Tetrahedron Lett*., 2004, **45**, 9573.
19 K. Tanaka and F. Toda, *Chem. Rev*., 2000, **100**, 1025.
20 G.B. Dharma, M.P. Kaushik and A.K. Halve, *Tetrahedron Lett.*, 2012, **53**, 2741.
21 H.S. Mona and S. Hashem, *Tetrahedron*, 2005, **61**, 10903.
22 T. Fatemeh, A.A. Mohammad and S. Leily, *Tetrahedron Lett.*, 2005, **46**, 7841.
23 M. Barbero, S. Cadamuro, L. Degani, R. Fochi, A. Gatti and V. Regondi, *J. Org. Chem*., 1988, **53**, 2245.
24 R. Greenhouse, C. Ramirez and J.M. Muchowski, *J. Org. Chem*., 1985, **50**, 2961.
25 A.G. Anderson and M.M. Exner, *J. Org. Chem*., 1977, **42**, 3952.
26 P.D. Croce, L.R. Concetta and R. Alberto, *Synthesis*, 1989, 783.
27 W.K. Su, C.L. Wu and H. Su, *J. Chem. Res*., 2005, 67.