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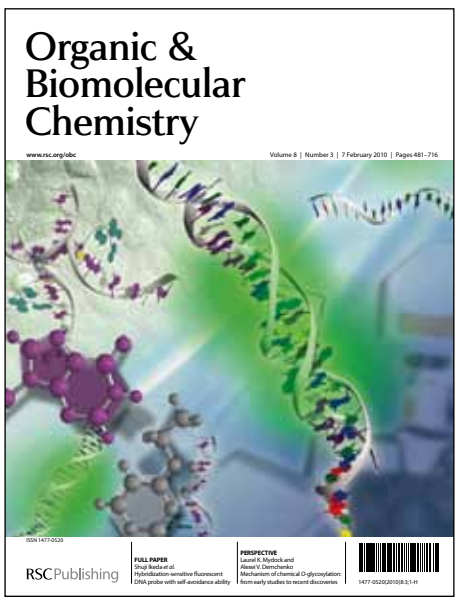

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Organic & Biomolecular Chemistry

Cite this: DOI: 10.1039/c0xx00000x

PAPER

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Synthesis of Polysubstituted Pyrroles *via* [3 + 2]-Annulation of Aziridines and *β*-Nitroalkenes Under Aerobic Conditions

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Received (in XXX, XXX) Xth XXXXXXXXX 20XX, Accepted Xth XXXXXXXXX 20XX

DOI: 10.1039/b000000x

Polysubstituted pyrroles were regioselectively synthesized in moderate to good yields *via* the copper acetate-catalyzed [3 + 2] annulation reaction of readily accessible aziridines and nitroalkenes. This reaction was proposed to proceed through a key azomethine ylide intermediate generated by selective C-C bond cleavage of the aziridine followed by annulation with nitroalkenes under aerobic conditions.

Introduction

Pyrroles and their derivatives are an important family of heterocyclic compounds with various applications in organic synthesis, functional materials and pharmaceuticals.[1-2] The development of efficient synthetic approaches to pyyroles has attracted long-standing interests among organic chemists. Besides classic methods like the Hantzsch reaction,[3] and the Paal-Knorr synthesis,[4] various cycloaddition methods[5] and metal-catalyzed approaches[6] have also been developed. Despite these advances, the development of efficient methods for the synthesis of pyrroles from simple and readily available starting materials, especially those with rich substitution types, is still of a great importance given their broad utilities in diverse fields.

Owing to the electronegativity of the nitrogen atom and the ring strain of the three-membered ring, aziridines exhibited intriguing and diverse reactivity, and thus have become unique and versatile synthons in organic synthesis.[7] The ring of aziridine can easily undergo C–N/C-C bond cleavage to serve as useful three-atom synthons with extensive applications in organic synthesis.[7-9] Many efforts have been devoted to the selective ring opening of the aziridine ring for specific purpose. Particularly, aziridines are known to react by thermal or photochemical ring-opening via C–C bond cleavage to give azomethine ylides as useful reactive species for a wide range of synthetic applications.[9] For example, Schirmeister[9f] has confirmed the intermediacy of the azomethine ylide species in the reactions of aziridine-2,2-dicarboxylates with dipolarophiles (alkenes or aldehydes) under thermal conditions. Some Lewis acids catalyzed C–C bond heterolysis of aziridines under mild conditions to form corresponding azomethine ylides have also been reported.[10] Engels also investigated the breakages of the C–N vs. C–C bonds of aziridines through computation methods.[11] On the other hand, a similar azomethine ylide have been proposed as the key intermediate in the Cu(I)-catalyzed three-component synthesis of polysubstituted pyrroles from *α*-diazoketones, nitroalkenes, and amines.[12a] Our group have been interested in the utilization of aziridines as three-atom building-blocks in annulation reactions for the syntheses of useful nitrogen-containing heterocyclic compounds.[12b] Inspired by the researches described above, we report herein an efficient cascade reaction of aziridines with *β*-nitroalkenes[13] through selective C-C cleavage of aziridines catalyzed by $Cu(OAc)_2 \cdot H_2O$, enabling facile access to 2,3,5-trisubstituted and 2,3,4,5-tetrasubstituted pyrroles.

Results and discussion

Initial optimization of the reaction conditions were done with the model reaction between aziridine **1a** and *β*-nitrostyrene **2a** in dimethyl sulphoxide (DMSO) under air (Table 1). In the absence of a catalyst, the desired product **3a** was obtained in only 20% yield (entry 1). The addition of the catalyst $Cu(OAc)_2 \cdot H_2O$ greatly improved the yield, and a screen of catalyst loading amount revealed that 5 mol % was best for the reaction (entry 3). Varying the reaction temperature (entries 5-6), using other cupric salt catalysts such as $Cu(NO_3)_2$, nano CuO, $Cu(OTf)_2$, $CuCl_2$ or cuprous salt catalysts such as CuCl, CuBr (entries 7-12) all failed to improve the results significantly. Notably, the reaction proceeded smoothly under darkness (entry 17), which was not in support of photochemical ring-opening of the aziridine ring for this reaction and thus a thermal process might be considered.[9] Moreover, some other solvents such as DMF, 1,4-dioxane, THF and toluene were also examined to give inferior results (entries 14-17), and the yield dropped sharply when the reaction was run under argon atmosphere (entry 18). Generally, unreacted *β*-nitrostyrene **2a** and some unidenfiable mixture (probably due to the decomposition of aziridine **1a**) accounted for the mass balance where the yields were modest or poor. Thus, the reaction was best performed in DMSO at 110 °C for 18 h under air in the presence of 5 mol % of $Cu(OAc)_2 \cdot H_2O$ (entry 3).

Next, the scope of the reaction was investigated under the

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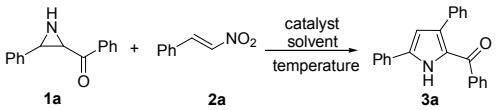
optimized reaction conditions, and the results were presented in Table 2. With regard to the tolerance of *β*-nitroalkenes, different substituted *β*-nitroalkenes **2a**–**2n** were studied with aziridine **1a**. For *β*-nitroalkenes derived from substituted benzaldehydes, substrates with electron-donating substituents on the benzene ring generally gave better yields than those with electron-withdrawing ones (entries 2-8), while the influence of the position of the substitutent seemed negligible. The heterocyclic substrate with a furan ring was also tolerated in the reaction (entry 9). Moreover, nitroalkenes derived from aliphatic aldehydes (entries 10-11), and disubstituted nitroalkenes (gave tetrasubstituted pyrrole products) also participated in the reaction, albeit with somewhat decreased yields (entries 12-14).

Table 1 Screen of reaction conditions[a]



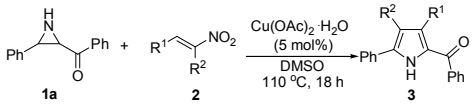
1a **2a** **3a**

Entry	Catalyst (mol %)	Temp (^oC)	Time (h)	Solvent	Yield (%)[b]
1	No catalyst	110	18	DMSO	20
2	$Cu(OAc)_2·H_2O$ (2)	110	18	DMSO	52
3	$Cu(OAc)_2·H_2O$ (5)	110	18	DMSO	72
4	$Cu(OAc)_2·H_2O$ (10)	110	18	DMSO	70
5	$Cu(OAc)_2·H_2O$ (5)	100	24	DMSO	68
6	$Cu(OAc)_2·H_2O$ (5)	120	18	DMSO	72
7	$Cu(NO_3)_2·H_2O$ (5)	110	18	DMSO	70
8	40 nm CuO (5)	110	18	DMSO	71
9	$Cu(OTf)_2$ (5)	110	18	DMSO	68
10	$CuCl_2·2H_2O$ (5)	110	18	DMSO	65
11	CuCl (5)	110	18	DMSO	60
12	CuBr (5)	110	18	DMSO	56
13	$Cu(OAc)_2·H_2O$ (5)	110	18	DMSO	70[c]
14	$Cu(OAc)_2·H_2O$ (5)	110	18	DMF	10
15	$Cu(OAc)_2·H_2O$ (5)	reflux	18	1,4-dioxane	60
16	$Cu(OAc)_2·H_2O$ (5)	reflux	36	THF	46
17	$Cu(OAc)_2·H_2O$ (5)	110	22	Toluene	63[c]
18	$Cu(OAc)_2·H_2O$ (5)	110	22	Toluene	13[d]

[a]Reaction conditions: **1a** (0.5 mmol), **2a** (0.5 mmol), solvent (2 mL), the reaction was monitored by TLC. [b]Yield of the isolated product. [c]Under darkness. [d]Under argon atmosphere.

Then different aziridines **1a**–**1j** were studied in the reaction with *trans*-nitrostyrene **2a** (Table 3). Aziridines bearing electron-withdrawing substituents on the benzene ring of R^3 seemed to be favored over those with electron-donating groups (entries 1-3), while a reversed electronic effect was observed in the case of R^4 (entries 5-8). Notably, when R^4 was 2-furyl, the reaction still proceeded uneventfully to give the desired product in good yield (entry 9). The tolerance of heterocyclic structures like furans should hold great promise for application and further useful conversion of these products in organic synthesis and related fields. Also notable is the excellent regioselectivity observed in all these examples examined, which allows for facile access to these polysubstituted pyrroles.

Table 2 Scope study with different nitroalkenes **2**[a]

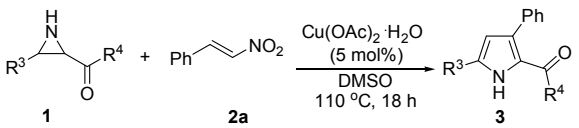


1a **2** **3**

Entry	R^1/ R^2	3	Yield (%)[b]
1	Ph/H (**2a**)	**3a**	72
2	2-$MeOC_6H_4$/H (**2b**)	**3b**	82
3	4-$MeOC_6H_4$/H (**2c**)	**3c**	78
4	2-$NO_2C_6H_4$/H (**2d**)	**3d**	74
5	2-ClC_6H_4/H (**2e**)	**3e**	73
6	3-ClC_6H_4/H (**2f**)	**3f**	71
7	3,4-$Cl_2C_6H_3$/H (**2g**)	**3g**	68
8	2-BrC_6H_4/H (**2h**)	**3h**	70
9	2-Furyl/H (**2i**)	**3i**	66
10	*n*-Pr/H (**2j**)	**3j**	47
11	*i*-Pr/H (**2k**)	**3k**	51
12	C_6H_5/Me (**2l**)	**3l**	41
13	4-$MeOC_6H_4$/Me (**2m**)	**3m**	45
14	4-ClC_6H_4/Me (**2n**)	**3n**	52

[a]Reaction conditions: **1a** (0.5 mmol), **2a** (0.5 mmol), $Cu(OAc)_2·H_2O$ (0.025 mmol), DMSO (2 mL), under air. [b]Yield of the isolated product.

Table 3 Scope study with different aziridines **1**[a]



1 **2a** **3**

Entry	R^3/R^4	3	Yield (%)[b]
1	4-$MeOC_6H_4$/Ph (**1b**)	**3o**	74
2	4-ClC_6H_4/Ph (**1c**)	**3p**	81
3	2,4-$Cl_2C_6H_3$/Ph (**1d**)	**3q**	83
4	1-naphthyl/Ph (**1e**)	**3r**	80
5	Ph/4-$MeOC_6H_4$ (**1f**)	**3s**	73
6	Ph /4-PhC_6H_4 (**1g**)	**3t**	80
7	Ph /4-FC_6H_4 (**1h**)	**3u**	62
8	Ph /4-BrC_6H_4 (**1i**)	**3v**	56
9	Ph /2-furyl (**1j**)	**3w**	70

[a]Reaction conditions: **1a** (0.5 mmol), **2a** (0.5 mmol), $Cu(OAc)_2·H_2O$ (0.025 mmol), DMSO (2 mL), under air. [b]Yield of the isolated product.

A probable mechanism for the present cascade reaction was shown in Scheme 1. Under the thermal conditions,[9f]

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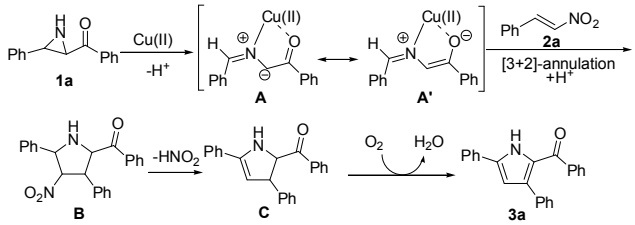
regioselective C-C bond cleavage of aziridine **1a** would form a key azomethine ylide **A** (this process might be facilitated by the presence of Cu(II) salts), which has previously been presumed to be generated from α-diazoketones and benzylamine under Cu(I) catalysis.[12a] **A** would then regioselectively react with *trans*-nitrostyrene **2a** to produce the pyrrolidine **B** *via* a copper-catalyzed [3 + 2] annulation process.[14] After elimination of HNO_2 and a dehydrogenative aromatization process, the polysubstituted pyrrole **3a** was obtained. The significantly lower yield obtained when the reaction was performed under argon atmosphere (Table 1, entry 15) suggests that the oxygen in air should be crucial for the dehydrogenative aromatization process.



Scheme 1 Possible mechanism for the [3+2] annulation.

Conclusions

In summary, we have developed an efficient approach to polysubstituted pyrroles via copper acetate-catalyzed cascade reactions of aziridines wtih β-nitroalkenes under aerobic conditions. The cascade process was proposed to involve a regioselective C-C bond cleavage of aziridines to give an azomethine ylide, which would undergo [3+2] cycloaddition with β-nitroalkenes. The easy availability of the starting materials, simple operation and broad substrate scope may make this method practically useful for the synthesis of pyrroles for applications to organic synthesis and related fields.

Acknowledgements

This work was supported by the Natural Science Foundation of Anhui Province (1308085QB25), the Research Fund for the Doctoral Program of Wannan Medical College, the Science Foundation for Post-doctoral Scientists of Anhui Province, and the National Natural Science Foundation of China (21372010, 21072004, 21202001).

Experimental

General methods

Flash column chromatography was performed using silica gel (200–400 mesh). For thin-layer chromatography (TLC), silica gel plates (HSGF 254) were used and compounds were visualized by irradiation with UV light. ^{1}H NMR (300 MHz) and ^{13}C NMR (75 MHz) spectra were recorded at 300 MHz NMR spectrometer in $CDCl_3$. All chemical shifts (δ) are given in ppm relative to TMS (δ = 0 ppm) as internal standard. Data are reported as follows: chemical shift, multiplicity, coupling constants and integration. Melting points were uncorrected. IR spectra were reported in frequency of absorption (cm^{-1}). High resolution mass spectral (HRMS) data were obtained with an ionization mode of ESI and a TOF analyzer. The aziridines **1** were synthesized according to reference methods.[15]

General procedure for the preparation of pyrrole derivatives 3a−w

A solution of aziridine **1** (0.5 mmol), β-nitroalkenes **2** (0.5 mmol) and $Cu(OAc)_2{\cdot}H_2O$ (0.025 mmol) in DMSO (5 mL) was stirred under air at 110 °C for 18 h. After being cooled down to room temperature, the mixture was diluted with ethyl acetate (20 mL), washed with saturated NaCl solution (10 mL) and dried over anhydrous Na_2SO_4. The solvent was rotaevaporated and the crude product was purified by silica gel column chromatography with hexane-EtOAc (10:1, v/v).

(3,5-Diphenyl-1*H*-pyrrol-2-yl)(phenyl)methanone(3a).[12a] Yellow solid (116.4 mg, 72%); M.p. 162-163 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.09 (s, 1H), 7.71 (d, *J* = 7.2 Hz, 2H), 7.50 – 7.35 (m, 5H), 7.28 – 7.21 (m, 1H), 7.05 – 6.95 (s, 7H), 6.70 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 187.0, 138.0, 137.5, 135.4, 131.2, 130.8, 129.7, 129.4, 129.0, 128.3, 128.0, 127.7, 127.5, 126.6, 125.2, 110.4; IR (KBr) 3292, 3066, 1601, 1568, 1452, 1290 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{17}NO + H]^+$): 324.1383; found: 324.1383.

(3-(2-Methoxyphenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3b). Yellow solid (144.9 mg, 82%); M.p. 171 – 172 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.09 (s, 1H), 7.70 (d, *J* = 7.1 Hz, 2H), 7.58 – 7.14 (m, 7H), 7.13 – 6.95 (m, 3H), 6.92 – 6.75 (m, 1H), 6.65 (s, 1H), 6.41 (d, *J* = 8.0 Hz, 1H), 3.36 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 187.2, 155.8, 138.1, 137.5, 131.0, 130.9, 130.8, 129.8, 128.8, 128.7, 128.6, 127.8, 126.9, 125.2, 125.0, 120.2, 110.8, 109.7, 54.6; IR (KBr) 3288, 1609, 1427, 1275, 1248, 907, 750, 733 cm^{-1}; HRMS: m/z calcd for ($[C_{24}H_{19}NO_2 + H]^+$): 354.1489; found: 354.1486.

(3-(4-Methoxyphenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3c).[12a] Yellow solid (137.8 mg, 78%); M.p. 208 – 209 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.12 (s, 1H), 7.71 (d, *J* = 7.1 Hz, 2H), 7.57 – 7.20 (m, 6H), 7.18 – 6.94 (m, 4H), 6.75 – 6.47 (m, 3H), 3.72 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.9, 158.5, 138.1, 137.4, 135.2, 131.1, 130.8, 130.7, 129.3, 129.0, 128.2, 127.8, 127.5, 125.1, 113.2, 110.2, 55.2; IR (KBr) 3311, 1597, 1523, 1427, 1275, 908, 737 cm^{-1}; HRMS: m/z calcd for ($[C_{24}H_{19}NO_2 + H]^+$): 354.1489; found: 354.1489.

(3-(2-Nitrophenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3d). Yellow solid (136.3 mg, 74%); M.p. 223 – 224 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.18 (s, 1H), 7.80 – 7.62 (m, 3H), 7.55 (d, *J* = 7.2 Hz, 2H), 7.48 – 7.31 (m, 3H), 7.30 – 7.13 (m, 6H), 7.13 – 6.94 (m, 3H), 6.56 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.2, 149.0, 138.0, 137.7, 133.5, 131.5, 131.2, 130.4, 130.3, 129.6, 129.1, 128.7, 128.7, 128.5, 127.9, 127.6, 125.2, 123.7, 109.9; IR (KBr) 3302, 1593, 1435, 1300, 1238, 824, 694 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}N_2O_3 + H]^+$): 369.1234; found: 369.1233.

(3-(2-Chlorophenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3e).[12a] Yellow solid (130.6 mg, 73%); M.p. 235 – 236 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.24 (s, 1H), 7.72 (d, *J* = 7.1 Hz, 2H), 7.57 – 7.30 (m, 5H), 7.29 – 7.13 (m, 2H), 7.12 - 6.86 (m, 5H), 6.70 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.8, 138.0, 137.2, 134.7, 133.4, 132.5, 131.4, 131.1, 130.7, 129.1, 129.0, 129.0, 128.9, 128.3, 128.3, 127.2, 126.0, 125.2, 111.2; IR (KBr) 3277, 1585, 1465, 1431, 1298, 766 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}ClNO + H]^+$): 358.0993; found: 358.0991.

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DOI: 10.1039/C3OB42324G

(3-(4-Chlorophenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3f). White solid (127.0 mg, 71%); M.p. 178 – 179 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.24 (s, 1H), 7.72 (d, *J* = 7.1 Hz, 2H), 7.57 – 7.30 (m, 5H), 7.29 – 7.13 (m, 2H), 7.12 – 6.86 (m, 5H), 6.70 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 187.0, 138.0, 137.9, 137.2, 133.9, 133.5, 131.5, 130.6, 129.6, 129.2, 129.0, 128.8, 128.4, 128.2, 127.8, 127.6, 126.6, 125.3, 110.2. IR (KBr) 3275, 1589, 1571, 1464, 1429, 1273, 762 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}ClNO + H]^+$): 358.0993; found: 358.0991.

(3-(3,4-Dichlorophenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3g). White solid (133.4 mg, 68%); M.p. 207 – 208 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.25 (s, 1H), 7.71 (d, *J* = 7.1 Hz, 2H), 7.61 – 7.29 (m, 6H), 7.23 – 7.03 (m, 4H), 6.90 (d, *J* = 8.1 Hz, 1H), 6.67 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.6, 137.9, 137.7, 135.4, 132.5, 131.6, 131.3, 130.7, 130.4, 129.5, 129.2, 129.1, 128.8, 128.6, 128.1, 127.8, 125.2, 110.1. IR (KBr) 3302, 1589, 1574, 1462, 1427, 1273, 812, 762 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{15}Cl_2NO + H]^+$): 392.0603; found: 392.0603.

(3-(2-Bromophenyl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3h). Yellow solid (140.8 mg, 70%); M.p. 234 – 235 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.61 (s, 1H), 7.67 – 7.56 (m, 2H), 7.56 – 7.46 (m, 2H), 7.45 – 7.33 (m, 3H), 7.31 – 7.21 (m, 1H), 7.12 – 7.00 (m, 4H), 6.99 – 6.91 (m, 2H), 2.15 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.8, 138.0, 137.1, 136.6, 133.2, 132.6, 132.4, 131.1, 130.7, 129.1, 129.0, 128.5, 128.3, 127.2, 126.6, 125.2, 124.0, 111.3. IR (KBr) 3310, 1601, 1571, 1464, 1427, 1277, 760 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}BrNO + H]^+$): 402.0488; found: 402.0487.

(3-(Furan-2-yl)-5-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3i).[12a] Yellow solid (103.4 mg, 66%); M.p. 175 – 176 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.87 (s, 1H), 7.82 – 7.56 (m, 4H), 7.54 – 7.28 (m, 6H), 7.13 (s, 1H), 6.86 (s, 1H), 6.23 (s, 2H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.5, 148.6, 141.6, 138.8, 137.6, 131.5, 130.6, 129.0, 128.8, 128.3, 128.1, 127.3, 125.2, 123.9, 111.2, 109.1, 108.6. IR (KBr) 3290, 1593, 1570, 1452, 1423, 1288, 813, 735, 696 cm^{-1}; HRMS: m/z calcd for ($[C_{21}H_{15}NO_2 + H]^+$): 314.1176; found: 314.1175.

Phenyl(5-phenyl-3-propyl-1*H*-pyrrol-2-yl)methanone (3j). Yellow solid (68.0 mg, 47%); M.p. 134 – 135 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.60 (s, 1H), 7.83 – 7.19 (m, 10H), 6.51 (s, 1H), 2.35 (t, *J* = 7.3 Hz, 2H), 1.62 – 1.36 (m, 2H), 0.77 (t, *J* = 6.9 Hz, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.6, 140.1, 137.5, 136.2, 131.1, 130.9, 129.0, 128.8, 128.3, 128.1, 128.1, 125.0, 110.0, 29.5, 24.1, 13.9. IR (KBr) 3302, 2953, 1589, 1468, 1435, 1298, 1277, 762 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{17}NO + H]^+$): 324.1383; found: 324.1383.

(3-Isopropyl-5-phenyl-1*H*-pyrrol-2-yl)(phenyl)methanone (3k). White solid (73.8 mg, 51%); M.p. 180 – 181 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.44 (s, 1H), 7.71 (d, *J* = 7.0 Hz, 2H), 7.66 – 7.19 (m, 8H), 6.58 (s, 1H), 3.07 – 2.74 (m, 1H), 1.14 (d, *J* = 6.5 Hz, 6H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.5, 143.2, 140.2, 137.5, 131.2, 130.9, 129.0, 128.3, 128.1, 128.1, 127.7, 125.0, 107.0, 25.6, 24.2. IR (KBr) 3307, 2963, 1591, 1571, 1470, 1454, 1435, 1294, 1277, 762 cm^{-1}; HRMS: m/z calcd for ($[C_{20}H_{19}NO + H]^+$): 290.1539; found: 290.1538.

(4-Methyl-3,5-diphenyl-1*H*-pyrrol-2-yl)(phenyl)methanone (3l).[12a] White solid (69.2 mg, 41%); M.p. 176 – 177 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.67 (s, 1H), 7.62 (d, *J* = 7.7 Hz, 2H), 7.49 (t, *J* = 7.4 Hz, 2H), 7.44 – 7.32 (m, 3H), 7.18 (t, *J* = 6.9 Hz, 1H), 7.12 – 6.94 (m, 7H), 2.17 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.8, 138.1, 135.2, 134.7, 134.4, 131.9, 130.8, 130.7, 128.94, 128.9, 128.0, 127.8, 127.5, 127.2, 126.4, 118.2, 11.1. IR (KBr) 3289, 2962, 1595, 1572, 1450, 1418, 1296, 1230, 736, 694 cm^{-1}; HRMS: m/z calcd for ($[C_{24}H_{19}NO + H]^+$): 338.1539; found: 338.1539.

(3-(4-Methoxyphenyl)-4-methyl-5-phenyl-1*H*-pyrrol-2-yl) (phenyl)methanone (3m). Yellow solid (82.7 mg, 45%); M.p. 220 – 221 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.60 (s, 1H), 7.71 – 7.57 (m, 2H), 7.55 – 7.43 (m, 2H), 7.44 – 7.33 (m, 3H), 7.20 (t, *J* = 7.4 Hz, 1H), 7.12 – 6.99 (m, 2H), 6.99 – 6.88 (m, 2H), 6.70 – 6.56 (m, 2H), 3.72 (s, 3H), 2.17 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.8, 158.2, 138.2, 135.4, 134.2, 131.9, 131.8, 130.6, 129, 128.8, 127.9, 127.5, 127.2, 127.0, 118.1, 113.0, 55.2, 11.2. IR (KBr) 3311, 2961, 1597, 1523, 1427, 1275, 908, 737, 694 cm^{-1}; HRMS: m/z calcd for ($[C_{25}H_{21}NO_2 + H]^+$): 368.1645; found: 368.1644.

(3-(4-Chlorophenyl)-4-methyl-5-phenyl-1*H*-pyrrol-2-yl) (phenyl)methanone (3n). White solid (96.7 mg, 52%); M.p. 248 – 249 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.61 (s, 1H), 7.67 – 7.56 (m, 2H), 7.56 – 7.46 (m, 2H), 7.45 – 7.33 (m, 3H), 7.31 – 7.21 (m, 1H), 7.12 – 7.00 (m, 4H), 6.99 – 6.91 (m, 2H), 2.15 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.6, 138.0, 135.4, 133.2, 133.0, 132.5, 131.9, 131.7, 130.9, 128.9, 128.1, 127.8, 127.7, 127.5, 127.4, 118.1, 11.1. IR (KBr) 3307, 2962, 1591, 1571, 1470, 1435, 1294, 1277, 762 cm^{-1}; HRMS: m/z calcd for ($[C_{24}H_{18}ClNO + H]^+$): 372.1150; found: 372.1149.

(5-(4-Methoxyphenyl)-3-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3o). Yellow solid (130.8 mg, 74%); M.p. 96 – 97 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.71 (s, 1H), 7.75 (d, *J* = 6.9 Hz, 1H), 7.51 (d, *J* = 6.8 Hz, 2H), 7.40 - 7.20(m, 2H), 7.19 – 6.97 (m, 8H), 6.77 (s, 1H), 4.04 (s, 3H). ^{13}C NMR (75 MHz, CD_2Cl_2) δ 186.3, 156.0, 138.4, 135.5, 134.9, 134.1, 131.0, 129.6, 129.2, 129.1, 127.7, 127.6, 127.5, 126.9, 126.5, 121.4, 118.8, 111.7, 110.6, 55.8. IR (KBr) 3290, 1605, 1576, 1550, 1460, 1431, 1294, 1274, 750, 694 cm^{-1}. ; HRMS: m/z calcd for ($[C_{24}H_{19}NO_2 + H]^+$): 354.1489; found: 354.1489.

(5-(4-Chlorophenyl)-3-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3p).[12a] White solid (144.9 mg, 81%); M.p. 237 – 238 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.29 (s, 1H), 7.78 – 7.57 (m, 2H), 7.56 – 7.31 (m, 3H), 7.31 – 7.18 (m, 1H), 7.17 – 6.92 (m, 6H), 6.68 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.9, 158.5, 138.1, 137.4, 135.2, 131.1, 130.8, 130.7, 129.3, 129.0, 128.2, 127.8, 127.5, 125.1, 113.2, 110.2, 55.2. IR (KBr) 3279, 1591, 1466, 1416, 1296, 1275, 933, 764, 739 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}ClNO + H]^+$): 358.0993; found: 358.0993.

(5-(2,4-Dichlorophenyl)-3-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3q). White solid (162.8 mg, 83%); M.p. 229 – 230 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.15 (s, 1H), 7.61 (d, *J* = 8.3 Hz, 1H), 7.56 – 7.42 (m, 2H), 7.39 – 7.19 (m, 2H), 7.18 – 6.95 (m, 6H), 6.76 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.9, 137.6, 135.0, 134.4, 133.9, 133.0, 131.8, 131.5, 130.8, 130.6, 129.7, 129.3, 128.1, 128.0, 127.8, 127.6, 126.8, 113.7. IR (KBr) 3301, 1589, 1575, 1462, 1427, 1275, 812, 762 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{15}Cl_2NO + H]^+$): 392.0603; found: 392.0602.

(5-(Naphthalen-1-yl)-3-phenyl-1*H*-pyrrol-2-yl)(phenyl) methanone (3r). Yellow solid (149.4 mg, 80%); M.p. 181 – 182

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DOI: 10.1039/C3OB42324G

°C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.84 (s, 1H), 8.37 (d, J = 4.6 Hz, 1H), 8.04 – 7.82 (m, 2H), 7.78 – 7.64 (m, 1H), 7.63 – 7.42 (m, 5H), 7.26 (s, 1H), 7.20 – 6.94 (m, 7H), 6.71 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.9, 137.9, 136.5, 135.4, 134.6, 133.9, 131.2, 131.1, 129.8, 129.5, 129.4, 129.0, 128.5, 127.8, 127.7, 127.4, 127.0, 126.8, 126.6, 126.2, 125.4, 113.9. IR (KBr) 3306, 1591, 1572, 1429, 1277, 908, 760 cm^{-1}; HRMS: m/z calcd for ($[C_{27}H_{19}NO + H]^+$): 374.1539; found: 374.1538.

(3,5-Diphenyl-1*H*-pyrrol-2-yl)(4-methoxyphenyl) methanone (3s).[12a] Yellow solid (129.0 mg, 73%); M.p. 189 – 190 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.09 (s, 1H), 7.70 (d, J = 7.1 Hz, 2H), 7.51 (d, J = 8.1 Hz, 2H), 7.44 (t, J = 7.0 Hz, 2H), 7.38 – 7.30 (m, 1H), 7.22 – 7.01 (m, 5H), 6.71 (s, 1H), 6.56 (d, J = 8.0 Hz, 2H), 3.73 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 185.9, 162.2, 137.0, 135.6, 134.5, 131.8, 130.9, 130.4, 129.6, 129.0, 128.1, 127.8, 126.5, 125.1, 112.8, 110.1, 55.3. IR (KBr) 3217, 1604, 1582, 1566, 1429, 1254, 910, 764 cm^{-1}; HRMS: m/z calcd for ($[C_{24}H_{19}NO_2 + H]^+$): 354.1489; found: 354.1489.

Biphenyl-4-yl(3,5-diphenyl-1*H*-pyrrol-2-yl)methanone (3t). Yellow solid (159.8 mg, 80%); M.p. 205 – 206 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.05 (s, 1H), 7.72 (d, J = 7.2 Hz, 2H), 7.54 (d, J = 7.8 Hz, 2H), 7.51 – 7.32 (m, 8H), 7.31 – 7.21 (m, 2H), 7.20 – 6.97 (m, 5H), 6.72 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 186.6, 143.8, 140.4, 137.8, 136.8, 135.5, 130.8, 130.0, 129.7, 129.0, 128.7, 128.3, 128.2, 127.7, 127.7, 127.1, 126.5, 126.1, 125.3, 110.3. IR (KBr) 3292, 1600, 1569, 1452, 1290, 910, 731 cm^{-1}; HRMS: m/z calcd for ($[C_{29}H_{21}NO + H]^+$): 400.1696; found: 400.1696.

(3,5-Diphenyl-1*H*-pyrrol-2-yl)(4-fluorophenyl)methanone (3u). White solid (105.8 mg, 62%); M.p. 181 – 182 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.29 (s, 1H), 7.72 (d, J = 6.9 Hz, 2H), 7.63 – 7.30 (m, 5H), 7.22 – 7.00 (m, 5H), 6.88 – 6.63 (m, 3H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 185.5, 164.5 (d, $J_{C\text{-}F}$ = 250.5 Hz), 137.9, 135.5, 135.3, 134.2, 131.9 ($J_{C\text{-}F}$ = 9.0 Hz) 130.7, 129.7, 129.0, 128.3, 127.9, 127.8, 126.8, 125.3, 114.5 (d, J_{CF} = 21.7 Hz), 110.4. IR (KBr) 3273, 1599, 1582, 1462, 1433, 1294, 1273, 1225, 910, 761 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}FNO + H]^+$): 342.1289; found: 342.1288.

(4-Bromophenyl)(3,5-diphenyl-1*H*-pyrrol-2-yl)methanone (3v).[12a] Yellow solid (112.6 mg, 56%); M.p. 220 – 221 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.32 (s, 1H), 7.73 (d, J = 6.8 Hz, 2H), 7.53 – 7.28 (m, 5H), 7.24 – 6.99 (m, 7H), 6.70 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 185.6, 138.0, 136.8, 135.7, 135.1, 130.0, 130.6, 129.6, 129.1, 128.4, 127.8, 126.9, 125.9, 125.2, 110.5. IR (KBr) 3277, 1585, 1464, 1431, 1292, 1273, 908, 760 cm^{-1}; HRMS: m/z calcd for ($[C_{23}H_{16}BrNO + H]^+$): 402.0488; found: 402.0487.

(3,5-Diphenyl-1*H*-pyrrol-2-yl)(furan-2-yl)methanone (3w). Yellow solid (109.7 mg, 70%); M.p. 176 – 177 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 10.03 (s, 1H), 7.79 – 7.59 (m, 2H), 7.57 – 7.17 (m, 9H), 6.85 (s, 1H), 6.71 (s, 1H), 6.32 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ 172.1, 152.1, 145.3, 137.2, 136.0, 135.1, 130.8, 129.2, 129.1, 128.2, 128.0, 127.2, 126.9, 125.1, 118.6, 111.9, 110.6. IR (KBr) 3306, 1603, 1572, 1452, 1427, 1275, 907, 760 cm^{-1}; HRMS: m/z calcd for ($[C_{21}H_{15}NO_2 + H]^+$): 314.1176; found: 314.1176.

Notes and references

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†Electronic Supplementary Information (ESI) available: Detailed experimental procedures, characterization data, copies of ^{1}H and ^{13}C NMR spectra for **3a**–**3w**. See DOI: 10.1039/b000000x/

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