A Convenient Synthesis of Indolo- and Pyrrolobenzazepines via a Threefold Norbornene-Mediated Domino Reaction

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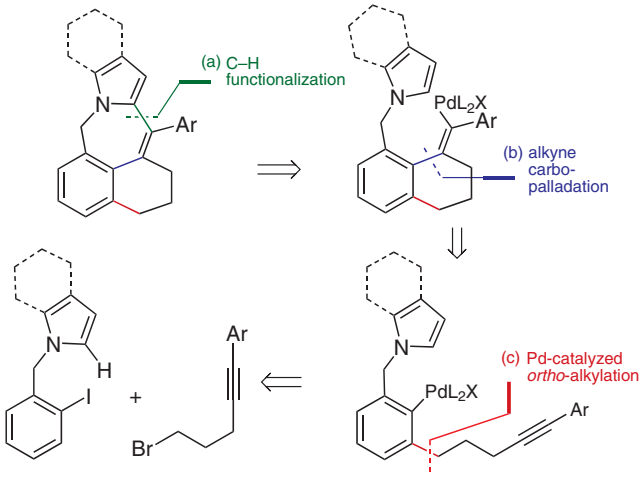
Abstract: A practical synthesis of a novel class of fused heterocycles was developed from 1-(2-iodobenzyl)-1*H*-pyrrole and -indoles with various bromoalkyl aryl alkynes. This palladium(0)-catalyzed norbornene-mediated domino reaction allows the efficient formation of three carbon–carbon bonds in a one-pot procedure with $PdCl_2$ and tri-2-furylphosphine (TFP), in the presence of norbornene and Cs_2CO_3 in acetonitrile at 90 °C. New seven-membered-ring fused heterocycles are obtained in moderate to excellent yields.

Key words: norbornene, domino reaction, indoles, pyrroles, palladium

The development of efficient processes towards the synthesis of unusual and complex molecules starting from simple substrates is an ongoing challenge in organic synthesis. In recent years, important novel domino processes in which two or more bonds are sequentially formed under the same reaction conditions have received increasing interest.[1] This strategy leads to classes of complex target molecules without isolating the intermediates and under one set of conditions. Contributing to extensive work in the field, we have recently reported a palladium(0)-catalyzed synthesis of tetracyclic fused pyrroles[2] mediated by norbornene, and which occurs via sequential carbopalladation, *o*-alkylation[3] and C–H functionalization.[4] This reaction forms three carbon–carbon bonds in a single operation.

Herein, we report the extension of this methodology to the synthesis of a novel class of fused seven-membered-ring indoles and pyrroles. These compounds may be of pharmaceutical interest as pyrrole and indole scaffolds are found in several biologically active molecules.[5]

Starting from easily available substrates, this simple protocol would allow the rapid preparation of complex and unique compounds difficult to obtain by existing methods.[6] The retrosynthetic analysis is outlined in Scheme 1. A C–C bond disconnection involves a vinylpalladium(II) species and the heterocycle via a C–H functionalization (path a). The vinylpalladium(II) intermediate is formed by a cyclocarbopalladation of an arylpalladium(II) species onto a tethered alkyne (path b). Finally, the generation of the arylpalladium(II) species as well as the introduction of a tethered alkyne could be achieved by a norbornene-mediated *o*-alkylation–C–H functionalization of an aryl iodide, using a bromoalkyl aryl alkyne **2** (path c).



Scheme 1 Retrosynthetic analysis of fused indoles and pyrroles

We began our investigation using the conditions reported with the 1-(2-iodobenzyl)-1*H*-indole[7] **1a** and a variety of bromoalkyl-aryl alkynes **2a**–**g** (Table 1).[8] To our delight, the protocol proved to be general for a wide range of aromatic alkynes,[9] and gave the desired product in good to excellent yields (Table 1).

The iodobenzyl-indole **1a** reacted with the phenyl alkyne **2a** to give the corresponding product in high yield (Table 1, entry 1). Aromatic alkynes bearing an electron-withdrawing or -donating substituent are suitable substrates for this transformation. The position of the substituent did not influence the reaction conversion (Table 1, entries 1–6), whereas aromatic alkynes bearing electron-withdrawing groups in most cases gave a slightly lower yield (Table 1, entries 2, 3, and 6). The reaction was even more efficient with the *ortho*-methoxy substituted aryl alkyne **2d** (Table 1, entry 4). While a substituent on the aromatic ring of the alkyne had almost no influence, the presence of an electron-withdrawing group on the indole moiety gave a lower yield (Table 1, entry 5). This effect may be due to decreased electron density at C-2 of the indole core, which makes the C–H bond less reactive toward the C–H functionalization. Both the naphthyl and the indole alkynes provided the desired products in excellent yields (Table 1, entries 7 and 8). However, in the latter case, the presence of an ester on the 1-(2-iodobenzyl)-1*H*-indole gave the corresponding product with a lower yield

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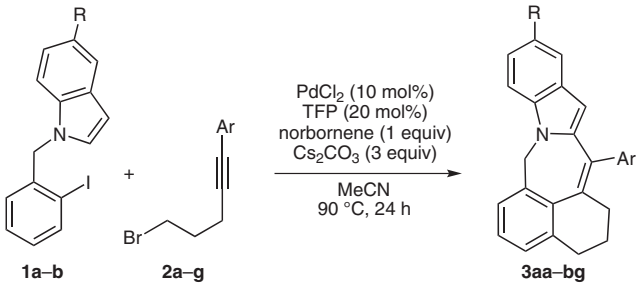
Table 1 Synthesis of Fused Indoles[a]



Entry	R	Ar	Product	Yield (%)[b]
1	**1a** H	**2a** Ph	**3aa**	79
2	**1a** H	**2b** 4-$O_2NC_6H_4$	**3ab**	76
3	**1a** H	**2c** 2-ClC_6H_4	**3ac**	70
4	**1a** H	**2d** 2-$MeOC_6H_4$	**3ad**	88
5	**1b** MeO_2C	**2d** 2-$MeOC_6H_4$	**3bd**	70
6	**1a** H	**2e** 3-$EtO_2CC_6H_4$	**3ae**	87
7	**1a** H	**2f** 1-naphthyl	**3af**	90
8[c]	**1a** H	**2g** 3-(1-tosyl)-indolyl	**3ag**	90
9[c]	**1b** MeO_2C	**2** 3-(1-tosyl)-indolyl	**3bg**	42

[a] Conditions: 1 equiv of **2** and 1.2 equiv of **1** were used in the reaction.
[b] Isolated yield.
[c] Conditions: 2 equiv of the indole derivative **1** was used.

in analogy to the results with **3bd**[9] (Table 1, entries 9 and 5, respectively).

The products are crystalline and the structure of the pentacycle **3ab** was confirmed by X-ray crystallographic analysis (Figure 1). In addition, it is worth mentioning that all these products exhibit strong fluorescence when subjected to UV light at 366 nm.

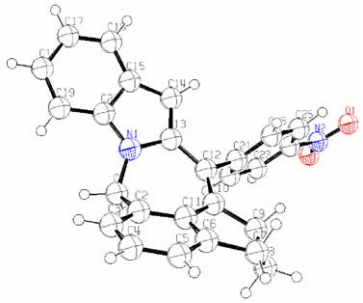
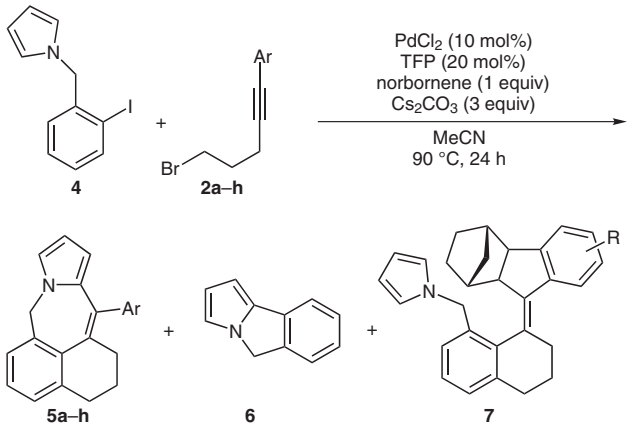


Figure 1 ORTEP representation of compound **3ab**

With these conditions in hand, we explored other heterocyclic systems. The synthesis of seven-membered ring-fused pyrroles gave lower yields then the indole series (Table 2). In some cases, byproducts **6** or **7** were formed, sometimes in significant amounts. The tricyclic byproduct **6** came from a direct coupling between the pyrrole and the aryl iodide moiety. The intriguing heptacyclic byproduct **7** was most likely formed by sequential insertion of norbornene into the vinylpalladium intermediate followed by a second C–H functionalization with the aryl moiety of the starting alkyne. From the practical standpoint, these byproducts made the purification of our desired compounds difficult as they showed similar polarity.

Table 2 Synthesis of Fused Pyrroles[a]



Entry	Ar	Yields (%)[b]				
		5		**6**	**7**	
1	**2a** Ph	**5a**	40	–		–
2	**2b** 4-$O_2NC_6H_4$	**5b**	53	–	**7b**	32
3	**2c** 2-ClC_6H_4	**5c**	79[c]	20		–
4	**2d** 2-$MeOC_6H_4$	**5d**	60	38		–
5	**2e** 3-$EtO_2CC_6H_4$	**5e**	30	63		–
6	**2f** 1-naphthyl	**5f**	49	30		–
7	**2h** 4-MeC_6H_4	**5g**	34	21		–
8	**2i** 3,4,5-$(MeO)_3C_6H_2$	**5h**	20	–		–

[a] Conditions: 1 equiv of **2** and 1.2 equiv of **4** were used in the reaction.
[b] Isolated yields.
[c] Yield based on NMR as the product **5c** could not be separated from **6**.

We investigated the influence of the number of equivalents of norbornene in the reaction of pyrrole **4** with alkynes **2b** and **2e** (Table 3). The presence of stoichiometric or substoichiometric amounts of norbornene favored the direct C–H functionalization of the pyrrole to give the byproduct **6** together with the desired product (Table 3, entries 1 and 3). When an excess of norbornene was used, the formation of the byproduct **7** was favored over the desired product **5** (Table 3, entries 2, 4–7).

In summary, we have developed a practical procedure to access to complex seven-membered-ring-fused systems via palladium-catalyzed norbornene-mediated domino reaction. This protocol is efficient, uses easily accessible substrates, and has broad functional-group tolerance. This strategy allows rapid preparation of complex compounds otherwise difficult to access by conventional approaches.

Table 3 Influence of the Amount of Norbornene[a]

Entry	Norbornene (equiv)	Yields (%)[b]		
		5	**6**	**7**
1	0.5	**5b** 35	32	–
2	1	**5b** 53	–	**7b** 32
3	1	**5e** 30	63	–
4	2	**5b** 38	–	**7b** 56
5	2	**5e** 36	–	**7e** 42
6	3	**5b** 35	–	**7b** 62
7	4	**5b** 22	–	**7b** 75

[a] Reaction conditions: **4** (1.2 equiv), **2b** (1 equiv), $PdCl_2$ (10 mol%), TFP (20 mol%), norbornene, Cs_2CO_3 (3 equiv), MeCN, 90 °C, 24 h.
[b] Isolated yields.

These heterocyclic systems have similar structures to compounds of pharmaceutical interest and, in addition, exhibit interesting fluorescent properties which might be useful for electroluminescent devices in material science. Further studies of the described methodology regarding the introduction of other heterocycles are in progress.

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(7) Compounds **1a**,**b** and **4** were prepared by alkylation of the corresponding pyrrole or indole with 2-bromomethyl-iodobenzene, according to a known procedure: Heaney, H.; Ley, S. V. *J. Chem. Soc., Perkin Trans. 1* **1973**, 499.

(8) For the starting material synthesis and the optimization of the reaction conditions, see ref. 2.

(9) **General Procedure**
A 10 mL sealable reaction vessel was charged with 1-(2-iodobenzyl)-1*H*-indole or -pyrrole (0.36 mmol, 1.2 equiv), bromoalkyl aryl alkyne (0.30 mmol, 1.0 equiv), norbornene (28 mg, 0.30 mmol, 1.0 equiv), Cs_2CO_3 (293 mg, 0.90 mmol, 3.0 equiv), $PdCl_2$ (5.3 mg, 0.03 mmol, 10 mol%), tri-2-furylphosphine (13.9 mg, 0.06 mmol, 20 mol%), and MeCN (3 mL). The mixture was stirred at r.t. for 10 min while being purged with argon. The tube was sealed and put into a preheated oil bath at 90 °C for 24 h. The reaction mixture was diluted with CH_2Cl_2, filtered onto a short plug of Celite, and washed with CH_2Cl_2. The solvent was evaporated in vacuo. The crude was purified by SiO_2 flash chromatography (pentane → pentane–EtOAc, 50:1, depending on the polarity of the product) to afford the desired compound.
Indole 3aa: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.68 (m, 2 H), 7.50–7.00 (m, 9 H), 6.62 (s, 1 H), 5.90 (s, 1 H), 5.05 (s, 2 H), 2.86 (t, 2 H, *J* = 6.5 Hz), 2.47 (m, 2 H), 1.90 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 141.9, 140.6, 135.8, 134.5, 133.0, 129.6, 128.7, 128.6, 128.3, 128.0, 127.9, 127.2, 127.1, 123.7, 121.9, 121.7, 121.1, 119.8, 109.4, 91.5, 48.6, 31.5, 30.4, 24.3 ppm. HRMS (EI): *m/z* calcd for $C_{26}H_{21}N$ [M^+]: 347.1674; found: 347.1671.
Indole 3ab: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.35–8.29 (m, 2 H), 7.56–7.49 (m, 3 H), 7.46–7.42 (m, 1 H), 7.31–7.12 (m, 4 H), 7.06–6.99 (m, 1 H), 5.83 (s, 1 H), 5.18 (s, 2 H), 2.89 (t, 2 H, *J* = 6.7 Hz), 2.47–2.40 (m, 2 H), 1.93 (mc, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 149.4, 147.3, 140.3, 139.1, 135.9, 135.7, 135.3, 130.8, 130.3, 128.8, 128.6, 128.1, 125.8, 124.2, 122.2, 121.0, 120.0, 108.9, 102.7, 47.9, 31.7, 30.2, 24.2 ppm. HRMS (EI): *m/z* calcd for $C_{26}H_{20}N_2O_2$ [M^+]: 392.1520; found: 392.1525.
Indole 3ac: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50 (m, 2 H), 7.43 (m, 2 H), 7.38 (m, 1 H), 7.33 (m, 1 H), 7.28 (m, 1 H), 7.24 (m, 1 H), 7.19 (m, 1 H), 7.12 (m, 1 H), 7.0 (dt, 1H, *J* = 7.1, 7.9 Hz), 5.94 (s, 1 H), 5.23 (d, 1 H, *J* = 13.9 Hz), 5.17 (d, 1 H, *J* = 13.9 Hz), 2.80 (m, 2 H), 2.48 (m, 1 H), 2.35 (m, 1 H), 1.86 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 140.6, 140.4, 138.8, 135.9, 135.6, 135.4, 135.0, 133.4, 130.6, 129.9, 129.3, 128.6, 128.1 (2), 128.0, 127.0, 125.6, 121.4, 120.7, 119.4, 108.6, 101.2, 47.7, 31.0, 30.3, 23.5 ppm. HRMS (EI): *m/z* calcd for $C_{26}H_{20}NCl$ [M^+]: 381.1284; found: 381.1293.
Indole 3ad: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50 (br d, 1 H, *J* = 6.1 Hz), 7.44–7.32 (m, 2 H), 7.30–6.94 (m, 8 H), 5.95 (s, 1 H), 5.17 (s, 2 H), 3.73 (s, 3 H), 2.85–2.78 (m, 2 H), 2.57–2.45 (m, 1 H), 2.41–2.30 (m, 1 H), 1.86 (m_c, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 156.8, 140.4, 140.3, 136.3, 136.1, 135.6, 134.9, 131.5, 130.7, 128.8, 128.6, 128.4, 128.3, 127.9, 125.6, 121.3, 120.9, 120.8, 119.4, 111.5, 108.7, 101.0, 55.9, 47.9, 31.4, 30.6, 23.9. HRMS (EI): *m/z* calcd for $C_{27}H_{23}NO$ [M^+]: 377.1780; found: 377.1780.
Indole 3bd: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.18 (br s, 1 H), 7.87 (d, 1 H, *J* = 8.6 Hz), 7.45 (d, 1 H, *J* = 8.8 Hz), 7.37 (br t, 1 H, *J* = 7.8 Hz), 7.32–7.18 (m, 4 H), 7.15–6.96 (m, 3 H), 6.04 (s, 1 H), 5.18 (s, 2 H), 3.88 (s, 3 H), 3.74 (s, 3 H),

2.86–2.78 (m, 2 H), 2.60–2.45 (m, 1 H), 2.42–2.28 (m, 1 H), 1.94–1.80 (m_c, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 168.5, 156.7, 141.7, 140.5, 137.8, 136.1, 135.9, 135.6, 131.1, 130.6, 129.0, 128.6, 128.2, 127.8, 125.7, 123.8, 122.7, 121.4, 121.0, 111.5, 108.3, 102.3, 55.9, 51.9, 48.1, 31.4, 30.6, 23.8. HRMS (EI): *m/z* calcd for $C_{29}H_{26}NO_3$ [M + H$^+$]: 436.1926; found: 436.1907.

Indole 3ae: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.06 (m, 2 H), 7.52 (m, 3 H), 7.42 (d, 1 H, *J* = 7.9 Hz), 7.28–7.15 (m, 4 H), 7.00 (m, 1 H), 5.85 (s, 1 H), 5.17 (s, 2 H), 4.38 (q, 2 H, *J* = 7.1 Hz), 2.86 (t, 2 H, *J* = 6.5 Hz), 2.45 (t, 2 H, *J* = 6.3 Hz), 1.90 (m, 2 H), 1.39 (t, 3 H, *J* = 7.1 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 166.8, 142.8, 140.2 (2), 136.3, 135.8, 135.7, 134.9, 134.1, 131.5, 131.2, 130.8, 128.8, 128.4, 128.5, 128.3, 128.2, 125.7, 121.9, 120.9, 119.8, 108.8,102.6, 61.3, 47.9, 31.7, 30.3, 24.3, 14.6. HRMS (EI): *m/z* calcd for $C_{29}H_{25}NO_2$ [M$^+$]: 419.1885; found: 419.1882.

Indole 3af: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.95 (d, 1 H, *J* = 8.3 Hz), 7.90 (m, 2 H), 7.60–7.30 (m, 8 H), 7.16 (m, 2 H), 6.96 (m, 1 H), 5.84 (s, 1 H), 5.30 (s, 2 H), 2.82 (t, 2 H, *J* = 6.4 Hz), 2.47 (m, 1 H), 2.24 (m, 1 H), 1.78 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 140.6, 140.0, 135.9, 135.7 (2), 134.2, 131.8, 130.4, 128.6 (2), 128.5, 128.3 (2), 128.2, 127.7, 126.8, 126.5, 126.1, 126.0(2), 125.8, 121.7, 120.9, 119.6, 108.7, 102.0, 48.2, 31.5, 30.6, 24.0. HRMS (EI): *m/z* calcd for $C_{30}H_{23}N$ [M$^+$]: 397.1813; found: 397.1843.

Indole 3ag: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.10–8.05 (m, 1 H), 7.82–7.77 (m, 2 H), 7.60 (s, 1 H), 7.51 (br d, 1 H, *J* = 8.2 Hz), 7.38–7.11 (m, 10 H), 6.99 (m_c, 1 H), 5.79 (s, 1 H), 5.20 (s, 2 H), 2.84 (t, 2 H, *J* = 6.5 Hz), 2.52–2.42 (m, 2 H), 2.37 (s, 3 H), 1.96 (m_c, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 145.2, 140.4, 137.8, 136.1, 135.9, 135.7, 135.5, 135.4, 131.2, 130.1, 128.6, 128.4, 128.2, 127.0, 125.7, 125.2, 124.6, 123.9, 121.9, 121.8, 120.8, 120.6, 119.7, 114.3, 108.8, 101.6, 139.5, 124.4, 48.0, 31.6, 30.4, 24.3, 21.9. HRMS (EI): *m/z* calcd for $C_{35}H_{29}N_2O_2S$ [M + H$^+$]: 541.1921; found: 541.1944.

Indole 3bg: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.12–8.07 (m, 2 H), 7.89 (dd, 1 H, *J* = 8.7, 1.6 Hz), 7.81–7.76 (m, 2 H), 7.60 (s, 1 H), 7.50 (br d, 1 H, *J* = 8.9 Hz), 7.39–7.14 (m, 8 H), 5.80 (s, 1 H), 5.21 (s, 2 H), 3.88 (s, 3 H), 2.86 (t, 2 H, *J* = 6.5 Hz), 2.55–2.45 (m, 2 H), 2.41 (s, 3 H), 1.96 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 168.3, 145.4, 140.6, 138.8, 137.9, 135.9, 135.6, 135.4, 135.4, 131.0, 130.2, 128.9, 128.7, 127.6, 127.0, 125.8, 125.3, 124.7, 124.2, 124.0, 123.8, 123.1, 121.7, 121.5, 120.4, 114.4, 108.5, 102.9, 52.0, 48.3, 31.7, 30.4, 24.2, 21.8. HRMS (EI): *m/z* calcd for $C_{37}H_{31}ON_2O_4S$ [M + H$^+$]: 599.1968; found: 599.1999.

Pyrrole 5a: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.40 (m, 1 H), 7.30 (m, 4 H), 7.18 (d, 1 H, *J* = 7.3 Hz), 7.12 (m, 2 H), 6.70 (m, 1 H, *J* = 2.5 Hz), 6.04 (dd, 1 H, *J* = 3.7, 2.6 Hz), 5.58 (dd, 1 H, *J* = 3.7, 1.8 Hz), 4.93 (s, 2 H), 2.84 (t, 2 H, *J* = 6.5 Hz), 2.40 (br s, 2 H), 1.90–1.82 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 142.9, 139.9, 136.7, 135.4, 132.7, 130.3, 129.5, 128.5 (2), 128.2, 127.6, 126.9, 125.5, 120.5, 110.1, 108.4, 52.8, 31.2, 30.6, 24.5. HRMS (EI): *m/z* calcd for $C_{22}H_{19}N$ [M$^+$]: 297.1517; found: 297.1522.

Pyrrole 5b: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.29 (d, 2 H, *J* = 8.8 Hz), 7.48 (d, 2 H, *J* = 8.8 Hz), 7.24–7.22 (m, 1 H), 7.16–7.13 (m, 2 H), 6.74 (dd, 1 H, *J* = 2.5, 1.8 Hz), 6.07 (dd, 1 H, *J* = 3.7, 2.6 Hz), 5.52 (dd, 1 H, *J* = 3.7, 1.7 Hz), 4.96 (s, 2 H), 2.87 (t, 2 H, *J* = 6.5 Hz), 2.37 (t, 2 H, *J* = 6.5 Hz), 1.88 (quint, 2 H, *J* = 6.5 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 149.7, 147.0, 139.9, 135.9, 135.3, 132.8, 131.1, 130.6, 130.4, 128.6, 128.1, 125.6, 123.9, 121.1, 110.2, 108.6, 52.7, 31.2, 30.3, 24.3. HRMS (EI): *m/z* calcd for $C_{22}H_{18}N_2O_2$ [M$^+$]: 342.1368; found: 342.1383.

Pyrrole 5c: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.46 (m, 1 H), 7.30 (m, 4 H), 7.14–7.02 (m, 2 H), 6.69 (dd, 1 H, *J* = 2.5, 1.8 Hz), 6.05 (dd, 1 H, *J* = 3.6, 2.6 Hz), 5.62 (dd, 1 H, *J* = 3.6, 1.6 Hz), 4.89 (s, 2 H), 2.83–2.70 (m, 2 H), 2.39 (m, 1 H), 2.28 (m, 1 H), 1.81 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 141.0, 140.5, 135.7, 135.5, 132.4, 130.9, 130.5, 129.7, 129.5, 128.3, 127.9 (2), 127.6, 126.9, 125.5, 120.3, 108.9, 108.3, 52.4, 30.6, 30.5, 23.6. HRMS (EI): *m/z* calcd for $C_{22}H_{18}NCl$ [M$^+$]: 331.1128; found: 331.1136.

Pyrrole 5d: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.34–7.29 (m, 1 H), 7.20–7.08 (m, 4 H), 7.02–6.95 (m, 2 H), 6.66 (dd, 1 H, *J* = 2.4, 1.8 Hz), 6.03 (dd, 1 H, *J* = 3.6, 2.6 Hz), 5.64 (dd, 1 H, *J* = 3.6, 1.7 Hz), 4.97 (d, 1 H, *J* = 13.5 Hz), 4.90 (d, 1 H, *J* = 13.4 Hz) 3.75 (s, 3 H), 2.80–2.76 (m, 2 H), 2.42–2.28 (m, 2 H), 1.85–1.79 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 157.4, 138.9, 134.5, 130.6, 129.6, 129.5, 127.2, 126.9, 126.2, 124.3, 123.8, 119.6, 118.8, 117.6, 110.1 (2), 107.6, 107.0, 54.6, 51.4, 29.8, 29.6, 22.7. HRMS (EI): *m/z* calcd for $C_{23}H_{21}NO$ [M$^+$]: 327.1627; found: 327.1623.

Pyrrole 5e: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.04–8.00 (m, 1 H), 7.99–7.97 (m, 1 H), 7.50–7.48 (m, 2 H), 7.22–7.19 (m, 1 H), 7.15–7.10 (m, 2 H), 6.72 (dd, 1 H, *J* = 1.8, 2.5 Hz), 6.04 (dd, 1 H, *J* = 2.5, 3.7 Hz), 5.54 (dd, 1 H, *J* = 1.8, 3.7 Hz), 4.94 (s, 2 H), 4.38 (q, 2 H, *J* = 7.1 Hz), 2.84 (t, 2 H, *J* = 6.4 Hz), 2.37 (m, 2 H), 1.86 (quint, 2 H, *J* = 6.4 Hz), 1.39 (t, 3 H, *J* = 7.1 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 166.8, 143.0, 139.9, 136.3, 135.4, 133.9, 133.8, 131.6, 130.9, 130.7 (2), 128.6, 128.4, 128.1, 127.7, 125.5, 120.7, 110.1, 108.4, 61.2, 52.7, 31.2, 30.4, 24.3, 14.5. HRMS (EI): *m/z* calcd for $C_{25}H_{23}NO_2$ [M$^+$]: 369.1729; found: 369.1721.

Pyrrole 5f: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.92 (d, 1 H, 8.3 Hz), 7.86 (m, 2 H), 7.53 (m, 1 H), 7.46 (m, 1 H), 7.40 (m, 2 H), 7.23 (d, 1 H, *J* = 9.2 Hz), 7.20 (m, 1 H), 7.14 (m, 1 H), 6.71 (dd, 1 H, *J* = 2.5, 1.8 Hz), 5.97 (dd, 1 H, *J* = 3.7, 2.6 Hz), 5.51 (br s, 1 H), 5.06 (s, 2 H), 2.78 (t, 2 H, *J* = 6.2 Hz), 2.38 (m, 1 H), 2.17 (m, 1 H), 1.73 (m, 2 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 140.3 (2), 136.4, 135.5, 134.1, 133.8, 131.7, 128.5 (2), 128.3, 127.7, 127.3, 126.3, 126.1, 126.0(2), 125.7, 120.7, 120.6, 109.7, 108.5, 53.0, 31.0, 30.8, 24.0. HRMS (EI): *m/z* calcd for $C_{26}H_{21}N$ [M$^+$]: 347.1674; found: 347.1667.

Pyrrole 5g: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 7.23–7.16 (m, 5 H), 7.14–7.10 (m, 2 H), 6.70–6.69 (m, 1 H), 6.05 (dd, 1 H, *J* = 3.7, 2.6 Hz), 5.60 (dd, 1 H, *J* = 3.7, 1.7 Hz), 4.93 (s, 2 H), 2.85 (t, 2 H, *J* = 6.5 Hz), 2.43–2.39 (m, 2 H), 2.41 (s, 3 H), 1.87 (quint, 2 H, *J* = 6.4 Hz). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 139.9, 139.8, 136.7, 136.3, 135.3, 132.6, 130.2, 129.3, 129.1, 128.9, 128.3, 127.4, 125.3, 120.4, 109.9, 108.3, 52.7, 31.1, 30.5, 24.5, 21.4. HRMS (EI): *m/z* calcd for $C_{23}H_{21}N$ [M$^+$]: 311.1674; found: 311.1668.

Pyrrole 5h: ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.23–7.18 (m, 1 H), 7.13–7.08 (m, 2 H), 6.72 (dd, 1 H, *J* = 2.3, 2.0 Hz), 6.51 (s, 2 H), 6.08 (dd, 1 H, *J* = 3.7, 2.6 Hz), 5.73 (dd, 1 H, *J* = 3.7, 1.7 Hz), 4.93 (s, 2 H), 3.91 (s, 3 H), 3.86 (s, 6 H), 2.86 (t, 2 H, *J* = 6.5 Hz), 2.48–2.40 (m, 2 H), 1.89 (quint, 2 H, *J* = 6.4 Hz). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 153.3, 139.7, 138.3, 136.8, 136.5, 135.3, 133.8, 132.4, 130.4, 128.4, 127.6, 125.4, 120.6, 109.8, 108.3, 106.4, 61.1, 56.3, 52.7, 31.1, 30.4, 24.5. ESI-HRMS: *m/z* calcd for $C_{25}H_{26}NO_3$ [M + H$^+$]: 388.1894; found: 388.1907.

Compound 7b: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.12–8.09 (m, 2 H), 7.77–7.74 (m, 1 H), 7.23–7.19 (m, 1 H), 7.13–7.08 (m, 2 H), 6.49 (t, 2 H, *J* = 2.1 Hz), 6.08 (t, 2 H, *J* = 2.1 Hz), 5.32 (d, 1 H, *J* = 14.6 Hz), 5.01 (d, 1 H, *J* = 14.6 Hz), 3.31–3.23 (m, 1 H), 3.09 (d, 1 H, *J* = 7.7 Hz), 2.92 (d, 1 H, *J* = 7.8 Hz), 2.64 (dt, 1 H, *J* = 13.8, 3.1 Hz), 2.57–2.51 (m, 1 H), 2.35 (d, 1 H, *J* = 4.2 Hz), 2.30 (dt, 1 H, *J* = 4.3, 13.5 Hz),

2.14–2.07 (m, 1 H), 1.56–1.47 (m, 1 H), 1.46–1.36 (m, 2 H), 1.35–1.19 (m, 2 H), 0.96–0.81 (m, 3 H). ^{13}C NMR (75.5 MHz, $CDCl_3$): δ = 151.7, 149.6, 147.1, 142.8, 142.2, 138.2, 135.4, 134.0, 127.9, 127.5, 126.0, 125.1, 122.3, 121.0, 120.5, 108.3, 53.6, 52.0, 51.4, 43.7, 41.1, 32.6, 30.1, 29.6, 29.1, 28.4, 22.8. HRMS (EI): *m/z* calcd for $C_{29}H_{28}N_2O_2$ [M^+]: 436.2151; found: 436.2166.

Compound 7e: ^{1}H NMR (400 MHz, $CDCl_3$): δ = 8.34 (br s, 1 H), 7.92 (dd, 1 H, *J* = 7.9, 1.2 Hz), 7.32 (d, 1 H, *J* = 7.9 Hz), 7.18–7.14 (m, 1 H), 7.10–7.03 (m, 2 H), 6.54 (t, 2 H, *J* = 2.1 Hz), 6.09 (t, 2 H, *J* = 2.1 Hz), 5.33 (d, 1 H, *J* = 14.6 Hz), 5.02 (d, 1 H, *J* = 14.6 Hz), 4.45–4.37 (m, 2 H), 3.41–3.33 (m, 1 H), 3.04 (d, 1 H, *J* = 7.6 Hz), 2.85 (d, 1 H, *J* = 7.5 Hz), 2.66–2.55 (m, 2 H), 2.34–2.26 (m, 2 H), 2.15–2.07 (m, 1 H), 1.56–1.45 (m, 1 H), 1.44–1.34 (m, 2 H), 1.42 (t, 3 H, *J* = 7.1 Hz), 1.33–1.17 (m, 2 H), 0.96–0.94 (m, 1 H), 0.91–0.84 (m, 1 H), 0.79–0.76 (m, 1 H). ^{13}C NMR (100 MHz, $CDCl_3$): δ = 171.3, 167.1, 155.6, 143.5, 142.8, 138.7, 134.0, 131.0, 129.2, 129.0, 127.3, 127.0, 126.3, 125.7, 125.2, 121.0, 108.2, 61.1, 53.4, 52.5, 51.2, 43.7, 41.0, 32.7, 30.2, 29.3, 29.2, 28.5, 23.2, 14.6. HRMS (EI): *m/z* calcd for $C_{32}H_{33}NO_2$ [M^+]: 463.2511; found: 463.2519.