Tetrahedron 69 (2013) 7011–7018

Contents lists available at SciVerse ScienceDirect

Tetrahedron

journal homepage: www.elsevier.com/locate/tet

One-pot four-component synthesis of highly substituted pyrroles in gluconic acid aqueous solution

Bao-Le Li, Pei-He Li, Xue-Na Fang, Chun-Xiao Li, Jing-Lei Sun, Li-Ping Mo, Zhan-Hui Zhang *

College of Chemistry & Material Science, Hebei Normal University, Shijiazhuang 050024, China

ARTICLE INFO

Article history:
Received 25 April 2013
Received in revised form 3 June 2013
Accepted 13 June 2013
Available online 21 June 2013

Keywords:
Pyrroles
Multicomponent reaction
One-pot synthesis
Gluconic acid aqueous solution
Green solvent

ABSTRACT

Four-component coupling of amines, aldehydes, 1,3-dicarbonyl compounds, and nitromethane has been achieved in gluconic acid aqueous solution (GAAS) to produce polysubstituted pyrroles in high yield. Gluconic acid aqueous solution could be recycled and reused several times without significant loss of its efficiency.

1. Introduction

Among compounds containing nitrogen heterocyclic frameworks, pyrrole is one of the most popular core units in many natural products, synthetic pharmaceuticals, and useful building blocks for various biologically active molecules and functional materials.[1] Highly functionalized pyrroles are subunits of considerable importance in heme, chlorophyll, bile pigments, vitamin B_{12}, and marine source-derived pyrrole alkaloids. Lipitor, which contains pyrrole as the core structural unit, is a widely prescribed HMG-CoA reductase inhibitor used to lower low-density lipoprotein cholesterol levels.[2] It is the best-selling drug in past several years. As a result, a large number of synthetic methods for the preparation of diversely substituted pyrroles have been developed. The Hantzsch procedure ,[3] Paal–Knorr synthesis,[4] and Clauson-Kaas reaction[5] have been widely used as classic approaches but with some drawbacks such as multistep synthetic operation, inaccessible starting materials, limited scope, and functional group compatibility. Recently, a range of new approaches have been developed, which involve rearrangement reaction,[6] transition metal-mediated cyclization,[7] Trofimov reaction,[8] reductive coupling,[9] Sonogashira coupling reaction,[10] Barbier reaction,[11] and annulations reactions.[12] In spite of these outstanding efforts, it is still challenging to prepare polysubstituted pyrroles possessing diverse substituents directly from readily available precursors in a single synthetic operation.

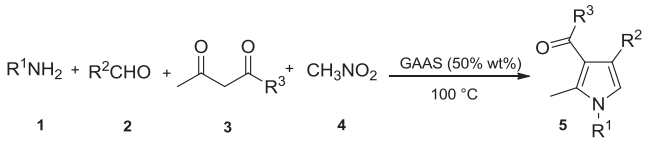
Multicomponent reactions (MCRs) are known to provide structurally complex molecules in a single pot ensuring high atom economy, good overall yields and high selectivity, minimizing waste, labor, less time consuming, and avoidance of costly purification processes.[13] Actually, MCRs have been demonstrated to be a straightforward approach for the synthesis of pyrroles, which have been extensively reviewed.[14] In this context, four-component coupling reactions for the synthesis of highly substituted pyrroles have received much attention. Kassaee et al. reported that highly functionalized pyrrole derivatives can be synthesized via a four-component reaction of two primary amines and diketene in the presence of nitrostyrene.[15] Kassaee and co-workers have developed a convenient method for the synthesis of tetrasubstituted pyrroles via four-component reaction of butane-2,3-dione, triphenylphosphine, dialkylacetylenedicarboxylate, and ammoniumacetate.[16] A new four-component domino reaction was also established to provide multifunctionalized pyrrole derivatives. The reaction is performed by mixing readily available staring materials, 1,3-dicarbonyl compounds, amines, aldehydes, and nitroalkanes in the presence of $FeCl_3$,[17] $NiCl_2$,[18] or I_2.[19] However, above approaches show varying degrees of success as well as limitations, such as the use of unrecyclable catalysts,[17–19] low product yields for aromatic amines,[19] and potential contamination of the products,[17,18] which make these procedures less attractive to the pharmaceutical industry.

* Corresponding author. Fax: +86 311 80787431; e-mail addresses: zhanhui@mail.nankai.edu.cn, zhanhui@126.com (Z.-H. Zhang).

0040-4020/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.tet.2013.06.049

With the increasing demand for environmentally friendly methods, the application of bio-based materials as green and biodegradable reaction solvents for synthesis and catalysis has received extensive attention. Although some bio-based chemicals, such as glycerol,[20] ethyl lactate,[21] γ-valerolactone,[22] 2-methyltetrahydrofuran,[23] (*R*)-(+)-limonene-limonene,[24] lactic acid,[25] and carbohydrates-based low melting mixtures,[26] have been proposed as green solvents, the number of available bio-based solvents is far from abundant at this stage. Recently, Gu et al. introduced gluconic acid aqueous solution (50 wt %, GAAS) as a promoting medium for organic transformations.[27] Gluconic acid is abundantly available in plants, fruits, and other foodstuffs such as rice, meat, dairy products, wine, honey, and vinegar. It is a biodegradable, recyclable, nonvolatile, low price, largely available organic acid. In particular, the low toxicity of gluconic acid also allows its use in the formulation of food, pharmaceutical, and hygienic products. Thus, such media may constitute alternative solvent for the development of sustainable chemistry.

The combination of multicomponent reactions and benign reaction media has become a promising frontier field of research, which enables simultaneous growth of both MCRs and green solvents toward ideal organic synthesis.[28] As part of an ongoing project devoted toward the development of novel and environmental benign synthetic methodologies,[29] herein, we report for the first time one-pot synthesis of polysubstituted pyrroles via four-component condensation reaction of amines, aldehydes, 1,3-dicarbonyl compounds, and nitromethane using gluconic acid aqueous solution as an efficient and reusable promoting medium (Scheme 1).

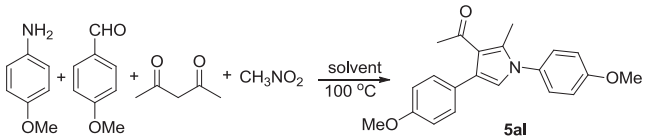


Scheme 1. Synthesis of functionalized pyrroles in gluconic acid aqueous solution.

2. Results and discussion

As depicted in Table 1, the investigations were initiated with 4-methoxyaniline, 4-methoxybenzaldehyde, acetylacetone, and nitromethane as model substrates to find the optimal conditions. The blank experiment revealed that only a trace amount of product was detected under catalyst-free conditions (Table 1, entry 1). Addition of some readily available acids, such as H_3BO_3, oxalic acid, L-proline, Amberlyst 15, montmorillonite K-10, to the reaction system, did not improve the performance of the reaction. A clear improvement of the yield was observed when *p*-toluenesulfonic acid, camphor-10-sulfonic acid, sulfamic acid, phosphomolybdic acid, tungstophosphoric acid, or silicotungstic acid was added, however, the yields are still far from satisfactory. Our next attempts were focused on the evaluation of the efficiency of various solvents under catalyst-free conditions. Solvents screening studies revealed that solvents such as glycerol, PEG 400, [bmin]BF_4, [bmin]PF_4, and H_2O are not suitable for this reaction. Similarly, deep eutectic solvents (DES),[30] such as choline chloride-urea, L-(+)-tartaric acid-choline chloride were examined and displayed less efficiency (entries 18 and 19). When the reaction was performed in acetic acid or trifluoroacetic acid, the target product **5al** was obtained in very low yield (entries 20 and 21). Pleasingly, when gluconic acid aqueous solution was used as the solvent, the reaction yield can be significantly improved (90%, entry 25). When the amount of gluconic acid aqueous solution was decreased to 1 ml, the product yield was decreased (61%, entry 22), but addition of larger amount of gluconic acid aqueous solution, no further improvement of the product yields was observed (entries 26 and 27).

Table 1
Reaction of 4-methoxyaniline, 4-methoxybenzaldehyde, acetylacetone, and nitromethane in different conditions[a]



Entry	Catalyst	Solvent	Time (h)	Yield (%)
1	No	No	12	Trace
2[b]	H_3BO_3	No	12	Trace
3[b]	Oxalic acid	No	12	Trace
4[b]	L-Proline	No	12	Trace
5[c]	Amberlyst 15	No	12	Trace
6[c]	Montmorillonite K-10	No	12	Trace
7[b]	*p*-Toluenesulfonic acid	No	12	10
8[b]	Camphor-10-sulfonic acid	No	12	15
9[b]	Sulfamic acid	No	12	12
10[b]	Phosphomolybdic acid	No	12	40
11[b]	Tungstophosphoric acid	No	12	15
12[b]	Silicotungstic acid	No	12	17
13[d]	No	Glycerol	10	Trace
14[d]	No	PEG 400	10	Trace
15[d]	No	[bmin]BF_4	12	Trace
16[d]	No	[bmin]PF_4	12	Trace
17[d]	No	H_2O	12	Trace
18[e]	No	Choline chloride-urea	12	Trace
19[f]	No	L-(+)-Tartaric acid-choline chloride	12	Trace
20[d]	No	Acetic acid	12	5
21[d]	No	CF_3COOH	12	6
22	No	GAAS (1 ml)	6	61
23	No	GAAS (3 ml)	6	75
24	No	GAAS (4 ml)	6	82
25	No	GAAS (5 ml)	5.5	90
26	No	GAAS (6 ml)	5.5	90
27	No	GAAS (8 ml)	5.5	90
28[g]	No	GAAS (5 ml)	5.5	88
29[h]	No	GAAS (5 ml)	5.5	91

[a] Reaction condition: 4-methoxyaniline (1 mmol), 4-methoxybenzaldehyde (1 mmol), acetylacetone (1 mmol), nitromethane (1 ml), 100 °C.
[b] 10 mol %.
[c] 50 mg.
[d] 5 ml.
[e] Choline chloride–urea (54.1:45.9) (5 g).
[f] L-(+)-Tartaric acid–choline chloride (50:50) (5 g).
[g] Gluconic acid aqueous solution was reused for the third time.
[h] The reaction was carried out in 10 mmol scale.

Our attention was then turned to the possibility of recycling gluconic acid aqueous solution since the recovery and reuse of the medium are highly preferable for a greener process. After completion of the reaction, the reaction mixture was cooled to room temperature and extracted with ethyl acetate. The recovered gluconic acid aqueous solution was then subjected to the next run in the model reaction. After three recycles, gluconic acid aqueous solution still showed a high activity and gave the corresponding product in high yield (Table 1, entry 28). Furthermore, the present this four-component reaction was easily practicable in a larger scale. The model reaction was carried out in 10 mmol scale. As expected, the desired product was obtained in 91% yield after purification (entry 29), which is comparable to the yield obtained in small-scale reaction (1 mmol, entry 25). In this process, gluconic acid aqueous solution plays a dual role as the solvent and catalyst.

With the identification of the optimal reaction conditions as shown for entry 25 in Table 1, we investigate the scope and limitation of this multicomponent protocol and the typical results are complied in Table 2. We first examined the reaction of aniline, acetylacetone and nitromethane with a diverse array of aldehydes.

Table 2
Synthesis of functionalized pyrroles **5** in gluconic acid aqueous solution

Entry	Amine	Aldehyde	R^3	Product	Time (h)	Yield (%)[a]	Mp (°C)
1	$PhNH_2$	PhCHO	Me	**5a**	7.0	87	
2	$PhNH_2$	4-$CH_3C_6H_4CHO$	Me	**5b**	8.0	80	106–107 (105–107[17])
3	$PhNH_2$	4-$OCH_3C_6H_4CHO$	Me	**5c**	13.0	78	Oil
4	$PhNH_2$	4-$SCH_3C_6H_4CHO$	Me	**5d**	6.0	72	Oil
5	$PhNH_2$	2-FC_6H_4CHO	Me	**5e**	5.0	91	127–128
6	$PhNH_2$	2-ClC_6H_4CHO	Me	**5f**	4.5	89	125–126
7	$PhNH_2$	3-ClC_6H_4CHO	Me	**5g**	5.0	88	Oil
8	$PhNH_2$	4-ClC_6H_4CHO	Me	**5h**	4.5	86	105–106
9	$PhNH_2$	4-BrC_6H_4CHO	Me	**5i**	4.5	87	90–92
10	$PhNH_2$	3-$NO_2C_6H_4CHO$	Me	**5j**	10.0	81	Oil
11	$PhNH_2$	4-$NO_2C_6H_4CHO$	Me	**5k**	9.0	83	Oil
12	$PhNH_2$	3-$CF_3C_6H_4CHO$	Me	**5l**	7.0	80	Oil
13	$PhNH_2$	4-$CF_3C_6H_4CHO$	Me	**5m**	6.5	85	Oil
14	$PhNH_2$	Furan-2-carbaldehyde	Me	**5n**	7.5	63	91–92
15	$PhNH_2$	Thiophene-2-carbaldehyde	Me	**5o**	6.0	70	105–106
16	$PhNH_2$	1-Naphthaldehyde	Me	**5p**	10.0	80	114–115
17	4-$OCH_3C_6H_4NH_2$	PhCHO	Me	**5q**	5.0	90	91–92 (90–91[17])
18	4-$OEtC_6H_4NH_2$	PhCHO	Me	**5r**	3.0	93	89–90
19	3-$CH_3C_6H_4NH_2$	PhCHO	Me	**5s**	4.0	92	126–128
20	4-$CH_3C_6H_4NH_2$	PhCHO	Me	**5t**	4.5	89	109–111
21	3,4-$Me_2C_6H_3NH_2$	PhCHO	Me	**5u**	5.0	92	Oil
22	4-$CMe_3C_6H_4NH_2$	PhCHO	Me	**5v**	5.0	91	148–149
23	3-$FC_6H_4NH_2$	PhCHO	Me	**5w**	7.0	89	79–80
24	4-$FC_6H_4NH_2$	PhCHO	Me	**5x**	7.5	90	130–131
25	4-$ClC_6H_4NH_2$	PhCHO	Me	**5y**	8.5	86	127–128
26	4-$BrC_6H_4NH_2$	PhCHO	Me	**5z**	12.0	85	141–143
27	4-$NO_2C_6H_4NH_2$	PhCHO	Me	**5aa**	48.0	48	171–172
28	4-$CF_3C_6H_4NH_2$	PhCHO	Me	**5ab**	18.0	80	146–147
29	Naphthalen-1-amine	PhCHO	Me	**5ac**	12.0	67	143–144
30	9*H*-Fluoren-2-amine	PhCHO	Me	**5ad**	5.5	89	147–149
31	$H_2C{=}CHCH_2NH_2$	PhCHO	Me	**5ae**	3.0	85[b]	Oil
32	$PhCH_2NH_2$	PhCHO	Me	**5af**	3.0	82[b]	87–88
33	(*S*)-1-Phenylethanamine	PhCHO	Me	**5ag**	3.0	80[b]	129–131
34	$PhNH_2$	PhCHO	OMe	**5ah**	5.5	91	Oil
35	$PhNH_2$	PhCHO	OEt	**5ai**	5.0	92	Oil
36	$PhNH_2$	PhCHO	OCH_2CH_2OMe	**5aj**	6.0	82	Oil
37	$PhNH_2$	PhCHO	$OCH_2CH{=}CH_2$	**5ak**	6.0	85	Oil
38	4-$OCH_3C_6H_4NH_2$	4-$OCH_3C_6H_4CHO$	Me	**5al**	5.5	90	136–137 (133–135[17])
39	4-$OCH_3C_6H_4NH_2$	Thiophene-2-carbaldehyde	Me	**5am**	7.0	71	Oil

[a] Isolated yield.
[b] 0.15 ml GAAS was used.

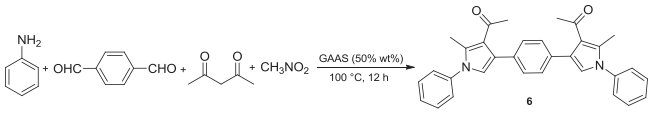
In general, benzaldehydes bearing electron-donating and electron-withdrawing groups, such as alkyl, methoxy, methylthio, fluoro, chloro, halo, nitro, and trifluoromethyl groups, underwent smooth conversion to furnish the corresponding pyrroles in high to excellent yields. The electronic effect of the substitutions has little influence on the reaction times and the yields of the products. Heteroaryl substrates, such as 2-furaldehyde and 2-thiophenealdehyde, were also efficiently transformed, affording the potentially bio-important pyrroles in good yields (Table 2, entries 14 and 15). When the aromatic ring was replaced by a hindered naphthyl group, the desired product **5p** was obtained in 80% yield (Table 2, entry 16). Unfortunately, the aliphatic aldehydes such as cyclohexanecarbaldehyde, and α,β-unsaturated aldehyde, such as cinnamaldehyde, are not appropriate starting materials under these reaction conditions, as the reactions produced a mixture of products along with unreacted starting materials.

With regard to amines, most of the reactions proceeded smoothly under the optimal conditions. As indicated in Table 2, it could be concluded that anilines bearing electron-donating groups required shorter time than electron-withdrawing groups and gave higher yields. Especially, the challenging substrate 4-nitroaniline containing a strongly electron-withdrawing functionality worked effectively in the present system to deliver the product **5aa** in 48% yield (entry 27). This indicated that 4-nitroaniline can be a substrate under this catalytic system in spite of the lower yield. The same methodology was further extended with 1-naphthalenamine and the desired product **5ac** was isolated in 67% yield (entry 29). We were pleased to find that under the stated conditions, 9*H*-fluoren-2-amine successfully reacted with benzaldehyde, acetylacetone, and nitromethane, furnishing **5ad** in 89% yield (entry 30). On the other hand, aliphatic and benzylic amines reacted slowly as compared to aryl amines and gave low yields of the products under the above optimized conditions. Further assessment of the reaction conditions indicated that 0.15 ml of GAAS was optimal for these amines and the corresponding products could be obtained in high yields (entries 31–33).

These encouraging results prompted us to expand the scope of this reaction with respect to 1,3-dicarbonyl compounds. Various β-ketoesters, such as methyl acetoacetate, ethyl acetoacetate, 2-methoxyethyl acetoacetate, and allyl acetoacetate were surveyed for this reaction. In general, the present method is also equally effective with β-ketoesters, producing the desired products in high yields (Table 2, entries 34–37). These successful results clearly indicate that this procedure is extendable to a wide variety of substrates.

Intrigued by the outcome of this study, we further explored the potential of this green process for the synthesis of dipyrrole derivative. Treatment of aniline (2 mmol), acetylacetone (2 mmol), and nitromethane (2 ml) with 1,4-phthalaldehyde (1 mmol) in gluconic acid aqueous solution (5 ml) was performed to generate corresponding dipyrrole **6** in 80% yield (Scheme 2).

The structures of the prepared products were identified from their IR, ^1H NMR, ^{13}C NMR spectra, MS, and elemental analysis. The structure of compound **5y** (CCDC 912403) was also established by single-crystal X-ray crystallographic analysis (Fig. 1).



Scheme 2. Synthesis of dipyrrole **6**.

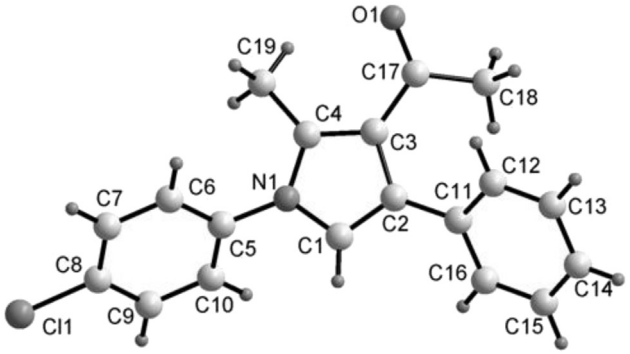
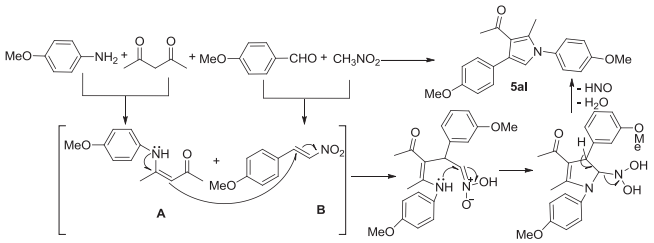


Fig. 1. X-ray crystal structural of compound **5y**.

In accordance with reports from the literature,[17–19] a plausible mechanism for the current gluconic acid aqueous solution-promoted tandem reaction was proposed (Scheme 3). Both intermediates (*Z*)-4-((4-methoxyphenyl)amino)pent-3-en-2-one (**A**) from 4-methox yaniline and acetylacetone and (*E*)-1-methoxy-4-(2-nitrovinyl)benzene (**B**) from 4-methoxybenzaldehyde and nitromethane were separated in the reaction process. These two intermediates reacted via Michael addition[31] and followed by cyclization with the elimination of nitroxyl and H_2O to provide the expected product **5al**. Though imine can be reasonable formed by the reaction of 4-methoxyaniline with 4-methoxybenzaldehyde, it was unstable during the progress of the reaction and was hydrolyzed back the corresponding amine and aldehyde. Additionally, intermediate **B** was separately prepared from 4-methoxybenzaldehyde and nitromethane and when a three-component coupling reaction of nitroolefin (intermediate **B**), 4-methoxyaniline, and acetylacetone was performed under same reaction conditions, the desired product **5al** could also be obtained.



Scheme 3. Plausible mechanism for the synthesis of pyrrole derivatives.

3. Conclusion

In conclusion, gluconic acid aqueous solution has been demonstrated for the first time, to be an effective promoting medium for synthesis of highly functionalized pyrroles through one-pot, four-component coupling reaction of amines, aldehydes, 1,3-dicarbonyl compounds, and nitromethane. Mild reaction conditions, wide substrate scope, excellent functional group tolerance, short reaction time, high yield of products, metal-free as well as the use of an inexpensive and environmentally benign solvent are the key advantages of the present method. Further investigations on the applications of bio-based solvents on other catalytically synthetic reactions are under progress in our group.

4. Experimental

4.1. General information

All chemicals and solvents were commercially available and used as received without further purification. Melting points were measured on an X-4 digital melting point apparatus without correction. IR spectra were recorded in the range 4000–600 cm^{-1} either as neat for liquid or KBr pellets for solid samples using a Bruker-TENSOR 27 spectrometer instrument. ^1H NMR and ^{13}C NMR spectra were recorded on Bruker DRX-500 spectrometer at 500 MHz and 125 MHz, respectively, using $CDCl_3$ as the solvent and TMS as an internal standard. Elemental analyses were determined on a Vario EL III CHNOS elemental analyzer. Mass spectra were performed on a ThermoFinnigan LCQ Advantage instrument with an ESI source (4.5 KeV).

4.2. Typical procedure for one-pot synthesis of functionalized pyrroles 5

The mixture of amine (1 mmol), aldehyde (1 mmol), 1,3-dicarbonyl compound (1 mmol), and CH_3NO_2 (1 ml) in gluconic acid aqueous solution (5 ml or 0.15 ml) was stirred at 100 °C in an oil-bath. Progress of the reaction was monitored by thin-layer chromatography. After completion of the reaction, the reaction mixture was cooled to room temperature and extracted with ethyl acetate. The obtained organic layer was dried over Na_2SO_4 and the solvent was removed under reduced pressure. The residue was adsorbed on silica gel and purified by flash chromatography using the mixture of petroleum ether and ethyl acetate as the eluting solvent to give the pure product.

4.3. Characterization data

*4.3.1. 1-(2-Methyl-1,4-diphenyl-1H-pyrrol-3-yl)ethanone (**5a**).* White solid (239 mg, 87%); IR (KBr): 31, 117, 3057, 2920, 1643, 1498, 1406, 1230, 759, 700 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.08 (s, 3H), 2.41 (s, 3H), 6.67 (s, 1H), 7.29–7.34 (m, 3H), 7.36–7.38 (m, 4H), 7.42 (t, J=7.5 Hz, 1H), 7.47–7.50 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 120.6, 122.6, 126.2, 126.3, 126.8, 128.1, 128.3, 129.3, 129.3, 135.3, 136.0, 138.7, 197.6 ppm; Anal. Calcd for $C_{19}H_{17}NO$: C, 82.88; H, 6.22; N, 5.09. Found: C, 82.60; H, 6.03; N, 4.91; ESI-MS: m/z=276 $(M+1)^+$.

*4.3.2. 1-(2-Methyl-1-phenyl-5-(p-tolyl)-1H-pyrrol-3-yl)ethanone (**5b**).* White solid (231 mg, 80%); IR (KBr): 3024, 2922, 1651, 1506, 1417, 1220, 825, 756, 702 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.08 (s, 3H), 2.38 (s, 3H), 3.40 (s, 3H), 6.65 (s, 1H), 7.19 (d, J=8.0 Hz, 2H), 7.27 (d, J=8.0 Hz, 2H), 7.32–7.33 (m, 2H), 7.42 (t, J=8.0 Hz, 1H), 7.49 (t, J=7.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.0, 21.2, 31.1, 120.5, 122.6, 126.2, 126.3, 128.1, 129.0, 129.2, 129.3, 133.0, 135.2, 136.5, 138.8, 197.8 ppm; Anal. Calcd for $C_{20}H_{19}NO$: C, 83.01; H, 6.62; N, 4.84. Found: C, 82.92; H, 6.46; N, 5.02; ESI-MS: m/z=290 $(M+1)^+$.

*4.3.3. 1-(4-(4-Methoxyphenyl)-2-methyl-1-phenyl-1H-pyrrol-3-yl) ethanone (**5c**).* Yellow sticky liquid (238 mg, 78%); IR (neat): 2995, 2835, 1647, 1518, 1400, 1246, 835, 769, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.40 (s, 3H), 3.84 (s, 3H), 6.63 (s, 1H), 6.93 (d, J=8.0 Hz, 2H), 7.28–7.33 (m, 4H), 7.42 (t, J=7.5 Hz, 1H), 7.49 (t, J=7.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.7, 30.8, 55.0, 113.5, 120.2, 122.3, 125.7, 126.0, 127.8, 128.1, 129.1, 130.1, 134.9, 138.5, 158.4, 197.4 ppm; Anal. Calcd for $C_{20}H_{19}NO_2$: C, 78.66; H, 6.27; N, 4.59. Found: C, 78.85; H, 6.46; N, 4.40; ESI-MS: m/z=306 $(M+1)^+$.

*4.3.4. 1-(2-Methyl-5-(5-(methylthio)phenyl)-1-phenyl-1H-pyrrol-3-yl)ethanone (**5d**).* Brown sticky liquid (231 mg, 72%); IR (neat):

2982, 2922, 1653, 1498, 1410, 1242, 827, 765, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.10 (s, 3H), 2.40 (s, 3H), 2.51 (s, 3H), 6.65 (s, 1H), 7.28–7.33 (m, 6H), 7.42 (t, J=7.5 Hz, 1H), 7.49 (t, J=7.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 15.8, 31.1, 120.6, 122.5, 125.7, 126.2, 126.4, 128.1, 129.3, 129.7, 132.8, 135.3, 136.9, 138.7, 197.5 ppm; Anal. Calcd for $C_{20}H_{19}NOS$: C, 74.73; H, 5.96; N, 4.36. Found: C, 74.90; H, 6.13; N, 4.55; ESI-MS: m/z=322 $(M+1)^+$.

*4.3.5. 1-(4-(2-Fluorophenyl)-2-methyl-1-phenyl-1H-pyrrol-3-yl) ethanone (**5e**).* White solid (267 mg, 91%); IR (KBr): 3117, 3064, 2922, 1643, 1504, 1406, 1232, 1213, 759, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.11 (s, 3H), 2.43 (s, 3H), 6.72 (s, 1H), 7.11–7.18 (m, 2H), 7.31–7.38 (m, 5H), 7.43 (t, J=7.5 Hz, 1H), 7.32–7.33 (m, 2H), 7.42 (t, J=8.0 Hz, 2H), 7.49 (t, J=7.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.0, 30.0, 115.6 (d, $^2J_{CF}$=22.2 Hz), 118.8, 121.5, 122.7, 123.8, 123.9, 124.1, 124.1, 126.2, 128.2, 128.8 (d, $^3J_{CF}$=8.0 Hz), 129.4, 131.6 (d, $^4J_{CF}$=3.2 Hz), 135.4, 138.6, 161.0 (d, $^1J_{CF}$=244.1 Hz), 197.8 ppm; Anal. Calcd for $C_{19}H_{16}FNO$: C, 77.80; H, 5.50; N, 4.77. Found: C, 77.98; H, 5.32; N, 4.95; ESI-MS: m/z=294 $(M+1)^+$.

*4.3.6. 1-(4-(2-Chlorophenyl)-2-methyl-1-phenyl-1H-pyrrol-3-yl) ethanone (**5f**).* White solid (275 mg, 89%); IR (KBr): 3120, 3063, 2920, 1647, 1502, 1410, 1230, 1051, 758, 696 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.11 (s, 3H), 2.40 (s, 3H), 6.68 (s, 1H), 7.27–7.28 (m, 2H), 7.29–7.30 (m, 2H), 7.38–7.40 (m, 1H), 7.42 (t, J=7.5 Hz, 1H), 7.45–7.50 (m, 3H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.2, 30.0, 121.2, 122.5, 122.8, 126.2, 126.6, 128.1, 128.6, 129.3, 129.5, 132.0, 134.4, 135.4, 135.4, 138.6, 196.5 ppm; Anal. Calcd for $C_{19}H_{16}ClNO$: C, 73.66; H, 5.21; N, 4.52. Found: C, 73.85; H, 5.03; N, 4.70; ESI-MS: m/z=310 $(M+1)^+$.

*4.3.7. 1-(4-(3-Chlorophenyl)-2-methyl-1-phenyl-1H-pyrrol-3-yl) ethanone (**5g**).* Colorless sticky liquid (272 mg, 88%); IR (neat): 3128, 3057, 2922, 1647, 1516, 1406, 1224, 1076, 802, 767, 696 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.11 (s, 3H), 2.40 (s, 3H), 6.68 (s, 1H), 7.24–7.33 (m, 5H), 7.39 (s, 1H), 7.43 (t, J=7.5 Hz, 1H), 7.49 (t, J=7.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 120.9, 122.5, 124.8, 126.2, 126.8, 127.5, 128.3, 129.1, 129.5, 129.5, 134.1, 135.5, 137.9, 138.5, 197.1 ppm; Anal. Calcd for $C_{19}H_{16}ClNO$: C, 73.66; H, 5.21; N, 4.52. Found: C, 73.83; H, 5.05; N, 4.71; ESI-MS: m/z=310 $(M+1)^+$.

*4.3.8. 1-(4-(4-Chlorophenyl)-2-methyl-1-phenyl-1H-pyrrol-3-yl) ethanone (**5h**).* White solid (266 mg, 86%); IR (KBr): 3117, 3047, 2922, 1647, 1500, 1410, 1087, 837, 767, 700 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.09 (s, 3H), 2.39 (s, 3H), 6.66 (s, 1H), 7.30–7.36 (m, 6H), 7.43 (t, J=7.5 Hz, 1H), 7.49 (t, J=7.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 120.7, 122.5, 125.0, 126.2, 128.2, 128.4, 129.5, 130.5, 132.7, 134.5, 135.5, 137.9, 138.6, 197.1 ppm; Anal. Calcd for $C_{19}H_{16}ClNO$: C, 73.66; H, 5.21; N, 4.52. Found: C, 73.80; H, 5.01; N, 4.69; ESI-MS: m/z=310 $(M+1)^+$.

*4.3.9. 1-(4-(4-Bromophenyl)-2-methyl-1-phenyl-1H-pyrrol-3-yl) ethanone (**5i**).* White solid (307 mg, 87%); IR (KBr): 3040, 2922, 1647, 1506, 1408, 1228, 835, 765, 700 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.10 (s, 3H), 2.39 (s, 3H), 6.66 (s, 1H), 7.25 (d, J=7.5 Hz, 2H), 7.32 (d, J=7.5 Hz, 2H), 7.43 (t, J=7.5 Hz, 1H), 7.48–7.51 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.2, 120.7, 120.8, 122.5, 125.0, 126.2, 128.2, 129.5, 130.8, 131.5, 135.0, 135.5, 138.6, 197.1 ppm; Anal. Calcd for $C_{19}H_{16}BrNO$: C, 64.42; H, 4.55; N, 3.95. Found: C, 64.60; H, 4.37; N, 4.13; ESI-MS: m/z=355 $(M+1)^+$.

*4.3.10. 1-(2-Methyl-4-(3-nitrophenyl)-1-phenyl-1H-pyrrol-3-yl) ethanone (**5j**).* Brown sticky liquid (259 mg, 81%); IR (neat): 3080, 2922, 1647, 1560, 1506, 1400, 1340, 1224, 869, 765, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.15 (s, 3H), 2.42 (s, 3H), 6.76 (s, 1H), 7.33–7.35 (m, 2H), 7.46 (t, J=7.5 Hz, 1H), 7.50–7.56 (m, 3H), 7.70 (d, J=8.0 Hz, 1H), 8.16 (d, J=8.0 Hz, 1H), 8.27 (t, J=6.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.0, 31.2, 121.5, 121.6, 122.3, 123.6, 123.9, 126.3, 128.5, 129.0, 129.5, 135.4, 136.0, 137.8, 138.3, 148.2, 196.7 ppm; Anal. Calcd for $C_{19}H_{16}N_2O_3$: C, 71.24; H, 5.03; N, 8.74. Found: C, 71.42; H, 4.85; N, 8.93; ESI-MS: m/z=321 $(M+1)^+$.

*4.3.11. 1-(2-Methyl-5-(5-nitrophenyl)-1-phenyl-1H-pyrrol-3-yl) ethanone (**5k**).* Brown sticky liquid (266 mg, 83%); IR (neat): 3132, 2922, 1653, 1541, 1516, 1419, 1340, 1224, 854, 752, 696 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.18 (s, 3H), 2.39 (s, 3H), 6.77 (s, 1H), 7.33 (d, J=8.0 Hz, 2H), 7.46 (t, J=7.5 Hz, 1H), 7.50–7.55 (m, 3H), 8.25 (d, J=8.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.2, 121.7, 122.5, 123.6, 125.1, 126.2, 128.6, 129.5, 129.5, 136.1, 138.3, 153.0, 156.5, 196.7 ppm; Anal. Calcd for $C_{19}H_{16}N_2O_3$: C, 71.24; H, 5.03; N, 8.74. Found: C, 71.40; H, 4.86; N, 8.95; ESI-MS: m/z=321 $(M+1)^+$.

*4.3.12. 1-(2-Methyl-1-phenyl-4-(3-(trifluoromethyl)phenyl)-1H-pyrrol-3-yl)ethanone (**5l**).* Yellow sticky liquid (274 mg, 80%); IR (neat): 3126, 3076, 2924, 1654, 1519, 1408, 1325, 1224, 1122, 813, 767, 696 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.09 (s, 3H), 2.41 (s, 3H), 6.72 (s, 1H), 7.33 (d, J=7.0 Hz, 2H), 7.45 (t, J=7.5 Hz, 1H), 7.48–7.51 (m, 3H), 7.56 (d, J=8.0 Hz, 2H), 7.66 (s, 1H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 121.1, 122.4, 124.2 (q, $^1J_{FC}$=270.7 Hz), 123.4 (q, $^3J_{FC}$=4.0 Hz), 124.8, 125.8 (q, $^3J_{FC}$=4.0 Hz), 126.2, 128.3, 128.7, 129.4, 130.7 (q, $^2J_{FC}$=32.1 Hz), 132.6, 135.8, 136.8, 138.5, 196.8 ppm; Anal. Calcd for $C_{20}H_{16}F_3NO$: C, 69.96; H, 4.70; N, 4.08. Found: C, 70.15; H, 4.86; N, 3.90; ESI-MS: m/z=344 $(M+1)^+$.

*4.3.13. 1-(2-Methyl-1-phenyl-5-(5-(trifluoromethyl)phenyl)-1H-pyrrol-3-yl)ethanone (**5m**).* Yellow sticky liquid (292 mg, 85%); IR (neat): 3049, 2929, 1654, 1502, 1417, 1325, 1224, 1124, 848, 769, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.12 (s, 3H), 2.40 (s, 3H), 6.71 (s, 1H), 7.33 (d, J=8.0 Hz, 2H), 7.45 (t, J=7.5 Hz, 1H), 7.48–7.51 (m, 5H), 7.63 (d, J=8.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.2, 121.1, 122.5, 124.2 (q, $^1J_{FC}$=270.2 Hz), 124.8, 125.2 (q, $^3J_{FC}$=3.6 Hz), 128.3, 128.8 (q, $^2J_{FC}$=32.0 Hz), 129.3, 129.4, 135.7, 138.5, 139.8197.0 ppm; Anal. Calcd for $C_{20}H_{16}F_3NO$: C, 69.96; H, 4.70; N, 4.08. Found: C, 70.13; H, 4.90; N, 3.91; ESI-MS: m/z=344 $(M+1)^+$.

*4.3.14. 1-(4-(Furan-2-yl)-2-methyl-1-phenyl-1H-pyrrol-3-yl)ethanone (**5n**).* White solid (167 mg, 63%); IR (KBr): 3120, 2982, 2926, 1647, 1498, 1410, 1240, 1049, 952, 769 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.22 (s, 3H), 2.40 (s, 3H), 6.43–6.45 (m, 2H), 6.85 (s, 1H), 7.30 (d, J=7.5 Hz, 2H), 7.44 (t, J=7.5 Hz, 1H), 7.47–7.50 (m, 3H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.0, 29.9, 107.9, 111.1, 115.3, 121.7, 121.8, 126.3, 128.3, 129.4, 135.8, 138.5, 141.7, 148.8, 196.6 ppm; Anal. Calcd for $C_{17}H_{15}NO_2$: C, 76.96; H, 5.70; N, 5.28. Found: C, 77.15; H, 5.90; N, 5.45; ESI-MS: m/z=266 $(M+1)^+$.

*4.3.15. 1-(2-Methyl-1-phenyl-4-(thiophen-2-yl)-1H-pyrrol-3-yl) ethanone (**5o**).* Yellow solid (197 mg, 70%); IR (KBr): 3113, 3051, 2926, 1653, 1506, 1406, 1234, 831, 771, 702 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.18 (s, 3H), 2.40 (s, 3H), 6.76 (s, 1H), 7.02 (s, 1H), 7.05–7.06 (m, 1H), 7.28 (d, J=5.0 Hz, 1H), 7.31 (d, J=8.0 Hz, 2H), 7.43 (t, J=7.0 Hz, 1H), 7.49 (t, J=7.5 Hz, 2H), ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.0, 30.6, 117.7, 122.0, 122.9, 125.0, 126.2, 127.0, 127.2, 128.3, 129.4, 135.6, 136.8, 138.4, 159.5, 197.0 ppm; Anal. Calcd for $C_{17}H_{15}NOS$: C, 72.57; H, 5.37; N, 4.98. Found: C, 72.40; H, 5.56; N, 5.17; ESI-MS: m/z=282 $(M+1)^+$.

*4.3.16. 1-(2-Methyl-5-(naphthalen-1-yl)-1-phenyl-1H-pyrrol-3-yl) ethanone (**5p**).* White solid (260 mg, 80%); IR (KBr): 3111, 3034, 2914, 1653, 1504, 1398, 1238, 802, 767, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 1.71 (s, 3H), 2.54 (s, 3H), 6.74 (s, 1H), 7.39–7.52 (m, 9H), 7.86 (t, J=5.0 Hz, 1H), 7.88 (d, J=8.0 Hz, 1H), 7.95 (d, J=8.0 Hz, 1H)

ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 118.8, 119.6, 120.7, 122.5, 124.1, 126.2, 126.8, 127.7, 128.3, 129.3, 130.0, 133.5, 135.5, 136.0, 156.3, 157.4, 197.6 ppm; Anal. Calcd for $C_{23}H_{19}NO$: C, 84.89; H, 5.89; N, 4.30. Found: C, 85.06; H, 6.03; N, 4.18; ESI-MS: m/z=326 $(M+1)^+$.

*4.3.17. 1-(1-(4-Methoxyphenyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl) ethanone (**5q**).* Yellow solid (275 mg, 90%); IR (KBr): 3109, 3009, 2835, 1653, 1508, 1386, 1222, 837, 773, 705 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.38 (s, 3H), 3.86 (s, 3H), 6.63 (s, 1H), 6.98 (d, J=9.0 Hz, 2H), 7.24 (d, J=9.0 Hz, 2H), 7.28–7.33 (m, 1H), 7.37–7.38 (m, 4H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 31.1, 55.5, 114.4, 120.8, 122.2, 126.0, 126.7, 127.4, 128.2, 129.3, 131.6, 135.6, 136.1, 159.2, 197.6 ppm; Anal. Calcd for $C_{20}H_{19}NO_2$: C, 78.66; H, 6.27; N, 4.59. Found: C, 78.85; H, 6.44; N, 4.30; ESI-MS: m/z=306 $(M+1)^+$.

*4.3.18. 1-(1-(4-Ethoxyphenyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl) ethanone (**5r**).* Yellow solid (297 mg, 93%); IR (KBr): 3117, 3038, 2924, 1649, 1506, 1408, 1249, 1228, 842, 767, 702 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.45 (t, J=7.0 Hz, 3H), 2.07 (s, 3H), 2.37 (s, 3H), 4.08 (q, J=7.0 Hz, 2H), 6.62 (s, 1H), 6.97 (d, J=8.0 Hz, 2H), 7.22 (d, J=8.0 Hz, 2H), 7.28–7.38 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.7, 14.7, 31.0, 63.7, 114.8, 120.8, 122.1, 125.9, 126.6, 127.3, 128.2, 129.2, 131.3, 135.6, 136.0, 158.6, 197.5 ppm; Anal. Calcd for $C_{21}H_{21}NO_2$: C, 78.97; H, 6.63; N, 4.39. Found: C, 79.15; H, 6.81; N, 4.10; ESI-MS: m/z=320 $(M+1)^+$.

*4.3.19. 1-(2-Methyl-4-phenyl-1-(m-tolyl)-1H-pyrrol-3-yl)ethanone (**5s**).* White solid (266 mg, 92%); IR: 3105, 3072, 2924, 1647, 1500, 1394, 1238, 794, 702 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.40 (s, 3H), 2.41 (s, 3H), 6.65 (s, 1H), 7.11–7.15 (m, 2H), 7.22 (t, J=7.5 Hz, 1H), 7.29–7.37 (m, 6H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 21.3, 31.1, 120.6, 122.5, 123.3, 126.2, 126.8, 126.8, 128.3, 128.9, 129.1, 129.3, 135.3, 136.1, 138.7, 139.4, 197.5 ppm; Anal. Calcd for $C_{20}H_{19}NO$: C, 83.01; H, 6.62; N, 4.84. Found: C, 82.83; H, 6.80; N, 4.66; ESI-MS: m/z=290 $(M+1)^+$.

*4.3.20. 1-(2-Methyl-4-phenyl-1-(p-tolyl)-1H-pyrrol-3-yl)ethanone (**5t**).* White solid (257 mg, 89%); IR (KBr): 3111, 3034, 2918, 1645, 1516, 1502, 1406, 1230, 821, 769, 704 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.39 (s, 3H), 2.42 (s, 3H), 6.64 (s, 1H), 7.21 (d, J=8.5 Hz, 2H), 7.28 (d, J=8.5 Hz, 2H), 7.31 (q, J=5.0 Hz, 1H), 7.37–7.38 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 21.1, 31.1, 120.7, 122.5, 126.0, 126.1, 126.8, 128.3, 129.3, 129.9, 135.4, 136.1, 136.2, 138.1, 197.6 ppm; Anal. Calcd for $C_{20}H_{19}NO$: C, 83.01; H, 6.62; N, 4.84. Found: C, 82.80; H, 6.78; N, 4.65; ESI-MS: m/z=290 $(M+1)^+$.

*4.3.21. 1-(1-(3,4-Dimethylphenyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl)ethanone (**5u**).* Yellow orange sticky liquid (279 mg, 92%); IR (neat): 3120, 3053, 2920, 1643, 1506, 1417, 1240, 763, 696 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.31 (s, 6H), 2.39 (s, 3H), 6.63 (s, 1H), 7.05 (d, J=8.0 Hz, 1H), 7.10 (s, 1H), 7.22 (d, J=8.0 Hz, 1H), 7.30 (s, 1H), 7.35–7.37 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 19.4, 19.8, 31.1, 120.7, 122.3, 123.5, 126.1, 126.7, 127.2, 128.3, 129.4, 133.0, 135.5, 136.2, 136.4, 136.7, 197.4 ppm; Anal. Calcd for $C_{21}H_{21}NO$: C, 83.13; H, 6.98; N, 4.62. Found: C, 82.95; H, 7.16; N, 4.80; ESI-MS: m/z=304 $(M+1)^+$.

*4.3.22. 1-(1-(5-(tert-Butyl)phenyl)-2-methyl-5-phenyl-1H-pyrrol-3-yl)ethanone (**5v**).* White solid (301 mg, 91%); IR (KBr): 2955, 1656, 1512, 1406, 1220, 842, 752, 700 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 1.37 (s, 9H), 2.07 (s, 3H), 2.51 (s, 3H), 6.65 (s, 1H), 7.25 (d, J=8.5 Hz, 2 H), 7.28–7.33 (m, 1H), 7.37–7.38 (m, 4H), 7.59 (d, J=8.5 Hz, 2 H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 31.3, 34.7, 120.7, 122.4, 125.7, 126.1, 126.2, 126.7, 128.2, 129.3, 135.4, 136.1, 136.1, 151.2, 197.6 ppm; Anal. Calcd for $C_{23}H_{25}NO$: C, 83.34; H, 7.60; N, 4.23. Found: C, 83.05; H, 7.78; N, 4.06; ESI-MS: m/z=332 $(M+1)^+$.

*4.3.23. 1-(1-(3-Fluorophenyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl) ethanone (**5w**).* White solid (261 mg, 89%); IR (KBr): 3122, 2922, 1645, 1506, 1404, 1253, 1190, 763, 696 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.06 (s, 3H), 2.42 (s, 3H), 6.67 (s, 1H), 7.08 (d, J=9.0 Hz, 1H), 7.14–7.15 (m, 2H), 7.31–7.33 (m, 1H), 7.36–7.40 (m, 4H), 7.46 (q, J=7.5 Hz, 1H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 31.1, 113.8 (d, $^2J_{CF}$=23.3 Hz), 115.1, 115.2, 120.3, 121.9 (d, $^4J_{CF}$=3.1 Hz), 122.9, 126.6, 126.9, 128.3, 129.2, 130.5 (d, $^3J_{CF}$=9.0 Hz), 135.0, 135.7, 140.1, 140.2, 162.7 (d, $^1J_{CF}$=247.3 Hz), 197.6 ppm; Anal. Calcd for $C_{19}H_{16}FNO$: C, 77.80; H, 5.50; N, 4.77. Found: C, 77.62; H, 5.68; N, 4.95; ESI-MS: m/z=294 $(M+1)^+$.

*4.3.24. 1-(1-(4-Fluorophenyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl) ethanone (**5x**).* White solid (264 mg, 90%); IR (KBr): 3080, 2922, 1647, 1512, 1415, 1219, 842, 722 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.06 (s, 3H), 2.38 (s, 3H), 6.62 (s, 1H), 7.16 (t, J=8.0 Hz, 2H), 7.28–7.31 (m, 3H), 7.36–7.37 (m, 4H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.7, 31.1, 116.3 (d, $^2J_{CF}$=22.7 Hz), 120.6, 122.6, 126.4, 126.9, 128.0 (d, $^3J_{CF}$=8.3 Hz), 128.3, 129.3, 134.8 (d, $^4J_{CF}$=2.8 Hz), 135.3, 135.8, 162.0 (d, $^1J_{CF}$=247.1 Hz), 197.5 ppm; Anal. Calcd for $C_{19}H_{16}FNO$: C, 77.80; H, 5.50; N, 4.77. Found: C, 77.65; H, 5.32; N, 4.60; ESI-MS: m/z=294 $(M+1)^+$.

*4.3.25. 1-(1-(5-Chlorophenyl)-2-methyl-5-phenyl-1H-pyrrol-3-yl) ethanone (**5y**).* Yellow solid (266 mg, 86%); IR (KBr): 3111, 3080, 2922, 1647, 1496, 1410, 1228, 840, 767, 704 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.06 (s, 3H), 2.39 (s, 3H), 6.64 (s, 1H), 7.27 (d, J=8.5 Hz, 2H), 7.31–7.40 (m, 5H), 7.46 (d, J=8.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 31.1, 120.4, 122.8, 126.6, 126.9, 127.4, 128.3, 129.3, 129.6, 134.0, 135.1, 135.7, 137.2, 197.6 ppm; Anal. Calcd for $C_{19}H_{16}ClNO$: C, 73.66; H, 5.21; N, 4.52. Found: C, 73.85; H, 5.40; N, 4.36; ESI-MS: m/z=310 $(M+1)^+$.

*4.3.26. 1-(1-(4-Bromophenyl)-2-methyl-4-phenyl-1H-pyrrol-3-yl) ethanone (**5z**).* White solid (318 mg, 90%); IR (KBr): 3109, 3078, 2920, 1647, 1506, 1491, 1408, 1228, 840, 767, 704 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.06 (s, 3H), 2.39 (s, 3H), 6.63 (s, 1H), 7.21 (d, J=8.0 Hz, 2H), 7.31–7.39 (m, 5H), 7.61 (d, J=8.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 31.1, 120.3, 122.0, 122.9, 126.6, 126.9, 127.8, 128.3, 129.3, 132.6, 135.0, 135.7, 137.7, 197.5 ppm; Anal. Calcd for $C_{19}H_{16}BrNO$: CC, 64.42; H, 4.55; N, 3.95. Found: C, 64.60; H, 4.73; N, 4.12; ESI-MS: m/z=355 $(M+1)^+$.

*4.3.27. 1-(2-Methyl-1-(4-nitrophenyl)-4-phenyl-1H-pyrrol-3-yl) ethanone (**5aa**).* Yellow solid (154 mg, 48%); IR (KBr): 3119, 3086, 2924, 1643, 1595, 1508, 1402, 1342, 1232, 868, 763, 698 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.46 (s, 3H), 6.72 (s, 1H), 7.33–7.42 (m, 5H), 7.54 (d, J=8.0 Hz, 2H), 8.39 (d, J=8.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.0, 31.1, 119.9, 124.0, 125.0, 126.5, 127.2, 127.5, 128.4, 129.2, 134.6, 135.2, 144.0, 146.8, 197.6 ppm; Anal. Calcd for $C_{19}H_{16}N_2O_3$: C, 71.24; H, 5.03; N, 8.74. Found: C, 71.06; H, 4.85; N, 8.93; ESI-MS: m/z=321 $(M+1)^+$.

*4.3.28. 1-(2-Methyl-4-phenyl-1-(4-(trifluoromethyl)phenyl)-1H-pyrrol-3-yl)ethanone (**5ab**).* Yellow solid (274 mg, 80%); IR: 3080, 3030, 2931, 1647, 1508, 1404, 1323, 1230, 852, 771, 705 cm^{-1}; ^{1}H NMR ($CDCl_3$, 500 MHz) δ 2.06 (s, 3H), 2.43 (s, 3H), 6.68 (s, 1H), 7.31–7.35 (m, 1H), 7.36–7.40 (m, 5H), 7.48 (d, J=8.0 Hz, 2H), 7.77 (d, J=8.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 120.2, 123.3, 123.8 (q, $^1J_{FC}$=270.7 Hz), 126.4, 126.6 (q, $^3J_{FC}$=3.6 Hz), 127.0, 127.0, 128.4, 129.2, 128.8 (q, $^2J_{FC}$=33.0 Hz), 134.9, 135.6, 141.7, 197.5 ppm; Anal. Calcd for $C_{20}H_{16}F_3NO$: C, 69.96; H, 4.70; N, 4.08. Found: C, 70.15; H, 4.88; N, 3.91; ESI-MS: m/z=344 $(M+1)^+$.

*4.3.29. 1-(2-Methyl-1-(naphthalen-1-yl)-4-phenyl-1H-pyrrol-3-yl) ethanone (**5ac**).* White solid (218 mg, 67%); IR: 3109, 2920, 1647,

1506, 1440, 1257, 1234, 1126, 950, 806, 777 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.15 (s, 3H), 2.22 (s, 3H), 6.71 (s, 1H), 7.32 (t, J=7.5 Hz, 1H), 7.38–7.48 (m, 6H), 7.50–7.58 (m, 3H), 7.96 (t, J=9.0 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.4, 31.2, 121.7, 121.8, 122.9, 125.2, 125.3, 126.1, 126.8, 126.9, 127.6, 128.2, 128.3, 129.3, 129.4, 130.6, 134.1, 135.3, 136.1, 137.0, 197.7 ppm; Anal. Calcd for $C_{23}H_{19}NO$: C, 84.89; H, 5.89; N, 4.30. Found: C, 85.06; H, 6.08; N, 4.12; ESI-MS: m/z=326 $(M+1)^+$.

*4.3.30. 1-(1-(9H-Fluoren-2-yl)-2-methyl-4-phenyl-1H-pyrrol-3-yl) ethanone (**5ad**).* White solid (323 mg, 89%); IR (KBr): 3055, 2916, 1651, 1512, 1404, 1238, 771, 732 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.09 (s, 3H), 2.44 (s, 3H), 3.97 (s, 2H), 6.72 (s, 1H), 7.30–7.43 (m, 8H), 7.50 (s, 1H), 7.58 (d, J=7.5 Hz, 1H), 7.82 (d, J=7.5 Hz, 1H), 7.86 (d, J=7.5 Hz, 1H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 13.1, 31.2, 36.9, 120.2, 120.3, 120.8, 122.5, 123.0, 125.0, 125.2, 126.3, 126.8, 127.1, 127.3, 128.3, 129.4, 135.5, 136.1, 137.2, 140.5, 141.7, 143.4, 145.3, 197.6 ppm; Anal. Calcd for $C_{26}H_{21}NO$: C, 85.92; H, 5.82; N, 3.85. Found: C, 86.10; H, 6.01; N, 4.03; ESI-MS: m/z=364 $(M+1)^+$.

*4.3.31. 1-(1-Allyl-2-methyl-4-phenyl-1H-pyrrol-3-yl)ethanone (**5ae**).* Yellow sticky liquid (203 mg, 85%); IR (neat): 3080, 2926, 1734, 1645, 1506, 1410, 1280, 1242, 756, 704 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.01 (s, 3H), 2.46 (s, 3H), 4.45 (d, J=5.0 Hz, 2H), 5.04 (d, J=17.0 Hz, 1H), 5.23 (d, J=10.0 Hz, 1H), 5.89–5.97 (m, 1H), 6.49 (s, 1H), 7.27–7.37 (m, 5H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 11.3, 31.0, 48.9, 117.5, 119.6, 121.8, 125.7, 126.6, 128.2, 129.3, 132.9, 134.9, 136.4, 197.4 ppm; Anal. Calcd for $C_{16}H_{17}NO$: C, 80.30; H, 7.16; N, 5.85. Found: C, 80.13; H, 6.98; N, 6.04; ESI-MS: m/z=240 $(M+1)^+$.

*4.3.32. 1-(1-Benzyl-2-methyl-4-phenyl-1H-pyrrol-3-yl)ethanone (**5af**).* White solid (237 mg, 82%); IR (KBr): 3080, 2931, 1645, 1508, 1415, 1354, 1276, 1180, 759, 705 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.03 (s, 3H), 2.43 (s, 3H), 5.06 (s, 2H), 6.54 (s, 1H), 7.09 (d, J=7.5 Hz, 2H), 7.27–7.37 (m, 8H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 11.6, 31.1, 50.3, 120.1, 122.1, 125.9, 126.7, 127.8, 128.2, 128.9, 129.4, 135.1, 136.3, 136.6, 197.4 ppm; Anal. Calcd for $C_{20}H_{19}NO$: C, 83.01; H, 6.62; N, 4.84. Found: C, 82.92; H, 6.80; N, 5.03; ESI-MS: m/z=290 $(M+1)^+$.

*4.3.33. (R)-1-(2-Methyl-5-phenyl-1-(1-phenylethyl)-1H-pyrrol-3-yl) ethanone (**5ag**).* White solid (242 mg, 80%); IR (KBr): 3136, 3028, 1643, 1508, 1402, 1220, 761, 702 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 1.82 (d, J=7.1 Hz, 3H), 2.03 (s, 3H), 2.40 (s, 3H), 5.37 (q, J=7.0 Hz, 1 H), 6.67 (s, 1H), 7.09 (d, J=7.5 Hz, 2H), 7.28–7.35 (m, 7H) ppm; ^{13}C NMR ($CDCl_3$, 75 MHz) δ 11.5, 22.1, 31.1, 54.9, 116.6, 121.9, 125.6, 125.9, 126.6, 127.6, 128.2, 128.8, 129.3, 135.0, 136.5, 141.9, 197.9 ppm; Anal. Calcd for $C_{21}H_{21}NO$: C, 83.13; H, 6.98; N, 4.62. Found: C, 82.94; H, 7.15; N, 4.80; ESI-MS: m/z=304 $(M+1)^+$.

*4.3.34. Methyl 2-methyl-1,4-diphenyl-1H-pyrrole-3-carboxylate (**5ah**).* Yellow sticky liquid (265 mg, 91%); IR (neat): 3057, 2914, 1699, 1506, 1420, 1224, 750, 696 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.45 (s, 3H), 3.70 (s, 3H), 6.71 (s, 1H), 7.26–7.28 (m, 1H), 7.31–7.36 (m, 5H), 7.51–7.53 (m, 3H), 7.57–7.50 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 50.6, 111.4, 121.0, 126.3, 126.6, 127.7, 128.1, 129.1, 129.4, 135.5, 136.8, 138.9, 166.3 ppm; Anal. Calcd for $C_{19}H_{17}NO_2$: C, 78.33; H, 5.88; N, 4.81. Found: C, 78.50; H, 6.06; N, 4.62; ESI-MS: m/z=292 $(M+1)^+$.

*4.3.35. Ethyl 2-methyl-1,5-diphenyl-1H-pyrrole-3-carboxylate (**5ai**).* Yellow sticky liquid (281 mg, 92%); IR (neat): 3055, 2980, 1695, 1597, 1519, 1384, 1224, 752 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 1.14 (t, J=7.0 Hz, 3H), 2.45 (s, 3H), 4.18 (q, J=7.0 Hz, 2H), 6.71 (s, 1H), 7.25–7.27 (m, 1H), 7.32–7.35 (m, 5H), 7.40–7.43 (m, 3H), 7.47–7.50 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.7, 14.1, 59.5, 111.8, 120.9, 126.3, 126.7, 127.6, 128.1, 129.3, 129.4, 135.6, 136.6, 139.0, 165.8 ppm; Anal. Calcd for $C_{20}H_{19}NO_2$: C, 78.66; H, 6.27; N, 4.59. Found: C, 78.85; H, 6.08; N, 4.40; ESI-MS: m/z=306 $(M+1)^+$.

*4.3.36. 2-Methoxyethyl 2-methyl-1,4-diphenyl-1H-pyrrole-3-carboxylate (**5aj**).* Yellow sticky liquid (275 mg, 82%); IR (neat): 3055, 2928, 1695, 1519, 1420, 1222, 752, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.476 (s, 3H), 3.24 (s, 3H), 3.47 (t, J=5.0 Hz, 2H), 4.27 (t, J=5.0 Hz, 2H), 6.70 (s, 1H), 7.26–7.28 (m, 1H), 7.31–7.35 (m, 5H), 7.40–7.45 (m, 3H), 7.47–7.50 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 58.7, 62.6, 70.4, 111.4, 121.0, 126.8, 127.6, 128.1, 129.4, 135.6, 136.9, 138.9, 165.6 ppm; Anal. Calcd for $C_{21}H_{21}NO_3$: C, 75.20; H, 6.31; N, 4.18. Found: C, 75.38; H, 6.15; N, 3.99; ESI-MS: m/z=336 $(M+1)^+$.

*4.3.37. Allyl 2-methyl-1,4-diphenyl-1H-pyrrole-3-carboxylate (**5ak**).* Yellow sticky liquid (315 mg, 85%); IR (neat): 3057, 2929, 1942, 1697, 1521, 1408, 1276, 1222, 1136, 977, 752, 698 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.46 (s, 3H), 4.65 (d, J=5.5 Hz, 2H), 5.07–5.10 (m, 2H), 5.78–5.86 (m, 1H), 6.71 (s, 1H), 7.25–7.27 (m, 1H), 7.31–7.35 (m, 5H), 7.41–7.45 (m, 3H), 7.47–7.50 (m, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 64.4, 111.5, 117.4, 121.0, 126.3, 126.4, 126.8, 127.7, 128.2, 129.3, 129.4, 132.6, 135.6, 136.9, 138.9, 165.4 ppm; Anal. Calcd for $C_{21}H_{19}NO_2$: C, 79.47; H, 6.03; N, 4.41. Found: C, 79.65; H, 5.86; N, 4.60; ESI-MS: m/z=318 $(M+1)^+$.

*4.3.38. 1-(1,4-Bis(4-methoxyphenyl)-2-methyl-1H-pyrrol-3-yl)ethanone (**5al**).* Yellow solid (302 mg, 90%); mp 136–137 °C; IR (KBr): 3115, 2895, 1716, 1683, 1653, 1516, 1456, 1247, 1033, 831 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.07 (s, 3H), 2.37 (s, 3H), 3.84 (s, 3H), 3.86 (s, 3H), 6.58 (s, 1H), 6.92 (d, J=8.5 Hz, 2H), 6.98 (d, J=8.5 Hz, 2H), 7.23 (d, J=8.5 Hz, 2H), 7.28 (d, J=8.5 Hz, 2H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.8, 31.0, 55.2, 55.5, 113.7, 114.4, 120.7, 122.2, 125.6, 127.4, 128.4, 130.4, 131.6, 135.5, 158.6, 159.2, 197.6 ppm; Anal. Calcd for $C_{21}H_{21}NO_3$: C, 75.20; H, 6.31; N, 4.18. Found: C, 75.39; H, 6.15; N, 3.99; ESI-MS: m/z=336 $(M+1)^+$.

*4.3.39. 1-(2-Methyl-1-phenyl-5-(thiophen-2-yl)-1H-pyrrol-3-yl) ethanone (**5am**).* Yellow sticky liquid (221 mg, 71%); IR (neat): 3101, 2928, 1651, 1514, 1406, 1249, 1222, 839, 715 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.18 (s, 3H), 2.36 (s, 3H), 3.86 (s, 3H), 6.71 (s, 1H), 7.00 (d, J=9.0 Hz, 2H), 7.03 (dd, J=1.5 Hz, 3.5 Hz, 1H), 7.08 (dd, J=3.5 Hz, 5.0 Hz, 1H), 7.25 (d, J=9.0 Hz, 2H), 7.30 (dd, J=1.5 Hz, 5.0 Hz, 1H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 30.5, 35.7, 114.5, 117.5, 122.2, 122.5, 124.9, 127.0, 127.2, 127.4, 131.2, 136.0, 136.9, 159.4, 196.9 ppm; Anal. Calcd for $C_{18}H_{17}NO_2S$: C, 69.43; H, 5.50; N, 4.50. Found: C, 69.60; H, 5.32; N, 4.68; ESI-MS: m/z=312 $(M+1)^+$.

*4.3.40. 1,1′-(5,5′-(1,5-Phenylene)bis(2-methyl-1-phenyl-1H-pyrrole-5,3-diyl))diethanone (**6**).* White solid (378 mg, 80%); mp 219–220 °C; IR (KBr): 3100, 2920, 1645, 1498, 1398, 1224, 852, 761, 700 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.12 (s, 6H), 2.41 (s, 6H), 6.73 (s, 2H), 7.35 (d, J=7.5 Hz, 4H), 7.40–7.44 (m, 6H), 7.50 (t, J=7.5 Hz, 4H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 12.9, 31.1, 122.7, 125.9, 126.2, 128.1, 129.2, 129.3, 134.5, 135.3, 138.7, 197.6 ppm; Anal. Calcd for $C_{32}H_{28}N_2O_2$: C, 81.33; H, 5.97; N, 5.93. Found: C, 81.52; H, 6.15; N, 6.12; ESI-MS: m/z=473 $(M+1)^+$.

*4.3.41. (Z)-4-((4-Methoxyphenyl)amino)pent-3-en-2-one (**intermediate A**).* Yellow sticky liquid[32]; IR (neat): 3335, 2999, 2928, 2835, 1608, 1558, 1516, 1435, 1247, 1186, 1220 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 1.90 (s, 3H), 2.08 (s, 3H), 3.80 (s, 3H), 5.15 (s, 1H), 6.86 (d, J=7.0 Hz, 2H), 7.03 (d, J=7.0 Hz, 2H), 12.28 (s, 1H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 19.5, 28.9, 55.2, 96.7, 114.1, 126.4, 131.4, 157.6, 161.0, 195.5 ppm; ESI-MS: m/z=206 $(M+1)^+$.

*4.3.42. (E)-1-Methoxy-4-(2-nitrovinyl)benzene (**intermediate B**).* Yellow solid; mp 87–88 °C (lit.[33] Mp 86–88 °C); IR (KBr): 2995,

1768, 1604, 1496, 1247 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 3.87 (s, 3H), 6.95 (d, J=9.0 Hz, 2H), 7.50 (d, J=9.0 Hz, 2H), 7.52 (d, J=13.5 Hz, 1H), 7.98 (d, J=13.5 Hz, 1H) ppm; ^{13}C NMR ($CDCl_3$, 125 MHz) δ 55.5, 114.9, 122.5, 131.1, 135.0, 139.0, 162.9 ppm; ESI-MS: m/z=180 $(M+1)^+$

Acknowledgements

We gratefully acknowledge financial support from the National Natural Science Foundation of China (Nos. 21272053, 21072042 and 20872025) and Nature Science Foundation of Hebei Province (B2011205031).

References and notes

1. Cadierno, V.; Crochet, P. *Curr. Org. Synth.* **2008**, *5*, 343–364.
2. Kawato, Y.; Iwata, M.; Yazaki, R.; Kumagai, N.; Shibasaki, M. *Tetrahedron* **2011**, *67*, 6539–6546.
3. Koukabi, N.; Kolvari, E.; Zolfigol, M. A.; Khazaei, A.; Shaghasemi, B. S.; Fasahati, B. *Adv. Synth. Catal.* **2012**, *354*, 2001–2008.
4. Zhang, Z. H.; Li, J. J.; Li, T. S. *Ultrason. Sonochem.* **2008**, *15*, 673–676.
5. Deng, H. J.; Fang, Y. J.; Chen, M. C.; Liu, M. C.; Wu, H. Y.; Chen, J. X. *Appl. Organomet. Chem.* **2012**, *26*, 164–167.
6. (a) Ngwerume, S.; Camp, J. E. *Chem. Commun.* **2011**, 1857–1859; (b) Jiang, Y. J.; Chan, W. C.; Park, C. M. *J. Am. Chem. Soc.* **2012**, *134*, 4104–4107; (c) Ngwerume, S.; Camp, J. E. *J. Org. Chem.* **2010**, *75*, 6271–6274; (d) Wang, H. Y.; Mueller, D. S.; Sachwani, R. M.; Kapadia, R.; Londino, H. N.; Anderson, L. L. *J. Org. Chem.* **2011**, *76*, 3203–3221.
7. (a) Gabriele, B.; Veltri, L.; Mancuso, R.; Salerno, G.; Magg, S.; Aresta, B. M. *J. Org. Chem.* **2012**, *77*, 4005–4016; (b) Yan, R. L.; Luo, J.; Wang, C. X.; Ma, C. W.; Huang, G. S.; Liang, Y. M. *J. Org. Chem.* **2010**, *75*, 5395–5397; (c) Kim, J. H.; Lee, S. B.; Lee, W. K.; Yoon, D. H.; Ha, H. J. *Tetrahedron* **2011**, *67*, 3553–3558.
8. Madabhushi, S.; Vangipuram, V. S.; Mallu, K. K. R.; Chinthala, N.; Beeram, C. R. *Adv. Synth. Catal.* **2012**, *354*, 1413–1416.
9. Thompson, B. B.; Montgomery, J. *Org. Lett.* **2011**, *13*, 3289–3291.
10. Zhu, D.; Zhao, J.; Wei, Y. X.; Zhou, H. W. *Synlett* **2011**, 2185–2186.
11. Kim, S. H.; Kim, S. H.; Lee, K. Y.; Kim, J. N. *Tetrahedron Lett.* **2009**, *50*, 5744–5747.
12. Ng, E. P. J.; Wang, Y. F.; Chiba, S. *Synlett* **2011**, 783–786.
13. (a) Li, M.; Kong, W.; Wen, L.-R.; Liu, F.-H. *Tetrahedron* **2012**, *68*, 4838–4845; (b) Gao, H.; Sun, J.; Yan, C.-G. *Tetrahedron* **2013**, *69*, 589–594; (c) Li, Y.; Li, Q.-Y.; Xu, H.-W.; Fan, W.; Jiang, B.; Wang, S.-L.; Tu, S.-J. *Tetrahedron* **2013**, *69*, 2941–2946; (d) Quan, Z.-J.; Xu, Q.; Zhang, Z.; Da, Y.-X.; Wang, X.-C. *Tetrahedron* **2013**, *69*, 881–887.
14. (a) Attanasi, O. A.; Favi, G.; Mantellini, F.; Moscatelli, G.; Santeusanio, S. *Adv. Synth. Catal.* **2011**, *353*, 1519–1524; (b) Lin, X. F.; Mao, Z. J.; Dai, X. X.; Lu, P.; Wang, Y. G. *Chem. Commun.* **2011**, 6620–6622; (c) Reddy, G. R.; Reddy, T. R.; Joseph, S. C.; Reddy, K. S.; Reddy, L. S.; Kumar, P. M.; Krishna, G. R.; Reddy, C. M.; Rambabu, D.; Kapavarapu, R.; Lakshmi, C.; Meda, T.; Priya, K. K.; Parsa, K. V. L.; Pal, M. *Chem. Commun.* **2011**, 7779–7781; (d) Attanasi, O. A.; Favi, G.; Mantellini, F.; Moscatelli, G.; Santeusanio, S. *J. Org. Chem.* **2011**, *76*, 2860–2866; (e) Liu, X. T.; Hao, L.; Lin, M.; Chen, L.; Zhan, Z. P. *Org. Biomol. Chem.* **2010**, *8*, 3064–3072; (f) Hong, D.; Zhu, Y. X.; Li, Y.; Lin, X. F.; Lu, P.; Wang, Y. G. *Org. Lett.* **2011**, *13*, 4668–4671; (g) Reddy, G. R.; Reddy, T. R.; Joseph, S. C.; Reddy, K. S.; Meda, C. L. T.; Kandale, A.; Rambabu, D.; Krishna, G. R.; Reddy, C. M.; Parsa, K. V. L.; Kumar, K. S.; Pal, M. *RSC Adv.* **2012**, *2*, 9142–9150; (h) Das, B.; Reddy, G. C.; Balasubramanyam, P.; Veeranjaneyulu, B. *Synthesis* **2010**, 1625–1628; (i) Lin, M.; Hao, L.; Ma, R. D.; Zhan, Z. P. *Synlett* **2010**, 2345–2351; (j) Tamaddon, F.; Farahi, M. *Synlett* **2012**, 1379–1383; (k) Ghabraie, E.; Balalaie, S.; Bararjanian, M.; Bijanzadeh, H. R.; Rominger, F. *Tetrahedron* **2011**, *67*, 5415–5420; (l) Han, Y.; Sun, Y.; Sun, J.; Yan, C. G. *Tetrahedron* **2012**, *68*, 8256–8260; (m) Anary-Abbasinejad, M.; Charkhati, K.; Anaraki-Ardakani, H. *Synlett* **2009**, 1115–1117; (n) Estevez, V.; Villacampa, M.; Menendez, J. C. *Chem. Soc. Rev.* **2010**, *39*, 4402–4421.
15. Alizadeh, A.; Rezvanian, A.; Bijanzadeh, H. R. *Synthesis* **2008**, 725–728.
16. Kassaee, M. Z.; Masrouri, H.; Movahedi, F.; Partovi, T. *Helv. Chim. Acta* **2008**, *91*, 227–231.
17. Maiti, S.; Biswas, S.; Jana, U. *J. Org. Chem.* **2010**, *75*, 1674–1683.
18. Khan, A. T.; Lal, M.; Bagdi, P. R.; Basha, R. S.; Saravanan, P.; Patra, S. *Tetrahedron Lett.* **2012**, *53*, 4145–4150.
19. Reddy, G. R.; Reddy, T. R.; Joseph, S. C.; Reddy, K. S.; Pal, M. *RSC Adv.* **2012**, *2*, 3387–3395.
20. (a) Diaz-Alvarez, A. E.; Francos, J.; Lastra-Barreira, B.; Crochet, P.; Cadierno, V. *Chem. Commun.* **2011**, 6208–6227; (b) Bachhav, H. M.; Bhagat, S. B.; Telvekar, V. N. *Tetrahedron Lett.* **2011**, *52*, 5697–5701; (c) Gu, Y. L.; Barrault, J.; Jerome, F. *Adv. Synth. Catal.* **2008**, *350*, 2007–2012; (d) Gu, Y. L.; Jerome, F. *Green Chem.* **2010**, *12*, 1127–1138; (e) He, F.; Li, P.; Gu, Y. L.; Li, G. X. *Green Chem.* **2009**, *11*, 1767–1773; (f) Li, M. H.; Chen, C.; He, F.; Gu, Y. L. *Adv. Synth. Catal.* **2010**, *352*, 519–530; (g) Safaei, H. R.; Shekouhy, M.; Rahmanpur, S.; Shirinfeshan, A. *Green Chem.* **2012**, *14*, 1696–1704; (h) Ricordi, V. G.; Freitas, C. S.; Perin, G.; Lenardao, E. J.; Jacob, R. G.; Savegnago, L.; Alves, D. *Green Chem.* **2012**, *14*, 1030–1034.
21. (a) Aparicio, S.; Alcalde, R. *Green Chem.* **2009**, *11*, 65–78; (b) Pereira, C. S. M.; Silva, V.; Rodrigues, A. E. *Green Chem.* **2011**, *13*, 2658–2671.
22. Duan, Z. Q.; Hu, F. *Green Chem.* **2012**, *14*, 1581–1583.
23. (a) Pace, V. *Aust. J. Chem.* **2012**, *65*, 301–302; (b) Pace, V.; Hoyos, P.; Castoldi, L.; de Maria, P. D.; Alcantara, A. R. *ChemSusChem* **2012**, *5*, 1369–1379; (c) Pace, V.; Hoyos, P.; Fernandez, M.; Sinisterra, J. V.; Alcantara, A. R. *Green Chem.* **2010**, *12*, 1380–1382.
24. Clark, J. H.; Macquarrie, D. J.; Sherwood, J. *Green Chem.* **2012**, *14*, 90–93.
25. Yang, J.; Tan, J. N.; Gu, Y. L. *Green Chem.* **2012**, *14*, 3304–3317.
26. (a) Russ, C.; König, B. *Green Chem.* **2012**, *14*, 2969–2982; (b) Zhang, Z. H.; Zhang, X. N.; Mo, L. P.; Li, Y. X.; Ma, F. P. *Green Chem.* **2012**, *14*, 1502–1506; (c) Ma, F. P.; Cheng, G. T.; He, Z. G.; Zhang, Z. H. *Aust. J. Chem.* **2012**, *65*, 409–416; (d) Gore, S.; Baskaran, S.; König, B. *Org. Lett.* **2012**, *14*, 4568–4571.
27. (a) Zhou, B. H.; Yang, J.; Li, M. H.; Gu, Y. L. *Green Chem.* **2011**, *13*, 2204–2211; (b) Yang, J.; Li, H. Q.; Li, M. H.; Peng, J. J.; Gu, Y. L. *Adv. Synth. Catal.* **2012**, *354*, 688–700; (c) Yang, J.; Zhou, B. H.; Li, M. H.; Gu, Y. L. *Tetrahedron* **2013**, *69*, 1057–1064.
28. Gu, Y. L. *Green Chem.* **2012**, *14*, 2091–2128.
29. (a) Zhang, Z. H.; Lü, H. Y.; Yang, S. H.; Gao, J. W. *J. Comb. Chem.* **2010**, *12*, 643–646; (b) Deng, J.; Mo, L. P.; Zhao, F. Y.; Hou, L. L.; Yang, L.; Zhang, Z. H. *Green Chem.* **2011**, *13*, 2576–2584; (c) Wang, H. J.; Mo, L. P.; Zhang, Z. H. *ACS Comb. Sci.* **2011**, *13*, 181–185; (d) Zhang, X. N.; Li, Y. X.; Zhang, Z. H. *Tetrahedron* **2011**, *67*, 7426–7430; (e) Deng, J.; Mo, L. P.; Zhao, F. Y.; Zhang, Z. H.; Liu, S. X. *ACS Comb. Sci.* **2012**, *14*, 335–341; (f) Liu, Y. H.; Deng, J.; Gao, J. W.; Zhang, Z. H. *Adv. Synth. Catal.* **2012**, *354*, 441–447; (g) Ma, F. P.; Li, P. H.; Li, B. L.; Mo, L. P.; Liu, N.; Kang, H. J.; Liu, Y. N.; Zhang, Z. H. *Appl. Catal., A* **2013**, *457*, 34–41; (h) Guo, R. Y.; Wang, P.; Wang, G. D.; Mo, L. P.; Zhang, Z. H. *Tetrahedron* **2013**, *69*, 2056–2061; (i) Li, P. H.; Ma, F. P.; Wang, P.; Zhang, Z. H. *Chin. J. Chem.* **2013**, *31*, 757–763.
30. Zhang, Q. H.; de Oliveira Vigier, K.; Royer, S.; Jérôme, F. *Chem. Soc. Rev.* **2012**, *41*, 7108–7146.
31. (a) Guan, Z.-H.; Li, L.; Ren, Z.-H.; Li, J.; Zhao, M.-N. *Green Chem.* **2011**, *13*, 1664–1668; (b) Palmieri, A.; Gabrielli, S.; Climarelli, C.; Ballini, R. *Green Chem.* **2011**, *13*, 3333–3336.
32. Zhang, Z. H.; Yin, L.; Wang, Y. M. *Adv. Synth. Catal.* **2006**, *348*, 184–190.
33. Greger, J. G.; Yoon-Miller, S. J. P.; Bechtold, N. R.; Flewelling, S. A.; MacDonald, J. P.; Downey, C. R.; Cohen, E. A.; Pelkey, E. T. *J. Org. Chem.* **2011**, *76*, 8203–8214.