Tetrahedron 70 (2014) 7490–7495

Contents lists available at ScienceDirect

Tetrahedron

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

Palladium-catalyzed C2-acylation of indoles with aryl and alkyl aldehydes

Xiao-Biao Yan [a], Yong-Wen Shen [b], Dao-Qian Chen [a], Pin Gao [a], Ying-Xiu Li [a], Xian-Rong Song [a], Xue-Yuan Liu [a,*], Yong-Min Liang [a]

[a] State Key Laboratory of Applied Organic Chemistry, Lanzhou University, Lanzhou 730000, PR China
[b] College of Chemistry and Chemical Engineering, Lanzhou University, Lanzhou 730000, PR China

ARTICLE INFO

Article history:
Received 24 April 2014
Received in revised form 29 July 2014
Accepted 8 August 2014
Available online 15 August 2014

Keywords:
Palladium
Acylation
Indole
Aldehyde
2-Aroylindole

ABSTRACT

A palladium-catalyzed C2-acylation of indoles with aryl and alkyl aldehydes via C–H functionalization is reported. The method shows excellent functional group tolerance and provides a straightforward way for the preparation of 2-aroylindoles.

1. Introduction

Transition-metal-catalyzed C–H bond functionalization directed by heteroatom directing groups is one of the most powerful tools in recent organic synthesis for the regioselective formation of carbon–carbon and carbon–heteroatom bonds.[1] In particular, the palladium-catalyzed directed acylation of the arene C–H bonds has attracted great interest. In 2009, Cheng[2] first reported a palladium-catalyzed oxidative coupling of 2-arylpyridines with aromatic aldehydes to afford aromatic ketones. Later, palladium-catalyzed the directed acylations of 2-arylpyridines,[3] anilides,[4] oxime,[5] azoarenes,[6] and benzylamines[7] with aldehydes, alcohols or aryl methanes were described. Furthermore, palladium-catalyzed decarboxylative acylations of the arene C–H bond using α-oxocarboxylic acids as acyl sources were reported.[8] The carbo-acylation of 2-arylpyridines with α-diketones via Pd-catalyzed C–H bond activation and C–C bond cleavage were also reported.[9]

Meanwhile, owing to their ubiquity in biologically active compounds, pharmaceuticals, and natural products, the efficient construction of functionalized indolyl analogues is a long-standing focus for synthetic chemists.[10] However, challenging still remain, because regioselectivities must be well controlled by avoiding the formation of intractable isomeric mixtures. In particular, the 2-aroylindole moiety attracts much attention as it is prevalent in drug fragments.[11] In 2012, Li[12] reported a rhodium-catalyzed oxidative C2-acylation of indoles with aryl and alkyl aldehydes via C–H bond activation. Zhu and co-workers[13] disclosed a palladium-catalyzed decarboxylative C2-acylation of indoles with α-oxocarboxylic acids leading to 2-aroylindole. However, these approaches need stoichiometric silver salt as an oxidant. In addition, for alkyl aldehydes, the former shows lower activity and needs longer reaction time, the latter does not give alkyl acylation product. Therefore, novel and efficient methods to synthesis C2-acylation of indoles is still desired. Herein, we describe a palladium-catalyzed C2-acylation of indoles with aldehydes using a more desirable reagent, TBHP (*tert*-butyl hydroperoxide), as the oxidant. This reaction proceeds smoothly with aromatic and aliphatic aldehydes, and shows broad substrate generality. The 2-pyridinyl director is readily removable on the indole nitrogen atom.

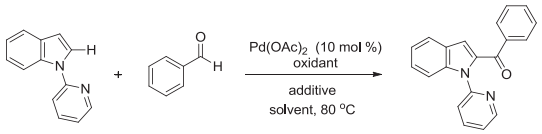
2. Results and discussion

Initial studies began with the direct C–H acylation of 1-(pyridin-2-yl)-1H-indole (**1a**) with three equivalents of benzaldehyde (**2a**) in the presence of 10 mol % $Pd(OAc)_2$ and stoichiometric TBHP (2.0 equiv) in toluene at 80 °C for 10 h. As expected, the desired product **3a** was obtained in 51% yield (Table 1, entry 1). Increasing the amount of TBHP resulted in lower yield (Table 1,

* Corresponding author. Tel.: +86 931 891 2593; fax: +86 931 891 2582; e-mail address: liuxuey@lzu.edu.cn (X.-Y. Liu).

http://dx.doi.org/10.1016/j.tet.2014.08.025
0040-4020/

Table 1
Optimization of the reaction conditions[a]



1a 2a 3a

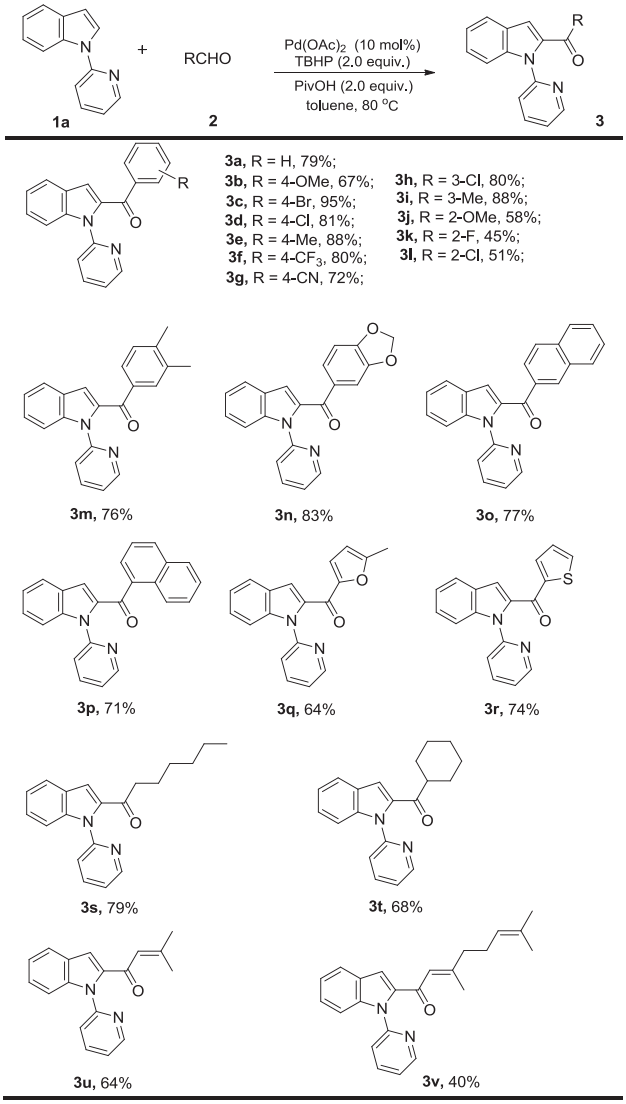
Entry	**2a** (equiv)	Oxidant	Additive	Solvent	Yield (%)[b]
1	3.0	TBHP	—	Toluene	51
2[c]	3.0	TBHP	—	Toluene	47
3[d]	3.0	TBHP	—	Toluene	34
4	5.0	TBHP	—	Toluene	67
5	5.0	DTBP	—	Toluene	n.r.[e]
6	5.0	$K_2S_2O_8$	—	Toluene	n.r.
7	5.0	Ag_2O	—	Toluene	n.r.
8	5.0	$PhI(OAc)_2$	—	Toluene	Trace
9	5.0	DCP	—	Toluene	n.r.
10	5.0	Benzoquinone	—	Toluene	n.r.
11	5.0	TBHP	—	DCE	Trace
12	5.0	TBHP	—	EtOAc	50
13	5.0	TBHP	—	MeCN	45
14	**5.0**	**TBHP**	**PivOH**	**Toluene**	**79**[f]
15[g]	5.0	TBHP	PivOH	Toluene	70
16	5.0	TBHP	AcOH	Toluene	39

[a] Reaction condition: **1a** (0.2 mmol), **2a**, $Pd(OAc)_2$ (10 mol %), TBHP (2.0 equiv, 70% aqueous solution), additive (2.0 equiv), toluene (2.0 mL), 80 °C, 10 h, under argon.
[b] Isolated yield.
[c] TBHP (3.0 equiv).
[d] TBHP (5.0 equiv).
[e] n.r.=no reaction.
[f] The optimal condition.
[g] PivOH (1.2 equiv).

entries 2 and 3). When 5 equiv of benzaldehyde were employed the reaction yield increased to 67% (Table 1, entry 4). Other oxidants, such as DTBP (di-*tert*-butyl peroxide), $K_2S_2O_8$, Ag_2O, $PhI(OAc)_2$, DCP (dicumyl peroxide), and benzoquinone, were ineffective for this reaction (Table 1, entries 5–10). Solvent screening showed that toluene was optimal solvent, whereas other solvents such as DCE, EtOAc, and MeCN failed to yield better results (Table 1, entries 11–13). After further optimization, the use of 2 equiv of PivOH (pivalic acid) as an additive resulted in the acylation reaction to afford the highest yield in 79% (Table 1, entry 14), because it can inhibit the side reactions and improve the yield of **3a**.[14] However, either decreasing the amount of PivOH or adding other acid additive (AcOH) was relatively ineffective (Table 1, entries 15 and 16).

To explore the substrate scope of this protocol, the optimized reaction conditions were applied to a series of aldehydes. As shown in Table 2, the C–H acylation of **1a** with various aryl aldehydes possessing electron-withdrawing or -donating substituents could proceed smoothly and furnished the corresponding products. Moreover, substrate with the strong electron-donating methoxy group at the para position of the phenyl ring delivered a lower yield than its counterparts substituted by the methyl group (**3b** vs **3e**). Meanwhile, the ortho-substituted benzaldehydes gave lower yields of acylated products possibly due to their higher steric hindrance (**3j**–**l**). 1-Naphthylaldehyde and 2-naphthylaldehyde also underwent the acylation reaction to afford product **3p** and **3o** in good yield. In addition, the heterocyclic aldehydes **2q** and **2r** also participated in the oxidative coupling to furnish **3q** and **3r** in good yields (64% and 74%). To our delight, this reaction is not limited to aryl aldehydes. Under the standard reaction conditions, aliphatic aldehydes such as *n*-heptanal (**2s**) and cyclohexanal (**2t**) could also undergo this coupling reaction smoothly to provide product **3s** and **3t** in 79% and 68% yield, respectively. It is worth noting that reactions with conjugated aldehydes underwent the reaction fluently and gave our desired products **3u** and **3v** in 64% and 40% yield, respectively.

Table 2
Scope of various aldehydes[a]

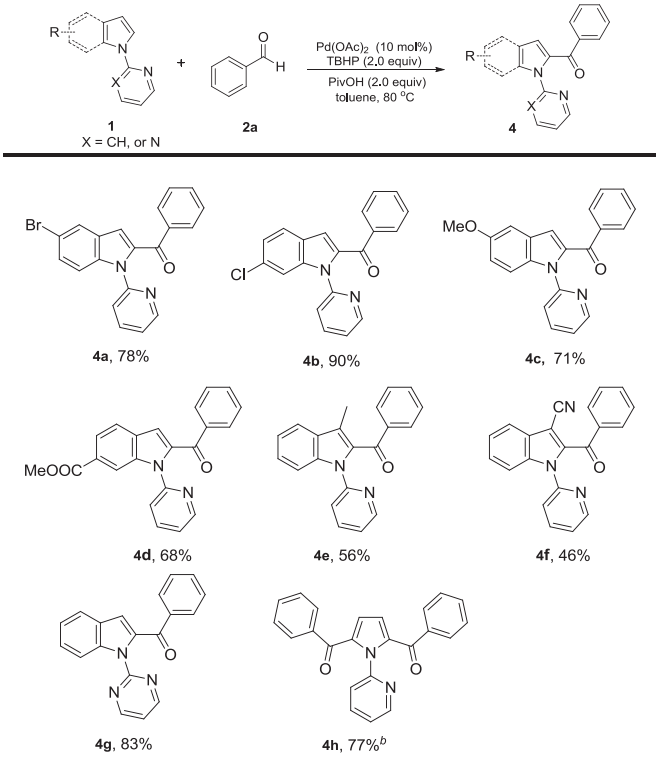


[a] Reaction condition: **1a** (0.2 mmol), **2** (5.0 equiv.), $Pd(OAc)_2$ (10 mol%), TBHP (2.0 equiv., 70% aqueous solution), PivOH (2.0 equiv.), toluene (2.0 mL), 80 °C, 10 h, under argon.

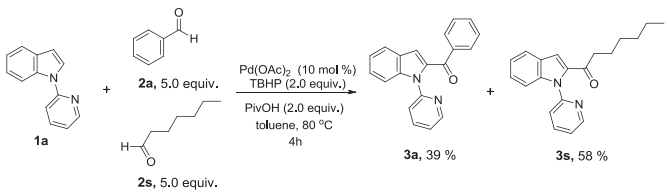
We next further investigated the scope of indoles. The results from Table 3 demonstrated that the substitution on the indoles showed no significant electronic effects. All the reactions proceeded smoothly in moderate to good yields and tolerated various functional groups such as methoxy, chloro, bromo, and ester groups. Yet, 3-substituted indoles gave an inferior yield due to steric hindrance (**4e** and **4f**). Acylation of indole derivatives is also possible by using a pyrimidine directing group. The corresponding 2-aroylindole was obtained in slightly higher yield (compare **3a** with **4g**). Furthermore, the reaction of 1-(pyridin-2-yl)-1*H*-pyrrole (**1i**) with benzaldehyde was also investigated and selective diacylation product **4h** was isolated in 77% yield.

To investigate the reactivities of aromatic and aliphatic aldehydes, a completing acylation reaction was carried out (Scheme 1). Exposure of **1a** to equimolar quantities of aromatic aldehyde **2a** and aliphatic aldehyde **2s** under the standard conditions provided **3a** and **3s** in 39% and 58% yield, respectively. The results indicate that aliphatic aldehydes are more reactive than aromatic aldehydes for the transformation under relatively low temperature.[7]

Table 3
Scope of indoles[a]

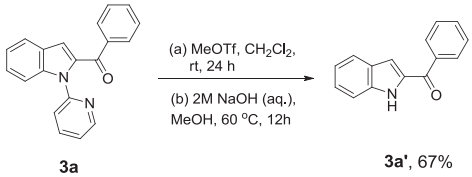


[a] Reaction condition: **1** (0.2 mmol), **2a** (5.0 equiv.), $Pd(OAc)_2$ (10 mol%), TBHP (2.0 equiv., 70% aqueous solution), PivOH (2.0 equiv.), toluene (2.0 mL), 80 °C, 10 h, under argon. [b] **2a** (10.0 equiv.), TBHP (4.0 equiv., 70% aqueous solution) were used.



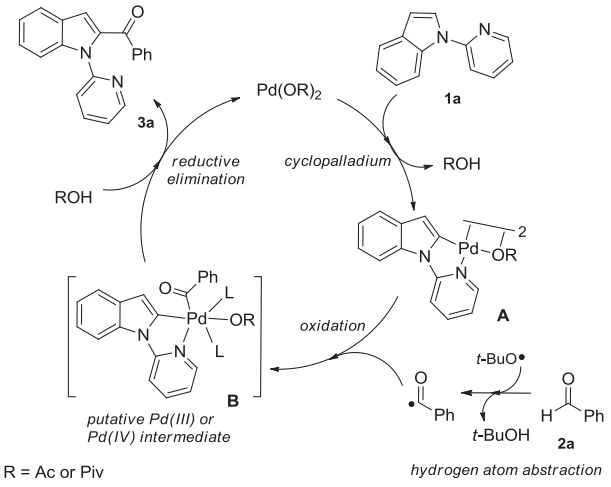
Scheme 1. Completing acylation of 1-(pyridin-2-yl)-1*H*-indole between aromatic and aliphatic aldehydes.

The 2-aroylindole is a common structural motif in many natural products and pharmaceutical compounds. If we can further remove the directing group (2-pyridinyl director) of acylated products, it would complete the synthetic approach to modified 2-aroylindoles. Then we attempted to remove the directing group from the acylated products in order to increase the reaction practicability. Compounds **3a** then underwent depyridination by treatment of MeOTf (methyl trifluoromethanesulfonate) in dichloromethane and sodium hydroxide in methanol.[15] Eventually, **3a**′ was produced in 67% yield (Scheme 2).



Scheme 2. Removal of 2-pyridinyl director.

On the basis of the previous reports,[3–7] a plausible catalytic cycle of this transformation is proposed (Scheme 3). Firstly, a five membered cyclopalladated intermediate **A** was generated through C–H activation of indole. Then the reaction of aldehyde with TBHP generated a reactive acyl radical, which next reacted with intermediate **A** to realize the oxidation of Pd(II) to dimeric Pd(III)[16] or Pd(IV)[17] species **B**. Finally, the species **B** underwent reductive elimination to afford the acylated product and released the Pd(II) species for the next run. Consistent with the involvement of radical intermediates, no acylated product was observed in the presence of a radical inhibitor (2.0 equiv), TEMPO (2,2,6,6-tetramethylpiperidinooxy).



Scheme 3. Plausible reaction mechanism.

3. Conclusions

In summary, we have developed an efficient protocol for the Pd-catalyzed C2-acylation of indoles with aldehydes using TBHP as an oxidant and PivOH as an additive. The method allows for using aromatic, aliphatic, and conjugated aldehydes as acyl sources, shows excellent functional group tolerance, and provides a convenient access toward various types of 2-aroylindoles.

4. Experimental section

4.1. General

All reactions were carried out under an atmosphere of argon unless otherwise noted. Column chromatography was carried out on silica gel. ^1H NMR and ^{13}C NMR spectra were measured on 400 MHz spectrometer, using $CDCl_3$ as the solvent with tetramethylsilane (TMS) as the internal standard. Chemical shifts (δ) are given in parts per million relative to TMS, the coupling constants J are given in Hertz. All products were further characterized by high resolution mass spectra. Copies of their ^1H NMR and ^{13}C NMR spectra are provided. All melting points were determined on a microscopic apparatus and were uncorrected.

4.2. General procedure for the acylation of indoles

A 10 mL of reaction tube was charged with indole (**1**, 0.20 mmol), aldehyde (**2**, 1.00 mmol), $Pd(OAc)_2$ (4.5 mg, 0.02 mmol), TBHP (55 μL, 0.40 mmol, 70% aqueous solution), PivOH (40.8 mg, 0.4 mmol), and toluene (2.0 mL) under argon atmosphere. The reaction vessel was placed in an oil bath. After the reaction was carried out at 80 °C for 10 h, it was cooled to room temperature, extracted with EtOAc (3×10 mL). The organic layers were combined, dried over Na_2SO_4, and concentrated to yield the crude product, which

was further purified by flash chromatography, affording the desired product **3**.

4.3. General procedure for the removal of 2-pyridinyl director

Methyl trifluoromethanesulfonate (27 μL, 0.24 mmol) was added dropwise to a solution of **3a** (59.6 mg, 0.20 mmol) in dry CH_2Cl_2 (5.0 mL) at 0 °C, and the resulting solution was stirred for 12 h at room temperature. Then the solvent was removed under vacuum, and the residue was dissolved in MeOH (3.0 mL). A 2 M aq NaOH solution (1.2 mL) was added, and stirring was continued at 60 °C for 12 h. The solvents were removed, and the resulting residue was extracted with EtOAc (2×15 mL). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated in vacuo. The residue was purified by flash chromatography, affording the desired product **3a′** (29.4 mg, 67%) as a white solid.

4.4. Characterization data of products

*4.4.1. Phenyl(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3a**).* (47.0 mg, 79%), white solid. Mp 31–33 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.56–8.58 (m, 1H), 8.00 (d, *J*=7.2 Hz, 2H), 7.84–7.88 (m, 1H), 7.73 (d, *J*=8.0 Hz, 1H), 7.58–7.62 (m, 1H), 7.47–7.54 (m, 3H), 7.43 (d, *J*=8.0 Hz, 1H), 7.35–7.39 (m, 1H), 7.29–7.32 (m, 1H), 7.24–7.25 (m, 1H), 7.20–7.22 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.9, 151.5, 149.3, 139.7, 138.2, 138.0, 136.0, 132.6, 129.9, 128.3, 126.8, 126.6, 123.0, 122.2, 122.0, 121.1, 116.2, 111.5. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{15}N_2O$ $[M+H]^+$: 299.1179, found: 299.1184.

*4.4.2. (4-Methoxyphenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3b**).* (44.0 mg, 67%), white solid. Mp 92–94 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.55–8.56 (m, 1H), 8.01–8.03 (m, 2H), 7.82–7.86 (m, 1H), 7.72 (d, *J*=8.0 Hz, 1H), 7.55 (d, *J*=8.4 Hz, 1H), 7.33–7.41 (m, 2H), 7.21–7.29 (m, 2H), 7.16 (s, 1H), 6.96–6.98 (m, 2H), 3.87 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.7, 163.4, 151.4, 149.2, 139.3, 138.0, 136.2, 132.2, 130.8, 126.9, 126.2, 122.8, 122.1, 121.8, 120.9, 115.1, 113.6, 111.4, 55.5. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{17}N_2O_2$ $[M+H]^+$: 329.1285, found: 329.1281.

*4.4.3. (4-Bromophenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3c**).* (71.9 mg, 95%), white solid. Mp 37–39 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.56–8.57 (m, 1H), 7.85–7.90 (m, 3H), 7.73 (d, *J*=8.0 Hz, 1H), 7.62–7.64 (m, 2H), 7.51 (d, *J*=8.4 Hz, 1H), 7.44 (d, *J*=8.0 Hz, 1H), 7.36–7.40 (m, 1H), 7.30–7.33 (m, 1H), 7.22–7.26 (m, 1H), 7.18 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.7, 151.2, 149.3, 139.7, 138.2, 136.9, 135.5, 131.6, 131.3, 127.7, 126.8, 126.7, 123.1, 122.4, 122.1, 120.9, 116.1, 111.4. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}BrN_2O$ $[M+H]^+$: 377.0284, found: 377.0288.

*4.4.4. (4-Chlorophenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3d**).* (54.0 mg, 81%), white solid. Mp 36–38 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.56–8.57 (m, 1H), 7.94 (d, *J*=8.4 Hz, 2H), 7.84–7.89 (m, 1H), 7.73 (d, *J*=7.6 Hz, 1H), 7.50 (d, *J*=8.4 Hz, 1H), 7.43–7.47 (m, 3H), 7.35–7.39 (m, 1H), 7.29–7.32 (m, 1H), 7.22–7.26 (m, 1H), 7.17 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.6, 151.2, 149.3, 139.6, 139.0, 138.2, 136.4, 135.6, 131.2, 128.6, 126.8, 126.7, 123.0, 122.4, 122.1, 120.9, 116.1, 111.4. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}ClN_2O$ $[M+H]^+$: 333.0789, found: 333.0793.

*4.4.5. (1-(Pyridin-2-yl)-1H-indol-2-yl)(p-tolyl)methanone (**3e**).* (55.1 mg, 88%), white solid. Mp 39–41 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.55–8.57 (m, 1H), 7.92 (d, *J*=8.0 Hz, 2H), 7.82–7.86 (m, 1H), 7.72 (d, *J*=8.0 Hz, 1H), 7.54 (d, *J*=8.4 Hz, 1H), 7.40 (d, *J*=8.0 Hz, 1H), 7.33–7.38 (m, 1H), 7.27–7.30 (m, 3H), 7.20–7.24 (m, 1H), 7.18 (s, 1H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.6, 151.5, 149.2, 143.4, 139.5, 138.0, 136.1, 135.5, 130.0, 129.0, 126.8, 126.4, 122.9, 122.1, 121.9, 121.0, 115.7, 111.5, 21.6. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{17}N_2O$ $[M+H]^+$: 313.1335, found: 313.1341.

*4.4.6. (1-(Pyridin-2-yl)-1H-indol-2-yl)(4-(trifluoromethyl)phenyl)methanone (**3f**).* (58.9 mg, 80%), semi-solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.56–8.57 (m, 1H), 8.09 (d, *J*=8.0 Hz, 2H), 7.87–7.91 (m, 1H), 7.73–7.77 (m, 3H), 7.45–7.51 (m, 2H), 7.38–7.41 (m, 1H), 7.31–7.35 (m, 1H), 7.23–7.27 (m, 1H), 7.20 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.6, 151.2, 149.4, 141.1, 139.9, 138.2, 135.4, 133.8 (q, *J*=32.0 Hz), 130.0, 127.1, 126.7, 125.3, 125.3, 123.7 (q, *J*=271.0 Hz), 123.2, 122.5, 122.2, 121.0, 116.8, 111.5. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{14}F_3N_2O$ $[M+H]^+$: 367.1053, found: 367.1049.

*4.4.7. 4-(1-(Pyridin-2-yl)-1H-indole-2-carbonyl)benzonitrile (**3g**).* (46.7 mg, 72%), white solid. Mp 50–52 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.55–8.57 (m, 1H), 8.05–8.07 (m, 2H), 7.89–7.93 (m, 1H), 7.74–7.80 (m, 3H), 7.46–7.51 (m, 2H), 7.39–7.43 (m, 1H), 7.33–7.36 (m, 1H), 7.24–7.28 (m, 1H), 7.19 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.1, 151.1, 149.5, 141.7, 140.0, 138.3, 135.1, 132.1, 130.1, 127.3, 126.7, 123.3, 122.6, 122.3, 120.9, 118.1, 116.8, 115.8, 111.5. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{14}N_3O$ $[M+H]^+$: 324.1131, found: 324.1130.

*4.4.8. (3-Chlorophenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3h**).* (53.5 mg, 80%), white solid. Mp 31–33 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.57–8.58 (m, 1H), 7.97–7.98 (m, 1H), 7.87–7.91 (m, 2H), 7.75 (d, *J*=8.0 Hz, 1H), 7.55–7.57 (m, 1H), 7.50–7.52 (m, 1H), 7.42–7.46 (m, 2H), 7.36–7.40 (m, 1H), 7.31–7.34 (m, 1H), 7.25–7.27 (m, 1H), 7.21–7.23 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.3, 151.2, 149.3, 139.7, 139.7, 138.2, 135.4, 134.5, 132.5, 129.8, 129.6, 127.9, 126.9, 126.7, 123.1, 122.4, 122.1, 121.0, 116.5, 111.4. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}ClN_2O$ $[M+H]^+$: 333.0789, found: 333.0792.

*4.4.9. (1-(Pyridin-2-yl)-1H-indol-2-yl)(m-tolyl)methanone (**3i**).* (55.1 mg, 88%), semi-solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.57–8.59 (m, 1H), 7.81–7.88 (m, 3H), 7.74 (d, *J*=8.0 Hz, 1H), 7.53 (d, *J*=8.4 Hz, 1H), 7.35–7.43 (m, 4H), 7.28–7.31 (m, 1H), 7.23–7.25 (m, 1H), 7.20–7.21 (m, 1H), 2.42 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 187.0, 151.4, 149.2, 139.6, 138.1, 136.1, 134.1, 133.4, 130.5, 130.4, 128.1, 127.2, 126.8, 126.5, 123.0, 122.2, 121.9, 121.0, 116.0, 111.5, 21.3. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{17}N_2O$ $[M+H]^+$: 313.1335, found: 313.1338.

*4.4.10. (2-Methoxyphenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3j**).* (37.8 mg, 58%), white solid. Mp 35–37 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.61–8.63 (m, 1H), 7.81–7.86 (m, 1H), 7.67 (d, *J*=8.0 Hz, 1H), 7.52–7.57 (m, 2H), 7.44–7.49 (m, 1H), 7.30–7.41 (m, 3H), 7.18–7.22 (m, 1H), 6.97–7.06 (m, 3H), 3.79 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.6, 157.8, 151.7, 148.9, 140.1, 137.8, 137.1, 132.2, 130.4, 128.8, 126.7, 126.7, 123.0, 122.2, 121.9, 121.8, 120.0, 116.5, 111.9, 111.4, 55.7. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{17}N_2O_2$ $[M+H]^+$: 329.1285, found: 329.1289.

*4.4.11. (2-Fluorophenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3k**).* (28.5 mg, 45%), white solid. Mp 28–30 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.62–8.63 (m, 1H), 7.85–7.90 (m, 1H), 7.68–7.72 (m, 2H), 7.48–7.54 (m, 2H), 7.43 (d, *J*=8.0 Hz, 1H), 7.32–7.39 (m, 2H), 7.22–7.26 (m, 2H), 7.14–7.20 (m, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 183.5, 160.3 (d, *J*=253.0 Hz), 151.4, 149.2, 140.2, 138.1, 136.3, 133.2 (d, *J*=8.0 Hz), 131.0 (d, *J*=2.0 Hz), 127.4, 127.3, 127.1, 126.7, 123.9 (d, *J*=3.0 Hz), 123.2, 122.5, 122.0, 121.6, 117.1 (d, *J*=2.0 Hz), 116.4 (d, *J*=21.0 Hz), 111.7. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}FN_2O$ $[M+H]^+$: 317.1085, found: 317.1082.

*4.4.12. (2-Chlorophenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3l**).* (33.9 mg, 51%), white solid. Mp 34–36 °C. ^{1}H NMR (400 MHz,

$CDCl_3$): δ 8.63–8.65 (m, 1H), 7.86–7.90 (m, 1H), 7.68 (d, *J*=8.0 Hz, 1H), 7.57–7.59 (m, 1H), 7.43–7.51 (m, 4H), 7.33–7.41 (m, 3H), 7.19–7.23 (m, 1H), 7.04 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.5, 151.4, 149.1, 140.6, 138.4, 138.1, 135.8, 131.9, 131.4, 130.2, 130.0, 127.4, 126.6, 126.4, 123.2, 122.6, 122.1, 121.9, 117.9, 112.0. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}ClN_2O$ $[M+H]^+$: 333.0789, found: 333.0791.

*4.4.13. (3,4-Dimethylphenyl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3m**).* (52.0 mg, 76%), white solid. Mp 168–170 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.56–8.57 (m, 1H), 7.81–7.86 (m, 1H), 7.77–7.80 (m, 2H), 7.73 (d, *J*=8.0 Hz, 1H), 7.55 (d, *J*=8.4 Hz, 1H), 7.40 (d, *J*=7.6 Hz, 1H), 7.33–7.37 (m, 1H), 7.26–7.30 (m, 1H), 7.21–7.25 (m, 2H), 7.18 (s, 1H), 2.34 (s, 3H), 2.32 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.8, 151.5, 149.2, 142.2, 139.4, 138.0, 136.7, 136.2, 135.8, 131.0, 129.5, 127.8, 126.8, 126.3, 122.9, 122.1, 121.8, 120.9, 115.6, 111.5, 20.0, 19.7. HRMS (ESI) *m*/*z*: calculated for $C_{22}H_{19}N_2O$ $[M+H]^+$: 327.1492, found: 327.1498.

*4.4.14. (1,3-Dihydroisobenzofuran-5-yl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3n**).* (56.7 mg, 83%), white solid. Mp 48–50 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.55–8.57 (m, 1H), 7.83–7.87 (m, 1H), 7.73 (d, *J*=8.0 Hz, 1H), 7.67–7.69 (m, 1H), 7.55 (d, *J*=8.4 Hz, 1H), 7.48 (d, *J*=1.2 Hz, 1H), 7.41 (d, *J*=7.6 Hz, 1H), 7.34–7.38 (m, 1H), 7.27–7.30 (m, 1H), 7.21–7.25 (m, 1H), 7.17 (s, 1H), 6.88 (d, *J*=8.4 Hz, 1H), 6.05 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.3, 151.7, 151.4, 149.3, 147.9, 139.3, 138.1, 136.0, 132.6, 126.8, 126.5, 126.3, 122.8, 122.1, 121.9, 120.8, 115.1, 111.4, 109.6, 107.7, 101.8. HRMS (ESI) *m*/*z*: calculated for $C_{22}H_{17}N_2O_2$ $[M+H]^+$: 341.1285, found: 341.1292.

*4.4.15. Naphthalen-2-yl(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3o**).* (53.6 mg, 77%), white solid. Mp 52–54 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.60 (s, 1H), 8.56–8.57 (m, 1H), 8.03 (d, *J*=8.4 Hz, 1H), 7.89–7.97 (m, 3H), 7.83–7.88 (m, 1H), 7.75 (d, *J*=8.0 Hz, 1H), 7.53–7.63 (m, 3H), 7.47 (d, *J*=8.0 Hz, 1H), 7.37–7.41 (m, 1H), 7.23–7.30 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.9, 151.4, 149.3, 139.6, 138.1, 136.2, 135.4, 132.3, 131.8, 129.5, 128.3, 127.8, 126.9, 126.7, 126.5, 125.4, 123.0, 122.2, 122.0, 120.9, 116.1, 111.5. HRMS (ESI) *m*/*z*: calculated for $C_{24}H_{17}N_2O$ $[M+H]^+$: 349.1335, found: 349.1337.

*4.4.16. Naphthalen-1-yl(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3p**).* (49.7 mg, 71%), white solid. Mp 49–51 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.59–8.60 (m, 1H), 8.36–8.39 (m, 1H), 7.96–8.01 (m, 2H), 7.84–7.90 (m, 2H), 7.66 (d, *J*=8.0 Hz, 1H), 7.48–7.53 (m, 5H), 7.35–7.39 (m, 1H), 7.29–7.32 (m, 1H), 7.19–7.24 (m, 1H), 7.06 (d, *J*=0.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 188.2, 151.6, 149.3, 140.1, 138.1, 137.7, 136.0, 133.7, 132.0, 131.0, 129.1, 128.2, 127.4, 126.9, 126.7, 126.4, 125.7, 124.1, 123.1, 122.4, 122.0, 121.3, 117.2, 111.6. HRMS (ESI) *m*/*z*: calculated for $C_{24}H_{17}N_2O$ $[M+H]^+$: 349.1335, found: 349.1339.

*4.4.17. (5-Methylfuran-2-yl)(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3q**).* (38.6 mg, 64%), white solid. Mp 30–32 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.57–8.58 (m, 1H), 7.84–7.88 (m, 1H), 7.76 (d, *J*=7.6 Hz, 1H), 7.50–7.52 (m, 2H), 7.41 (d, *J*=8.0 Hz, 1H), 7.33–7.37 (m, 1H), 7.28–7.31 (m, 2H), 7.22–7.26 (m, 1H), 6.22 (d, *J*=3.2 Hz, 1H), 2.44 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 172.9, 158.4, 151.5, 151.4, 149.3, 139.4, 138.0, 135.3, 127.0, 126.2, 122.9, 122.2, 121.9, 121.8, 121.0, 113.9, 111.5, 109.1, 14.2. HRMS (ESI) *m*/*z*: calculated for $C_{19}H_{15}N_2O_2$ $[M+H]^+$: 303.1128, found: 303.1125.

*4.4.18. (1-(Pyridin-2-yl)-1H-indol-2-yl)(thiophen-2-yl)methanone (**3r**).* (45.2 mg, 74%), white solid. Mp 31–33 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.57–8.58 (m, 1H), 7.95–7.96 (m, 1H), 7.85–7.89 (m, 1H), 7.76 (d, *J*=8.0 Hz, 1H), 7.70–7.71 (m, 1H), 7.52–7.54 (m, 1H), 7.42–7.44 (m, 2H), 7.35–7.39 (m, 1H), 7.29–7.32 (m, 1H), 7.25–7.27 (m, 1H), 7.18–7.21 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 178.4, 151.3, 149.3, 144.0, 139.5, 138.1, 135.7, 134.0, 133.8, 128.0, 126.9, 126.5, 122.9, 122.3, 122.0, 121.0, 114.7, 111.5. HRMS (ESI) *m*/*z*: calculated for $C_{18}H_{13}N_2OS$ $[M+H]^+$: 305.0743, found: 305.0741.

*4.4.19. 1-(1-(Pyridin-2-yl)-1H-indol-2-yl)heptan-1-one (**3s**).* (48.6 mg, 79%), colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 8.60–8.62 (m, 1H), 7.85–7.90 (m, 1H), 7.74 (d, *J*=8.0 Hz, 1H), 7.43 (s, 1H), 7.30–7.38 (m, 3H), 7.19–7.26 (m, 2H), 2.96 (t, *J*=7.6 Hz, 2H), 1.67–1.74 (m, 2H), 1.26–1.38 (m, 6H), 0.88 (t, *J*=6.8 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 192.8, 152.0, 149.2, 140.2, 138.0, 136.1, 126.6, 126.5, 122.8, 122.7, 122.0, 121.7, 112.9, 111.5, 39.6, 31.6, 29.0, 24.7, 22.5, 14.0. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{23}N_2O$ $[M+H]^+$: 307.1805, found: 307.1807.

*4.4.20. Cyclohexyl(1-(pyridin-2-yl)-1H-indol-2-yl)methanone (**3t**).* (41.2 mg, 68%), colorless oil. ^1H NMR (400 MHz, $CDCl_3$): δ 8.61–8.62 (m, 1H), 7.84–7.88 (m, 1H), 7.74 (d, *J*=8.0 Hz, 1H), 7.45 (s, 1H), 7.33–7.37 (m, 1H), 7.25–7.31 (m, 3H), 7.18–7.22 (m, 1H), 3.18–3.24 (m, 1H), 1.94–1.97 (m, 2H), 1.82–1.86 (m, 2H), 1.71–1.74 (m, 1H), 1.34–1.55 (m, 4H), 1.21–1.29 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 196.2, 152.0, 149.1, 140.3, 138.0, 135.4, 126.5, 126.5, 122.8, 122.7, 122.0, 121.7, 112.6, 111.5, 47.4, 29.6, 25.8. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{21}N_2O$ $[M+H]^+$: 305.1648, found: 305.1650.

*4.4.21. 3-Methyl-1-(1-(pyridin-2-yl)-1H-indol-2-yl)but-2-en-1-one (**3u**).* (35.4 mg, 64%), white solid. Mp 88–90 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.61–8.63 (m, 1H), 7.85–7.89 (m, 1H), 7.73 (d, *J*=8.0 Hz, 1H), 7.30–7.37 (m, 5H), 7.18–7.22 (m, 1H), 6.78–6.79 (m, 1H), 2.14 (d, *J*=0.8 Hz, 3H), 1.99 (d, *J*=1.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 182.8, 156.4, 152.1, 149.2, 140.0, 138.4, 138.0, 126.8, 126.2, 122.8, 122.5, 121.9, 121.8, 121.7, 112.2, 111.5, 28.0, 21.1. HRMS (ESI) *m*/*z*: calculated for $C_{18}H_{17}N_2O$ $[M+H]^+$: 277.1335, found: 277.1333.

*4.4.22. (E)-3,7-Dimethyl-1-(1-(pyridin-2-yl)-1H-indol-2-yl)octa-2,6-dien-1-one (**3v**).* (27.4 mg, 40%), white solid. Mp 36–38 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.61–8.63 (m, 1H), 7.85–7.89 (m, 1H), 7.73 (d, *J*=8.0 Hz, 1H), 7.34–7.36 (m, 3H), 7.30–7.33 (m, 2H), 7.18–7.22 (m, 1H), 6.76 (s, 1H), 5.14–5.15 (m, 1H), 2.24 (br, 4H), 2.13 (d, *J*=0.8 Hz, 3H), 1.73 (s, 3H), 1.64 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 183.1, 159.4, 152.1, 149.2, 140.0, 138.5, 138.0, 132.5, 126.8, 126.2, 123.2, 122.8, 122.5, 121.8, 121.7, 121.4, 112.3, 111.5, 41.4, 26.2, 25.7, 19.7, 17.8. HRMS (ESI) *m*/*z*: calculated for $C_{23}H_{25}N_2O$ $[M+H]^+$: 345.1961, found: 345.1960.

*4.4.23. (5-Bromo-1-(pyridin-2-yl)-1H-indol-2-yl)(phenyl)methanone (**4a**).* (58.9 mg, 78%), white solid. Mp 40–42 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.56–8.57 (m, 1H), 7.97–7.99 (m, 2H), 7.84–7.88 (m, 2H), 7.59–7.63 (m, 1H), 7.48–7.51 (m, 2H), 7.43 (s, 2H), 7.38 (d, *J*=8.0 Hz, 1H), 7.30–7.33 (m, 1H), 7.11 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.7, 151.0, 149.3, 138.2, 138.0, 137.7, 136.7, 132.9, 129.9, 129.3, 128.4, 128.3, 125.2, 122.5, 120.9, 114.9, 114.6, 113.1. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}BrN_2O$ $[M+H]^+$: 377.0284, found: 377.0281.

*4.4.24. (6-Chloro-1-(pyridin-2-yl)-1H-indol-2-yl)(phenyl)methanone (**4b**).* (59.8 mg, 90%), white solid. Mp 116–118 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.58–8.60 (m, 1H), 7.97–7.99 (m, 2H), 7.85–7.89 (m, 1H), 7.58–7.64 (m, 2H), 7.54 (d, *J*=0.8 Hz, 1H), 7.47–7.51 (m, 2H), 7.39 (d, *J*=8.0 Hz, 1H), 7.31–7.35 (m, 1H), 7.18–7.21 (m, 1H), 7.16 (d, *J*=0.4 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.5, 150.9, 149.3, 139.8, 138.3, 137.8, 136.5, 132.8, 132.6, 129.8, 128.3, 125.2, 123.9, 122.9, 122.6, 121.0, 115.8, 111.6. HRMS (ESI) *m*/*z*: calculated for $C_{20}H_{14}ClN_2O$ $[M+H]^+$: 333.0789, found: 333.0793.

*4.4.25. (5-Methoxy-1-(pyridin-2-yl)-1H-indol-2-yl)(phenyl)methanone (**4c**).* (46.5 mg, 71%), white solid. Mp 42–44 °C. ^1H NMR

(400 MHz, $CDCl_3$): δ 8.56–8.57 (m, 1H), 8.00 (d, *J*=7.2 Hz, 2H), 7.81–7.86 (m, 1H), 7.58–7.61 (m, 1H), 7.45–7.50 (m, 3H), 7.38 (d, *J*=8.0 Hz, 1H), 7.27–7.30 (m, 1H), 7.11–7.13 (m, 2H), 7.02–7.05 (m, 1H), 3.86 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.7, 155.4, 151.5, 149.2, 138.1, 138.0, 136.1, 135.1, 132.6, 129.8, 128.2, 127.2, 122.1, 120.9, 117.8, 115.9, 112.6, 102.9, 55.6. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{17}N_2O_2$ $[M+H]^+$: 329.1285, found: 329.1289.

4.4.26. Methyl 2-benzoyl-1-(pyridin-2-yl)-1H-indole-6-carboxylate (***4d***). (48.1 mg, 68%), white solid. Mp 120–122 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.56–8.58 (m, 1H), 8.23 (s, 1H), 8.00–8.02 (m, 2H), 7.89–7.94 (m, 2H), 7.76–7.78 (m, 1H), 7.60–7.64 (m, 1H), 7.48–7.52 (m, 3H), 7.33–7.36 (m, 1H), 7.20 (s, 1H), 3.92 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.9, 167.3, 150.7, 149.5, 138.6, 138.4, 138.4, 137.6, 133.0, 130.1, 129.9, 128.4, 127.7, 122.7, 122.6, 120.9, 114.7, 113.7, 52.2. HRMS (ESI) *m*/*z*: calculated for $C_{22}H_{17}N_2O_3$ $[M+H]^+$: 357.1234, found: 357.1231.

4.4.27. (3-Methyl-1-(pyridin-2-yl)-1H-indol-2-yl)(phenyl)methanone (***4e***). (35.1 mg, 56%), white solid. Mp 44–46 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.37–8.39 (m, 1H), 7.80–7.82 (m, 2H), 7.67–7.73 (m, 3H), 7.44–7.48 (m, 1H), 7.31–7.41 (m, 4H), 7.26–7.27 (m, 1H), 7.05–7.08 (m, 1H), 2.35 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 189.6, 151.3, 149.1, 138.9, 137.9, 137.4, 133.7, 132.6, 129.5, 128.9, 128.3, 126.1, 121.5, 121.5, 121.0, 120.8, 119.4, 111.3, 10.2. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{17}N_2O$ $[M+H]^+$: 313.1335, found: 313.1336.

4.4.28. 2-Benzoyl-1-(pyridin-2-yl)-1H-indole-3-carbonitrile (***4f***). (29.9 mg, 46%), white solid. Mp 60–62 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.45–8.47 (m, 1H), 7.95–7.97 (m, 2H), 7.87–7.91 (m, 2H), 7.62–7.66 (m, 2H), 7.47–7.54 (m, 4H), 7.42–7.46 (m, 1H), 7.30–7.33 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 186.4, 149.7, 149.3, 141.3, 138.6, 136.5, 136.4, 134.3, 130.1, 128.7, 127.2, 127.1, 124.1, 123.3, 121.0, 120.1, 113.8, 112.0, 93.5. HRMS (ESI) *m*/*z*: calculated for $C_{21}H_{14}N_3O$ $[M+H]^+$: 324.1131, found: 324.1127.

4.4.29. Phenyl(1-(pyrimidin-2-yl)-1H-indol-2-yl)methanone (***4g***). (49.8 mg, 83%), white solid. Mp 121–123 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.63 (d, *J*=4.8 Hz, 2H), 8.39 (d, *J*=8.8 Hz, 1H), 7.97 (d, *J*=7.6 Hz, 2H), 7.70 (d, *J*=8.0 Hz, 1H), 7.53–7.56 (m, 1H), 7.42–7.46 (m, 3H), 7.27–7.31 (m, 1H), 7.13 (s, 1H), 7.04–7.06 (m, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 187.5, 157.9, 157.2, 138.2, 137.9, 137.1, 132.7, 129.5, 128.3, 127.9, 126.5, 122.8, 122.5, 117.4, 115.4, 114.1. HRMS (ESI) *m*/*z*: calculated for $C_{19}H_{14}N_3O$ $[M+H]^+$: 300.1131, found: 300.1127.

4.4.30. (1-(Pyridin-2-yl)-1H-pyrrole-2,5-diyl)bis(phenylmethanone) (***4h***). (54.3 mg, 77%), white solid. Mp 110–112 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 8.46–8.48 (m, 1H), 7.90–7.92 (m, 4H), 7.79–7.84 (m, 1H), 7.57–7.60 (m, 2H), 7.44–7.49 (m, 5H), 7.32–7.36 (m, 1H), 6.83 (s, 2H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 185.9, 151.8, 148.5, 137.9, 137.5, 136.0, 132.8, 129.7, 128.3, 123.2, 122.4, 119.4. HRMS (ESI) *m*/*z*: calculated for $C_{23}H_{17}N_2O_2$ $[M+H]^+$: 353.1285, found: 353.1284.

4.4.31. (1H-Indol-2-yl)(phenyl)methanone (***3a′***). (29.4 mg, 67%), white solid. Mp 151–153 °C. ^1H NMR (400 MHz, $CDCl_3$): δ 9.44 (s, 1H), 7.99–8.01 (m, 2H), 7.71–7.73 (m, 1H), 7.61–7.65 (m, 1H), 7.48–7.56 (m, 3H), 7.36–7.40 (m, 1H), 7.15–7.19 (m, 2H), 7.16 (s, 1H). ^{13}C NMR (100 MHz, $CDCl_3$): δ 187.2, 138.0, 137.5, 134.3, 132.4, 129.2, 128.5, 127.7, 126.5, 123.2, 121.0, 112.8, 112.2. HRMS (ESI) *m*/*z*: calculated for $C_{15}H_{12}NO$ $[M+H]^+$: 222.0913, found: 222.0907.

Acknowledgements

We thank the National Natural Science Foundation of China (No. 21072081 and 201302076) for financial support.

Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.tet.2014.08.025.

References and notes

1. Selected reviews, see: (a) Chen, X.; Engle, K. M.; Wang, D.-H.; Yu, J.-Q. *Angew. Chem., Int. Ed.* **2009**, *48*, 5094–5115; (b) Daugulis, O.; Do, H.-Q.; Shabashov, D. *Acc. Chem. Res.* **2009**, *42*, 1074–1086; (c) Lyons, T. W.; Sanford, M. S. *Chem. Rev.* **2010**, *110*, 1147–1169; (d) Ackermann, L. *Chem. Rev.* **2011**, *111*, 1315–1345; (e) Liu, C.; Zhang, H.; Shi, W.; Lei, A. *Chem. Rev.* **2011**, *111*, 1780–1824; (f) Wencel-Delord, J.; Dröge, T.; Liu, F.; Glorius, F. *Chem. Soc. Rev.* **2011**, *40*, 4740–4761; (g) Yeung, C. S.; Dong, V. M. *Chem. Rev.* **2011**, *111*, 1215–1292; (h) Colby, D. A.; Tsai, A. S.; Bergman, R. G.; Ellman, J. A. *Acc. Chem. Res.* **2012**, *45*, 814–825; (i) Song, G.; Wang, F.; Li, X. *Chem. Soc. Rev.* **2012**, *41*, 3651–3678; (j) Patureau, F. W.; Wencel-Delord, J.; Glorius, F. *Aldrichimica Acta* **2012**, *45*, 31–41; (k) Pan, C.; Jia, X.; Cheng, J. *Synthesis* **2012**, *44*, 677–685; (l) Mei, T.-S.; Kou, L.; Ma, S.; Engle, K. M.; Yu, J.-Q. *Synthesis* **2012**, *44*, 1778–1791.
2. Jia, X.; Zhang, S.; Wang, W.; Luo, F.; Cheng, J. *Org. Lett.* **2009**, *11*, 3120–3123.
3. (a) Baslé, O.; Bidange, J.; Shuai, Q.; Li, C.-J. *Adv. Synth. Catal.* **2010**, *352*, 1145–1149; (b) Xiao, F.; Shuai, Q.; Zhao, F.; Baslé, O.; Deng, G.; Li, C.-J. *Org. Lett.* **2011**, *13*, 1614–1617.
4. (a) Wu, Y.; Li, B.; Mao, F.; Li, X.; Kwong, F. Y. *Org. Lett.* **2011**, *13*, 3258–3261; (b) Li, C.; Wang, L.; Li, P.; Zhou, W. *Chem.—Eur. J.* **2011**, *17*, 10208–10212; (c) Chan, C.-W.; Zhou, Z.; Yu, W.-Y. *Adv. Synth. Catal.* **2011**, *353*, 2999–3006; (d) Szabó, F.; Daru, J.; Simkó, D.; Nagy, T. Z.; Stirling, A.; Novák, Z. *Adv. Synth. Catal.* **2013**, *355*, 685–691.
5. Chan, C.-W.; Zhou, Z.; Chan, A. S. C.; Yu, W.-Y. *Org. Lett.* **2010**, *12*, 3926–3929.
6. (a) Li, H.; Li, P.; Wang, L. *Org. Lett.* **2013**, *15*, 620–623; (b) Xiong, F.; Qian, C.; Lin, D.; Zeng, W.; Lu, X. *Org. Lett.* **2013**, *15*, 5444–5447.
7. Sharma, S.; Park, J.; Park, E.; Kim, A.; Kim, M.; Kwak, J. H.; Jung, Y. H.; Kim, I. S. *Adv. Synth. Catal.* **2013**, *355*, 332–336.
8. Selected recent examples, see: (a) Li, M.; Ge, H. *Org. Lett.* **2010**, *12*, 3464–3467; (b) Fang, P.; Li, M.; Ge, H. *J. Am. Chem. Soc.* **2010**, *132*, 11898–11899; (c) Wang, H.; Guo, L.-N.; Duan, X.-H. *Org. Lett.* **2012**, *14*, 4358–4361; (d) Kim, M.; Park, J.; Sharma, S.; Kim, A.; Park, E.; Kwak, J. H.; Jung, Y. H.; Kim, I. S. *Chem. Commun.* **2013**, 925–927; (e) Yang, Z.; Chen, X.; Liu, J.; Gui, Q.; Xie, K.; Li, M.; Tan, Z. *Chem. Commun.* **2013**, 1560–1562.
9. Zhou, W.; Li, H.; Wang, L. *Org. Lett.* **2012**, *14*, 4594–4597.
10. (a) Sundberg, R. J. *Indoles*; Academic: New York, NY, 1996; (b) Eicher, T.; Hauptmann, S. *The Chemistry of Heterocycles*; Wiley-VCH: Weinheim, Germany, 2003; (c) Humphrey, G. R.; Kuethe, J. T. *Chem. Rev.* **2006**, *106*, 2875–2911; (d) Higuchi, K.; Kawasaki, T. *Nat. Prod. Rep.* **2007**, *24*, 843–868; (e) Kochanowska-Karamyan, A. J.; Hamann, M. T. *Chem. Rev.* **2010**, *110*, 4489–4497.
11. (a) Willson, T. M.; Brown, P. J.; Sternbach, D. D.; Henke, B. R. *J. Med. Chem.* **2000**, *43*, 527–550; (b) Mahboobi, S.; Teller, S.; Pongratz, H.; Hufsky, H.; Sellmer, A.; Botzki, A.; Uecker, A.; Beckers, T.; Baasner, S.; Schächtele, C.; Uberall, F.; Kassack, M. U.; Dove, S.; Böhmer, F. D. *J. Med. Chem.* **2002**, *45*, 1002–1018; (c) Brancale, A.; Silvestri, R. *Med. Res. Rev.* **2007**, *27*, 209–238; (d) Mahboobi, S.; Sellmer, A.; Hocher, H.; Garhammer, C.; Pongratz, H.; Maier, T. T.; Ciossek, T.; Beckers, T. *J. Med. Chem.* **2007**, *50*, 4405–4418.
12. Zhou, B.; Yang, Y.; Li, Y. *Chem. Commun.* **2012**, 5163–5165.
13. Pan, C.; Jin, H.; Liu, X.; Cheng, Y.; Zhu, C. *Chem. Commun.* **2013**, 2933–2935.
14. The roles of PivOH, see: (a) Li, D.; Wang, M.; Liu, J.; Zhao, Q.; Wang, L. *Chem. Commun.* **2013**, 3640–3642; (b) Li, Y.; Wang, W.-H.; He, K.-H.; Shi, Z.-J. *Organometallics* **2012**, *31*, 4397–4400.
15. (a) Chu, J.-H.; Wu, C.-C.; Chang, D.-H.; Lee, Y.-M.; Wu, M.-J. *Organometallics* **2013**, *32*, 272–282; (b) Jana, C. K.; Grimme, S.; Studer, A. *Chem.—Eur. J.* **2009**, *15*, 9078–9084.
16. (a) Powers, D. C.; Geibel, M. A. L.; Klein, J. E. M. N.; Ritter, T. *J. Am. Chem. Soc.* **2009**, *131*, 17050–17051; (b) Powers, D. C.; Ritter, T. *Nat. Chem.* **2009**, *1*, 302–309.
17. (a) Deprez, N. R.; Sanford, M. S. *J. Am. Chem. Soc.* **2009**, *131*, 11234–11241; (b) Racowski, J. M.; Dick, A. R.; Sanford, M. S. *J. Am. Chem. Soc.* **2009**, *131*, 10974–10983.