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Palladium-Catalyzed Synthesis of 3-Acylated Indoles Involving Oxidative Cross-Coupling of Indoles with α-Amino Carbonyl Compounds

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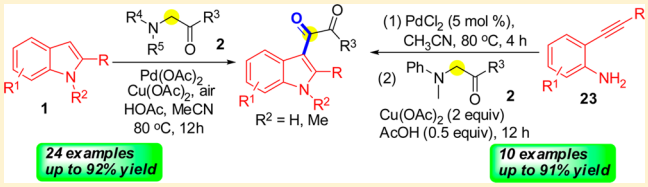
Supporting Information

ABSTRACT: A new and selective C−N bond oxidative cleavage method to 3-acylated indoles by Pd-catalyzed oxidative cross coupling of indoles with α-amino carbonyl compounds has been developed; moreover, one-pot synthesis of 3-acylated indoles from 2-ethynylanilines and α-amino carbonyl compounds has also been established. Importantly, the products 3-acylated indoles can be used to construct polyheterocyclic compound, which can be employed as efficient probes for Hg^{2+} and Fe^{3+}.



INTRODUCTION

Indoles, including 3-acylindoles, are ubiquitous in natural products, pharmaceutical molecules, and functional materials, as well as are valuable synthetic intermediates in organic synthesis.[1,2] Therefore, new, selective methods for their synthesis are an important and popular topic of research, particularly for 3-acylindole preparation due to wide applications of its carbonyl group as a versatile intermediate in the syntheses of a broad range of indole derivatives.[1] Traditionally, Friedel−Crafts acylations,[3a−e] Vilsmeier−Haack acylations,[1a,3f] and the reactions of indole salts with acyl chlorides[2e,3g−i] are usually employed for the synthesis of 3-acylindoles; however, the majority of these methods suffer from the requirement of stoichiometric metal Lewis acids, harsh reaction conditions (often strict exclusion of moisture), unsatisfactory selectivity, and unwanted waste. Thus, the development of new, catalytic routes to selectively accessing 3-acylindoles using readily available starting materials is highly desirable.

Recently, Su's group reported a convenient and general method for acylation of indoles using secondary anilines as the acyl resources by oxidative cleaving the C−N bond of secondary anilines.[4] Subsequently, Cheng's group[5] has also developed a $CuCl_2/O_2$ system for efficient formylation of indole with tertiary amines with a good functional group tolerance. Very recently, we illustrated a mild route to the selective synthesis of 2-(1*H*-indol-3-yl)-2-iminocarbonyls and 2-(1*H*-indol-3-yl)-2-oxocarbonyls via copper-catalyzed C−H oxidation/cross-coupling of α-amino carbonyls with indoles in the presence of TBHP (Scheme 1a).[6] Interestingly, the selectivity toward either 2-(1*H*-indol-3-yl)-2-iminocarbonyl compounds or 2-(1*H*-indol-3-yl)-2-oxocarbonyl compounds can be accessed by slight modification of the reaction conditions. However, the reaction could not be applied to tertiary amines. As part of our continuing interest in this area, we decided to explore a viable catalytic system and expand this method to tertiary amines. After a series of trials, we found that $Pd(OAc)_2$ combined with $Cu(OAc)_2$ and air was a viable catalytic system for the reaction between indoles and tertiary amines leading to 3-acylated indoles. Herein we report our findings that indoles can undergo the oxidative cross coupling with α-amino carbonyl compounds to afford 2-(1*H*-indol-3-yl)-2-oxocarbonyl compounds in moderate to good yields using the $Pd(OAc)_2/Cu(OAc)_2$/air system, wherein the carbonyl resources is from α-amino carbonyl compounds through the C−N bond cleavage (Scheme 1b);[7] moreover, a one-pot synthesis for the expected 3-acylated indoles from 2-ethynylanilines and α-amino carbonyl compounds has also been established.[1e,8] Importantly, the products, 2-(1*H*-indol-3-yl)-2-oxocarbonyl compounds, can react with indoles to construct polyindoles,[9] which can be used as efficient probes for Hg^{2+} and Fe^{3+}.[10]

RESULTS AND DISCUSSION

Oxidative Cross-Coupling of Indoles with α-Amino Carbonyl Compounds to 2-(1*H*-Indol-3-yl)-2-oxocarbonyl Compounds. Our investigation began with the oxidative cross-coupling of indole **1a** with 2-(methyl(phenyl)amino)-1-phenylethanone **2a** (Table 1). In the presence of 10 mol % of $Pd(OAc)_2$, treatment of indole **1a** with substrate **2a** in MeCN at 80 °C under air atmosphere afforded a trace amount of the expected product **3** (entry 1). To our delight, the presence of $Cu(OAc)_2$ oxidant was found to facilitate the reaction: the yield of **3** was enhanced sharply to 53% with 1 equiv of $Cu(OAc)_2$

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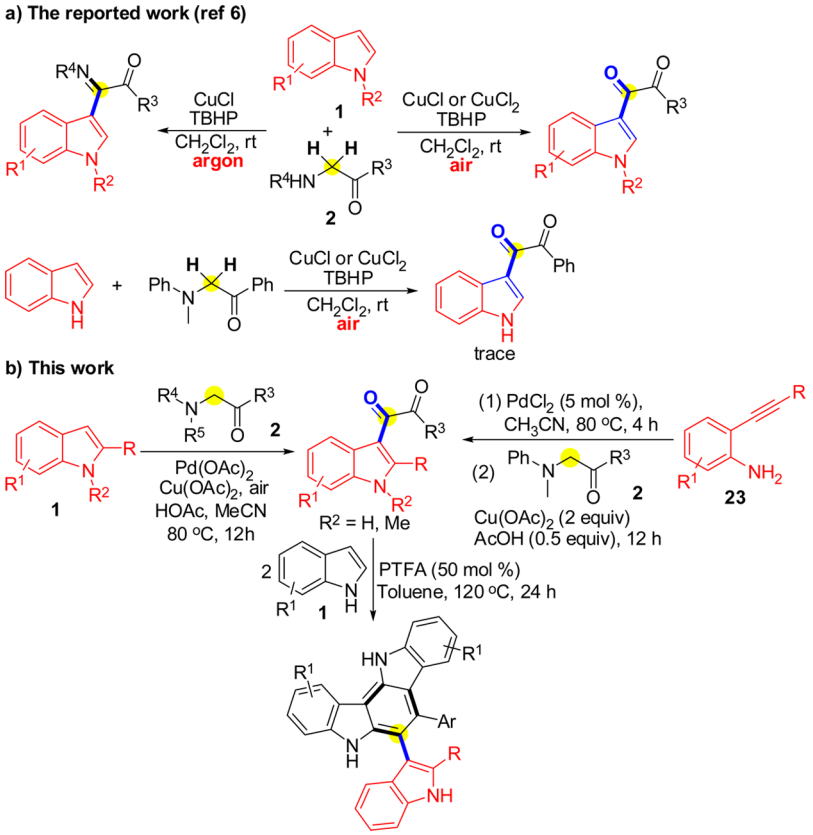
Scheme 1. Synthesis and Applications of 3-Acylated Indoles



(entry 2) and to 62% using 2 equiv of $Cu(OAc)_2$ (entry 3). Results identical to those with 2 equiv of $Cu(OAc)_2$ were obtained when the reaction was carried out with 3 equiv of $Cu(OAc)_2$ (entry 4). Subsequently, a series of other oxidants, including $Cu(OTf)_2$, $CuCl_2$, AgOAc, and TBHP, were examined, and they were less effective than $Cu(OAc)_2$ (entries 5−8); moreover, both $Cu(OTf)_2$ and TBHP have no effect on the reaction (entries 5 and 8). Extensive screening revealed that the reaction between indole **1a** and substrate **2a** at 5 mol % of $Pd(OAc)_2$ worked well and gave the target product **3** in 60% yield (entry 9); however, the yield was lowered to 54% using 2 mol % of $Pd(OAc)_2$ (entry 10). Notably, in the presence of 2 equiv of $Cu(OAc)_2$, the reaction could take place without Pd catalysts, albeit with a lower yield (entry 11). Two other Pd catalysts, $PdCl_2$ and $Pd(dba)_2$, were evaluated, and they were less active than $Pd(OAc)_2$ (entries 14 and 15). The reported literature suggested that the presence of organic acids can improve the C−N bond cleavage reaction.[7] Therefore, a number of acids, such as HOAc, CF_3CO_2H, PivOH, and $PhCO_2H$, were tested (entries 16−20). As expected, the presence of 0.5 equiv of HOAc enhanced the yield of **3** to 80% (entry 16) and 1 equiv of HOAc to 78% (entry 17). However, PivOH has no obvious role in promoting the reaction (entry 19), and both CF_3CO_2H and $PhCO_2H$ suppressed the reaction. Among the effect of solvents examined, it turned out that MeCN is the most efficient medium (entries 16 and 21−23). It is noteworthy that the reaction is successful with 65% yield of **3** under N_2 atmosphere (entry 24). Compared with the results under air atmosphere, we deduced that the role of air was used as an oxidant to improve the reaction (entry 16 vs entry 24). Finally, the use of $Cu(OAc)_2/O_2$ as combined oxidants was investigated: the $Cu(OAc)_2/O_2$ system was ineffective, and only a 40% yield of product **3** was obtained (entry 25).

With the optimal reaction conditions in hand, we turned our attention to exploring the viable substituents on the nitrogen atom in amines (**2**) (Scheme 2). The reactivity of substrate **2b** with a free N−H bond, 1-phenyl-2-(phenylamino)ethanone, was very low in terms of yield. Unfortunately, substrates **2c** and **2d** with two alkyl groups on the nitrogen atom were unsuitable for the reaction. *N*-Benzyl-*N*-methylaniline (**2e**), the reported efficient C−N cleavage reagent,[7a] was inert under the optimal conditions.

Inspired by the results described above, we next set out to investigate the scope of this oxidative cross coupling reaction with respect to both indoles **1** and α-amino carbonyl compounds **2** in the presence of 5 mol % of $Pd(OAc)_2$, 2 equiv of $Cu(OAc)_2$, 0.5 equiv of HOAc, and air (Table 2). Gratifyingly, this protocol was general to a wide range of α-amino carbonyl compounds **2**. Initial screening on α-amino ketones revealed that several substitiuents, including MeO, F, Cl, CF_3, and CN groups, on the aromatic ring of the 1-arylethanone moiety were well-tolerated (products **4**−**8**), and the reactive order is electron-withdrawing groups > electron-donating groups. While 1-(4-methoxyphenyl)-2-(methyl-(phenyl)amino)ethanone gave the desired product **4** in 64% yield, 2-(methyl(phenyl)amino)-1-(4-(trifluoromethyl)phenyl)-ethanone and 4-(2-(methyl(phenyl)amino)acetyl)benzonitrile furnished products **7** and **8** in 77% and 81% yields, respectively. Unexpectedly, the reaction of CF_3-containing substrate afforded a mixture of 2- and 3-acylated indoles **7** with 1:4 ratio. Using 2-(methyl(phenyl)amino)-1-(naphthalen-1-yl)ethanone, good yield was still achieved (product **9**). We were pleased to find that the optimal conditions were compatible with 1-(methyl-

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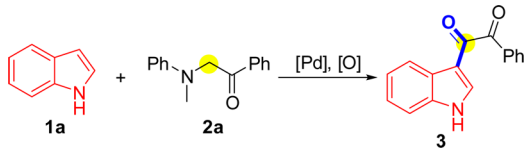
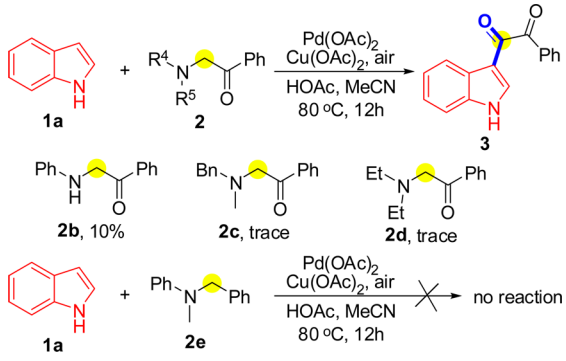
Table 1. Screening of Optimal Conditions[a]



entry	[Pd] (mol %)	[O] (equiv)	additive (equiv)	solvent	T (°C)	yield (%)
1	$Pd(OAc)_2$ (10)			MeCN	80	trace
2	$Pd(OAc)_2$ (10)	$Cu(OAc)_2$ (1)		MeCN	80	53
3	$Pd(OAc)_2$ (10)	$Cu(OAc)_2$ (2)		MeCN	80	62
4	$Pd(OAc)_2$ (10)	$Cu(OAc)_2$ (3)		MeCN	80	62
5	$Pd(OAc)_2$ (10)	$Cu(OTf)_2$ (2)		MeCN	80	trace
6	$Pd(OAc)_2$ (10)	$CuCl_2$ (2)		MeCN	80	15
7	$Pd(OAc)_2$ (10)	AgOAc (2)		MeCN	80	6
8	$Pd(OAc)_2$ (10)	TBHP (2)		MeCN	80	trace
9	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)		MeCN	80	60
10	$Pd(OAc)_2$ (2)	$Cu(OAc)_2$ (2)		MeCN	80	54
11		$Cu(OAc)_2$ (2)		MeCN	80	12
12	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)		MeCN	60	41
13	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)		MeCN	120	59
14	$PdCl_2$ (5)	$Cu(OAc)_2$ (2)		MeCN	80	52
15	$Pd(dba)_2$ (5)	$Cu(OAc)_2$ (2)		MeCN	80	49
16	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	HOAc (0.5)	MeCN	80	80
17	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	HOAc (1)	MeCN	80	78
18	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	CF_3CO_2H (0.5)	MeCN	80	trace
19	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	PivOH (0.5)	MeCN	80	63
20	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	$PhCO_2H$ (0.5)	MeCN	80	58
21	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	HOAc (0.5)	dioxane	80	55
22	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	HOAc (0.5)	CH_2ClCH_2Cl	80	48
23	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	HOAc (0.5)	DMSO	80	trace
24[b]	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (2)	HOAc (0.5)	MeCN	80	65
25[c]	$Pd(OAc)_2$ (5)	$Cu(OAc)_2$ (0.2)	HOAc (0.5)	MeCN	80	40

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.24 mmol), [M], [O], additive, and solvent (2 mL) under air atmosphere for 12 h. [b]Under N_2 atmosphere. [c]Under O_2 (1 atm) atmosphere.

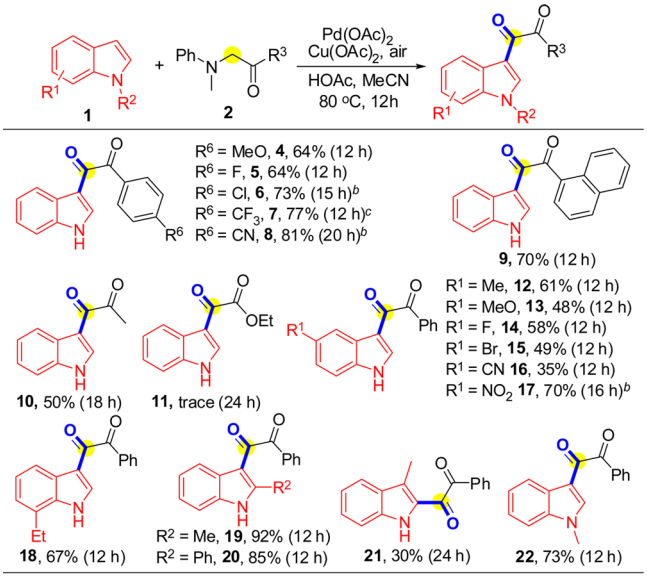
Scheme 2. Screening Scope of Viable Substituents on the Nitrogen Atom in Amines (2)



(phenyl)amino)propan-2-one (product **10**) but were ineffective for α-amino ester (product **11**). The reason might be that the electron-withdrawing properties of ester group dramatically decreased the reactivity of the α-CH_2 group in α-amino ester for the insertion of the active Pd species into the α-C−H bond, resulting in the failure of the reaction.

The optimal conditions were subjected to a wide range of indoles **1** (products **12**−**22**). For example, indoles **1** with a substituent, such as Me, MeO, F, Br, CN, and NO_2, at the 5 position were consistent with the optimal conditions, providing the corresponding products **12**−**17** in moderate to good yields.

Table 2. Pd-Catalyzed Cross-Coupling of Indoles (1) with α-Amino Carbonyl Compounds (2)[a]



[a]Reaction conditions: **1** (0.2 mmol), **2** (0.24 mmol), $Pd(OAc)_2$ (5 mol %), $Cu(OAc)_2$ (2 equiv), HOAc (0.5 equiv), and MeCN (2 mL) at 80 °C under air atmosphere. [b]At 100 °C. [c]A mixture of 2- and 3-acylated indoles was obtained with 1:4 ratio.

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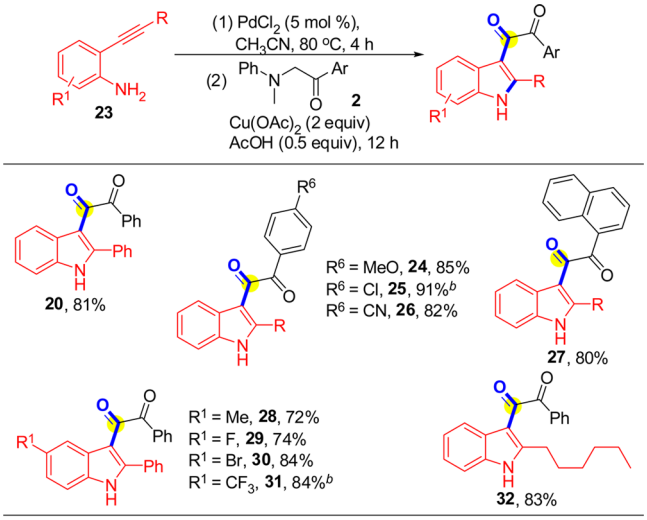
Importantly, F, Cl, or Br groups on the aryl ring of either indoles **1** or α-amino carbonyl compounds **2** could be perfectly tolerated, thereby facilitating possible additional modifications at the halogenated positions (products **5**, **6**, **14**, and **15**). Using 7-Et-susbtituted indole, the expect product **18** was obtained in 67% yield from the reaction with 2-(methyl(phenyl)amino)-1-phenylethanone **2a**. Interestingly, indoles **1** with a substituent at the 2 position displayed high activity, leading to the corresponding products **19** and **20** in good yields. This protocol could be applied to construct 2-acylated product **21** when 3-Me-substituted indole was used, albeit with a low yield. It is noteworthy that 1-methyl-1*H*-indole is also viable for the reaction with 2-(methyl(phenyl)amino)-1-phenylethanone **2a** in good yield (product **22**).

One-Pot Tandem Route to 2-(1*H*-Indol-3-yl)-2-oxocarbonyl Compounds. It is known that indoles can be readily prepared from 2-ethynylanilines **23** in the presence of transition metals (for example, Pd).[8] Thus, we next investigated the feasibility of one-pot synthesis of 2-(1*H*-indol-3-yl)-2-oxocarbonyl compounds from the reaction of 2-ethynylanilines **23** with α-amino carbonyl compounds **2**, which will make this methodology more useful in organic synthesis (Table 3). After

Table 3. One-Pot Tandem Route to 2-(1*H*-Indol-3-yl)-2-oxocarbonyl Compounds[a]

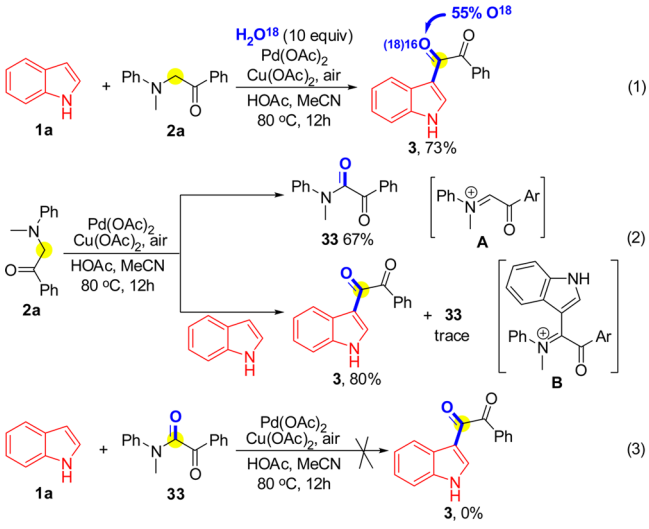


[a]Reaction conditions: (1) **1** (0.2 mmol), $PdCl_2$ (5 mol %), and MeCN (2 mL) at 80 °C for 4 h under air atmosphere; (2) **2** (0.24 mmol), $Cu(OAc)_2$ (2 equiv), and HOAc (0.5 equiv) at 80 °C for 12 h. [b]For 24 h.

a series of trials (Table S1 in Supporting Information), we found that 2-phenylindole could be in situ generated in the presence of 2-(phenylethynyl)aniline **23a** and $PdCl_2$, and addition of 2-(methyl(phenyl)amino)-1-phenylethanone **2a**, $Cu(OAc)_2$, and AcOH resulted in the expected 1-phenyl-2-(2-phenyl-1*H*-indol-3-yl)ethane-1,2-dione **20** in 81% yield. Encouraged by these results, the other four α-amino carbonyl compounds **2** were employed to react with 2-(phenylethynyl)-aniline **23a**: they are all suitable substrates for the one-pot reaction with substrate **23a**, giving the corresponding products **24**–**27** in high yields. Subsequently, a variety of 2-ethynylanilines were examined in the presence of 2-(methyl(phenyl)-amino)-1-phenylethanone **2a** (products **28**–**32**). 2-(Phenylethynyl)anilines with a substituents, such as Me, F, Br, and CF_3 groups, on the aryl ring of the aniline moiety could be easily converted into the corresponding indoles, and cross coupling with substrate **2a**, $Cu(OAc)_2$, and AcOH afforded the expected products **28**–**31** in 72–84% yields. Interestingly, aliphatic alkyne was also viable to react with substrate **2a**, offering product **32** in 83% yield.

To elucidate the mechanism, some control experiments were carried out (Scheme 3).[9] In the presence of $H_2{}^{18}O$, 55% of

Scheme 3. Control Experiments



product **3** contained the ^{18}O atom, suggesting that the oxygen of the new formed carbonyl group was from water (Scheme 3, eq 1). In the absence of indoles, substrate **2a** was converted to *N*-methyl-2-oxo-*N*,2-diphenylacetamide **33** in 67% yield (Scheme 3, eq 2), and the GC–MS analysis results showed that intermediate **A** was in situ formed and disappeared after the reaction finished (Figure S1, Supporting Information). Notably, intermediate **B** was also in situ determined from the reaction of indole **1a** with substrate **2a** by HRMS analysis (Scheme 3, eq 2, and Figure S2, Supporting Information). The results showed that *N*-methyl-2-oxo-*N*,2-diphenylacetamide **33** was not suitable to react with indole **1a** under the optimal conditions (Scheme 3, eq 3).

Consequently, possible mechanisms outlined in Scheme 4 are proposed.[4−7] Initially, α-amino carbonyl compound **2** reacts with the Pd active species to produce intermediate **C**, followed by reaction with indoles to afford intermediate **D**. It is noted that intermediate **C** can be readily oxidized to iminium ion **A** in the presence of $Cu(OAc)_2$ and air.[4−7] Reductive elimination of intermediate **D** takes place leading to intermediate **E**. Alternately, iminium ion **A** can simply react with indole to give intermediate **E** directly. Intermediate **E** can be quickly converted into intermediate **B** in the presence of oxidants. Hydrolysis of intermediate **B** gives the desired 3-acylated indoles and *N*-methylaniline.

Gratifyingly, the obtained indolyl diketone products could be used to construct conjugated polyheterocyclic compounds, which have good electronic chemistry and fluorescence properties: in the presence of PTFA, polyheterocyclic compounds **34**–**37** were prepared from the reaction of indolyl 1,2-diketones with 1*H*-indoles (Scheme 5).[9]

Generally, highly conjugated polyheterocyclic molecules usually serve as metal ion probes because they have good fluorescence properties.[10] As expected, preliminary experiments

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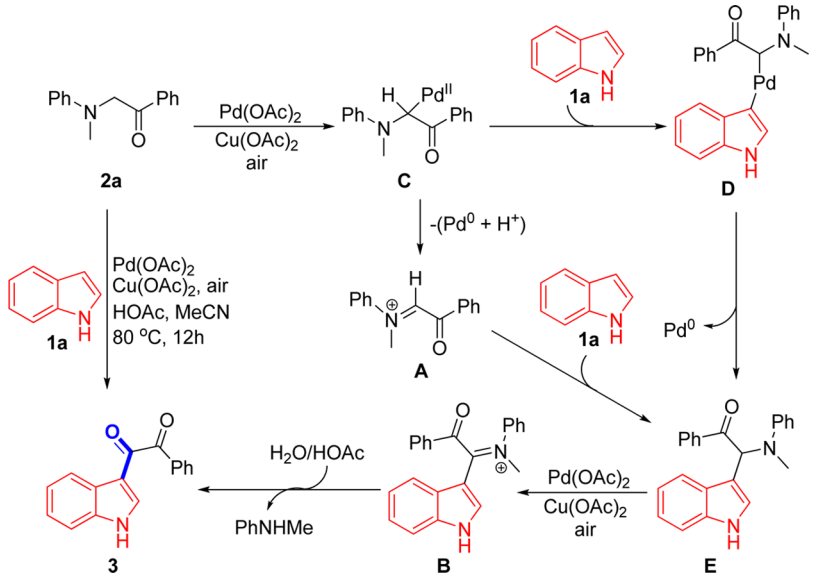
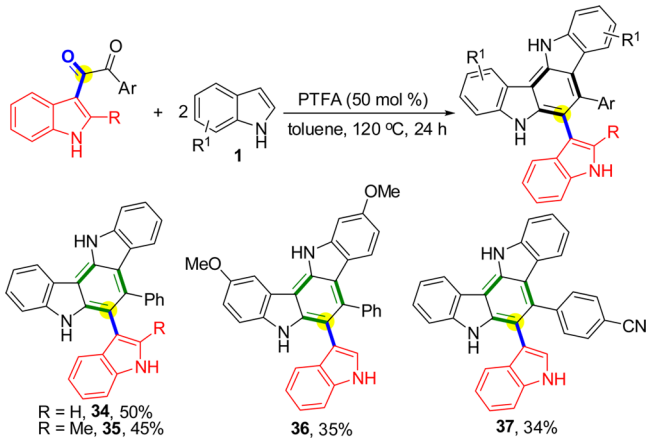
Scheme 4. Possible Mechanisms



Scheme 5. Application of 3-Acylated Indoles



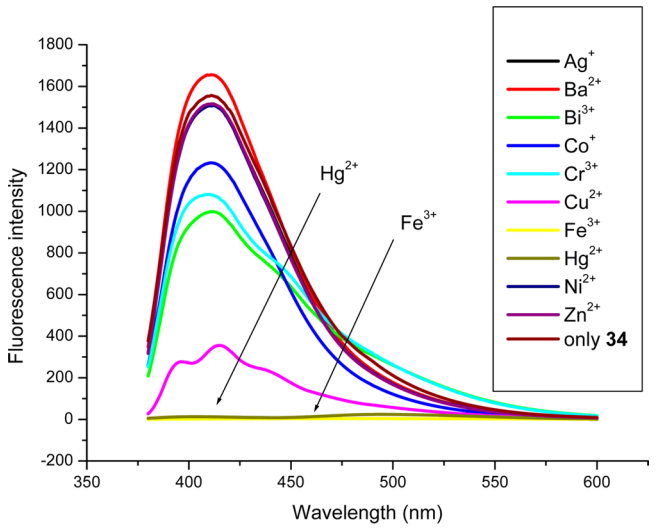


Figure 1. Fluorescence emission spectra of compound **34** in the presence of different metal ions Ag^{+}, Ba^{2+}, Bi^{2+}, Co^{+}, Cr^{3+}, Cu^{2+}, Fe^{3+}, Hg^{2+}, Ni^{2+}, and Zn^{2+} in CH_3CN/H_2O (100:1). λ_{ex} = 370 nm, [**35**] = 2.5 × 10^{-4} M, [M^{n+}] = 1 × 10^{-3} M.

were conducted to investigate the probe functionality of compound **34** (Figure 1). As shown in Figure 1, 4 equiv of M^{n+} ion (including Ag^{+}, Ba^{2+}, Bi^{3+}, Co^{2+}, Cr^{3+}, Cu^{2+}, Fe^{3+}, Hg^{2+}, Ni^{2+}, and Zn^{2+}) was introduced to a solution of **34** in CH_3CN/H_2O to test the change of fluorescence emission intensity. We found that Hg^{2+}, Fe^{3+}, and Cu^{2+} could distinctly depress the fluorescence. In particular, both Hg^{2+} and Fe^{3+} quenched the fluorescence completely, implying that compound **34** is a good probe for Hg^{2+} and Fe^{3+} ions.

CONCLUSIONS

In summary, we have described a novel and general palladium-catalyzed C−H oxidative/cross-coupling of indoles with α-amino carbonyl compounds to furnish 3-acylated indoles via a selectively C−N bond cleavage process. Notablely, the present system allows the tandem reaction of 2-(phenylethynyl)aniline with α-amino carbonyls to afford diversified 2-arylindolyl diketones which should be significant for the construction of indole libraries. Moreover, these indolyl diketones can be transformed to highly polyheterocyclic compounds, which serve as excellent probes for metal ions, such as Hg^{2+} and Fe^{3+}.

EXPERIMENTAL SECTION

General Considerations. The ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ or DMSO solvent on a NMR spectrometer using TMS as internal standard. LRMS was performed on a GC-MS instrument and HRMS was measured on an electrospray ionization (ESI) apparatus using time-of-flight (TOF) mass spectrometry. Melting points are uncorrected.

Preparation of α-Amino Carbonyl Compounds (2) and 2-Ethynylanilines (23). Both α-amino carbonyl compounds (**1**)[11] and 2-ethynylanilines (**23**)[8] were prepared according to the known procedures.

Typical Experimental Procedure for the Oxidative Cross Coupling of Indoles (1) with α-Amino Carbonyl Compounds (2). To a Schlenk tube were added indoles **1** (0.2 mmol), α-amino carbonyl compounds **2** (0.24 mmol), $Pd(OAc)_2$ (5 mol %), $Cu(OAc)_2$ (2 equiv), HOAc (0.5 equiv), and MeCN (2 mL). Then the tube was charged with air and stirred at 80 °C (oil bath temperature) for the indicated time until complete consumption of starting material as

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monitored by TLC and GC−MS analysis. After the reaction was finished, the reaction mixture was washed with brine. The aqueous phase was re-extracted with ethyl acetate. The combined organic extracts were dried over Na_2SO_4 and concentrated in vacuum, and the resulting residue was purified by silica gel column chromatography (only hexane) to afford the desired product.

Typical Experimental Procedure for the One-Pot Tandem Route to 2-(1*H*-Indol-3-yl)-2-oxocarbonyl Compounds from Oxidative Cross-Coupling of 2-Ethynylanilines (23) and α-Amino Carbonyl Compounds (2). A mixture of 2-ethynylanilines **23** (0.2 mmol), $PdCl_2$ (5 mol %), and MeCN (2 mL) was stirred at 80 °C (oil bath temperature) for 4 h, and then α-amino carbonyl compounds **2** (0.24 mmol), $Cu(OAc)_2$ (2 equiv), and HOAc (0.5 equiv) were added. The mixture was stirred at 80 °C for 12 h until complete consumption of the starting material as monitored by TLC and GC−MS analysis. After the reaction was finished, the reaction mixture was washed with brine. The aqueous phase was re-extracted with ethyl acetate. The combined organic extracts were dried over Na_2SO_4 and concentrated in vacuum, and the resulting residue was purified by silica gel column chromatography (only hexane) to afford the desired product.

Typical Experimental Procedure for the Synthesis of Polyheterocyclic Compounds 34−37 from 2-(1*H*-Indol-3-yl)-2-oxocarbonyl Compounds. To a Schlenk tube were added 2-(1*H*-indol-3-yl)-2-oxocarbonyl compounds (0.1 mmol), indole **1a** (0.2 mmol), PTFA (0.5 equiv), and toluene (1 mL). Then the tube was charged with argon and stirred at 120 °C (oil bath temperature) for the indicated time until complete consumption of starting material as monitored by TLC and GC−MS analysis. After the reaction was finished, the reaction mixture was washed with brine. The aqueous phase was re-extracted with ethyl acetate. The combined organic extracts were dried over Na_2SO_4 and concentrated in vacuum, and the resulting residue was purified by silica gel column chromatography (only hexane) to afford the desired product.

*1-(1H-Indol-3-yl)-2-phenylethane-1,2-dione (**3**):*[6] 80% yield (39.8 mg), yellow solid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.90 (brs, 1H), 8.50 (d, *J* = 8.7 Hz, 1H), 8.11 (d, *J* = 8.7 Hz, 1H), 7.95 (d, *J* = 3.2 Hz, 1H), 7.65−7.37 (m, 5H), 7.15 (d, *J* = 8.7 Hz, 1H), 6.83 (d, *J* = 8.8 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 193.5, 188.3, 136.4, 135.4, 134.3, 133.4, 130.3, 128.8, 127.8, 124.6, 123.5, 122.6, 114.1, 111.6; IR (neat, cm^{-1}): 1735, 1682, 1384, 1271, 1208; HRMS (ESI) calcd for $C_{16}H_{11}NO_2Na$ $[M + Na]^+$ 272.0682, found 272.0689.

*1-(1H-Indol-3-yl)-2-(4-methoxyphenyl)ethane-1,2-dione (**4**):*[6] 64% yield (35.7 mg), yellow solid; ^{1}H NMR (500 MHz, DMSO-d_6) δ 12.37 (brs, 1H), 8.21−8.20 (m, 1H), 8.12 (s, 1H), 7.94 (d, *J* = 9.0 Hz, 2H), 7.56−7.54 (m, 1H), 7.34−7.27 (m, 2H), 7.11(d, *J* = 9.0 Hz, 2H), 3.87 (s, 3H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 193.2, 189.6, 164.8, 138.1, 137.4, 132.7, 126.3, 125.5, 124.3, 123.3, 121.7, 115.0, 113.2, 56.3; IR (neat, cm^{-1}) 1714, 1596, 1516, 1436, 1269; HRMS (ESI) calcd for $C_{17}H_{14}NO_3$ $[M + H]^+$ 280.0968, found 280.0973.

*1-(4-Fluorophenyl)-2-(1H-indol-3-yl)ethane-1,2-dione (**5**):*[6] 64% yield (34.2 mg), yellow solid; ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.44 (brs, 1H), 8.23−8.20 (m, 2H), 8.08−8.04 (m, 2H), 7.57−7.28 (m, 5H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 192.9, 188.6, 166.3 (d, *J* = 252.9 Hz, 1C), 138.6, 137.5, 133.5, 133.4, 130.3 (d, *J* = 2.5 Hz, 1C), 125.6, 124.4, 123.4, 121.7, 116.8 (d, *J* = 22.1 Hz, 1C), 113.2 (d, *J* = 30.4 Hz, 1C); IR (neat, cm^{-1}) 1776, 1418, 1232, 1013, 854; HRMS (ESI) calcd for $C_{16}H_{11}FNO_2$ $[M + H]^+$ 268.0768, found 268.0775.

*1-(4-Chlorophenyl)-2-(1H-indol-3-yl)ethane-1,2-dione (**6**):*[6] 73% yield (41.3 mg), yellow solid; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.31 (brs, 1H), 8.25−8.22 (m, 1H), 8.01 (d, *J* = 3.2 Hz, 1H), 7.92 (d, *J* = 8.5 Hz, 2H), 7.48−7.44 (m, 3H), 7.21−7.17 (m, 2H); ^{13}C NMR (125 MHz, acetone-d_6) δ 193.3, 188.7, 141.0, 138.1, 138.1, 133.2, 132.5, 130.0, 126.6, 124.9, 123.8, 122.7, 114.3, 113.4; IR (neat, cm^{-1}) 1715, 1507, 1266, 1207, 704; HRMS (ESI) Calcd for $C_{16}H_{11}ClNO_2$ $[M + H]^+$ 284.0473, found 284.0464.

*1-(1H-Indol-3-yl)-2-(4-(trifluoromethyl)phenyl)ethane-1,2-dione (**7**):* 77% yield (48.8 mg), yellow solid; mp 174−175 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.36 (brs, 1H), 8.25−8.23 (m, 1H), 8.13 (d, *J* = 8.1 Hz, 2H), 8.10 (s, 1H), 7.82 (d, *J* = 8.2 Hz, 2H), 7.49−7.46 (m, 1H), 7.24−7.20 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 192.0, 186.8, 136.4, 136.2, 135.9, 135.3 (q, *J* = 32.5 Hz, 1C), 130.7, 128.9, 125.7 (q, *J* = 3.7 Hz, 1C), 125.5, 124.8, 123.4 (q, *J* = 271.3 Hz, 1C), 123.7, 122.5, 114.3, 111.8; IR (neat, cm^{-1}) 1731, 1685, 1332, 1267, 1204; HRMS (ESI) calcd for $C_{17}H_{11}F_3NO_2$ $[M + H]^+$ 318.0736, found 318.0715.

*4-(2-(1H-Indol-3-yl)-2-oxoacetyl)benzonitrile (**8**):* 81% yield (44.3 mg), yellow solid; mp 178−180 °C; ^{1}HNMR (500 MHz, DMSO-d_6) δ 12.55 (brs, 1H), 8.32 (s, 1H), 8.28−8.26 (m, 1H), 8.16 (d, *J* = 7.0 Hz, 2H), 8.10 (d, *J* = 7.0 Hz, 2H), 7.63−7.60 (m, 1H), 7.39−7.34 (m, 2H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 191.2, 185.7, 137.5, 135.9, 135.1, 131.9, 129.1, 123.9, 122.9, 121.9, 120.1, 116.8, 115.1, 111.7, 111.2; IR (neat, cm^{-1}) 1716, 1617, 1516, 1269, 1129; HRMS (ESI) calcd for $C_{17}H_{11}N_2O_2$ $[M + H]^+$ 275.0815, found 275.0796.

*1-(1H-Indol-3-yl)-2-(naphthalen-2-yl)ethane-1,2-dione (**9**):*[6] 70% yield (41.8 mg), yellow solid; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.29 (brs, 1H), 8.51 (s, 1H), 8.29 (m, 1H), 8.02−7.87 (m, 5H), 7.56 (t, *J* = 7.4 Hz, 1H), 7.49−7.46 (m, 2H), 7.24−7.20 (m, 2H); ^{13}C NMR (125 MHz, acetone-d_6) δ 194.8, 189.6, 138.2, 137.9, 137.1, 134.0, 133.5, 131.9, 130.8, 130.2, 129.7, 128.8, 128.0, 126.6, 125.0, 124.9, 123.7, 122.7, 114.6, 113.3; IR (neat, cm^{-1}) 1731, 1695, 1268, 1208, 1029; HRMS (ESI) calcd for $C_{20}H_{14}NO_2$ $[M + H]^+$ 300.1019, found 300.0992.

*1-(1H-Indol-3-yl)propane-1,2-dione (**10**):*[6] 61% yield (22.8 mg), pale yellow solid; ^{1}H NMR (500 MHz, DMSO-d_6) δ 12.28 (brs, 1H), 8.34 (d, *J* = 3.0 Hz, 1H), 8.20 (d, *J* = 6.5 Hz, 1H), 7.54 (d, *J* = 6.5 Hz, 1H), 7.29−7.24 (m, 2H), 2.44 (s, 3H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 201.7, 185.5, 138.4 (2C), 137.1, 126.4, 124.2, 123.2, 121.8, 111.1, 26.1; IR (KBr, cm^{-1}) 1704, 1593; HRMS (ESI) for $C_{11}H_{10}NO_2$ $[M + H]^+$ calcd 188.0706, found 188.0690.

*1-(5-Methyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**12**):* 61% yield (32.0 mg), yellow solid, mp 175−177 °C; ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.32 (brs, 1H), 8.11 (s, 1H), 8.06 (s, 1H), 7.96 (d, *J* = 7.2 Hz, 2H), 7.74 (t, *J* = 7.4 Hz, 1H), 7.59 (t, *J* = 7.6 Hz, 2H), 7.44 (d, *J* = 8.3 Hz, 1H), 7.15 (d, *J* = 7.3 Hz, 1H), 3.37 (s, 3H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 194.0, 188.5, 137.8, 135.3, 134.6, 133.0, 131.9, 129.7, 129.1, 125.3, 125.2, 120.9, 112.4, 112.2, 21.3; IR (neat, cm^{-1}) 3054, 1269, 1205, 1024, 993; HRMS (ESI) calcd for $C_{17}H_{14}NO_2$ $[M + H]^+$ 264.1019, found 264.1023.

*1-(5-Methoxy-1H-indol-3-yl)-2-phenylethane-1,2-dione (**13**):*[6] 48% yield (26.7 mg), yellow solid; ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.32 (brs, 1H), 8.10 (s, 1H), 7.98−7.96 (m, 2H), 7.77−7.72 (m, 2H), 7.60 (t, *J* = 7.6 Hz, 2H), 7.46 (d, *J* = 8.8 Hz, 1H), 6.95 (dd, *J* = 8.8, 2.5 Hz, 1H), 3.83 (s, 3H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 194.5, 188.9, 156.7, 138.2, 135.1, 133.5, 132.2, 130.2, 129.6, 126.4, 114.1, 114.0, 113.0, 103.6, 55.9; IR (neat, cm^{-1})1733, 1634, 1486, 1266, 1213; HRMS (ESI) calcd for $C_{17}H_{14}NO_3$ $[M + H]^+$ 280.0968, found 280.0974.

*1-(5-Fluoro-1H-indol-3-yl)-2-phenylethane-1,2-dione (**14**):*[6] 58% yield (30.9 mg), yellow solid; ^{1}H NMR (500 MHz, DMSO-d_6) δ 12.52 (brs, 1H), 8.25 (s, 1H), 7.98−7.96 (m, 2H), 7.90 (d, *J* = 10.0 Hz, 1H), 7.75−7.72 (m, 1H), 7.60−7.57 (m, 3H), 7.20−7.16 (m, 1H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 194.2, 188.8, 159.7 (d, *J* = 234.9 Hz, 1C), 139.7, 135.2, 134.1, 133.4, 130.3, 129.6, 126.3 (d, *J* = 11.0 Hz, 1C), 114.7 (d, *J* = 9.75 Hz, 1C), 113.1 (d, *J* = 4.4 Hz, 1C), 112.5 (d, *J* = 25.8 Hz, 1C), 106.7 (d, *J* = 24.6 Hz, 1C); IR (neat, cm^{-1}) 1756, 1426, 1268, 1007, 973; HRMS (ESI) calcd for $C_{16}H_{11}FNO_2$ $[M + H]^+$ 268.0768, found 268.0776.

*1-(5-Bromo-1H-indol-3-yl)-2-phenylethane-1,2-dione (**15**):* 49% yield (32.0 mg), yellow solid; mp 216−217 °C; ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.60 (brs, 1H), 8.37 (s, 1H), 8.26 (s, 1H), 7.99−7.96 (m, 2H), 7.80−7.23 (m, 1H), 7.63−7.42 (m, 4H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 193.5, 188.3, 138.9, 135.7, 134.8, 132.8, 129.8, 129.1, 126.8, 126.5, 123.3, 115.6, 114.8, 112.0; IR (neat, cm^{-1}) 1715, 1517, 1269, 1209, 993; HRMS (ESI) calcd for $C_{16}H_{11}BrNO_2$ $[M + H]^+$ 327.9968 and 329.9948, found 327.9978 and 329.9957.

*3-(2-Oxo-2-phenylacetyl)-1H-indole-5-carbonitrile (**16**):* 35% yield (19.2 mg), yellow solid; mp 188−190 °C; ^{1}H NMR (500 MHz, DMSO-d_6) δ 12.87 (brs, 1H), 8.60 (s, 1H), 8.44 (s, 1H), 7.99 (d, *J* = 8.3 Hz, 2H), 7.79−7.73 (m, 3H), 7.62 (t, *J* = 7.8 Hz, 2H); ^{13}C NMR

(125 MHz, DMSO-d_6) δ 193.3, 188.4, 140.2, 138.8, 134.9, 132.6, 129.8, 129.1, 126.8, 126.1, 124.9, 119.8, 114.3, 112.6, 105.1; IR (neat, cm^{-1}) 1639, 1269, 1186, 796, 665; HRMS (ESI) calcd for $C_{17}H_{11}N_2O_2$ $[M + H]^+$ 275.0815, found 275.0809.

1-(5-Nitro-1H-indol-3-yl)-2-phenylethane-1,2-dione (**17**): 70% yield (41.1 mg), yellow solid; mp 190−191 °C. ^{1}H NMR (300 MHz, DMSO-d_6) δ 12.99 (brs, 1H), 9.09 (s, 1H), 8.51 (s, 1H), 8.28−8.19 (m, 1H), 8.04−7.99 (m, 2H), 7.81−7.74 (m, 2H), 7.64−7.59 (m, 2H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 193.2, 188.4, 143.3, 141.3, 140.3, 134.9, 132.6, 129.9, 129.2, 124.6, 119.2, 117.4, 113.7, 113.6; IR (neat, cm^{-1})1716, 1507, 1326, 1209; HRMS (ESI) calcd for $C_{16}H_{11}N_2O_4$ $[M + H]^+$ 295.0713, found 295.0721.

1-(7-Ethyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**18**):[6] 67% yield (37.1 mg), yellow solid; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.80 (brs, 1H), 8.29 (d, J = 7.9 Hz, 1H), 8.07 (d, J = 7.2 Hz, 2H), 7.76 (d, J = 2.9 Hz, 1H), 7.60 (t, J = 7.4 Hz, 1H), 7.47 (t, J = 7.6 Hz, 2H), 7.31 (m, 1H), 7.18 (d, J = 7.3 Hz, 1H), 2.89 (q, J = 7.6 Hz, 2H), 1.33 (t, J = 7.6 Hz, 3H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 194.5, 189.1, 137.9, 136.2, 135.1, 133.6, 130.2, 129.6, 129.1, 125.6, 123.7, 123.3, 119.3, 113.5, 24.0, 15.2; IR (neat, cm^{-1}) 1674, 1594, 1268, 1155, 791; HRMS (ESI) calcd for $C_{18}H_{15}NO_2Na$ $[M + Na]^+$ 300.0995, found 300.0989.

1-(2-Methyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**19**):[6] 92% yield (48.3 mg), yellow solid; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.11 (brs, 1H), 7.88−7.83 (m, 3H), 7.56 (m, 1H), 7.43 (t, J = 7.8 Hz, 2H), 7.30−7.29 (m, 1H), 7.07−7.01 (m, 2H), 2.42 (s, 3H); ^{13}C NMR (125 MHz, acetone-d_6) δ 196.4, 191.0, 148.0, 136.5, 135.4, 134.4, 130.5, 130.1, 127.9, 123.9, 123.3, 121.5, 112.4, 111.4, 14.7; IR (neat, cm^{-1}) 1762, 1388, 1268, 1207, 1030; HRMS (ESI) calcd for $C_{17}H_{14}NO_2$ $[M + H]^+$ 264.1019, found 264.1023.

1-Phenyl-2-(2-phenyl-1H-indol-3-yl)ethane-1,2-dione (**20**): 85% yield (55.2 mg), yellow solid; mp 190−191 °C; ^{1}H NMR (300 MHz, acetone-d_6) δ 11.49 (brs, 1H), 8.36−8.33 (m, 1H), 7.74 (d, J = 7.5 Hz, 2H), 7.66−7.56 (m, 2H), 7.47 (t, J = 7.7 Hz, 2H), 7.41−7.33 (m, 5H), 7.19 (t, J = 7.7 Hz, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 193.8, 191.1, 148.0, 135.5, 133.8, 133.7, 130.5, 130.0, 129.9, 129.6, 128.4, 128.2, 127.3, 124.4, 123.5, 122.5, 111.9, 111.2; IR (neat, cm^{-1})1668, 1596, 1450, 1181, 831; HRMS (ESI) calcd for $C_{22}H_{16}NO_2$ $[M + H]^+$ 326.1176, found 326.1175.

1-(3-Methyl-1H-indol-2-yl)-2-phenylethane-1,2-dione (**21**): 30% yield (15.7 mg), yellow solid; mp 53−54 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.59 (d, J = 7.6 Hz, 1H), 8.08 (d, J = 7.7 Hz, 2H), 7.72 (t, J = 7.2 Hz, 1H), 7.59−7.54 (m, 3H), 7.50−7.39 (m, 2H), 6.99 (br s, 1H), 2.25 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 187.6, 162.8, 134.4, 134.3, 131.6, 131.0, 129.2, 128.2, 124.7, 123.8, 120.7, 119.7, 118.1, 115.9, 8.6; IR (neat, cm¯1): 1673, 1445, 1397, 1208, 843, 671; HRMS (ESI) calcd for $C_{17}H_{14}NO_2$ $[M + H]^+$ 264.1019, found 264.1038.

1-(1-Methyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**22**):[6] 73% yield (38.4 mg), yellow solid; ^{1}H NMR (500 MHz, acetone-d_6) δ 8.23 (d, J = 8.0, 2H), 7.97 (d, J = 8.0, 1H), 7.47 (m, 1H), 7.63−7.58 (m, 3H), 7.41−7.35 (m, 2H), 3.87 (s, 3H); ^{13}C NMR (125 MHz, acetone-d_6) δ 194.5, 188.6, 141.7, 138.2, 135.3, 133.4, 130.3, 129.7, 125.9, 124.5, 123.8, 121.8, 111.9, 111.8, 34.0; IR (neat, cm^{-1}) 3643, 1716, 1457, 1267, 1173; HRMS (ESI) calcd for $C_{17}H_{14}NO_2$ $[M + H]^+$ 264.1019, found 264.1013.

1-(4-Methoxyphenyl)-2-(2-phenyl-1H-indol-3-yl)ethane-1,2-dione (**24**): 85% yield (60.3 mg), yellow solid; mp 159−161 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.26 (brs, 1H), 8.17 (d, J = 7.0 Hz, 1H), 7.56 (d, J = 8.0 Hz, 2H), 7.41 (d, J = 7.0 Hz, 1H), 7.27−7.25 (m, 2H), 7.21−7.15 (m, 3H), 7.06 (t, J = 7.7 Hz, 2H), 6.82 (d, J = 8.0, 2H), 3.73 (s, 3H); ^{13}C NMR (125 MHz, acetone-d_6) δ 193.4, 192.2, 165.2, 132.6, 132.5, 131.1, 130.4, 130.2, 128.8, 128.4, 128.0, 127.9, 124.7, 123.6, 122.6, 115.1, 114.8, 112.8, 56.1; IR (neat, cm^{-1}) 1716, 1596, 1451, 1267, 1169; HRMS (ESI) calcd for $C_{23}H_{18}NO_3$ $[M + H]^+$ 356.1281, found 3561288.

1-(4-Chlorophenyl)-2-(2-phenyl-1H-indol-3-yl)ethane-1,2-dione (**25**): 91% yield (65.3 mg), yellow solid; mp 180−182 °C; ^{1}H NMR (500 MHz, DMSO-d_6) δ 12.66 (brs, 1H), 8.21 (d, J = 7.1 Hz, 1H), 7.68 (d, J = 8.5, 2H), 7.57−7.54 (m, 3H), 7.39−7.32 (m, 5H), 7.23 (t, J = 7.7 Hz, 2H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 192.3, 189.8, 148.9, 139.1, 136.0, 131.8, 130.9, 130.4, 130.2, 129.8, 129.0, 127.9, 126.8, 123.9, 122.9, 121.1, 112.3, 110.2; IR (neat, cm^{-1}) 1716, 1682, 1272, 1186, 1024, 820; HRMS (ESI) calcd for $C_{22}H_{14}ClNO_2Na$ $[M + Na]^+$ 382.0605, found 382.0604.

4-(2-Oxo-2-(2-phenyl-1H-indol-3-yl)acetyl)benzonitrile (**26**): 82% yield (57.4 mg), yellow solid; mp 210−211 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.41 (brs, 1H), 8.25−8.23 (m, 1H), 7.76−7.72 (m, 4H), 7.46−7.44 (m, 1H), 7.24−7.23 (m, 5H), 7.08 (t, J = 7.8 Hz, 2H); ^{13}C NMR (125 MHz, acetone-d_6) δ 193.0, 190.6, 149.9, 137.7, 137.2, 133.4, 131.73, 131.3, 130.8, 130.6, 129.0, 128.3, 125.0, 124.0, 122.7, 118.6, 117.5, 112.9, 112.1; IR (neat, cm^{-1}) 1769, 1715, 1559, 1270, 1192; HRMS (ESI) calcd for $C_{23}H_{15}N_2O_2$ $[M + H]^+$ 351.1128, found 351,1131.

1-(Naphthalen-2-yl)-2-(2-phenyl-1H-indol-3-yl)ethane-1,2-dione (**27**): 80% yield (60.0 mg), yellow solid; mp 172−173 °C; ^{1}H NMR (300 MHz, acetone-d_6) δ 11.42 (brs, 1H), 8.66 (s, 1H), 8.45−8.42 (m, 1H), 8.17−8.01 (m, 7H), 7.74−7.60 (m, 4H), 7.40−7.30 (m, 3H); ^{13}C NMR (125 MHz, acetone-d_6) δ 194.8, 189.7, 138.0, 137.7, 137.1, 134.0, 133.4, 131.9, 130.8, 130.2, 129.7, 128.8, 128.0, 126.6, 125.0, 124.9, 123.7, 122.7, 114.6, 113.3; IR (neat, cm^{-1}) 1668, 1596, 1450, 1181, 831; HRMS (ESI) calcd for $C_{26}H_{18}NO_2$ $[M + H]^+$ 376.1332, found 376.1333.

1-(5-Methyl-2-phenyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**28**): 72% yield (48.8 mg), yellow solid; mp 167−169 °C; ^{1}H NMR (300 MHz, $CDCl_3$) δ 9.13 (brs, 1H), 8.25 (s, 1H), 7.68 (d, J = 7.7 Hz, 2H), 7.52 (t, J = 7.4 Hz, 1H), 7.33−7.04 (m, 9H), 2.52 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 193.9, 191.1, 148.2, 133.9, 133.8, 133.7, 133.2, 130.6, 130.0, 129.8, 129.5, 128.4, 128.1, 127.5, 125.8, 122.2, 111.5, 111.0, 21.7; IR (neat, cm^{-1}) 1675, 1449, 1269, 1208, 859; HRMS (ESI) calcd for $C_{23}H_{18}NO_2$ $[M + H]^+$ 340.1332, found 340.1353.

1-(5-Fluoro-2-phenyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**29**): 74% yield (50.7 mg), yellow solid; mp 211−212 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.46 (brs, 1H), 7.90 (d, J = 9.8 Hz, 1H), 7.59 (d, J = 8.2 Hz, 2H), 7.51−7.44 (m, 2H), 7.32−7.19 (m, 5H), 7.05−6.99 (m, 3H); ^{13}C NMR (125 MHz, acetone-d_6) δ 194.2, 191.7, 160.6 (d, J = 234.9 Hz, 1C), 134.8, 134.7, 131.5, 131.1, 130.7, 130.2, 129.5, 129.5, 129.4, 128.9, 114.1 (d, J = 9.71 Hz, 1C), 112.8 (d, J = 26.1 Hz, 1C), 107.7 (d, J = 25.2 Hz, 1C); IR (neat, cm^{-1}) 1716, 1364, 1270, 1226, 1192; HRMS (ESI) calcd for $C_{22}H_{15}FNO_2$ $[M + H]^+$ 344.1081, found 344.1061.

1-(5-Bromo-2-phenyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**30**): 84% yield (67.7 mg), yellow solid; mp 212−213 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.47 (brs, 1H), 8.42 (s, 1H), 7.59−7.03 (m, 12H); ^{13}C NMR (125 MHz, acetone-d_6) δ 194.1, 191.7, 134.8, 134.7, 131.3, 131.1, 130.8, 130.2, 129.6, 129.5, 129.4, 128.9, 127.6, 125.1, 123.8, 116.8, 114.7, 113.9; IR (neat, cm^{-1}) 1696, 1391, 1341, 1268, 1208; HRMS (ESI) calcd for $C_{22}H_{15}BrNO_2$ $[M + H]^+$ 404.0281 and 406.0261, found 404.0288 and 406.0278.

1-Phenyl-2-(2-phenyl-5-(trifluoromethyl)-1H-indol-3-yl)ethane-1,2-dione (**31**): 84% yield (66.0 mg), yellow solid; mp 201−203 °C; ^{1}H NMR (500 MHz, DMSO-d_6) δ 13.02 (brs, 1H), 8.58 (s, 1H), 7.74−7.66 (m, 5H), 7.48 (t, J = 7.8 Hz, 2H), 7.40−7.37 (m, 3H), 7.21 (t, J = 7.7 Hz, 2H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 193.0, 190.6, 150.8, 134.3, 132.9, 130.1, 130.0, 129.2, 128.8, 127.9, 126.4, 125.1 (q, J = 270.0, 1C), 124.0, 123.6, 123.3, 120.4, 118.3, 113.3, 110.6; IR (neat, cm^{-1}) 1713, 1269, 1111, 862, 823; HRMS (ESI) calcd for $C_{23}H_{15}F_3NO_2$ $[M + H]^+$ 394.1049, found 394.1054.

1-(2-Hexyl-1H-indol-3-yl)-2-phenylethane-1,2-dione (**32**): 83% yield (55.2 mg), yellow solid; mp 155−156 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 11.15 (brs, 1H), 7.91−7.89 (m, 2H), 7.82 (d, J = 7.5 Hz, 1H), 7.62−7.59 (m, 1H), 7.49−7.46 (m, 2H), 7.32−7.31 (m, 1H), 7.09−7.02 (m, 2H), 2.85 (t, J = 8.0 Hz, 2H), 1.16−1.13 (m, 8H), 0.70 (t, J = 7.1 Hz, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 195.1, 190.3, 151.1, 134.9, 134.4, 130.1, 129.7, 128.9, 128.5, 126.8, 123.3, 122.9, 122.5, 110.9, 31.4, 29.2, 29.1, 28.6, 22.5, 14.0; IR (neat, cm^{-1}) 3689, 3643, 1734, 1457, 1268; HRMS (ESI) calcd for $C_{22}H_{24}NO_2$ $[M + H]^+$ 334,1802, found 334.1825.

N-Methyl-2-oxo-N,2-diphenylacetamide (**33**):[12] 67% yield (32.0 mg), yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.79 (d, J = 8.0 Hz,

2H), 7.52−7.41 (m, 1H), 7.40−7.36 (m, 3H), 7.19−7.08 (m, 2H), 7.06 (d, J = 7.5 Hz,2H), 3.43 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 190.8, 167.1, 141.2, 134.2, 133.6, 130.1, 129.5, 129.4, 128.7, 128.4, 128.1, 126.7, 36.2; IR (neat, cm^{-1}) 1736, 1508, 1467, 1265; HRMS (ESI) calcd for $C_{15}H_{14}NO_2$ $[M + H]^+$ 240.1019, found 240.1013.

*6-(1H-Indol-3-yl)-7-phenyl-5,8-dihydroindolo[2,3-c]carbazole (**34**):* 50% yield (22.3 mg), gray solid; mp 116−117 °C; ^{1}H NMR (300 MHz, DMSO-d_6) δ 11.84 (brs, 1H), 11.07 (brs, 1H), 10.55 (br s, 1H), 8.71 (d, J = 7.4 Hz, 1H), 7.64−7.06 (m, 14H), 6.84 (t, J = 7.4 Hz, 1H), 6.49 (t, J = 8.7 Hz, 1H), 6.51 (d, J = 8.2, 1H); ^{13}C NMR (125 MHz, DMSO-d_6) δ 140.9, 139.6, 139.4, 139.1, 135.9, 135.0, 132.8, 130.4, 129.1, 128.0, 127.8, 127.6, 126.6, 125.7, 123.8, 123.7, 122.9, 121.5, 120.9, 120.7, 120.0, 119.2, 118.5, 118.3, 113.6, 111.4, 110.8, 110.5, 110.0, 105.2; IR (neat, cm^{-1}) 1773, 1714, 1684, 1387, 1270; HRMS (ESI) calcd for $C_{32}H_{22}N_3$ $[M + H]^+$ 448.1808, found 448.1813.

*6-(1-Methyl-1H-indol-3-yl)-7-phenyl-5,8-dihydroindolo[2,3-c]-carbazole (**35**):* 45% yield (20.7 mg), gray solid; mp 118−119 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.78 (brs, 1H), 8.24 (d, J = 7.4 Hz, 1H), 8.03 (brs, 1H), 7.84 (brs, 1H), 7.61 (d, J = 7.8 Hz, 1H), 7.59 (d, J = 8.0 Hz, 1H), 7.40−6.96 (m, 14H), 1.95 (s, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 140.2, 139.7, 139.2, 138.6, 136.6, 135.4, 133.9, 133.5, 130.3, 129.8, 128.0, 127.5, 126.8, 124.4, 123.7, 122.4, 121.3, 121.2, 120.5, 119.7, 119.6, 119.5, 119.1, 114.9, 110.9, 110.5, 110.3, 109.5,108.7, 105.5, 12.5; IR (neat, cm^{-1}) 1743, 1682, 1384, 1270, 1030; HRMS (ESI) calcd for $C_{33}H_{24}N_3$ $[M + H]^+$ 462.1965, found 462.1973.

*6-(1H-Indol-3-yl)-2,11-dimethoxy-7-phenyl-5,8-dihydroindolo-[2,3-c]carbazole (**36**):* 35% yield (17.7 mg), gray solid; mp 116−118 °C; ^{1}H NMR (500 MHz, acetone-d_6) δ 10.81 (brs, 1H), 10.10 (brs, 1H), 9.63 (brs, 1H), 7.98 (brs, 1H), 7.42 (d, J = 7.7 Hz, 1H), 7.31−7.01 (m, 10H), 6.95 (t, J = 7.5 Hz, 1H), 6.87 (d, J = 8.7 Hz, 1H), 6.79 (t, J = 7.4 Hz, 1H), 6.70 (d, J = 8.7 Hz, 1H), 3.81 (s, 3H), 3.32 (s, 3H); ^{13}C NMR (125 MHz, acetone-d_6) δ 155.1, 154.2, 142.1, 141.4, 137.3, 136.3, 135.5, 135.1, 131.8, 130.5, 129.8, 129.2, 129.1, 128.7, 128.5, 127.4, 126.4, 126.2, 125.9, 123.5, 122.1, 120.5, 119.8, 114.1, 112.6, 112.6, 112.2, 111.8, 104.8, 104.6, 56.4, 55.4; IR (neat, cm^{-1}) 1733, 1634, 1486, 1266, 1213; HRMS (ESI) calcd for $C_{34}H_{26}N_3O_2$ $[M + H]^+$ 508.2020, found 508.2025.

*4-(7-(1H-Indol-3-yl)-5,8-dihydroindolo[2,3-c]carbazol-6-yl)-benzonitrile (**37**):* 34% yield (16.0 mg), gray solid; mp 201−202 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.88 (brs, 1H), 8.25 (d, J = 7.6 Hz, 1H), 8.20 (brs, 1H), 8.18 (brs, 1H), 7.70−7.68 (m, 2H), 7.60 (d, J = 8.0 Hz, 1H), 7.44−7.21 (m, 9H), 7.08 (t, J = 7.2 Hz, 1H), 6.99 (t, J = 7.5 Hz, 1H), 6.81 (d, J = 7.9 Hz, 1H), 6.74 (s, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 145.9, 139.3, 138.9, 138.7, 135.9, 133.6, 133.2, 132.1, 131.8, 131.5, 130.8, 127.4, 124.9, 124.8, 124.1, 122.6, 122.1, 120.8, 120.7, 120.3, 119.9, 119.8, 119.7, 114.3, 111.6, 111.3, 111.1, 110.9, 110.6, 109.9, 106.3; IR (neat, cm^{-1}) 1774, 1683, 1378, 1332, 1269; HRMS (ESI) calcd for $C_{33}H_{21}N_4$ $[M + H]^+$ 473.1761, found 473.1778.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Optimization of two reactions, in situ HRMS and GC−MS analysis, and copies of NMR spectra. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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