JOC The Journal of Organic Chemistry

Note

pubs.acs.org/joc

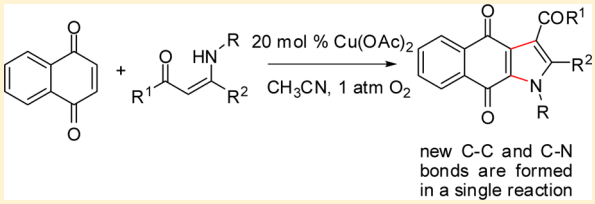
Copper(II)-Catalyzed Sequential C,N-Difunctionalization of 1,4-Naphthoquinone for the Synthesis of Benzo[*f*]indole-4,9-diones under Base-Free Condition

Jin-Wei Sun, Xiang-Shan Wang, and Yun Liu*

School of Chemistry and Chemical Engineering, Jiangsu Normal University, Xuzhou, 221116, Jiangsu, PR China

Supporting Information

ABSTRACT: An efficient synthesis of benzo[*f*]indole-4,9-diones has been achieved by copper(II)-catalyzed naphthoquinone sequential C,N-difunctionalization reactions with *β*-enaminones. New C−C and C−N bonds are easily formed in the reaction course. Copper(II) salt plays a dual role as Lewis acid and oxidative catalyst, and O_2 acts as the terminal oxidant. The advantage of this reaction is the high atom economy with broad substrate scope and excellent yields. The reaction can be scaled up to using at least grams of substrates.



Quinone moieties are important structural motifs in many natural and unnatural products that have a wide range of biological activity.[1] A basic structural unit in these quinone products is the indoloquinone core.[2] As benzannulated indoloquinones, the synthesis of benzo[*f*]indole-4,9-dione derivatives is drawing much attention because of their diversified biological activity, such as antineoplastic, antibacterial, virus-static, fungicidic, and anticoagulant activity.[3] Recently, 3-methyl-1*H*-benzo[*f*]indole-4,9-dione was isolated from *Goniothalamus tapis* Miq, which is known as an interesting source of various bioactive compounds.[3b] Utahmycin B, a derivative of benzo[*f*]indole-4,9-dione, was also isolated from *Streptomyces albus*.[3c]

Several synthetic methods have been reported for benzo[*f*]-indole-4,9-diones. They include: thermal conversion of 2-azido-3-vinyl-1,4-quinones to indolequinones;[4] photochemical reaction of 2-azido-1,4-quinones with conjugated dienes for the synthesis of the corresponding 2-alkenyl-2,3-dihydroindoloquinones;[5] Diels−Alder reaction of indole-4,7-dione with conjugated diene;[6] photoaddition of 2-amino-1,4-naphthoquinones with alkenes;[7] manganese(III) acetate initiated oxidative free radical reactions between 2-amino-1,4-naphthoquinones and *β*-dicarbonyl compounds[8a] or carbonyl compounds;[8b,c] Cerium salts initiated oxidative free radical reactions between 2-amino-1,4-naphthoquinones and *β*-dicarbonyl compounds;[8d] disubstitution reaction of dichloronaphthoquinone;[9] CAN-catalyzed three-component reaction of 2-bromo-1,4-naphthoquinone, primary amine and *β*-dicarbonyl compounds;[10] $Cu(OAc)_2$-mediated reaction of 2-bromonaphthoquinone with enamines;[11] and Pd-catalyzed synthesis using aminoquinone as reactants.[12] However, a majority of these methods suffer from limited reaction scope, are based on rather long reaction sequences, and need respectively complicatedly prefunctionalized naphthoquinones as reaction substrate. These methods also have the drawbacks of limited substituent range on substrates. As such, it is highly desirable to develop new methods allowing general and effective synthesis of benzo[*f*]-indole-4,9-diones from easily available materials with high atom economy.

Copper-catalyzed aerobic oxidation is a powerful and attractive reaction in organic synthesis.[13] Copper(II) is especially attractive as an oxidant in these reactions because, under appropriate conditions and with suitable substrates, the reactions can be carried out with catalytic Cu using ambient air or O_2 as the stoichiometric oxidant. Following our work on this research field[14] and expecting to expand the utility of this protocol to naphthoquinone difunctionalization reaction,[14a] we became interested in the synthesis of benzo[*f*]indole-4,9-diones via the reaction of naphthoquinone with *β*-enaminones in the presence of catalytic amount of copper salt. This is the first example of metal-catalyzed one-pot synthesis of benzo[*f*]-indole-4,9-diones using naphthoquinone as the reactant. Compared to previous reports, this method is highly atom economical, using simple and easily available starting materials without needing prefunctionalized naphthoquinone substrates. Catalytic amount of copper(II) salt is used to furnish the combination of naphthoquinone with enaminone in a single reaction process. As a result, this synthesis allows much wider substrate scope and provides a general and practical access to benzo[*f*]indole-4,9-dione derivatives.

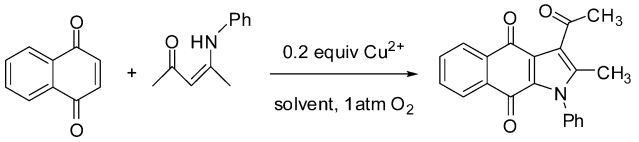
As an initial experiment, we began our investigation by testing the reaction of naphthoquinone **1** with *β*-enaminone **2a**. Under 1 atm of O_2, a mixture of naphthoquinone **1** (1.0 mmol), enaminone **2a** (1.0 mmol), and monohydrated copper(II) acetate (0.2 mmol) was heated in DMF at 80 °C for 12 h. To our delight, we found that benzo[*f*]indole-4,9-dione **3a** was obtained in 56% yield. The screening of the

Received: August 20, 2013
Published: September 26, 2013

   dx.doi.org/10.1021/jo401842d | *J. Org. Chem.* 2013, 78, 10560−10566

reaction conditions is summarized in Table 1. It was found that solvent, catalyst, and temperature may all play a critical role on

Table 1. Optimization of the Reaction Conditions[a]



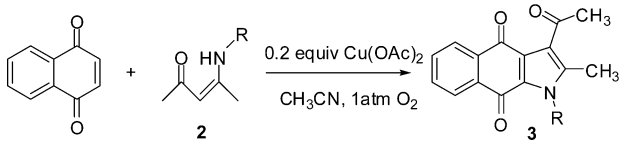
entry	solvent	catalyst (equiv)	temp (°C)	yield (%)[b]
1	DMF	$Cu(OAc)_2$ (0.2)	80	56
2	DMF	$Cu(OAc)_2$ (0.2)	100	68
3	C_6H_6	$Cu(OAc)_2$ (0.2)	reflux	41
4	C_2H_5OH	$Cu(OAc)_2$ (0.2)	reflux	33
5	toluene	$Cu(OAc)_2$ (0.2)	80	42
6	toluene	$Cu(OAc)_2$ (0.2)	100	50
7	**CH_3CN**	**$Cu(OAc)_2$ (0.2)**	**reflux**	**92**
8	CH_3CN	$CuCl_2$ (0.2)	reflux	86
9	CH_3CN	$CuBr_2$ (0.2)	reflux	83
10	CH_3CN	$Cu(acac)_2$ (0.2)	reflux	81
10	CH_3CN	$Cu(OTf)_2$ (0.2)	reflux	88
11	CH_3CN	$Cu(OAc)_2$ (0.15)	reflux	72
12	CH_3CN	none	reflux	0
13	CH_3CN	$Cu(OAc)_2$ (0.5)[c]	reflux	88
14	CH_3CN	$Cu(OAc)_2$ (0.2)	50	55
15	CH_3CN	$Cu(OAc)_2$ (0.2)[d]	reflux	78
16	CH_3CN	$Cu(OAc)_2$ (0.2)[e]	reflux	trace

[a]Reagents and conditions: Under 1 atm of O_2, naphthoquinone (1.0 mmol), β-enaminones (1.2 mmol), and catalytic amount of copper(II) salt were heated in solvent for 12 h. [b]Isolated yields. [c]Heated in the air. [d]Adding potassium carbonate (3.5 mmol) into the reaction system. [e]Adding acetic acid (2.0 mmol) into the reaction system.

the reaction efficiency. We first studied the influence of different solvents and found acetonitrile was a superior solvent compared to benzene, ethyl alcohol, toluene and DMF (entries 1−7, Table 1). The effect of different copper(II) salts were then investigated. Hydrated copper acetate showed high catalytic activity while other copper species such as copper chloride and copper bromide were less effective (entries 7−10, Table 1). Decreasing the amount of copper acetate to 0.15 equiv led to a lower yield (entry 11, Table 1). Without copper(II) catalyst, no desired product was generated (entry 12, Table 1). As the oxidant, oxygen is more efficient than ambient air. When the reaction was carried out in air, an increased amount of copper(II) salt was necessary to obtain the product in high yield (entry 13, Table 1). In contrast, when the reaction was carried out under an Ar atmosphere in the presence of 0.2 equiv of copper(II) salt, only trace amounts of product was formed. On the basis of these results, we tried different temperature with acetonitrile as the solvent and found the yield decreased with the lowering of the temperature (entry 14, Table 1). We also tried to add potassium carbonate or acetic acid into the reaction system and found that both base and acid hindered the generation of the target product (entry 15 and 16, Table 1). Therefore, heating the reactants in acetonitrile at reflux using 0.2 equiv of monohydrated copper(II) acetate as the catalyst in O_2 atmosphere is chosen as the optimized reaction condition.

With the optimized reaction conditions in hand, β-enaminones **2** derived from acetylacetone and various amines were surveyed to react with naphthoquinone **1**, and the results are presented in Table 2. Enaminones of aromatic amines **2b**−**2e** with electron-donating groups and electron-deficient groups in the *p*-position of aromatic ring all produced benzo[*f*]indole-4,9-diones derivatives efficiently (Table 2, entry 2−5). It is worth pointing out that the chloro or Br atoms onto the aromatic group of the enaminone remain unaffected by the reaction. The tolerance of the reaction for C−X bond in product ensures that it could be further transformed into different functionalities. Meanwhile, the reactivity of enaminone of aromatic amines **2f**−**2i** with *o*-, *m*- substituent in the aromatic ring were also screened. Under similar conditions, enaminones **2f**−**2i** reacted equally well to give **3f**−**3i** in high yields (Table 2, entry 6−9). These results showed that both electronic and steric factors have no significant influence on the efficiency of the reaction. To our delight, when we used enaminone of benzyl amine **2j** and butyl amine **2k** in the reaction, the desired products **3j** and **3k** were generated in 93 and 95% yield, respectively (Table 2, entries 10 and 11). This indicated that enaminones of both aryl amine and alkyl amine all have good activities in this reaction. Except for **3a**, all these benzo[*f*]indole-4,9-diones were unknown and have been fully characterized by analytical and spectroscopic (NMR and HRMS) data.

Table 2. Reactions of Naphthoquinone with β-Enaminones Derived from Acetylacetone[a]



entry	2	R	3	yield (%)[b]
1	**2a**	Ph	**3a**	92
2	**2b**	4-MePh	**3b**	96
3	**2c**	4-FPh	**3c**	95
4	**2d**	4-ClPh	**3d**	91
5	**2e**	4-BrPh	**3e**	90
6	**2f**	2-ClPh	**3f**	87
7	**2g**	3-ClPh	**3g**	88
8	**2h**	3,4-Cl_2Ph	**3h**	93
9	**2i**	3,4-$(MeO)_2$Ph	**3i**	91
10	**2j**	Bn	**3j**	93
11	**2k**	*n*-Bu	**3k**	95

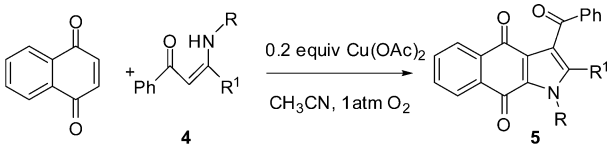
[a]Reagents and conditions: Under 1 atm of O_2, naphthoquinone (1.0 mmol), β-enaminone (1.2 mmol), and hydrated copper(II) acetate (0.2 mmol) were heated in acetonitrile at reflux for 12 h. [b]Isolated yields.

The β-enaminones derived from other acyclic dicarbonyl compounds were then studied. Using enaminone of diphenacyl methane **4a**−**4e** to react with naphthoquinone **1**, as we expected, gave the benzo[*f*]indole-4,9-diones **5a**−**5e** in 71−82% yield (Table 3, entry 1−5). When enaminones of asymmetrical dicarbonyl compounds **4f**−**4p** were used as substrates, the reaction also gave the desired products **5f**−**5p** with good to excellent yields and high regioselectivity (Table 3, entry 6−12). Besides NMR and HRMS data for all the products, the structure of **5a** was further established by X-ray crystallography (see Supporting Information).

To further extend the utility of this copper-catalyzed naphthoquinone difunctionalization reaction, we investigated the reactions of cyclic enaminone **6** to react with naphthoquinone **1**. It was found that various substituted cyclic enaminone **6a**−**6h** could also react with naphthoquinones

dx.doi.org/10.1021/jo401842d | J. Org. Chem. 2013, 78, 10560−10566

Table 3. Reactions of Naphthoquinone with Other Acyclic β-Enaminones[a]

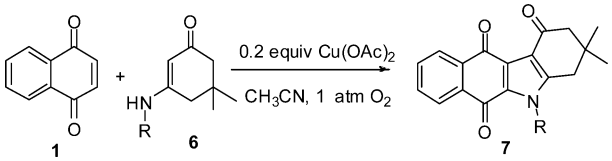


entry	4	R^1	R	5	yield (%)[b]
1	**4a**	Ph	Ph	**5a**	73
2	**4b**	Ph	4-MePh	**5b**	76
3	**4c**	Ph	4-FPh	**5c**	82
4	**4d**	Ph	4-ClPh	**5d**	78
5	**4e**	Ph	2-ClPh	**5e**	71
6	**4f**	Me	Ph	**5f**	88
7	**4g**	Me	4-MePh	**5g**	92
8	**4h**	Me	4-FPh	**5h**	95
9	**4i**	Me	4-ClPh	**5i**	92
10	**4j**	Me	4-BrPh	**5j**	90
11	**4k**	Me	Bn	**5k**	93
12	**4l**	Me	*n*-Bu	**5l**	95
13	**4m**	OEt	4-MePh	**5m**	82
14	**4n**	OEt	4-FPh	**5n**	88
15	**4o**	OEt	4-ClPh	**5o**	84
16	**4p**	OEt	2-ClPh	**5p**	80

[a]Reagents and conditions: Under 1 atm of O_2, naphthoquinone (1.0 mmol), β-enaminone (1.2 mmol), and hydrated copper(II) acetate (0.2 mmol) were heated in acetonitrile at reflux for 12 h. [b]Isolated yields.

smoothly under the optimal reaction condition to give the corresponding products **7a**−**7h** in excellent yields (Table 4).

Table 4. Reactions of Naphthoquinone with Cyclic β-Enaminones[a]



entry	7	R	7	yield (%)[b]
1	**7a**	Ph	**7a**	86
2	**7b**	4-MePh	**7b**	91
3	**7c**	4-FPh	**7c**	95
4	**7d**	4-ClPh	**7d**	92
5	**7e**	4-BrPh	**7e**	91
6	**7f**	2-ClPh	**7f**	83
7	**7g**	3,4-Cl_2Ph	**7g**	88
8	**7h**	3,4-$(MeO)_2$Ph	**7h**	87

[a]Reagents and conditions: Under 1 atm of O_2, naphthoquinone (1.0 mmol), β-enaminone (1.2 mmol), and hydrated copper(II) acetate (0.2 mmol) were heated in acetonitrile at reflux for 12 h. [b]Isolated yields.

Taking into account that reaction scale is a key restraining factor to the use of many methods in organic synthesis, we attempted to conduct the reaction on gram scale. Using 10 mmol (1.58 g) naphthoquinone **1** and 12 mmol (2.27 g) of enaminone **2b** as the reactants, under the optimal reaction conditions, 2.91 g (85%) of benzo[*f*]indole-4,9-dione **3b** was obtained. This demonstrated the feasibility to use this method in practical organic synthesis.

On the basis of the above experimental results, a plausible reaction pathway was suggested (Scheme 1). First, nucleophilic attack of α-carbon atom of β-enaminone **2a** to Cu^{2+}-complexed naphthoquinone followed by tautomerization and oxidation by Cu^{2+} result in the formation of intermediate **I**.[15] Intramolecular Michael addition then takes place to generate the intermediate **II**.[16] Finally, product **3a** was obtained by oxidative aromatization of intermediate **II**. Molecular oxygen is involved in the oxidation of Cu(I) for the regeneration of Cu(II) to complete the catalytic cycle.

In summary, an efficient synthesis of versatile benzo[*f*]-indole-4,9-diones derivatives, which have potential biological activities, has been achieved by copper-catalyzed naphthoquinone difunctionalization reaction with β-enaminones. This protocol is highly atom economical with broad substrate scope and results in high yields of products. The mechanism of this reaction includes naphthoquinone sequential functionalization with α-carban atom and nitrogen atom in the β-enaminones followed by oxidative aromatization. In this reaction, copper(II) plays a dual role as Lewis acid and oxidative catalyst, and O_2 acts as the terminal oxidant. This is the first example of metal-catalyzed one-pot synthesis of benzo[*f*]indole-4,9-diones using naphthoquinone as the reactant.

EXPERIMENTAL SECTION

General Methods. Melting points are uncorrected. ^{1}H NMR spectra were measured at 400 MHz with $CDCl_3$ as solvent. The chemical shifts (δ) are reported in parts per million relative to the residual deuterated solvent signal, and coupling constants (*J*) are given in Hertz. ^{13}C NMR spectra were measured at 100 MHz with $CDCl_3$ as solvent. HRMS (ESI) data were obtained in the electron impact (EI) (70 eV) mode.

General Experimental Procedures and Characterizations. Naphthoquinone **1** (1.0 mmol), β-enaminones (1.2 mmol), Cu-$(OAc)_2$·H_2O (0.2 mmol), and acetonitrile (15 mL) were added in a 50 mL bottle. The mixture was heated at reflux for 12 h under 1 atm of O_2. After cooling to room temperature, the volatiles were removed under reduced pressure, and the residue was purified by a flash column chromatography on silica gel to give the corresponding product.

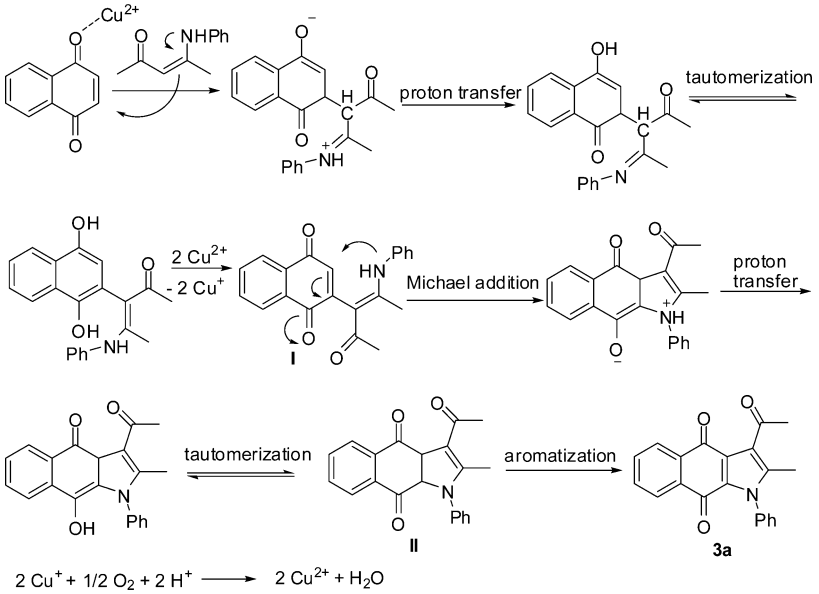
3-Acetyl-1-phenyl-2-methyl-1H-benzo[f]indole-4,9-dione (***3a***). Yellow solid (303 mg, 92%): mp 163−165 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.20 (s, 3H), 2.80 (s, 3H), 7.27−7.30 (m, 2H), 7.58−7.60 (m, 3H), 7.63−7.72 (m, 2H), 7.98 (d, *J* = 7.6 Hz, 1H), 8.17 (d, *J* = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.1, 181.0, 175.0, 142.7, 136.9, 133.6, 133.4, 133.3, 133.0, 131.0, 129.7, 129.1, 127.1, 126.8, 126.3, 125.6, 125.1, 124.8, 122.7, 31.8, 11.8; HRMS (ESI) calcd for $C_{21}H_{15}NNaO_3$ $[M + Na]^+$ 352.0950, found 352.0945.

3-Acetyl-2-methyl-1-p-tolyl-1H-benzo[f]indole-4,9-dione (***3b***). Yellow solid (328 mg, 96%): mp 217−219 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.12 (s, 3H), 2.42 (s, 3H), 2.72 (s, 3H), 7.08 (d, *J* = 8.0 Hz, 2H), 7.29 (d, *J* = 8.0 Hz, 2H), 7.57−7.62 (m, 2H), 7.92 (d, *J* = 7.6 Hz, 1H), 8.09 (d, *J* = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.1, 181.0, 175.0, 142.9, 139.7, 134.2, 133.6, 133.4, 133.3, 133.1, 131.1, 130.3, 126.8, 126.3, 125.1, 122.6, 31.8, 21.4, 11.8; HRMS (ESI) calcd for $C_{22}H_{17}NNaO_3$ $[M + Na]^+$ 366.1106, found 366.1110.

3-Acetyl-1-(4-fluorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3c***). Yellow solid (331 mg, 95%): mp 168−170 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.19 (s, 3H), 2.79 (s, 3H), 7.26 (s, 4H), 7.66−7.70 (m, 2H), 7.99 (d, *J* = 7.6 Hz, 1H), 8.17 (d, *J* = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.9, 180.8, 175.0, 162.9 (d, $^1J_{C-F}$ = 248.7 Hz), 142.7, 133.5, 133.4, 133.3, 132.9, 132.7 (d, $^4J_{C-F}$ = 3.4 Hz), 131.1, 129.0 (d, $^3J_{C-F}$ = 8.8 Hz), 126.8, 126.2, 125.2, 122.7, 116.8 (d, $^2J_{C-F}$ = 23.0 Hz), 31.8, 11.8; HRMS (ESI) calcd for $C_{21}H_{14}FNNaO_3$ $[M + Na]^+$ 370.0855, found 370.0856.

dx.doi.org/10.1021/jo401842d | J. Org. Chem. 2013, 78, 10560−10566

Scheme 1. Plausible Reaction Pathway



3-Acetyl-1-(4-chlorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3d***). Yellow solid (329 mg, 91%): mp 210−212 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.12 (s, 3H), 2.72 (s, 3H), 7.16 (d, J = 8.0 Hz, 2H), 7.48 (d, J = 8.0 Hz, 2H), 7.60−7.64 (m, 2H), 7.92 (d, J = 7.6 Hz, 1H), 8.10 (d, J = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.9, 180.8, 175.0, 142.5, 135.8, 135.3, 133.6, 133.5, 132.9, 131.0, 130.0, 128.5, 126.9, 126.2, 125.3, 122.9, 31.8, 11.8; HRMS (ESI) calcd for $C_{21}H_{14}ClNNaO_3$ $[M + Na]^+$ 386.0560; found 386.0557.

3-Acetyl-1-(4-bromophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3e***). Yellow solid (366 mg, 90%): mp 242−244 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.19 (s, 3H), 2.79 (s, 3H), 7.16 (d, J = 8.8 Hz, 2H), 7.66−7.73 (m, 4H), 7.99 (dd, J = 7.2, 1.6 Hz, 1H), 8.17 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.2, 181.1, 175.3, 142.7, 136.1, 133.9, 133.8, 133.7, 133.2, 131.3, 129.1, 127.2, 126.5, 125.6, 124.1, 123.2, 32.1, 12.1; HRMS (ESI) calcd for $C_{21}H_{14}BrNNaO_3$ $[M + Na]^+$ 430.0055, found 430.0054.

3-Acetyl-1-(2-chlorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3f***). Yellow solid (316 mg, 87%): mp 169−171 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (s, 3H), 2.73 (s, 3H), 7.27 (d, J = 7.6 Hz, 1H), 7.40−7.50 (m, 2H), 7.55−7.64 (m, 3H), 7.90 (d, J = 7.6 Hz, 1H), 8.09 (d, J = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.7, 180.9, 175.0, 142.7, 134.8, 133.7, 133.6, 133.4, 132.7, 132.2, 131.1, 130.9, 130.6, 128.9, 128.1, 126.9, 126.2, 125.2, 122.6, 31.9, 11.4; HRMS (ESI) calcd for $C_{21}H_{14}ClNNaO_3$ $[M + Na]^+$ 386.0560, found 386.0561.

3-Acetyl-1-(3-chlorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3g***). Yellow solid (319 mg, 88%): mp 168−170 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.13 (s, 3H), 2.72 (s, 3H), 7.12 (d, J = 7.6 Hz, 1H), 7.24 (s, 1H), 7.43−7.7.51 (m, 2H), 7.59−7.63 (m, 2H), 7.91 (d, J = 7.6 Hz, 1H), 8.10 (d, J = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.9, 180.8, 174.9, 142.5, 137.9, 135.3, 133.6, 133.5, 133.4, 132.9, 131.0, 130.6, 130.0, 127.6, 126.9, 126.3, 125.6, 125.2, 122.8, 31.8, 11.8; HRMS (ESI) calcd for $C_{21}H_{14}ClNNaO_3$ $[M + Na]^+$ 386.0560, found 386.0566.

3-Acetyl-1-(3,4-dichlorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3h***). Yellow solid (369 mg, 93%): mp 191−193 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.22 (s, 3H), 2.79 (s, 3H), 7.17 (dd, J = 8.8, 2.0 Hz, 1H), 7.25 (s, 1H), 7.65−7.74 (m, 3H), 7.99 (d, J = 7.6 Hz, 1H), 8.18 (d, J = 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 198.8, 180.7, 175.0, 142.4, 136.0, 134.4, 133.8, 133.7, 133.5, 132.8, 131.3, 131.0, 129.3, 127.0, 126.7, 126.3, 125.3, 123.0, 31.8, 11.8; HRMS (ESI) calcd for $C_{21}H_{13}Cl_2NNaO_3$ $[M + Na]^+$ 420.0170, found 420.0161.

3-Acetyl-1-(3,4-dimethoxylphenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (***3i***). Yellow solid (353 mg, 91%): mp 228−230 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.20 (s, 3H), 2.79 (s, 3H), 3.88 (s, 3H), 3.98 (s, 3H), 6.74 (s, 1H), 6.85 (dd, J = 7.6, 1.6 Hz, 1H), 7.01 (d, J = 8.8 Hz, 1H), 7.64−7.72 (m, 2H), 8.01 (d, J = 7.2 Hz, 1H), 8.17 (d, J = 7.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.2, 181.0, 175.0, 149.8, 149.6, 143.1, 133.6, 133.4, 133.3, 133.1, 131.1, 129.5, 126.8, 126.3, 125.0, 122.6, 119.2, 111.0, 110.2, 56.1, 56.0, 31.8, 11.8; HRMS (ESI) calcd for $C_{23}H_{19}NNaO_5$ $[M + Na]^+$ 412.1161, found 412.1166.

3-Acetyl-1-benzyl-2-methyl-1H-benzo[f]indole-4,9-dione (***3j***). Yellow solid (318 mg, 93%): mp 138−139 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.29 (s, 3H), 2.67 (s, 3H), 5.76 (s, 2H), 7.00 (d, J = 7.2 Hz, 2H), 7.20−7.27 (m, 3H), 7.61−7.64 (m, 2H), 8.04 (dd, J = 6.4, 2.8 Hz, 1H), 8.09 (dd, J = 6.4, 2.4 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.3, 180.8, 176.2, 142.1, 135.5, 133.5, 133.4, 133.3, 133.2, 129.8, 129.0, 127.9, 126.7, 126.5, 126.3, 126.2, 125.3, 123.1, 48.8, 31.8, 11.0; HRMS (ESI) calcd for $C_{22}H_{17}NNaO_3$ $[M + Na]^+$ 366.1106, found 366.1103.

3-Acetyl-1-butyl-2-methyl-1H-benzo[f]indole-4,9-dione (***3k***). Yellow solid (293 mg, 95%): mp 117−119 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.99 (t, J = 7.2 Hz, 3H), 1.43−1.47 (m, 2H), 1.73−1.77 (m, 2H), 2.43 (s, 3H), 2.71 (s, 3H), 4.47 (t, J = 7.6 Hz, 2H), 7.68−7.70 (m, 2H), 8.13−8.16 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 199.7, 181.0, 176.3, 141.5, 133.9, 133.6, 133.5, 133.4, 129.9, 127.0, 126.6, 125.5, 123.2, 46.0, 32.7, 32.0, 20.3, 14.0, 11.1; HRMS (ESI) calcd for $C_{19}H_{19}NNaO_3$ $[M + Na]^+$ 332.1263, found 332.1266.

3-Benzoyl-1,2-diphenyl-1H-benzo[f]indole-4,9-dione (***5a***). Yellow solid (331 mg, 73%): mp 246−248 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.11−7.16 (m, 5H), 7.28−7.30 (m, 2H), 7.39−7.43 (m, 5H), 7.53 (t, J = 7.2 Hz, 1H), 7.64−7.66 (m, 2H), 7.96 (d, J = 8.0 Hz, 2H), 8.05−8.07 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.8, 180.1, 175.1, 141.9, 137.7, 136.9, 133.8, 133.4, 133.3, 133.2, 130.7, 130.2, 129.4, 129.1, 128.9, 128.5, 128.2, 128.1, 128.0, 126.9, 126.7, 126.6, 122.6; HRMS (ESI) calcd for $C_{31}H_{19}NNaO_3$ $[M + Na]^+$ 476.1263, found 476.1265.

3-Benzoyl-2-phenyl-1-p-tolyl-1H-benzo[f]indole-4,9-dione (***5b***). Yellow solid (355 mg, 76%): mp 212−214 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.40 (s, 3H), 7.12−7.13 (m, 4H), 7.16−7.22 (m, 5H), 7.41 (t, J = 7.6 Hz, 2H), 7.53 (t, J = 7.2 Hz, 1H), 7.65−7.67 (m, 2H), 7.94 (d, J = 7.6 Hz, 2H), 8.04−8.08 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.8, 179.7, 173.3, 142.0, 139.2, 137.8, 136.6, 134.5, 134.3, 134.1, 132.9, 132.5, 130.9, 130.3, 129.6, 129.2, 129.1, 128.6, 128.3, 127.8, 127.5, 127.0, 122.6, 118.9, 21.4; HRMS (ESI) calcd for $C_{32}H_{21}NNaO_3$ $[M + Na]^+$ 490.1419, found 490.1422.

3-Benzoyl-2-phenyl-1-(4-fluorophenyl)-1H-benzo[f]indole-4,9-dione (***5c***). Yellow solid (385 mg, 82%): mp 236−238 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.07−7.19 (m, 7H), 7.26−7.29 (m, 2H), 7.40 (t, J = 7.6 Hz, 2H), 7.53 (t, J = 7.6 Hz, 1H), 7.67 (t, J = 7.6 Hz, 2H), 7.92

dx.doi.org/10.1021/jo401842d | J. Org. Chem. 2013, 78, 10560−10566

(d, J = 7.2 Hz, 2H), 8.05−8.07 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.6, 180.0, 175.2, 162.6 (d, $^1J_{C-F}$ = 248.3 Hz), 141.9, 137.7, 133.7, 133.5, 133.4, 133.1, 132.7 (d, $^4J_{C-F}$ = 3.0 Hz), 130.8, 130.3, 129.8 (d, $^3J_{C-F}$ = 8.7 Hz), 129.4, 129.1, 128.5, 128.3, 128.0, 127.0, 126.8, 126.6, 122.7, 116.0 (d, $^2J_{C-F}$ = 22.9 Hz); HRMS (ESI) calcd for $C_{31}H_{18}FNNaO_3$ $[M + Na]^+$ 494.1168, found 494.1156.

*3-Benzoyl-2-phenyl-1-(4-chlorophenyl)-1H-benzo[f]indole-4,9-dione (**5d**).* Yellow solid (379 mg, 78%): mp 206−208 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.12−7.26 (m, 7H), 7.39−7.44 (m, 4H), 7.55 (t, J = 7.2 Hz, 1H), 7.66−7.71 (m, 2H), 7.94 (d, J = 8.4 Hz, 2H), 8.06−8.09 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.0, 179.5, 174.7, 141.3, 137.1, 134.8, 134.7, 133.2, 133.1, 133.0, 132.9, 132.6, 130.2, 129.7, 128.9, 128.7, 128.0, 127.9, 127.4, 126.6, 126.3, 126.1, 122.3; HRMS (ESI) calcd for $C_{31}H_{18}ClNNaO_3$ $[M + Na]^+$ 510.0873, found 510.0877.

*3-Benzoyl-2-phenyl-1-(2-chlorophenyl)-1H-benzo[f]indole-4,9-dione (**5e**).* Yellow solid (345 mg, 71%): mp 234−236 °C; ^{1}H NMR ($CDCl_3$, 400 MHz) δ 7.13−7.20 (m, 6H), 7.31−7.35 (m, 2H), 7.40 (t, J = 7.6 Hz, 3H), 7.52 (t, J = 7.6 Hz, 1H), 7.63−7.66 (m, 2H), 7.92 (dd, J = 7.6, 1.2 Hz, 2H), 8.05 (td, J = 7.2, 1.5 Hz, 2H); ^{13}C NMR ($CDCl_3$, 100 MHz) δ 192.5, 180.0, 175.1, 141.8, 137.9, 137.6, 134.5, 133.7, 133.5, 133.4, 133.1, 130.7, 130.2, 129.9, 129.5, 129.4, 129.3, 128.5, 128.4, 127.9, 127.0, 126.8, 126.6, 126.5, 122.8; HRMS (ESI) calcd for $C_{31}H_{18}ClNNaO_3$ $[M + Na]^+$ 510.0873, found 510.0876.

*3-Benzoyl-2-methyl-1-phenyl-1H-benzo[f]indole-4,9-dione (**5f**).* Yellow solid (343 mg, 88%): mp 190−192 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.13 (s, 3H), 7.37−7.39 (m, 2H), 7.48 (t, J = 7.6 Hz, 2H), 7.58−7.63 (m, 6H), 7.96−8.02 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.1, 180.0, 174.9, 141.3, 138.2, 136.9, 133.4, 133.3, 133.2, 130.8, 129.7, 129.4, 128.5, 127.2, 126.7, 126.5, 126.4, 120.9, 11.4; HRMS (ESI) calcd for $C_{26}H_{17}NNaO_3$ $[M + Na]^+$ 414.1106, found 414.1108.

*3-Benzoyl-2-methyl-1-p-tolyl-1H-benzo[f]indole-4,9-dione (**5g**).* Yellow solid (372 mg, 92%): mp 228−230 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.13 (s, 3H), 2.50 (s, 3H), 7.24−7.26 (m, 2H), 7.39 (d, J = 8.0 Hz, 2H), 7.47 (t, J = 8.0 Hz, 2H), 7.57−7.63 (m, 3H), 7.95−8.00 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 180.4, 175.2, 141.7, 140.1, 138.7, 134.6, 133.9, 133.7, 133.6, 133.5, 131.2, 130.6, 129.8, 128.8, 127.2, 127.0, 126.9, 126.7, 121.2, 21.8, 11.7; HRMS (ESI) calcd for $C_{27}H_{19}NNaO_3$ $[M + Na]^+$ 428.1263, found 428.1260.

*3-Benzoyl-1-(4-fluorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (**5h**).* Yellow solid (389 mg, 95%): mp 223−225 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.14 (s, 3H), 7.30 (d, J = 8.0 Hz, 2H), 7.36−7.39 (m, 2H), 7.48 (t, J = 7.6 Hz, 2H), 7.59−7.64 (m, 3H), 7.96 (d, J = 7.6 Hz, 2H), 7.99−8.02 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.9, 179.9, 175.0, 163.0 (d, $^1J_{C-F}$ = 248.8 Hz), 141.3, 138.1, 133.4, 133.3, 133.2, 132.7 (d, $^4J_{C-F}$ = 3.2 Hz), 130.8, 129.4, 129.1 (d, $^3J_{C-F}$ = 8.8 Hz), 128.5, 126.8, 126.6, 126.4, 121.0, 116.8 (d, $^2J_{C-F}$ = 22.9 Hz), 11.4; HRMS (ESI) calcd for $C_{26}H_{16}FNNaO_3$ $[M + Na]^+$ 432.1012, found 432.1016.

*3-Benzoyl-1-(4-chlorophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (**5i**).* Yellow solid (392 mg, 92%): mp 248−250 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.14 (s, 3H), 7.33 (d, J = 8.8 Hz, 2H), 7.48 (t, J = 7.6 Hz, 2H), 7.57−7.65 (m, 5H) 7.95−8.01 (m, 4H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.8, 179.9, 174.9, 141.0, 138.1, 135.8, 135.3, 133.4, 133.3, 133.2, 130.7, 129.9, 129.4, 128.6, 128.5, 126.8, 126.7, 126.4, 121.1; HRMS (ESI) calcd for $C_{26}H_{16}ClNNaO_3$ $[M + Na]^+$ 448.0716, found 448.0716.

*3-Benzoyl-1-(4-bromophenyl)-2-methyl-1H-benzo[f]indole-4,9-dione (**5j**).* Yellow solid (421 mg, 90%): mp 268−270 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.12 (s, 3H), 7.24−7.26 (m, 2H), 7.46 (t, J = 7.6 Hz, 2H), 7.57−7.63 (m, 3H), 7.71 (d, J = 8.8 Hz, 2H), 7.94 (dd, J = 8.4, 1.2 Hz, 2H), 7.98−8.01 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.9, 179.9, 175.0, 141.0, 138.2, 135.9, 133.5, 133.4, 133.3, 133.0, 130.8, 129.5, 129.0, 128.6, 126.9, 126.8, 126.5, 124.0, 121.3, 11.4; HRMS (ESI) calcd for $C_{26}H_{16}BrNNaO_3$ $[M + Na]^+$ 492.0211, found 492.0215.

*3-Benzoyl-1-benzyl-2-methyl-1H-benzo[f]indole-4,9-dione (**5k**).* Yellow solid (378 mg, 93%): mp 218−220 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.29 (s, 3H), 5.57 (s, 2H), 7.14 (d, J = 6.8 Hz, 2H), 7.28 (d, J = 7.6 Hz, 1H), 7.34−7.37 (m, 2H), 7.44 (t, J = 8.0 Hz, 2H), 7.55−7.66 (m, 3H), 7.89 (dd, J = 7.2, 1.2 Hz, 2H), 7.98 (dd, J = 7.6, 1.2 Hz, 1H), 8.12 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.3, 180.0, 176.4, 141.1, 138.6, 136.0, 133.9, 133.5, 133.4, 129.9, 129.6, 129.3, 128.7, 128.2, 126.9, 126.8, 126.7, 126.6, 121.6, 49.2, 11.1; HMRS (ESI) calcd for $C_{27}H_{19}NNaO_3$ $[M + Na]^+$ 428.1263, found 428.1266.

*3-Benzoyl-1-butyl-2-methyl-1H-benzo[f]indole-4,9-dione (**5l**).* Yellow solid (353 mg, 95%): mp 154−156 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.02 (t, J = 7.6 Hz, 3H), 1.46−1.53 (m, 2H), 1.80−1.85 (m, 2H), 2.36 (s, 3H), 4.50 (t, J = 7.6 Hz, 2H), 7.43 (t, J = 7.6 Hz, 2H), 7.54−7.69 (m, 3H), 7.87−7.89 (m, 2H), 7.96 (dd, J = 7.6, 1.2 Hz, 1H), 8.15 (dd, J = 7.6, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.2, 179.7, 175.8, 140.0, 138.4, 133.6, 133.2, 133.1, 129.3, 129.2, 128.4, 126.6, 126.4, 126.3, 121.0, 45.9, 32.5, 20.0, 13.7, 10.6; HMRS (ESI) calcd for $C_{24}H_{21}NNaO_3$ $[M + Na]^+$ 394.1419, found 394.1422.

*Ethyl 4,9-dioxo-2-phenyl-1-p-tolyl-4,9-dihydro-1H-benzo[f]-indole-3-carboxylate (**5m**).* Yellow solid (356 mg, 82%): mp 141−143 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.20 (t, J = 7.2 Hz, 3H), 2.37 (s, 3H), 4.30 (q, J = 7.2 Hz, 2H), 7.07 (d, J = 8.4 Hz, 2H), 7.16−7.29 (m, 7H), 7.65−7.70 (m, 2H), 8.03 (dd, J = 7.2, 1.2 Hz, 1H), 8.20 (dd, J = 7.2, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.9, 175.1, 164.6, 142.6, 139.1, 135.4, 135.0, 134.1, 134.0, 133.3, 133.2, 131.7, 130.2, 129.5, 128.7, 128.0, 127.6, 127.0, 126.6, 126.4, 120.3, 61.5, 21.3, 13.8; HMRS (ESI) calcd for $C_{28}H_{21}NNaO_4$ $[M + Na]^+$ 458.1368, found 458.1372.

*Ethyl 1-(4-fluorophenyl)-4,9-dioxo-2-phenyl-4,9-dihydro-1H-benzo[f]indole-3-carboxylate (**5n**).* Yellow solid (387 mg, 88%): mp 192−194 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.20 (t, J = 7.2 Hz, 3H), 4.30 (q, J = 7.2 Hz, 2H), 7.06 (t, J = 8.4 Hz, 2H), 7.16−7.20 (m, 4H), 7.24−7.31 (m, 3H), 7.67 (td, J = 7.6, 1.6 Hz, 1H), 7.71 (td, J = 7.2, 1.6 Hz, 1H), 8.03 (dd, J = 7.2, 1.2 Hz, 1H), 8.20 (dd, J = 7.6, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.8, 175.2, 164.3, 162.4 (d, $^1J_{C-F}$ = 248.4 Hz), 142.7, 133.5, 133.4, 133.3, 132.7 (d, $^4J_{C-F}$ = 3.4 Hz), 131.0, 130.2, 129.8 (d, $^3J_{C-F}$ = 8.8 Hz), 129.2, 128.2, 128.1, 126.8, 126.4, 125.8, 116.3, 116.0 (d, $^2J_{C-F}$ = 23.0 Hz), 61.6, 13.9; HMRS (ESI) calcd for $C_{27}H_{18}FNNaO_4$ $[M + Na]^+$ 462.1118, found 462.1115.

*Ethyl 1-(4-chlorophenyl)-4,9-dioxo-2-phenyl-4,9-dihydro-1H-benzo[f]indole-3-carboxylate (**5o**).* Yellow solid (383 mg, 84%): mp 134−136 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.18 (t, J = 7.2 Hz, 3H), 4.28 (q, J = 7.2 Hz, 2H), 7.10−7.17 (m, 3H), 7.24−7.33 (m, 3H), 7.46 (t, J = 7.6 Hz, 1H), 7.58 (d, J = 8.8 Hz, 1H), 7.65−7.70 (m, 2H), 7.84 (d, J = 6.8 Hz, 1H), 8.01 (dd, J = 7.2, 1.6 Hz, 1H), 8.19 (dd, J = 7.2, 1.6 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 180.0, 175.4, 164.5, 142.8, 135.4, 135.3, 133.8, 133.7, 133.6, 133.5, 132.2, 130.4, 129.5, 129.4, 129.3, 129.0, 128.5, 128.3, 127.2, 127.0, 126.7, 121.7, 116.6, 61.8, 14.1; HMRS (ESI) calcd for $C_{27}H_{18}ClNNaO_4$ $[M + Na]^+$ 478.0822, found 478.0816.

*Ethyl 1-(2-chlorophenyl)-4,9-dioxo-2-phenyl-4,9-dihydro-1H-benzo[f]indole-3-carboxylate (**5p**).* Yellow solid (363 mg, 80%): mp 263−265 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.20 (t, J = 7.2 Hz, 3H), 4.30 (q, J = 7.2 Hz, 2H), 7.08−7.11 (m, 1H), 7.18−7.23 (m, 3H), 7.25−7.33 (m, 4H), 7.38−7.40 (m, 1H), 7.68−7.72 (m, 2H), 8.03 (dd, J = 7.2 Hz, 1H), 8.20 (dd, J = 7.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 179.7, 175.1, 164.2, 142.6, 137.7, 134.4, 133.5, 133.4, 133.3, 133.2, 130.9, 130.2, 129.7, 129.4, 129.3, 128.4, 128.2, 128.0, 126.8, 126.4, 126.3, 125.8, 116.3, 61.6, 13.8; HMRS (ESI) calcd for $C_{27}H_{18}ClNNaO_4$ $[M + Na]^+$ 478.0822, found 478.0815.

*3,3-Dimethyl-5-phenyl-3,4-dihydro-1H-benzo[b]carbazole-1,6,11(2H,5H)-trione (**7a**).* Yellow solid (317 mg, 86%): mp 266−268 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.01 (s, 6H), 2.47 (s, 2H), 2.55 (s, 2H), 7.31−7.33 (m, 2H), 7.60−7.65 (m, 4H), 7.70 (td, J = 7.6, 1.2 Hz, 1H), 7.97 (dd, J = 7.6, 1.2 Hz, 1H), 8.25 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.4, 179.2, 175.9, 151.0, 136.7, 134.0, 133.7, 133.0, 132.6, 129.8, 129.7, 127.4, 127.0, 126.1, 125.2, 118.2, 53.5, 36.6, 34.9, 28.4; HMRS (ESI) calcd for $C_{24}H_{19}NNaO_3$ $[M + Na]^+$ 392.1263, found 392.1266.

dx.doi.org/10.1021/jo401842d | J. Org. Chem. 2013, 78, 10560−10566

*3,3-Dimethyl-5-p-tolyl-3,4-dihydro-1H-benzo[b]carbazole-1,6,11-(2H,5H)-trione (**7b**).* Yellow solid (348 mg, 91%): mp 276−278 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (s, 6H), 2.47 (s, 2H), 2.50 (s, 3H), 2.53 (s, 2H), 7.19 (d, J = 8.0 Hz, 2H), 7.38 (d, J = 8.4 Hz, 2H), 7.60 (td, J = 7.6, 1.6 Hz, 1H), 7.67 (td, J = 7.6, 1.6 Hz, 1H), 7.95 (dd, J = 7.6, 1.2 Hz, 1H), 8.23 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.6, 179.4, 176.1, 151.4, 140.1, 134.2, 134.1, 133.9, 133.8, 133.2, 132.8, 130.6, 127.5, 126.8, 126.2, 125.3, 118.2, 53.6, 36.8, 35.0, 28.5, 21.7; HMRS (ESI) calcd for $C_{25}H_{21}NNaO_3$ $[M + Na]^+$ 406.1419, found 406.1413.

*3,3-Dimethyl-5-(4-fluorophenyl)-3,4-dihydro-1H-benzo[b]-carbazole-1,6,11(2H,5H)-trione (**7c**).* Yellow solid (367 mg, 95%): mp 296−298 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.07 (s, 6H), 2.44 (s, 2H), 2.50 (s, 2H), 7.24−7.33 (m, 4H), 7.60 (td, J = 7.2, 1.2 Hz, 1H), 7.66 (td, J = 7.2, 1.2 Hz, 1H), 7.91 (dd, J = 7.6, 1.2 Hz, 1H), 8.20 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.1, 178.9, 175.7, 163.1 (d, $^1J_{C-F}$ = 249.0 Hz), 151.0, 133.7, 133.6, 133.5, 132.9, 132.4 (d, $^4J_{C-F}$ = 3.5 Hz), 132.3, 128.8 (d, $^3J_{C-F}$ = 9.0 Hz), 127.1, 125.8, 125.0, 118.0, 116.7 (d, $^2J_{C-F}$ = 23.1 Hz), 53.2, 36.4, 34.7, 28.2; HMRS (ESI) calcd for $C_{24}H_{18}FNNaO_3$ $[M + Na]^+$ 410.1168, found 410.1171.

*3,3-Dimethyl-5-(4-chlorophenyl)-3,4-dihydro-1H-benzo[b]-carbazole-1,6,11(2H,5H)-trione (**7d**).* Yellow solid (371 mg, 92%): mp 267−269 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (s, 6H), 2.46 (s, 2H), 2.52 (s, 2H), 7.28−7.30 (m, 2H), 7.56−7.58 (m, 2H), 7.61 (td, J = 7.6, 1.2 Hz, 1H), 7.68 (td, J = 7.6, 1.2 Hz, 1H), 7.92 (dd, J = 7.2, 0.8 Hz, 1H), 8.21 (dd, J = 7.6, 0.8 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.1, 178.8, 175.7, 150.9, 135.8, 134.9, 133.7, 133.4, 133.0, 132.3, 129.9, 128.3, 127.2, 125.8, 125.0, 118.1, 53.2, 36.4, 34.7, 28.2; HMRS (ESI) calcd for $C_{24}H_{18}ClNNaO_3$ $[M + Na]^+$ 426.0873 found 426.0871.

*3,3-Dimethyl-5-(4-bromophenyl)-3,4-dihydro-1H-benzo[b]-carbazole-1,6,11(2H,5H)-trione (**7e**).* Yellow solid (408 mg, 91%): mp 273−275 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (s, 6H), 2.46 (s, 2H), 2.53 (s, 2H), 7.22 (dd, J = 6.8, 1.6 Hz, 2H), 7.63 (td, J = 7.6, 1.2 Hz, 1H), 7.68−7.74 (m, 3H), 7.94 (dd, J = 7.6, 1.2 Hz, 1H), 8.23 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.8, 178.5, 175.4, 150.4, 135.1, 133.4, 133.1, 132.7, 132.6, 132.0, 128.3, 126.9, 125.6, 124.8, 123.6, 117.8, 52.9, 36.1, 34.4, 27.9; HMRS (ESI) calcd for $C_{24}H_{18}BrNNaO_3$ $[M + Na]^+$ 470.0368 found 470.0372.

*3,3-Dimethyl-5-(2-chlorophenyl)-3,4-dihydro-1H-benzo[b]-carbazole-1,6,11(2H,5H)-trione (**7f**).* Yellow solid (335 mg, 83%): mp 263−265 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.11 (d, J = 7.6 Hz, 6H), 2.47 (d, J = 8.0 Hz, 2H), 2.55 (s, 2H), 7.22−7.25 (m, 1H), 7.35 (t, J = 2.0 Hz, 1H), 7.54 (t, J = 7.6 Hz, 1H), 7.58−7.63 (m, 1H), 7.65 (dd, J = 7.6, 1.6 Hz, 1H), 7.71 (td, J = 7.2, 1.2 Hz, 1H), 7.96 (dd, J = 7.6, 1.2 Hz, 1H), 8.25 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.2, 179.0, 175.7, 150.7, 137.6, 135.3, 133.8, 133.7, 133.6, 133.1, 132.3, 130.6, 130.1, 127.3, 126.0, 125.3, 125.1, 118.3, 53.3, 36.5, 34.8, 28.4, 28.2; HMRS (ESI) calcd for $C_{24}H_{18}ClNNaO_3$ $[M + Na]^+$ 426.0873 found 426.0878.

*3,3-Dimethyl-5-(3,4-dichlorophenyl)-3,4-dihydro-1H-benzo[b]-carbazole-1,6,11(2H,5H)-trione (**7g**).* Yellow solid (384 mg, 88%): mp 236−238 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.11 (d, J = 7.6 Hz, 6H), 2.47 (d, J = 8.4 Hz, 2H), 2.53 (s, 2H), 7.22 (dd, J = 8.4, 2.4 Hz, 1H), 7.48 (d, J = 6.4 Hz, 1H), 7.63−7.70 (m, 3H), 7.94 (dd, J = 7.6, 1.2 Hz, 1H), 8.22 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.9, 178.8, 175.7, 150.6, 135.6, 134.5, 133.9, 133.8, 133.5, 133.1, 132.2, 131.3, 129.0, 127.3, 126.5, 125.9, 125.2, 118.3, 53.2, 36.5, 34.8, 28.4, 28.1; HMRS (ESI) calcd for $C_{24}H_{17}Cl_2NNaO_3$ $[M + Na]^+$ 460.0483, found 460.0478.

*3,3-Dimethyl-5-(3,4-dimethoxylphenyl)-3,4-dihydro-1H-benzo-[b]carbazole-1,6,11(2H,5H)-trione (**7h**).* Yellow solid (373 mg, 87%): mp 247−249 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.09 (s, 6H), 2.47 (d, J = 6.0 Hz, 2H), 2.52 (s, 2H), 3.90 (s, 3H), 3.98 (s, 3H), 6.79 (d, J = 2.4 Hz, 1H), 6.87 (dd, J = 8.4 Hz, 2.4 Hz, 1H), 7.01 (d, J = 8.8 Hz, 1H), 7.62 (td, J = 7.6, 1.6 Hz, 1H), 7.68 (td, J = 7.6, 1.6 Hz, 1H), 7.96 (dd, J = 7.6, 1.2 Hz, 1H), 8.23 (dd, J = 7.6, 1.2 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.6, 179.4, 176.0, 151.7, 150.2, 149.9, 133.8, 133.2, 132.8, 129.5, 127.4, 127.3, 126.2, 119.3, 111.4, 110.5, 56.5, 56.3, 53.6, 36.7, 34.9, 28.6, 28.4; HMRS (ESI) calcd for $C_{26}H_{23}NNaO_5$ $[M + Na]^+$ 452.1474, found 452.1479.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

^{1}H and ^{13}C NMR spectra of all compounds and crystal data (CIF) for **5a**. This material is available free of charge via the Internet at http://pubs.acs.org.

■ AUTHOR INFORMATION

Corresponding Author

*E-mail: liu__yun3@sina.com.cn.

Notes

The authors declare no competing financial interest.

■ ACKNOWLEDGMENTS

The authors gratefully acknowledge the National Natural Science Foundation of China (NSFC 21172188 and 21071121), the Priority Academic Program Development of Jiangsu Higher Education Institutions (PAPD), and 333 project for the cultivation of high-level talents (33GC10002) for financial support of this work.

■ REFERENCES

(1) (a) *The Chemistry of Functional Groups: The Chemistry of the Quinoid Compounds*; Patai, S., Rappoport, Z., Eds.; Wiley: New York, 1988. (b) Monks, T. J.; Hanzlik, R. P.; Cohen, G. M.; Ross, D.; Graham, D. G. *Toxicol. Appl. Pharmacol.* **1992**, *112*, 2. (c) Thomson, R. H. *Naturally Occurring Quinones*, 4th ed.; Chapman and Hall: London, 1997. (d) Batton, J. L.; Trush, M. A.; Penning, T. M.; Dryhurst, G.; Monks, T. *J. Chem. Res. Toxicol.* **2000**, *13*, 135. (e) Quinones and Quinone Enzymes, Part A and B. In *Methods in Enzymology*; Sies, H., Packer, L., Eds.; Elsevier: San Diego, 2004; Vols. *378, 382*.

(2) See, for examples: (a) Bass, P. D.; Gubler, D. A.; Judd, T. C.; Williams, R. M. *Chem. Rev.* **2013**, *113*, 6816. (b) Schmidt, A. W.; Reddy, K. R.; Knölker, H.-J. *Chem. Rev.* **2012**, *112*, 3193. (c) Wang, C.; Sperry, J. *J. Org. Chem.* **2012**, *77*, 2584 and references cited therein. (d) Carr, G.; Chung, M. K. W.; Mauk, A. G.; Andersen, R. J. *J. Med. Chem.* **2008**, *51*, 2634. (e) Bobeck, D. R.; Warner, D. L.; Vedejs, E. *J. Org. Chem.* **2007**, *72*, 8506. (f) Brastianos, H. C.; Vottero, E.; Patrick, B. O.; Van Soest, R.; Matainaho, T.; Mauk, A. G.; Andersen, R. J. *J. Am. Chem. Soc.* **2006**, *128*, 16046. (g) Knölker, H.-J.; Reddy, K. R. *Chem. Rev.* **2002**, *102*, 4303.

(3) See, for examples: (a) Moharam, B. A.; Jantan, I.; Jalil, J.; Ahmad, F. *Phytother. Res.* **2012**, *26*, 687. (b) Efdi, M.; Fujita, S.; Inuzuka, T.; Koketsu, M. *Nat. Prod. Res.* **2010**, *24*, 657. (c) Bauer, J. D.; King, R. W.; Brady, S. F. *J. Nat. Prod.* **2010**, *73*, 976. (d) Ryu, C.-K.; Lee, J. Y.; Jeong, S. H.; Nho, J.-H. *Bioorg. Med. Chem. Lett.* **2009**, *19*, 146. (e) Park, H. J.; Lee, H.-J.; Min, H.-Y.; Chung, H.-J.; Suh, M. E.; Park-Choo, H.-Y.; Kim, C.; Kim, H. J.; Seo, E.-K.; Lee, S. K. *Eur. J. Pharmacol.* **2005**, *527*, 31. (f) Lee, E.-J.; Lee, H.-J.; Park, H.-J.; Min, H.-Y.; Suh, M.-E.; Chung, H.-J.; Lee, S. K. *Bioorg. Med. Chem. Lett.* **2004**, *14*, 5175. (g) Lee, H.-J.; Suh, M.-E.; Lee, C.-O. *Bioorg. Med. Chem.* **2003**, *11*, 1511.

(4) (a) Germeraad, P.; Moore, H. W. *J. Chem. Soc., Chem. Commun.* **1973**, 358. (b) Germeraad, P.; Moore, H. W. *J. Org. Chem.* **1974**, *39*, 774.

(5) Naruta, Y.; Yokota, T.; Nagai, N.; Maruyama, K. *J. Chem. Soc., Chem. Commun.* **1986**, 972.

(6) (a) Weeratunga, G.; Prasad, G. K. B.; Dilley, J.; Taylor, N. J.; Dmitrienko, G. I. *Tetrahedron Lett.* **1990**, *31*, 5713. (b) Mithani, S.; Weeratunga, G.; Taylor, N. J.; Dmitrienko, G. I. *J. Am. Chem. Soc.* **1994**, *116*, 2209.

(7) (a) Kobayashi, K.; Takeuchi, H.; Seko, S.; Suginome, H. *Helv. Chim. Acta* **1991**, *74*, 1091. (b) Kobayashi, K.; Takeuchi, H.; Seko, S.; Kanno, Y.; Kujime, S.; Suginome, H. *Helv. Chim. Acta* **1993**, *76*, 2942.
(8) (a) Jiang, M.-C.; Chuang, C.-P. *J. Org. Chem.* **2000**, *65*, 5409. (b) Wu, Y.-L.; Chuang, C.-P.; Lin, P.-Y. *Tetrahedron* **2001**, *57*, 5543. (c) Tseng, C.-C.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2002**, *58*, 7625. (d) Tseng, C.-M.; Wu, Y.-L.; Chuang, C.-P. *Tetrahedron* **2004**, *60*, 12249.
(9) Hu, H.-Y.; Liu, Y.; Ye, M.; Xu, J.-H. *Synlett* **2006**, 1913 and refs 3d and 3g.
(10) Suryavanshi, P. A.; Sridharan, V.; Menéndez, J. C. *Org. Biomol. Chem.* **2010**, *8*, 3426.
(11) (a) Inman, M.; Moody, C. J. *J. Org. Chem.* **2010**, 6023. (b) Inman, M.; Moody, C. J. *Eur. J. Org. Chem.* **2013**, 2179.
(12) (a) Shvartsberg, M. S.; Kolodina, E. A.; Lebedeva, N. I.; Fedenok, L. G. *Tetrahedron Lett.* **2009**, *50*, 6769. (b) Yamashita, M.; Ueda, K.; Sakaguchi, K.; Iida, A. *Tetrahedron Lett.* **2011**, *52*, 4665.
(13) For recent reviews on copper-catalyzed processes, see: (a) Allen, S. E.; Walvoord, R. R.; Padilla-Salinas, R. P.; Kozlowski, M. C. *Chem. Rev.* **2013**, 6234. (b) Zhang, C.; Tang, C.; Jiao, N. *Chem. Soc. Rev.* **2012**, *41*, 3464. (c) Wendlandt, A. E.; Suess, A. M.; Stahl, S. S. *Angew. Chem., Int. Ed.* **2011**, *50*, 11062. (d) Monnier, F.; Taillefer, M. *Angew. Chem., Int. Ed.* **2009**, *48*, 6954. (e) Evano, G.; Blanchard, N.; Toumi, M. *Chem. Rev.* **2008**, *108*, 3054.
(14) (a) Liu, Y.; Sun, J.-W. *J. Org. Chem.* **2012**, *77*, 1191. (b) Liu, Y.; Hu, H.-Y.; Su, X.-B.; Sun, J.-W.; Cao, C.-S.; Shi, Y.-H. *Eur. J. Org. Chem.* **2013**, 2020.
(15) Similar oxidative additions of carbon atom to naphthoquinone; see, for example: ref 14a.
(16) Similar oxidative additions of amine to naphthoquinone using Cu^{II} or Au^{III} as catalyst; see, for examples: (a) Lisboa, C. S.; Santos, V. G.; Vaz, B. G.; de Lucas, N. C.; Eberlin, M. N.; Garden, S. J. *J. Org. Chem.* **2011**, *76*, 5264. (b) Jiang, C. H.; Wang, S. Z. *Synlett* **2009**, 1099.