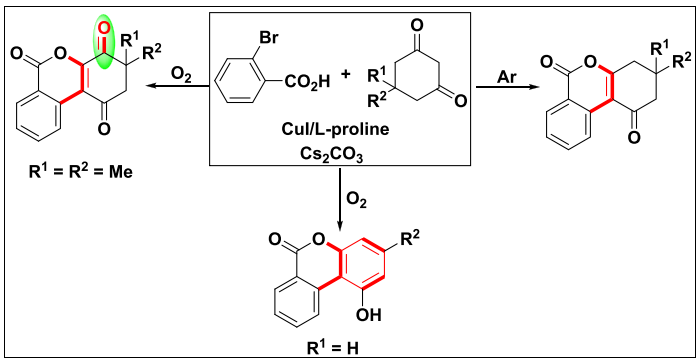
Synthesis of Structurally Diversified Benzo[*c*]chromene Derivatives under (An)aerobic Conditions Catalyzed by CuI

Fang Dong, Jian-Quan Liu,* and Xiang-Shan Wang*

School of Chemistry and Materials Science, Jiangsu Key Laboratory of Green Synthesis for Functional Materials, Jiangsu Normal University, Xuzhou, Jiangsu 221116, People's Republic of China
*E-mail: liujq316@jsnu.edu.cn; xswang1974@yahoo.com

Received January 9, 2019
DOI 10.1002/jhet.3666
Published online 00 Month 2019 in Wiley Online Library (wileyonlinelibrary.com).



2-Bromobenzoic acids underwent an *α*-arylation with cyclohexane-1,3-diones to give 1*H*-benzo[*c*]chromene-1,6(2*H*)-diones under Ar atmosphere catalyzed by CuI/L-proline in the presence of Cs_2CO_3. The subsequent regioselective oxidation took place under O_2 balloon automatically based on the substituents for the construction of structurally diversified benzo[*c*]coumarin derivatives.

J. Heterocyclic Chem., **00,** 00 (2019).

INTRODUCTION

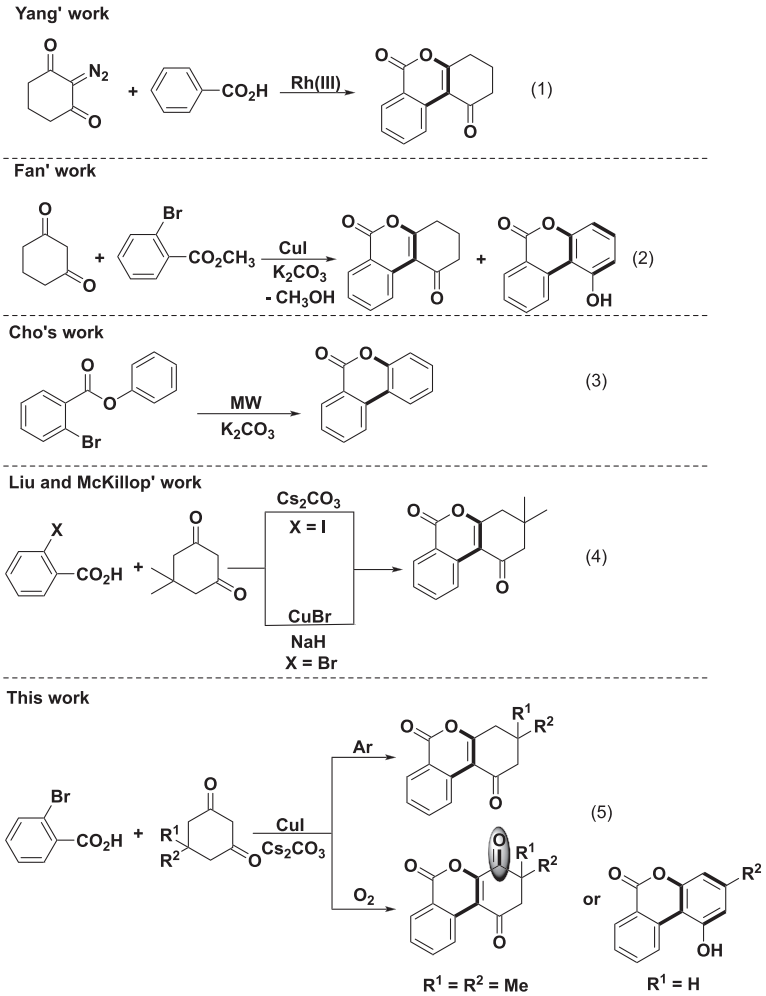
Coumarin is also named 2*H*-chromen-2-one, which is a bicyclic oxygen-containing heterocycle. It is reported that coumarin exists in numerous natural products [1], such as tanizin [2], anisucoumaramide [3], and defucogilvocarcin [4], and possesses good biological activities, for example, antitumor [5], anti-*Escherichia coli* [6], anticoagulation [7], and antifungal activities [8]. Acenocoumarol is a noteworthy anticoagulant drug that functions as a vitamin K antagonist [9]. In addition, dicoumarol [10] is a naturally occurring anticoagulant medication, which almost acts as the same function as acenocoumarol. According to its remarkable anticoagulant effect, many novel procedures for the synthesis of coumarins [11] have been reported in the past few years.

Benzo[*c*]coumarin is an important member of this large family whose derivatives also have the widespread applications [12]. In very recent, Yang's group [13] reported that Rh(III)-catalyzed C—H activation of cyclic 2-diazo-1,3-diketones and benzoic acids was an efficient method, leading to the functional benzo[*c*]coumarins in 2017 (Scheme 1, (1)). However, the cyclic 2-diazo-1,3-diketone was not a class of available reactants. In 2018, Cho's group [14] realized the synthesis of 6*H*-benzo[*c*]chromen-6-ones under metal–catalyst-free conditions using aryl 2-bromobenzoate as a reactant promoted by microwave in the presence of K_2CO_3 (Scheme 1, (2)).

Fan's group [15] utilized 2-bromobenzoate to react with cyclohexane-1,3-dione catalyzed by CuI with benzo[*c*]coumarins being obtained in moderate yields but losing a molecule of alcohol in ester (Scheme 1, (3)). In fact, using 2-halobenzoic acid as an easily available material to react with cyclohexane-1,3-dione was a very efficient and atomic economic method to synthesize 1*H*-benzo[*c*]chromene-1,6(2*H*)-diones. Only losing a molecule of water in the conversion, it concerns the concept of green chemistry in organic synthesis accordingly. In 2012, Liu's group [16] realized this reaction under transition-metal-free conditions. However, the valuable 2-iodobenzoic acid was used as a reactant (Scheme 1, (4)). As early as 1977, McKillop and Rao [17] also achieved a copper-catalyzed arylation of dimedone with 2-bromobenzoic acid, leading to 63% yield of 1*H*-benzo[*c*]chromene-1,6(2*H*)-dione. Only an example was reported but using the costly NaH as a base (Scheme 1, (4)). Therefore, a simple method for synthesizing this type of coumarins using easily available and cheap reactants is very essential.

In our lab, the same reaction of dimedone with 2-bromobenzoic acid was charged with CuI/L-proline using 1.0 equiv of Cs_2CO_3 as the base under Ar atmosphere. To our delight, the desired 1*H*-benzo[*c*]chromene-1,6(2*H*)-dione was obtained in 76% yield. With the deepening of our research, the methylene on 4-position could be oxidized regioselectively under aerobic

Scheme 1. Approaches to benzo[*c*]coumarins.



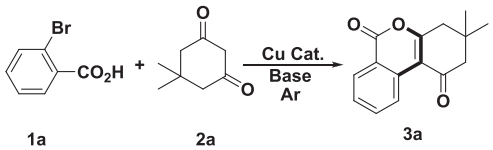
conditions, leading to 1*H*-benzo[*c*]chromene-1,4,6-trione in good yields. More interesting is that this oxidization could be controlled step by step via regulating the number of the substituents on cyclohexane-1,3-dione. The final products were 1-hydroxy-6*H*-benzo[*c*]chromen-6-ones through subsequent partial oxidation, dehydration, and enolization. As our continuous study on the construction of functionalized heterocycles catalyzed by copper [18], herein, we would like to report the reaction of 2-bromobenzoic acid and cyclohexane-1,3-dione catalyzed by CuI under aerobic or anaerobic conditions, leading to structurally diversified benzo[*c*]chromene derivatives (Scheme 1, (5)).

RESULTS AND DISCUSSION

In our initial study, the reaction of 2-bromobenzoic acid (**1a**) and dimedone (**2a**) was used as the model to optimize the reaction conditions (Table 1). Under argon atmosphere, the various kinds of copper sources, such as CuX (X = I, Br, Cl), CuOAc, Cu_2O, $CuBr_2$, and copper powder, were screened in the presence of K_2CO_3 (1.0 equiv) using DMF as a solvent at 100°C for 20 h, and the effect of cuprous salts was obviously better than that of Cu_2O. To our delight, the CuI gave the best result leading **3a** in 56% yield. However, the $CuBr_2$ and Cu powder were unreactive to this reaction, which no desired **3a** was observed by thin-layer chromatography (TLC). Then, organic bases, such as Et_3N and DBU, or inorganic bases including Na_2CO_3, Cs_2CO_3, and NaH, were also tested using 10 mol% CuI as the catalyst in DMF, and it was found that strong base was beneficial to this conversion. Cs_2CO_3 (100 mol%) gave almost the same result (63% yield, Table 1, entry 11) as that of NaH (64% yield), and organic bases nearly conducted nonreactivity for this reaction because only trace amount of **3a** was observed

Table 1

Optimization of the reaction conditions.[a]



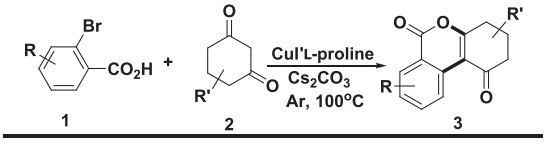
Entry	Catalyst	Ligand	Solvent	Base	Yields (%)[a]
1	CuI	—	DMF	K_2CO_3	56
2	CuBr	—	DMF	K_2CO_3	36
3	CuCl	—	DMF	K_2CO_3	21
4	CuOAc	—	DMF	K_2CO_3	38
5	Cu_2O	—	DMF	K_2CO_3	12
6	$CuBr_2$	—	DMF	K_2CO_3	0
7	Cu	—	DMF	K_2CO_3	0
8	CuI	—	DMF	Et_3N	Trace
9	CuI	—	DMF	DBU	Trace
10	CuI	—	DMF	Na_2CO_3	48
11	CuI	—	DMF	Cs_2CO_3	63
12	CuI	—	DMF	NaH	64
13	CuI	L-Proline	DMF	Cs_2CO_3	76
14	CuI	*o*-Phen	DMF	Cs_2CO_3	72
15	CuI	PPh_3	DMF	Cs_2CO_3	68
16	CuI	L-Proline	DMSO	Cs_2CO_3	72
17	CuI	L-Proline	DME	Cs_2CO_3	62
18	CuI	L-Proline	DMA	Cs_2CO_3	75

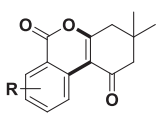
Reaction conditions: **1a** (101 mg, 0.5 mmol), **2a** (70 mg, 0.5 mmol), catalyst (0.05 mmol), ligand (0.1 mmol), solvent (10.0 mL), and base (0.5 mmol), 100°C, 20 h.
[a]Isolated yields.

by TLC. Moreover, when the common ligands of metal copper, such as L-proline, *o*-phen, and PPh_3, were added to the catalytic system, the coordinate CuI all indicated higher catalytic activity comparing with ligand-free conditions, and L-proline showed the highest activity, leading **3a** in 76% yield (Table 1, entry 13).

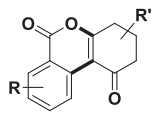
Table 2

Synthetic results of 1*H*-benzo[*c*]chromene-1,6(2*H*)-dione.





3a, R = H, 76%
3b, R = 7-Me, 78%
3c, R = 8-OMe, 82%
3d, R = 8-F, 75%
3e, R = 8-Me, 81%
3f, R = 9-Cl, 74%
3g, R = 9-F, 75%
3h, R = 9-Me, 80%
3i, R = 8,9-$(OMe)_2$, 82%

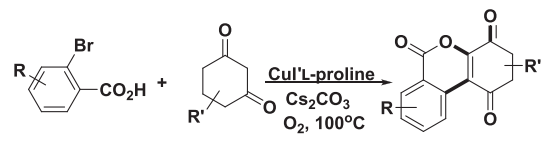


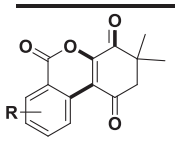
3j, R = 9-Me, R' = H, 73%
3k, R = 9-Me, R' = 3-Ph, 72%
3l, R = H, R' = 2,2-Me_2, 80%

Reaction condition: **1** (0.5 mmol), **2** (0.5 mmol), Cs_2CO_3 (163 mg, 0.5 mmol), CuI (10 mg, 0.05 mmol), L-proline (12 mg, 0.1 mmol), and DMF (10.0 mL), 20 h.

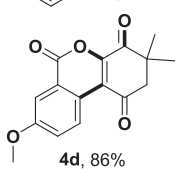
Table 3

Synthetic results of 1*H*-benzo[*c*]chromene-1,4,6-triones.

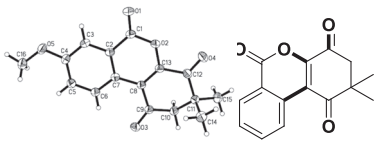




4a, R = H, 79%
4b, R = 7-Me, 84%
4c, R = 8-Me, 89%
4e, R = 9-Me, 55%
4f, R = 8,9-$(OMe)_2$, 80%



4d, 86%



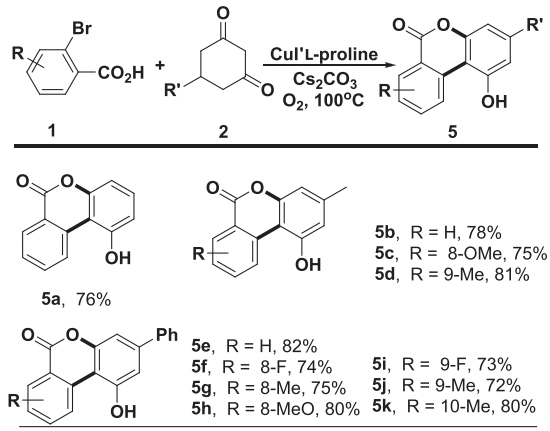
4g, 84%

Reaction condition: **1** (0.5 mmol), **2** (0.5 mmol), Cs_2CO_3 (163 mg, 0.5 mmol), CuI (10 mg, 0.05 mmol), L-proline (12 mg, 0.1 mmol), and DMF (10.0 mL), O_2 balloon, 20 h.

Finally, we tried to examine the use of a variety of solvents (e.g. DMSO, DME, and DMA) in order to further increase the reaction yield. However, they all failed to provide better result than in the solvent of DMF. After evaluating various conditions, we obtained the optimum results using 10 mol% CuI accompanied by 20 mol% L-porline, 1.0 equiv of Cs_2CO_3 in DMF at 100°C.

Table 4

Synthetic results of 1-hydroxy-6*H*-benzo[*c*]chromen-6-ones.

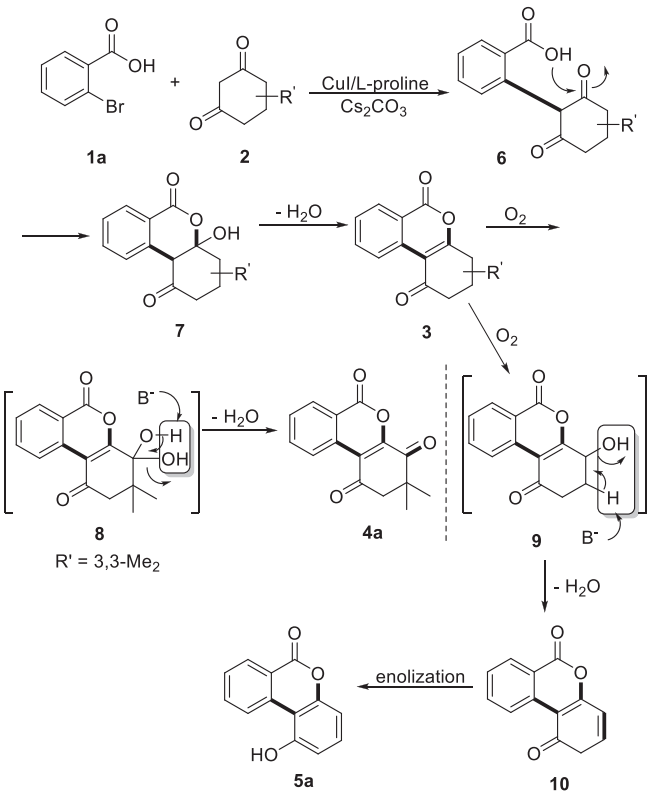


Reaction condition: **1** (0.5 mmol), **2** (0.5 mmol), Cs_2CO_3 (163 mg, 0.5 mmol), CuI (10 mg, 0.05 mmol), L-proline (12 mg, 0.1 mmol), and DMF (10.0 mL), O_2 balloon, 20 h.

Under the optimized reaction conditions, 2-bromobenzoic acids bearing electron-donating groups, such as methyl or methoxy, and electron-withdrawing groups (e.g. Cl or F), all gave **3a–3i** in the satisfied yields (Table 2, 74–82%). Other dimedone analogues, for example, cyclohexane-1,3-dione, 5-phenylcyclohexane-1,3-dione, and 4,4-dimethylcyclohexane-1,3-dione, also afforded the good results, leading to **3** in 72–80% yields (Table 2, **3j–3l**).

Surprisingly, the previously mentioned reaction also could be proceeded smoothly under air keeping all other reaction conditions as the same. However, a byproduct was observed by TLC gradually as reaction time was prolonged. Subsequently, it (R = 5-MeO, $R^1 = R^2$ = Me) was isolated in 42% yield by column chromatography. One of the methylene groups disappeared in ^{1}H-NMR. Instead, it changed to a new carbonyl group which was found in its ^{13}C-NMR. In order to identify which methylene was oxidized in the air? The X-ray diffraction analysis of product **4d** was determined, and it was 8-methoxy-3,3-dimethyl-2,3-dihydro-1*H*-benzo[*c*]chromene-1,4,6-trione. Table 3

Scheme 2. The possible reaction mechanism.



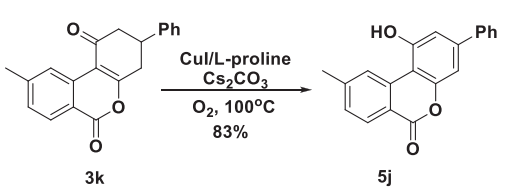
indicated that the methylene on 4-position was oxidized selectively to corresponding carbonyl group automatically.

Because the air functioned as a green oxidant in this subsequent oxidation reaction, we repeated the same reaction under the pure oxygen atmosphere. The yield of **4d** could be improved observably from 42% to 86%. Under O_2 balloon, total of seven 1*H*-benzo[*c*]chromene-1,4,6-triones were obtained in moderate yields with high regioselectivity.

It was very interesting that the regioselective oxidation reaction could be carried out step by step via group controlling. If one of the substituent groups (R^1 or R^2) was hydrogen atom, only one C—H bond was oxidized to C—OH. The dehydration took place unexpectedly followed by an enolization in cyclohexane-1,3-dione, and phenol analogue was obtained finally. Table 4 indicated that cyclohexane-1,3-dione, 5-methylcyclohexane-1,3-dione, and 5-phenylcyclohexane-1,3-dione, especially for 5-phenylcyclohexane-1,3-dione, all gave partial oxidation products in good yields (Table 4). The key step of this partial oxidation is enolization. If there are two substituent groups on one position in cyclohexane-1,3-dione, such as 5,5-dimethylcyclohexane-1,3-dione, or 4,4-dimethylcyclo hexane-1,3-dione (Table 3), the enolization was hold back. Therefore, the second oxidation went on to give ketone hydrate, which converted to corresponding product **4** immediately.

According to the previously mentioned results, we think that the first is α-arylation of carbonyl group catalyzed by CuI/L-proline, which was well documented by Ma and other groups [19]. And then, the carboxyl negative ion in **6** attacks the carbonyl followed by dehydration to give product **3**. Under aerobic conditions, the methylene on 4-position is oxidized into two C—O—H bonds (**8**, the similar allylic oxidations were realized by metal catalyst of $Rh_2(esp)_2$[20]), and **8** loses a molecule of water to afford product **4**. When there is a hydrogen atom on 3-position, the partial oxidation takes place first to lead intermediate product **9**. The dehydration preferentially conducts to give ketone structure **10**, and the final product **5** is obtained via an enolization. The possible reaction mechanism is outlined in Scheme 2.

Scheme 3. The controlled reaction.



If **3k** was treated with CuI/L-proline in the presence of Cs_2CO_3 under oxygen balloon at 100°C, product **5j** was obtained in 83% yield (Scheme 3). This controlled reaction indicated that the first conversion is cyclization to benzo[*c*]chromene analogue and then allylic oxidation.

CONCLUSION

In summary, the selective oxidation reaction of 2-bromobenzoic acid and cyclohexane-1,3-dione catalyzed by CuI/L-proline was found in the presence of Cs_2CO_3. Under Ar atmosphere, it gave normal 1*H*-benzo[*c*] chromene-1,6(2*H*)-dione derivatives in good yields. The O_2 as a greener oxidant could promote the subsequent regioselective oxidation to provide 1*H*-benzo[*c*]chromene-1,4,6-triones. It was controlled by substituents to undergo a partial oxidation, leading to structurally diversified 1-hydroxy-6*H*-benzo[*c*]chromen-6-one derivatives.

EXPERIMENTAL

Melting points were determined in open capillaries and are uncorrected. IR spectra were recorded on a TENSOR 27 spectrometer in KBr. NMR spectra were obtained from solution in $CDCl_3$ with Me_4Si as internal standard using a Bruker 400 spectrometer (Bruker Corp., Billerica, MA). HRMS analyses were carried out using a Bruker micrOTOF-Q MS analyzer (Bruker Corp.).

General procedure for the syntheses of 1*H*-benzo[*c*]chromene-1,6(2*H*)-diones 3 (using **3a** as a model). 2-Bromobenzoic acid (101 mg, 0.5 mmol), dimetone (70 mg, 0.5 mmol), CuI (10 mg, 0.05 mmol), L-proline (12 mg, 0.1 mmol), and Cs_2CO_3 (163 mg, 0.5 mmol) were added to a dry reaction flask with high vacuum valve. After three times in vacuum and replacement of argon, DMF (10.0 mL) was injected into the mixture. Before reaching completion, the reaction mixture was stirred and heated at 100°C under an Ar balloon. The mixture was poured into 50-mL water, and the yellow precipitate was formed and collected by filtration. The crude product was purified by chromatography over silica gel to give **3a** using ethyl acetate and petroleum ether (1:6) as an eluent.

3,3-Dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3a). Yield: 76% (92 mg); pale yellow solid; mp 127–128°C (lit. [13] mp 125–126°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.17 (s, 3H), 1.18 (s, 3H), 2.53 (d, J = 3.2 Hz, 2H), 2.80 (d, J = 2.8 Hz, 2H), 7.52–7.56 (m, 1H), 7.78–7.82 (m, 1H), 8.29 (d, J = 7.6 Hz, 1H), 9.05 (dd, J = 8.0 Hz, J' = 2.0 Hz, 1H); IR (KBr): ν 3117, 2966, 1736, 1668, 1618, 1482, 1372, 1335, 1323, 1248, 1195, 1155, 1061, 1035, 1022, 780 cm^{-1}; HRMS (TOF,

ESI, *m/z*): Calcd for $C_{15}H_{15}O_3$ $[M + H]^+$ 243.1016, found 243.1016.

3,3,7-Trimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3b). Yield: 78% (100 mg); pale yellow solid; mp 112–114°C (lit. [13] mp 109–110°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.17 (s, 6H, $2CH_3$), 2.51 (s, 2H), 2.77 (s, 2H), 2.80 (s, 3H), 7.33 (d, J = 7.6 Hz, 1H), 7.62–7.65 (m, 1H), 8.96 (d, J = 8.0 Hz, 1H); IR (KBr): ν 2961, 2929, 1744, 1674, 1621, 1473, 1426, 1383, 1363, 1328, 1295, 1240, 1163, 1065, 1012, 999, 768 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{17}O_3$ $[M + H]^+$ 257.1172, found 257.1168.

8-Methoxy-3,3-dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3c). Yield: 82% (112 mg); pale yellow solid; mp 141–142°C (lit. [15] mp 139–141°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.18 (s, 6H, $2CH_3$), 2.51 (s, 2H), 2.79 (s, 2H), 3.91 (s, 3H), 7.36 (dd, J = 8.8 Hz, J' = 2.8 Hz, 1H), 7.70 (d, J = 2.8 Hz, 1H), 8.98 (d, J = 9.2 Hz, 1H); IR (KBr): ν 2963, 2875, 1731, 1667, 1615, 1500, 1471, 1374, 1375, 1345, 1252, 1225, 1156, 1058, 1035, 884, 777 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{16}O_4Na$ $[M + Na]^+$ 295.0946, found 295.0952.

8-Fluoro-3,3-dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3d). Yield: 75% (98 mg); pale yellow solid; mp 147–148°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.19 (s, 6H, $2CH_3$), 2.53 (s, 2H), 2.81 (s, 2H), 7.48–7.53 (m, 1H), 7.91–7.94 (m, 1H), 9.10 (dd, J = 9.2 Hz, J' = 5.2 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 28.1, 32.0, 42.4, 52.7, 110.2, 115.0 (d, J_{F-C} = 23.1 Hz), 121.8 (d, J_{F-C} = 7.9 Hz), 123.6 (d, J_{F-C} = 21.7 Hz), 128.7 (d, J_{F-C} = 7.4 Hz), 130.4 (d, J_{F-C} = 2.9 Hz), 159.9 (d, J_{F-C} = 3.3 Hz), 161.8 (d, J_{F-C} = 249.5 Hz), 167.3, 196.8; IR (KBr): ν 3082, 2960, 2925, 1744, 1678, 1621, 1497, 1430, 1397, 1318, 1249, 1208, 1152, 1144, 1055, 1037, 947, 833, 781 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{15}H_{14}FO_3$ $[M + H]^+$ 261.0921, found 261.0911.

3,3,8-Trimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3e). Yield: 81% (104 mg); pale yellow solid; mp 153–155°C (lit. [13] mp 151–152°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.18 (s, 6H, $2CH_3$), 2.46 (s, 3H), 2.51 (s, 2H), 2.79 (s, 2H), 7.60 (dd, J = 8.8 Hz, J' = 2.0 Hz, 1H), 8.08 (s, 1H), 8.92 (d, J = 8.4 Hz, 1H); IR (KBr): ν 2966, 2921, 1731, 1673, 1619, 1504, 1467, 1365, 1331, 1254, 1157, 1065, 1041, 877, 784 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{17}O_3$ $[M + H]^+$ 257.1172, found 257.1177.

9-Chloro-3,3-dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3f). Yield: 74% (102 mg); pale yellow solid; mp 157–159°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.18 (s, 6H, $2CH_3$), 2.53 (s, 2H), 2.81 (s, 2H), 7.49 (dd, J = 8.4 Hz, J' = 2.0 Hz, 1H), 8.20 (d, J = 8.4 Hz, 1H), 9.11 (d, J = 2.0 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 28.1, 31.9, 42.6, 52.7, 109.8, 118.1, 125.8, 129.0, 131.1, 135.1, 142.8, 160.0, 169.1, 196.5; IR (KBr): ν 3114, 2967, 2871, 1740, 1666, 1593, 1475, 1374, 1373, 1307, 1240, 1161, 1084, 1035, 998, 904, 781 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{15}H_{14}ClO_3$ $[M + H]^+$ 277.0626, found 277.0627.

9-Fluoro-3,3-dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3g). Yield: 75% (98 mg); pale yellow solid; mp 171–172°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.19 (s, 6H, $2CH_3$), 2.53 (s, 2H), 2.81 (s, 2H), 7.20–7.25 (m, 1H), 8.31 (dd, J = 8.8 Hz, J' = 5.6 Hz, 1H), 8.80 (dd, J = 11.2 Hz, J' = 2.8 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 28.1, 32.0, 42.6, 52.6, 110.0 (d, J_{F-C} = 3.0 Hz), 112.5 (d, J_{F-C} = 26.0 Hz), 116.2 (d, J_{F-C} = 2.2 Hz), 116.7 (d, J_{F-C} = 23.3 Hz), 132.7 (d, J_{F-C} = 10.5 Hz), 136.6 (d, J_{F-C} = 12.3 Hz), 159.8, 167.3 (d, J_{F-C} = 254.6 Hz), 169.2, 196.8; IR (KBr): ν 3082, 2960, 2925, 1744, 1678, 1621, 1497, 1430, 1397, 1318, 1249, 1208, 1152, 1144, 1055, 1037, 947, 833, 781 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{15}H_{14}FO_3$ $[M + H]^+$ 261.0921, found 261.0935.

3,3,9-Trimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3h). Yield: 80% (102 mg); pale yellow solid; mp 147–148°C (lit. [13] mp 143–145°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.18 (s, 6H, $2CH_3$), 2.51 (s, 3H), 2.52 (s, 2H), 2.79 (s, 2H), 7.35 (dd, J = 8.0 Hz, J' = 1.2 Hz, 1H), 8.18 (d, J = 8.0 Hz, 1H), 8.87 (s, 1H); IR (KBr): ν 2965, 2929, 1744, 1675, 1621, 1566, 1488, 1368, 1314, 1249, 1159, 1149, 1033, 904, 830, 776 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{17}O_3$ $[M + H]^+$ 257.1172, found 257.1170.

8,9-Dimethoxy-3,3-dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3i). Yield: 82% (124 mg); pale yellow solid; mp 155–156°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.18 (s, 6H, $2CH_3$), 2.52 (s, 2H), 2.80 (s, 2H), 3.99 (s, 3H), 4.05 (s, 3H), 7.64 (s, 1H), 8.65 (s, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 28.1, 32.0, 42.5, 52.9, 56.2, 56.4, 107.0, 109.4, 110.3, 113.0, 129.7, 149.4, 155.5, 160.6, 167.3, 197.4; IR (KBr): ν 3125, 3034, 1717, 1686, 1621, 1598, 1575, 1450, 1374, 1396, 1299, 1202, 1096, 1048, 988, 900, 845, 778 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{17}H_{18}NaO_5$ $[M + Na]^+$ 325.1052, found 325.1052.

9-Methyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3j). Yield: 73% (83 mg); pale yellow solid; mp 127–128°C (lit. [13] mp 129–130°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 2.15–2.19 (m, 2H), 2.52 (s, 3H), 2.66 (t, J = 6.8 Hz, 2H), 2.93 (t, J = 6.8 Hz, 2H), 7.35 (d, J = 8.0 Hz, 1H), 8.17 (d, J = 8.4 Hz, 1H), 8.87 (s, 1H); IR (KBr): ν 2965, 2941, 1746, 1717, 1686, 1634, 1606, 1492, 1463, 1321, 1284, 1195, 1155, 1061, 1035, 1022, 780 cm^{-1}; HRMS (TOF, APCI, *m/z*): Calcd for $C_{14}H_{13}O_3$ $[M + H]^+$ 229.0859, found 229.0860.

9-Methyl-3-phenyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3k). Yield: 72% (109 mg); pale yellow solid; mp 170–171°C (lit. [13] mp 168–169°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 2.53 (s, 3H), 2.85–2.98

(m, 2H), 3.15–3.17 (m, 2H), 3.52–3.59 (m, 1H), 7.29–7.33 (m, 3H), 7.35–7.41 (m, 3H), 8.18 (d, J = 8.0 Hz, 1H), 8.90 (s, 1H); IR (KBr): ν 3163, 3125, 3033, 1717, 1687, 1621, 1598, 1419, 1397, 1299, 1202, 1096, 1048, 1013, 988, 970, 845, 777 cm^{-1}; HRMS (TOF, APCI, *m/z*): Calcd for $C_{20}H_{17}O_3$ $[M + H]^+$ 305.1172, found 305.1160.

2,2-Dimethyl-3,4-dihydro-1H-benzo[c]chromene-1,6(2H)-dione (3l). Yield: 80% (97 mg); pale yellow solid; mp 111–112°C (lit. [15] mp 109–110°C); ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.25 (s, 6H, $2CH_3$), 2.01 (t, J = 6.4 Hz, 2H), 2.95 (d, J = 6.4 Hz, 2H), 7.50–7.55 (m, 1H), 7.76–7.81 (m, 1H), 8.29 (dd, J = 8.0 Hz, J' = 1.2 Hz, 1H), 9.04 (d, J = 8.4 Hz, 1H); IR (KBr): ν 2969, 2633, 1766, 1736, 1666, 1617, 1563, 1480, 1450, 1375, 1366, 1317, 1246, 1185, 1156, 1018, 984, 840, 785 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{15}H_{15}O_3$ $[M + H]^+$ 243.1016, found 243.1000.

General procedure for the syntheses of 1*H*-benzo[*c*]chromene-1,4,6-triones 4 (using **4a** as a model). This procedure is almost the same as that of **3a**, except for replacement with oxygen and being controlled in an O_2 balloon until all **2a** was consumed.

3,3-Dimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4a). Yield: 79% (101 mg); pale yellow solid; mp 124–125°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.40 (s, 6H, $2CH_3$), 3.00 (s, 2H), 7.72–7.76 (m, 1H), 7.88–7.92 (m, 1H), 8.41 (d, J = 7.6 Hz, 1H), 8.95 (d, J = 8.4 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 25.8, 45.4, 53.5, 119.0, 122.7, 128.0, 130.3, 131.4, 131.5, 135.8, 150.6, 159.0, 193.8, 195.1.

3,3,7-Trimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4b). Yield: 84% (113 mg); pale yellow solid; mp 167–168°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.38 (s, 6H, $2CH_3$), 2.85 (s, 3H), 2.90 (s, 2H), 7.53 (d, J = 7.6 Hz, 1H), 7.77–7.75 (m, 1H), 8.80 (d, J = 8.0 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 23.7, 25.7, 29.7, 45.0, 53.9, 119.3, 120.9, 125.9, 132.6, 134.9, 144.3, 150.5, 158.1, 193.9, 195.2; IR (KBr): ν 3002, 2961, 2930, 1755, 1663, 1618, 1606, 1560, 1484, 1460, 1420, 1362, 1309, 1250, 1187, 1131, 1052, 1017, 987, 842, 773 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{15}O_4$ $[M + H]^+$ 271.0965, found 271.0955.

3,3,8-Trimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4c). Yield: 89% (120 mg); pale yellow solid; mp 177–179°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.39 (s, 6H, $2CH_3$), 2.53 (s, 3H), 2.99 (s, 2H), 7.69–7.72 (m, 1H), 8.21 (s, 1H), 8.82 (d, J = 8.4 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 22.4, 25.7, 45.0, 53.6, 119.1, 120.2, 128.1, 130.3, 131.3, 132.7, 147.3, 150.8, 159.0, 193.9, 195.9; IR (KBr): ν 3011, 2982, 2969, 2931, 1749, 1709, 1670, 1609, 1560, 1360, 1291, 1258, 1198, 1074, 1032, 918, 785 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{15}O_4$ $[M + H]^+$ 271.0965, found 271.0954.

8-Methoxy-3,3-dimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4d). Yield: 86% (123 mg); pale yellow solid; mp 173–175°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.38 (s, 6H, $2CH_3$), 2.98 (s, 2H), 3.96 (s, 3H), 7.43 (dd, J = 9.2 Hz, J' = 2.8 Hz, 1H), 7.80 (d, J = 2.8 Hz, 1H), 7.86 (d, J = 9.2 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 25.9, 44.9, 53.6, 55.9, 111.5, 119.4, 124.3, 124.6, 129.9, 148.9, 159.1, 162.0, 193.7, 195.4; IR (KBr): ν 3020, 2982, 2969, 2931, 1750, 1710, 1671, 1610, 1407, 1360, 1312, 1258, 1199, 1074, 1032, 918, 840, 774 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{14}NaO_5$ $[M + Na]^+$ 309.0739, found 309.0741.

3,3,9-Trimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4e). Yield: 55% (74 mg); pale yellow solid; mp 165–166°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.39 (s, 6H, $2CH_3$), 2.56 (s, 3H), 2.90 (s, 2H), 7.54 (d, J = 8.0 Hz, 1H), 8.28 (d, J = 8.0 Hz, 1H), 8.74 (s, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 22.4, 25.8, 45.0, 53.6, 119.1, 120.2, 128.1, 130.3, 131.3, 132.7, 147.3, 150.8, 159.0, 193.9, 195.3; IR (KBr): ν 3030, 2961, 2930, 1755, 1663, 1618, 1606, 1560, 1484, 1460, 1420, 1362, 1309, 1250, 1187, 1131, 1052, 1017, 987, 842, 773 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{16}H_{15}O_4$ $[M + H]^+$ 271.0965, found 271.0956.

8,9-Dimethoxy-3,3-dimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4f). Yield: 80% (126 mg); pale yellow solid; mp 197–198°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.39 (s, 6H, $2CH_3$), 3.00 (s, 2H), 4.03 (s, 3H), 4.07 (s, 3H), 7.73 (s, 1H), 8.47 (s, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 25.8, 44.9, 53.5, 56.4, 56.5, 108.6, 110.1, 116.7, 118.7, 126.4, 149.9, 151.9, 155.4, 158.9, 193.6, 195.9; IR (KBr): ν 3023, 2974, 2948, 1746, 1717, 1696, 1594, 1523, 1463, 1394, 1354, 1284, 1237, 1072, 1043, 878, 767 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{17}H_{16}NaO_6$ $[M + Na]^+$ 339.0845, found 339.0844.

2,2-Dimethyl-2,3-dihydro-1H-benzo[c]chromene-1,4,6-trione (4g). Yield: 84% (107 mg); pale yellow solid; mp 188–189°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 1.47 (s, 6H, $2CH_3$), 2.69–2.73 (m, 2H), 7.52–7.56 (m, 1H), 7.77–7.81 (m, 1H), 8.29 (dd, J = 8.0 Hz, J' = 1.2 Hz, 1H), 9.07 (dd, J = 8.4 Hz, J' = 0.4 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 26.3, 34.8, 35.8, 110.1, 119.8, 126.4, 128.4, 129.4, 134.2, 135.5, 160.7, 174.3, 197.0; IR (KBr): ν 3021, 2961, 2930, 1755, 1663, 1618, 1606, 1560, 1484, 1460, 1420, 1362, 1309, 1250, 1187, 1131, 1052, 1017, 987, 842, 773 cm^{-1}; HRMS (TOF, APCI, *m/z*): Calcd for $C_{15}H_{13}O_4$ $[M + H]^+$ 257.0808, found 257.0807.

General procedure for the syntheses of 1-hydroxy-6*H*-benzo[*c*]chromen-6-ones 5 (using **5a** as a model). This procedure is almost the same as that of **4a**, except for using a mixture of ethyl acetate and petroleum ether (1:4) as an eluant in the purification.

1-Hydroxy-6H-benzo[c]chromen-6-one (5a). Yield: 76% (81 mg); pale yellow solid; mp 231–233°C (lit. [15] mp 227–229°C); ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 6.87–6.93 (m, 2H), 7.33–7.37 (m, 1H), 7.61–7.65 (m, 1H), 7.90–7.94 (m, 1H), 8.28 (dd, J = 8.0 Hz, J' = 1.2 Hz, 1H), 9.15 (d, J = 8.4 Hz, 1H), 11.09 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 106.5, 108.2, 112.5, 120.5, 127.6, 128.5, 129.9, 130.7, 135.1, 135.5, 152.6, 157.2, 160.9; IR (KBr): ν 3250, 3130, 2917, 1704, 1616, 1604, 1486, 1434, 1356, 1320, 1262, 1219, 1103, 1052, 1021, 789 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{13}H_7O_3$ $[M - H]^-$ 211.0395, found 211.0392.

1-Hydroxy-3-methyl-6H-benzo[c]chromen-6-one (5b). Yield: 78% (88 mg); pale yellow solid; mp 216–217°C (lit. [15] mp 215–217°C); ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 2.31 (s, 3H), 6.72 (s, 2H), 7.57–7.61 (m, 1H), 7.87–7.91 (m, 1H), 8.24 (dd, J = 7.6 Hz, J' = 1.2 Hz, 1H), 9.07 (d, J = 8.4 Hz, 1H), 10.95 (s, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 21.4, 104.1, 108.7, 113.2, 120.1, 127.2, 128.0, 129.9, 135.2, 135.5, 141.0, 152.5, 156.8, 161.0; IR (KBr): ν 3347, 3030, 2924, 1701, 1617, 1608, 1405, 1314, 1269, 1112, 1059, 1029, 774 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{14}H_9O_3$ $[M - H]^-$ 225.0552, found 225.0564.

1-Hydroxy-8-methoxy-3-methyl-6H-benzo[c]chromen-6-one (5c). Yield: 75% (96 mg); pale yellow solid; mp 191–192°C; ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 2.30 (s, 3H), 3.89 (s, 3H), 6.71 (s, 2H), 7.50 (dd, J = 9.2 Hz, J' = 3.2 Hz, 1H), 7.68 (d, J = 2.8 Hz, 1H), 9.01 (d, J = 8.8 Hz, 1H), 10.84 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 21.4, 56.0, 104.1, 108.6, 111.6, 113.0, 121.5, 123.6, 128.5, 129.1, 139.8, 151.7, 156.0, 158.6, 160.9; IR (KBr): ν 3285, 3059, 1706, 1684, 1657, 1620, 1487, 1398, 1285, 1199, 1055, 833, 740 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{15}H_{11}O_4$ $[M - H]^-$ 255.0651, found 255.0671.

1-Hydroxy-3,9-dimethyl-6H-benzo[c]chromen-6-one (5d). Yield: 81% (97 mg); pale yellow solid; mp 187–189°C; ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 2.30 (s, 3H), 2.49 (s, 3H), 6.69 (s, 1H), 6.71 (s, 1H), 7.40 (dd, J = 8.0 Hz, J' = 0.8 Hz, 1H), 8.13 (d, J = 8.0 Hz, 1H), 8.89 (s, 1H), 10.89 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 21.4, 22.6, 104.0, 108.7, 113.1, 117.7, 127.3, 129.0, 129.9, 135.2, 140.9, 145.9, 152.7, 156.8, 161.0; IR (KBr): ν 3376, 3140, 1700, 1619, 1564, 1524, 1492, 1459, 1397, 1333, 1322, 1273, 1094, 929, 852, 741 cm^{-1}; HRMS (TOF, APCI, *m/z*): Calcd for $C_{15}H_{13}O_3$ $[M + H]^+$ 241.0859, found 241.0860.

1-Hydroxy-3-phenyl-6H-benzo[c]chromen-6-one (5e). Yield: 82% (118 mg); pale yellow solid; mp 273–275°C (lit. [15] mp 270–272°C); ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 7.20 (d, J = 1.2 Hz, 1H), 7.21 (d, J = 1.2 Hz, 1H), 7.41–7.45 (m, 1H), 7.50–7.53 (m, 2H), 7.62–7.66 (m, 1H), 7.70–7.72 (m, 2H), 7.91–7.96 (m, 1H), 8.29 (dd, J = 8.0 Hz, J' = 1.2 Hz, 1H), 9.15 (d, J = 7.6 Hz, 1H), 11.26 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 105.8, 106.3, 110.4, 120.5, 127.1, 127.5, 128.5, 128.9, 129.6, 130.0, 134.8, 135.6, 138.9, 142.2, 153.1, 157.4, 161.0; IR (KBr): ν 3241, 2917, 1690, 1628, 1606, 1480, 1412, 1325, 1304, 1280, 1224, 1105, 1065, 822, 724 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{19}H_{11}O_3$ $[M - H]^-$ 287.0708, found 287.0699.

8-Fluoro-1-hydroxy-3-phenyl-6H-benzo[c]chromen-6-one (5f). Yield: 74% (113 mg); pale yellow solid; mp 190–191°C; ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 7.20 (d, J = 1.2 Hz, 1H), 7.22 (d, J = 1.2 Hz, 1H), 7.41–7.45 (m, 1H), 7.49–7.53 (m, 2H), 7.69–7.71 (m, 2H), 7.79–7.84 (m, 1H), 7.97 (dd, J = 8.8 Hz, J' = 2.8 Hz, 1H), 9.19 (d, J = 9.2 Hz, J' = 5.2 Hz, 1H), 11.33 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 105.1 (d, J_{F-C} = 2.6 Hz), 106.3, 110.3, 113.4 (d, J_{F-C} = 26.0 Hz), 116.2 (d, J_{F-C} = 23.1 Hz), 117.3 (d, J_{F-C} = 2.0 Hz), 127.1, 129.0, 129.6, 133.4 (d, J_{F-C} = 10.6 Hz), 137.5 (d, J_{F-C} = 11.7 Hz), 138.7, 143.0, 153.3, 157.4, 160.1, 166.3 (d, J_{F-C} = 249.5 Hz); IR (KBr): ν 3365, 3034, 1705, 1616, 1604, 1600, 1512, 1471, 1322, 1196, 1103, 1036, 834, 789 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{19}H_{10}FO_3$ $[M - H]^-$ 305.0614, found 305.0629.

1-Hydroxy-8-methyl-3-phenyl-6H-benzo[c]chromen-6-one (5g). Yield: 75% (113 mg); pale yellow solid; mp 198–199°C; ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 2.47 (s, 3H), 7.17 (s, 1H), 7.18 (s, 1H), 7.40–7.44 (m, 1H), 7.49–7.52 (m, 2H), 7.69 (d, J = 8.0 Hz, 2H), 7.74 (d, J = 8.4 Hz, 1H), 8.09 (s, 1H), 9.02 (d, J = 8.8 Hz, 1H), 11.04 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 21.1, 106.0, 106.2, 110.4, 120.4, 127.0, 127.5, 128.7, 129.5, 129.7, 132.3, 136.5, 138.2, 139.1, 141.2, 152.9, 157.1, 161.0; IR (KBr): ν 3289, 3059, 3033, 1705, 1684, 1657, 1487, 1398, 1285, 1104, 1055, 834, 740 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{20}H_{13}O_3$ $[M - H]^-$ 301.0865, found 301.0881.

1-Hydroxy-8-methoxy-3-phenyl-6H-benzo[c]chromen-6-one (5h). Yield: 80% (127 mg); pale yellow solid; mp 210–211°C (lit. [15] mp 242–244°C); ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 3.90 (s, 3H), 7.16 (d, J = 1.2 Hz, 1H), 7.18 (d, J = 1.2 Hz, 1H), 7.40–7.43 (m, 1H), 7.48–7.54 (m, 3H), 7.68–7.70 (m, 3H), 9.06 (d, J = 9.2 Hz, 1H), 11.12 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 56.0, 105.9, 106.2, 110.3, 111.7, 121.9, 123.5, 127.0, 128.1, 128.7, 129.4, 129.6, 139.0, 141.1, 152.5, 156.5, 158.9, 160.8; IR (KBr): ν 3302, 3060, 1706, 1684, 1658, 1620, 1398, 1285, 1104, 1055, 857, 833, 789 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{20}H_{14}NaO_4$ $[M + Na]^+$ 341.0784, found 341.0780.

9-Fluoro-1-hydroxy-3-phenyl-6H-benzo[c]chromen-6-one (5i). Yield: 73% (112 mg); pale yellow solid; mp 193–195°C; ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 7.17 (s, 2H), 7.43–7.48 (m, 2H), 7.48–7.52 (m, 2H), 7.69–7.70 (m, 2H), 8.32 (dd, J = 8.8 Hz, J' = 6.4 Hz, 1H), 8.78 (dd, J = 12.0 Hz, J' = 2.4 Hz, 1H), 11.42 (s, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 105.0 (d, J_{F-C} = 2.6 Hz),

106.3, 110.3, 113.4 (d, J_{F-C} = 26.0 Hz), 116.2 (d, J_{F-C} = 23.1 Hz), 117.3 (d, J_{F-C} = 2.0 Hz), 127.1, 128.9, 129.6, 133.4 (d, J_{F-C} = 10.6 Hz), 137.5 (d, J_{F-C} = 11.7 Hz), 138.7, 142.9, 153.3, 157.4, 160.0, 166.3 (d, J_{F-C} = 249.5 Hz); IR (KBr): ν 3291, 3058, 3033, 1705, 1684, 1657, 1621, 1487, 1420, 1398, 1286, 1199, 1104, 1055, 834, 740 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{19}H_{10}FO_3$ $[M - H]^-$ 305.0614, found 305.0632.

1-Hydroxy-9-methyl-3-phenyl-6H-benzo[c]chromen-6-one (5j). Yield: 72% (109 mg); pale yellow solid; mp 185–187°C; ^{1}H-NMR (DMSO-d_6, 400 MHz): δ_H 2.51 (s, 3H), 7.17 (s, 1H), 7.18 (s, 1H), 7.38–7.43 (m, 2H), 7.50–7.53 (m, 2H), 7.70–7.72 (m, 2H), 8.16 (d, *J* = 8.0 Hz, 1H), 8.95 (s, 1H), 11.18 (brs, 1H); ^{13}C-NMR (DMSO-d_6, 100 MHz): δ_C 21.2, 105.9, 106.3, 110.3, 120.3, 127.0, 127.5, 128.8, 129.6, 129.7, 132.3, 136.6, 138.2, 139.0, 141.7, 152.8, 157.1, 161.0; IR (KBr): ν 3275, 1706, 1684, 1619, 1576, 1398, 1285, 1200, 1104, 1055, 833, 763, 740 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{20}H_{13}O_3$ $[M - H]^-$ 301.0865, found 301.0866.

1-Hydroxy-10-methyl-3-phenyl-6H-benzo[c]chromen-6-one (5k). Yield: 80% (121 mg); pale yellow solid; mp 197–198°C; ^{1}H-NMR ($CDCl_3$, 400 MHz): δ_H 2.59 (s, 3H), 5.59 (s, 1H), 7.01 (d, *J* = 1.2 Hz, 1H), 7.25 (d, *J* = 1.2 Hz, 1H), 7.42 (d, *J* = 7.6 Hz, 1H), 7.46–7.52 (m, 3H), 7.63–7.65 (m, 2H), 7.69 (d, *J* = 7.6 Hz, 1H), 8.24 (d, *J* = 8.0 Hz, 1H); ^{13}C-NMR ($CDCl_3$, 100 MHz): δ_C 23.1, 107.7, 110.5, 123.5, 126.9, 127.2, 127.7, 127.8, 128.4, 129.0, 132.5, 136.1, 137.8, 139.0, 143.1, 152.9, 158.5, 162.0; IR (KBr): ν 3273, 3061, 2916, 1706, 1659, 1591, 1506, 1482, 1377, 1340, 1246, 1034, 900, 778 cm^{-1}; HRMS (TOF, ESI, *m/z*): Calcd for $C_{20}H_{13}O_3$ $[M - H]^-$ 301.0865, found 301.0875.

Acknowledgments. This work was financially supported by the National Natural Science Foundation of China (no. 21702078) and Major Basic Research Project of the Natural Science Foundation of the Jiangsu Higher Education Institutions (17KJA150003).

REFERENCES AND NOTES

[1] (a) Liu, B.-Y.; Zhang, C.; Zeng, K.-W.; Li, J.; Guo, X.-Y.; Zhao, M.-B.; Tu, P.-F.; Jiang, Y. J Nat Prod 2018, 81, 22; (b) He, R.; Huang, X.; Zhang, Y.; Wu, L.; Nie, H.; Zhou, D.; Liu, B.; Deng, S.; Yang, R.; Huang, S.; Nong, Z.; Li, J.; Huang, Y. J Nat Prod 2016, 79, 2472; (c) Razavi, S. M.; Nahar, L.; Talischi, H.; Sarker, S. D. Nat Prod Res 2016, 30, 2183.

[2] Fernandes, T. S.; Copetti, D.; do Carmo, G.; Neto, A. T.; Pedroso, M.; Silva, U. F.; Mostardeiro, M. A.; Burrow, R. E.; Dalcol, I. I.; Morel, A. F. Phytochemistry 2017, 141, 131.

[3] Wang, Y.-S.; Li, B.-T.; Liu, S.-X.; Wen, Z.-Q.; Yang, J.-H.; Zhang, H.-B.; Hao, X.-J. J Nat Prod 2017, 80, 798.

[4] Pahari, P.; Kharel, M. K.; Shepherd, M. D.; van Lanen, S. G.; Rohr, J. Angew Chem Int Ed 2012, 51, 1216.

[5] Ashraf, R. H.; Hasanain, M.; Pandey, P.; Maheshwari, M.; Singh, L. R.; Siddiqui, M. Q.; Konwar, R.; Sashidhara, K. V.; Sarkar, J. Sci Rept 2017, 7, 45287.

[6] Dastan, D.; Salehi, P.; Aliahmadi, A.; Gohari, A. R.; Maroofi, H.; Ardalan, A. Nat Prod Res 2016, 30, 2747.

[7] Girolami, A.; Cosi, E.; Ferrari, S.; Girolami, B. J. Thromb Thrombolys 2018, 45, 135.

[8] Khajuria, R.; Mahajan, S.; Ambica, K.; Kamal, K. J. Chem Sci 2017, 129, 1549.

[9] Mugnai, G.; de Asmundis, C.; Iacopino, S.; Stroker, E.; Longobardi, M.; De Regibus, V.; Coutino-Moreno, H. E.; Takarada, K.; Choudhury, R.; Abugattas de Torres, J. P.; Storti, C.; Brugada, P.; Chierchia, G. B. Am J Cardiol 2017, 120, 223.

[10] Timson, D. J. Curr Drug Targets 2017, 18, 500.

[11] (a) Huang, X.; Zhu, T.; Huang, Z.; Zhang, Y.; Jin, Z.; Zanoni, G.; Chi, Y. R. Org Lett 2017, 19, 6188; (b) Sumida, Y.; Harada, R.; Kato-Sumida, T.; Johmoto, K.; Uekusa, H.; Hosoya, T. Org Lett 2014, 16, 6240; (c) Nandaluru, P. R.; Bodwell, G. J. J Org Chem 2012, 77, 8028; (d) Yang, S.-M.; Wang, C.-Y.; Lin, C.-K.; Karanam, P.; Reddy, G. M.; Tsai, Y.-L.; Lin, W. Angew Chem Int Ed 2018, 57, 1668; (e) Li, Q.; Zhao, X.; Li, Y.; Huang, M.; Kim, J. K.; Wu, Y. Org Biomol Chem 2017, 15, 9775; (f) Yang, Q.; Jia, Z.; Li, L.; Zhang, L.; Luo, S. Org Chem Front 2018, 5, 237; (g) Jin, S.-J.; Guo, J.-M.; Zhu, Y.-S.; Wang, Q.-L.; Bu, Z.-W. Org Biomol Chem 2017, 15, 8729.

[12] (a) Feng, Y.; Tan, G.; Zhou, L.; Wang, S.; Chen, H.; Li, X. Youji Huaxue 2017, 37, 429; (b) Krzeszewski, M.; Vakuliuk, O.; Gryko, D. T Eur J Org Chem 2013, 25, 5631; (c) Shi, J.; Liang, Y.; Zhang, Z. Z. Kristallogr Cryst Mater 2017, 232, 719.

[13] Yang, C.; He, X. W.; Zhang, L. L.; Han, G.; Zuo, Y. P.; Shang, Y. J. J Org Chem 2017, 82, 2081.

[14] Dao, P. D. Q.; Ho, S. L.; Lim, H.; Cho, C. S. J Org Chem 2018, 83, 4140.

[15] Fan, X. S.; He, Y.; Cui, L. Y.; Guo, S. H.; Wang, J. J.; Zhang, X. Y Eur J Org Chem 2012, 4, 673.

[16] Liu, L.; Hu, J.; Wang, X. C.; Zhong, M. J.; Liu, X. Y.; Yang, S. D.; Liang, Y. M. Tetrahedron 2012, 68, 5391.

[17] McKillop, A.; Rao, D. P Synthesis 1977, 11, 759.

[18] (a) Chen, D. S.; Dou, G. L.; Li, Y. L.; Liu, Y.; Wang, X. S. J Org Chem 2013, 78, 5700; (b) Feng, B. B.; Liu, J. Q.; Wang, X. S. J Org Chem 2017, 82, 1817; (c) Li, C.; Zhang, W. T.; Wang, X. S. J Org Chem 2014, 79, 5847; (d) Liu, J. Q.; Shen, X. Y.; Wang, Y.; Wang, X. S.; Bi, X. H. Org Lett 2018, 20, 6930.

[19] (a) Ma, D. W.; Cai, Q. Acc Chem Res 2008, 41, 1450; (b) Ma, D. W.; Geng, Q.; Zhang, H.; Jiang, Y. W. Angew Chem Int Ed 2010, 49, 1291; (c) Yang, T.; Lin, C.; Fu, H.; Jiang, Y.; Zhao, Y. Org Lett 2005, 7, 4781.

[20] Wang, Y.; Kuang, Y.; Wang, Y. Chem Commun 2015, 51, 5852.

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.