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Copper(II) Bromide-catalyzed Intramolecular Decarboxylative Functionalization to Form C(sp^3)–O Bond for the Synthesis of Furo[3,2-*c*]coumarins

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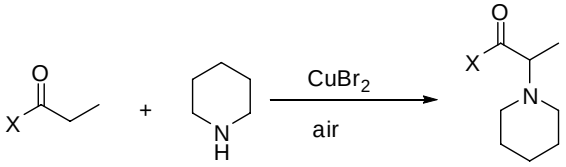
An efficient and eco-friendly copper(II) bromide-catalyzed intramolecular decarboxylative functionalization to form C(sp^3)-O bond for the synthesis of furo[3,2-*c*]coumarins has been developed. In this reaction, a copper(II) bromide-catalyzed intramolecular decarboxylative functionalization of *α*-carbonyl is successfully realized to generate an *α*-bromo carbonyl compound as a key intermediate.

Introduction

Furan is a privileged scaffold in a variety of biologically important natural products[1] and the development of efficient synthetic methods toward furan derivatives is an important task in modern organic synthesis.[2] As an important class of furan derivatives, furo[3,2-*c*]coumarins exhibit important biological activities[3] and are found in many natural products.[4] For example, Neo-tranchinlactone, a kind of furo[3,2-*c*]coumarin derivative, was isolated from Salvia miltiorrhiza and showed potent and selective antibreast cancer activity.[4e,4f] Consequently, much attention had been attracted for the construction of furo[3,2-*c*]coumarin derivatives.

There are several methods for the preparation of furo[3,2-*c*]coumarin derivatives. They mainly include: tandem alkylation and intramolecular aldolization reaction;[5] cycloaddition of coumarin methides with isocyanides;[6] cascade addition–cyclization–oxidation of 3-alkyne-chromone;[7] multi-component reaction between α-chloroketones, aldehydes and 4-hydroxycoumarin;[8] Pd-catalyzed annulation of 3-alkynyl-4-methoxycoumarins with aryl halides;[9] Cu-catalyzed cyclization of 3-alkynylchromone;[10] and Ag(I)-catalyzed cyclization reaction of 4-hydroxycoumarin with olefin.[11] Lately, a two-step reaction was reported for the synthesis of furo[3,2-*c*]coumarins in the presence of iodine and stoichiometric amount of $K_2S_2O_8$ by heating 3,3'-methylenedicoumarins at 120 ºC in PEG with limited reaction scope and moderate product yield.[12] Although many efforts have been devoted to this area, it is still highly desirable to develop more simple and efficient synthetic protocol for the preparation of furo[3,2-*c*]coumarins using easily available substrates under environmental benign conditions.

On the other hand, *α*-functionalization of carbonyl with nucleophile is an important research field of organic chemistry. The general protocol to achieve this is using stoichiometric or catalytic amount of halogen, NBS or NIS to reverse the activity of *α*-carbon of carbonyl.[13] Recently, copper salt was found to be an effective catalyst to *α*-functionalization of carbonyl compounds[14] and an elegant example of copper(II) bromide-catalyzed intermolecular dehydrogenative functionalization of *α*-carbonyl species for the synthesis of *α*-amino carbonyl adducts had been reported (Scheme 1).[15] In this reaction, copper(II) bromide was employed as catalysis to transiently render carbonyls electrophilic at the *α*-position, thereby enabling the in situ addition of a broad range of nitrogen coupling partners. Inspired by this work and following our continuing interest in transition-metal-catalyzed reaction,[16] we reported herein a simple and efficient copper(II) bromide-catalyzed three-component reaction to synthesize furo[3,2-*c*]coumarins derivatives. In this reaction, a copper(II) bromide-catalyzed intramolecular decarboxylative functionalization of *α*-carbonyl is successfully realized, which may be complementary to the limited examples of copper-catalyzed functionalization of *α*-carbonyl species with nucleophiles.[14,15] Compared with previous synthetic methods for furo[3,2-*c*]coumarins, our protocol has a much wider reaction scope and is highly atom-economic, furnishing the products in excellent yields in an operationally simple one-pot reaction.



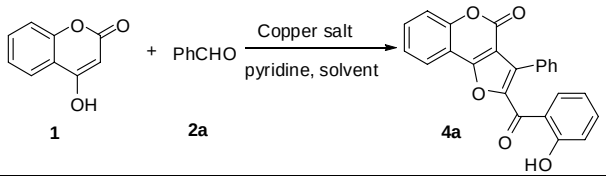
Scheme 1 $CuBr_2$-catalyzed intermolecular dehydrogenative functionalization of *α*-carbonyl species with nucleophile[15]

Results and discussion

In our initial attempt, we found that in the presence of copper bromide (1.0 equiv), 4-hydroxycoumarin **1** (2.0 equiv) may react with benzaldehyde **2a** (1.2 equiv) using pyridine (3.0 equiv) as a base to afford the desired furo[3,2-*c*]coumarin **4a** in 91% yield (Table 1, entry 1). On the basis of this promising result, we began to

optimize the reaction conditions using benzaldehyde **2a** and 4-hydroxycoumarin **1** as the model substrates. Firstly, different solvents were screened in the presence of 1.0 equiv of copper(II) bromide and it was found that changing acetonitrile to all the other solvents tested led to only trace amount of product (Table 1, entry 1–5). Without copper(II) bromide, no product was formed at all (Table 1, entry 6). Interestingly, using other copper(II) salt as copper(II) chloride, copper(II) triflate or copper(II) acetate to carry out this reaction in place of copper(II) bromide proved unsuccessful (Table 1, entry 7-9). Copper(I) bromide also showed low efficiency in mediating this transformtion (Table 1, entry 10). We then optimized the amount of base and found 2.0 equiv of pyridine only led to 65% yield of **4a** (Table 1, entry 11). Subsequently, the amount of copper(II) bromide was tested using acetonitrile as solvent. It was found that 0.3 equiv $CuBr_2$ was enough in the air, giving the target product **4a** in high yields (Table 1, entries 12–13). When the reaction was carried out in pure oxygen atmosphere, the amount of $CuBr_2$ could be reduced to 0.1 equiv (Table 1, entry 14). Contrary to this, stoichiometric amount of $CuBr_2$ was needed to give the product **4a** in high yield when the reaction was undertaken in N_2 atmosphere (Table 1, entry 15). Finally, we screened the reaction temperature and found that decreasing temperature led to poor yield of the product (Table 1, entry 16). Therefore, the optimal reaction conditions are refluxing the mixture of benzaldehyde **2a** (1.2 equiv), 4-hydroxycoumarin **1** (2.0 equiv), pyridine (3.0 equiv) and copper(II) bromide (0.1 equiv) in an oxygen atmosphere for 12 hours.

Table 1 Optimization of Reaction Conditions[a]



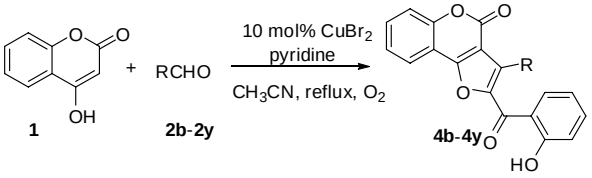
1 **2a** **4a**

Entry	Solvent	Copper (equiv)	Temp(°C)	Yield(%)[b]
1	CH_3CN	$CuBr_2$(1.0)	reflux	91
2	C_6H_6	$CuBr_2$(1.0)	reflux	Trace
3	Toluene	$CuBr_2$(1.0)	80	Trace
4	DMF	$CuBr_2$(1.0)	80	Trac
5	C_2H_5OH	$CuBr_2$(1.0)	reflux	Trace
6	CH_3CN	none	reflux	0
7	CH_3CN	$CuCl_2$(1.0)	reflux	Trace
8	CH_3CN	$Cu(OTf)_2$(1.0)	reflux	0
9	CH_3CN	$Cu(OAc)_2$(1.0)	reflux	0
10	CH_3CN	CuBr (1.0)	reflux	31
11	CH_3CN	$CuBr_2$ (1.0)[c]	reflux	65
12	CH_3CN	$CuBr_2$(0.3)	reflux	91
13	CH_3CN	$CuBr_2$(0.2)	reflux	78
14	CH_3CN	$CuBr_2$(0.1)[d]	reflux	91
15	CH_3CN	$CuBr_2$(2.0)[e]	reflux	88
16	CH_3CN	$CuBr_2$(0.1)[d]	50	Trace

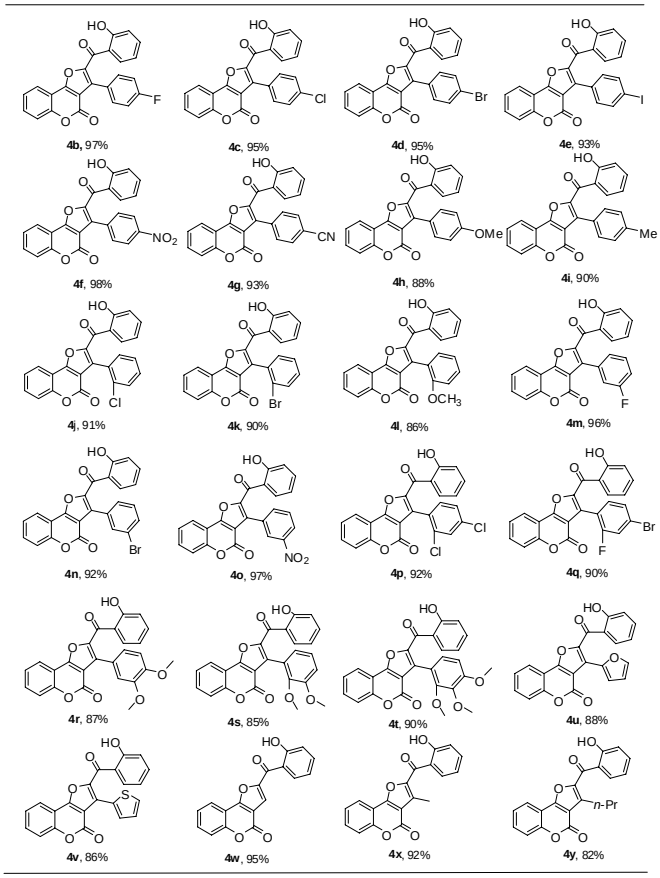
[a] Heating the mixture of 4-hydroxycoumarin **1** (2.0 mmol) with benzaldehyde **2a** (1.2 mmol), pyridine (3.0 mmol), and copper salt in solvent for 12 h. [b] Isolate yields. [c] 2.0 Equiv of pyridine was used. [d] Heated in O_2 atmosphere. [e] Heated in N_2 atmosphere.

With the optimized reaction conditions in hand, the substrate scope was then studied, as shown in Table 2. The electronic effect of substituent in benzaldehydes was first studied and it turned out that benzaldehydes with either electron–withdrawing or electron-donating group on the *para*- (**2b**–**2i**), *ortho*- (**2j**–**2l**) or *mata*-position (**2m**–**2o**) of the phenyl ring took part in the reaction smoothly under the optimal conditions, providing the desired products **4b**–**4i, 4j**–**4l** and **4m**–**4o** respectively in excellent yields. Multisubstituted benzaldehydes **2p**–**2t** reacted equally well to furnish the products **4p**–**4t** in 85–92% yields. In regard to the steric effect of the substituent, *ortho*-, *meta*-substituted benzaldehydes and multi-substituted benzaldehydes all turned out to be good substrates, indicating that steric hindrance had little effect to this reaction. Furthermore, heterocyclic aromatic aldehydes **2u**, **2v** and aliphatic aldehydes **2w–2y** were also tried, and they all led to the desired products in good to excellent yields without exception. Except for NMR and HRMS data for all the products, the structures of **4c** was further established by X-ray crystallographic analysis (see supporting information).

Table 2 Reaction of 4-Hydroxycoumarin **1** with Aldehydes[a]



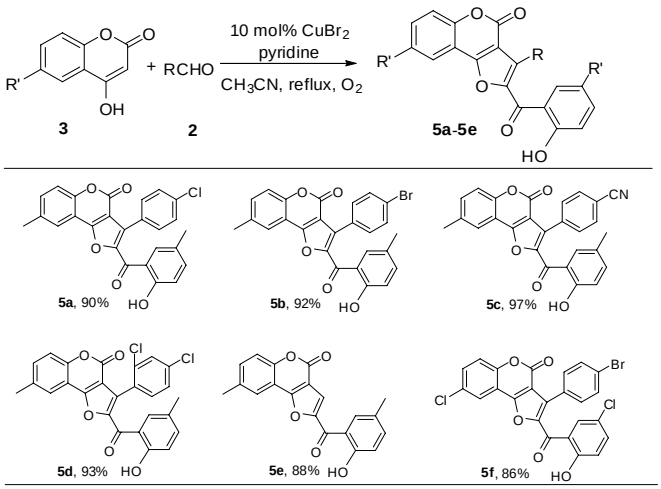
1 **2b-2y** **4b-4y**



[a] Refluxing the mixture of 4-hydroxycoumarin **1** (2.0 mmol), with aldehydes **2b-2y** (1.2 mmol), pyridine (3.0 mmol), and $CuBr_2$ (0.1 mmol) in CH_3CN for 12 h in O_2 atmosphere.

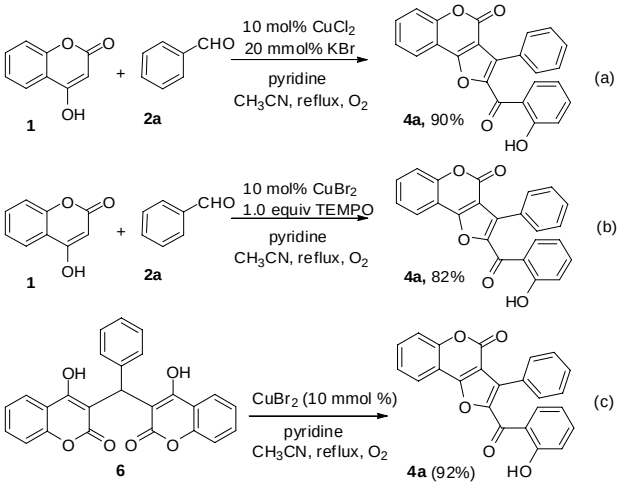
In order to expand the substrate scope further, substituted 4-hydroxycoumarin was applied in this reaction. As we expected, by refluxing a mixture of 6-methyl or 6-chloro-substituted 4-hydroxycoumarin **3** (2.0 mmol) with aromatic aldehydes or aliphatic aldehyde (1.2 mmol) under the optimal condition, the desired products **5a**–**5f** were obtained in excellent yield, as shown in Table 3 (For crystallographic structure of **5c**, see supporting information).

Table 3 Reaction of Substituted 4-Hydroxycoumarin **3** with Aldehydes[a]



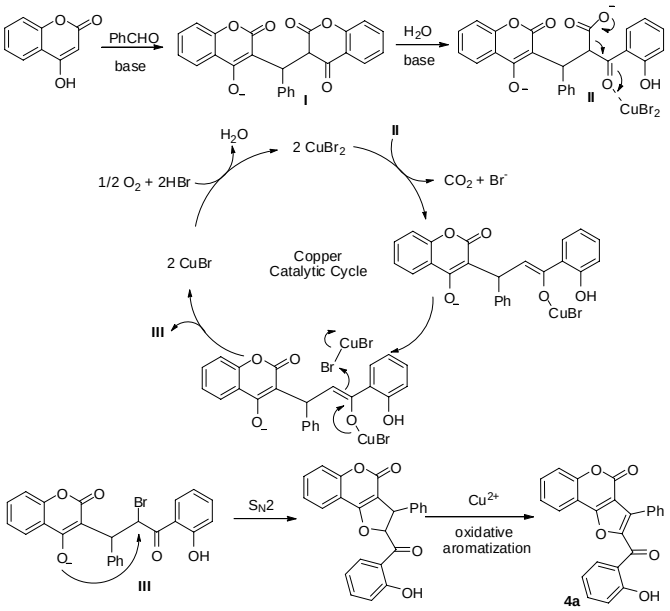
[a] Refluxing the mixture of 6-substituted 4-hydroxycoumarin **3** (2.0 mmol), with aldehydes **2** (1.2 mmol), pyridine (3.0 mmol), and $CuBr_2$ (0.1 mmol) in CH_3CN for 12 h in O_2 atmosphere. [b] Isolate yields.

To gain a better understanding of the reaction mechanism, the following control experiments were carried out. By refluxing 4-hydroxycoumarin **1** (2.0 mmol), with benzaldehyde **2a** (1.2 mmol) and pyridine (3.0 mmol) in O_2 atmosphere in the presence of copper(II) chloride (0.1 mmol) and potassium bromide (0.2 mmol), we also obtained the desired product **4a** in excellent yield (Scheme 2a). It was worth noting that using copper(II) chloride along as catalyst without the aid of potassium bromide could only generate product **4a** in trace amount (see Table 1, entry 10). These results indicated that the bromide anion (Br^-) was crucial in this reaction. Additionally, it was found that when a typical radical scavenger, tetramethylpiperidine *N*-oxide (TEMPO), was added into the reaction system under the standard condition, the reaction was not appreciably suppressed, which excluded significant involvement of any radical intermediate (Scheme 2b). Furthermore, refluxing compound **6** prepared according to previous literature[17] with copper(II) bromide (0.1 equiv) and pyridine (3.0 equiv) in acetonitrile for 12 hours in O_2 atmosphere also led to product **4a** in excellent yield (Scheme 2c).



Scheme 2 Control Experiments

On the basis of these experimental results and previous report,[18,19] a plausible mechanism is suggested, as shown in Scheme 3. Initially, intermediate **I** was formed by sequential reaction of one molecule of 4-hydroxycoumarine **1** with benzaldehyde **2a**, followed by a Michael addition with another 4-hydroxycoumarin in the basic reaction media. Subsequently, hydrolysis of **I** generated intermediate **II**, which upon decarboxylation and reacting with copper(II) bromide gave an α-bromo carbonyl **III** along with copper(I) bromide. Finally, an intramolecular S_N2 reaction in **III** led to a primary cyclization product which underwent oxidative aromatization to give the target product **4a**. Copper(II) may be regenerated via oxidation of copper(I) by oxygen in the presence of pyridine which may facilitate the oxidation of Cu(I).[20]



Scheme 3 Reaction Mechanism

Conclusions

In conclusion, we have developed a simple and efficient method for the synthesis of furo[3,2-*c*]coumarin derivatives. This reaction combines two molecules of 4–hydroxycoumarin with one molecule of aldehyde in one pot by using a catalytic amount of copper(II) bromide as the catalyst. A copper(II) bromide-catalyzed intramolecular decarboxylative functionalization of α-carbonyl with nucleophile is achieved in this reaction process.

Experimental

General

Melting points are uncorrected. ^1H 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.

General procedure for the synthesis of 4

A mixture of 4-hydroxycoumarin **1** (2.0 mmol), aldehydes **2** (1.2 mmol), pyridine (3.0 mmol), and copper bromide (0.1 mmol) in acetonitrile (15 ml) was refluxed for 12 h with magnetic stirring under 1 atm of O_2. After the reaction was completed, the solvent was

removed under reduced pressure, and the residue was separated by flash chromatography on a silica gel column with ethyl acetate/ petroleum ether (1:10) as eluent to give the products **4**.

3-Phenyl-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4a): Yellow solid, yield 347 mg (91%); mp 225─227 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.74 (td, J = 7.2, 1.2 Hz, 1H), 7.02 (dd, J = 8.8, 1.2 Hz, 1H), 7.40–7.54 (m, 8H), 7.63–7.67 (m, 1H), 7.73 (dd, J = 8.0, 1.6 Hz, 1H), 8.03 (dd, J = 8.0, 1.6 Hz, 1H), 11.61 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.5, 163.6, 158.9, 157.0, 153.9, 147.3, 137.2, 133.3, 132.9, 132.4, 130.6, 129.6, 128.5, 125.2, 122.1, 119.2, 119.0, 118.7, 117.8, 112.3, 110.5; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{15}O_5$: 383.0919; found: 383.0925.

3-(4-Fluorophenyl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4b): Yellow solid. yield 388 mg (97%); mp 220─222 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.79 (td, J = 7.6, 1.2 Hz, 1H), 7.03 (dd, J = 8.4, 0.8 Hz, 1H), 7.10 (t, J = 8.4 Hz, 2H), 7.44–7.56 (m, 5H), 7.64─7.68 (m, 1H), 7.75 (dd, J = 8.0, 1.6 Hz, 1H), 8.02 (dd, J = 7.6, 1.2 Hz, 1H), 11.59 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.1, 163.4, 163.3 (d, $^1J_{C\text{-}F}$ = 248 Hz), 158.7, 156.8, 153.7, 147.1, 137.1, 132.8, 132.5, 132.4, 132.2, 132.1, 125.1, 124.1, 124.0, 121.9, 119.1, 118.7, 118.6, 117.6, 115.4 (d, $^2J_{C\text{-}F}$ = 21.8 Hz), 112.0, 110.2; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}FO_5$: 401.0825; found: 401.0818.

3-(4-Chlorophenyl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4c): Yellow solid, yield 395 mg (95%); mp 206–207 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.82 (t, J = 7.6 Hz, 1H), 7.04 (d, J = 8.4 Hz, 1H), 7.38–7.52 (m, 7H), 7.66 (t, J = 7.2 Hz, 1H), 7.80 (dd, J = 8.4, 1.2 Hz, 1H), 8.02 (d, J = 8.0 Hz, 1H), 11.59 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.9, 163.4, 158.7, 156.7, 153.7, 147.1, 137.1, 135.6, 132.8, 132.0, 131.7, 128.5, 126.5, 125.0, 121.8, 119.1, 118.7, 118.6, 117.6, 111.9, 110.1. HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}ClO_5$: 417.0530; found: 417.0538.

2-(2-Hydroxybenzoyl)-3-(4-bromophenyl)-4H-furo[3,2-*c*]chromen-4-one (4d): Yellow solid, yield 436 mg (95%); mp. 222–223 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.82 (td, J = 7.6, 1.2 Hz, 1H), 7.04 (dd, J = 8.4, 0.8 Hz, 1H), 7.42–7.46 (m, 3H), 7.50–7.56 (m, 4H), 7.64─7.68 (m, 1H), 7.80 (dd, J = 8.0, 1.6 Hz, 1H), 8.02 (dd, J = 8.0, 1.6 Hz, 1H), 11.57 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.9, 163.4, 158.7, 156.7, 153.7, 147.1, 137.1, 132.8, 132.1, 132.0, 131.9, 131.4, 127.0, 125.0, 123.9, 121.8, 119.1, 118.7, 118.6, 117.6, 111.9, 110.0; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}BrO_5$: 461.0025; found: 461.0020.

2-(2-Hydroxybenzoyl)-3-(4-iodophenyl)-4H-furo[3,2-*c*]chromen-4-one (4e): Yellow solid, yield 471 mg (93%); mp 223–224 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.83 (t, J = 7.6 Hz, 1H), 7.04 (d, J = 8.4 Hz, 1H), 7.29 (d, J = 8.0 Hz, 2H), 7.44 (t, J = 7.6 Hz, 1H), 7.49–7.52 (m, 2H), 7.66 (t, J = 7.2 Hz, 1H), 7.75 (d, J = 8.0 Hz, 2H), 7.80 (dd, J = 8.0, 1.2 Hz, 1H), 8.01 (dd, J = 8.0, 1.2 Hz, 1H), 11.58 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.8, 163.4, 158.6, 156.6, 153.6, 147.0, 137.3, 137.0, 132.7, 132.1, 131.9, 131.8, 127.6, 125.0, 121.8, 119.1, 118.6, 118.5, 117.5, 111.8, 109.9, 95.9; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}IO_5$: 508.9886; found: 508.9886.

2-(2-Hydroxybenzoyl)-3-(4-nitrophenyl)-4H-furo[3,2-*c*]chromen-4-one (4f): Yellow solid, yield 419 mg (98%); mp 233─235 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.90 (td, J = 8.0, 0.8 Hz, 1H), 7.08 (dd, J = 8.0, 0.8 Hz, 1H), 7.49–7.56 (m, 3H), 7.69–7.78 (m, 3H), 7.93 (dd, J = 8.4, 1.2 Hz, 1H), 8.06 (dd, J = 8.0, 1.2 Hz, 1H), 8.31 (d, J = 8.8 Hz, 2H), 11.56 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.6, 164.0, 159.1, 156.8, 154.1, 148.5, 148.0, 137.8, 135.4, 133.4, 132.1, 131.7, 131.3, 125.6, 123.7, 122.2, 119.6, 119.2, 118.9, 118.1, 112.0, 110.4; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}NO_7$: 428.0770; found: 428.0769.

4-(2-(2-Hydroxybenzoyl)-4-oxo-4H-furo[3,2-*c*]chromen-3-yl) benzonitrile (4g): Yellow solid, yield 380 mg (93%); mp 253─255 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.88 (t, J = 7.6 Hz, 1H), 7.08 (d, J = 8.8 Hz, 1H), 7.47–7.57 (m, 3H), 7. 69–7.75 (m, 5H), 7.86 (dd, J = 8.0, 1.6 Hz, 1H), 8.05 (dd, J = 7.6, 1.2 Hz, 1H), 11.55 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.4, 163.6, 158.8, 156.5, 153.7, 147.5, 137.3, 133.0, 132.9, 131.8, 131.7, 131.2, 131.0, 125.2, 121.8, 119.2, 118.7, 118.5, 118.4, 117.6, 113.0, 111.7, 109.9; HMRS *m/z* $[M+H]^+$ calcd for $C_{25}H_{14}NO_5$: 408.0872; found: 408.0877.

2-(2-Hydroxybenzoyl)-3-(4-methoxyphenyl)-4H-furo[3,2-*c*] chromen-4-one (4h): Yellow solid, yield 362 mg (88%); mp 168─170 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.86 (s, 3H), 6.78 (t, J = 7.6 Hz, 1H), 6.94 (d, J = 8.8 Hz, 2H), 7.04 (d, J = 8.4 Hz, 1H), 7.45–7.53 (m, 5H), 7.66 (t, J = 7.6 Hz, 1H), 7.78 (dd, J = 8.0, 0.8 Hz, 1H), 8.04 (d, J = 7.6 Hz, 1H), 11.67 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.6, 163.5, 160.7, 158.9, 157.1, 153.9, 146.9, 137.0, 133.4, 132.8, 132.4, 132.2, 125.2, 122.1, 120.4, 119.3, 119.0, 118.7, 117.8, 114.0, 112.3, 110.4, 55.6; HMRS *m/z* $[M+H]^+$ calcd for $C_{25}H_{17}O_6$: 413.1025; found: 413.1022.

2-(2-Hydroxybenzoyl)-3-*p*-tolyl-4H-furo[3,2-*c*]chromen-4-one (4i): Yellow solid, yield 355 mg (90%); mp 171─172 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.41 (s, 3H), 6.80 (t, J = 8.0, 0.8 Hz, 1H), 7.05 (dd, J = 8.4, 0.8 Hz, 1H), 7.24 (d, J = 8.0 Hz, 2H), 7.46–7.54 (m, 5H), 7.67 (s, 1H), 7.81 (dd, J = 8.0, 1.6 Hz, 1H), 8.04 (dd, J = 8.0, 1.2 Hz, 1H), 11.66 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.2, 163.3, 158.6, 156.7, 153.6, 146.9, 139.4, 136.7, 133.4, 132.5, 132.1, 130.2, 128.9, 125.0, 124.8, 121.8, 118.9, 118.8, 118.4, 117.5, 112.0, 110.2, 21.5; HMRS *m/z* $[M+H]^+$ calcd for $C_{25}H_{17}O_5$: 397.1076; found: 397.1084.

3-(2-Chlorophenyl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4j): Yellow solid, yield 377 mg (91%); mp 245–247 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.83 (td, J = 8.0, 0.8 Hz, 1H), 7.01 (dd, J = 8.4, 0.8 Hz, 1H), 7.31–7.52 (m, 7H), 7.63–7.68 (m, 1H), 7.95 (dd, J = 8.0, 1.6 Hz, 1H), 8.05 (dd, J = 7.6, 1.2 Hz, 1H), 11.50 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.3, 163.3, 158.5, 156.3, 153.8, 148.1, 137.0, 133.8, 132.8, 131.8, 131.5, 130.6, 130.0, 129.7, 128.4, 126.8, 125.0, 121.9, 119.1, 118.7, 118.5, 117.7, 112.0, 111.2; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}ClO_5$: 417.0530; found: 417.0535.

2-(2-Hydroxybenzoyl)-3-(2-bromophenyl)-4H-furo[3,2-*c*]chromen-4-one (4k): Yellow solid, yield 415 mg (90%); mp 251–252 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.84 (td, J = 8.0, 1.2 Hz, 1H), 7.01 (dd, J = 7.6, 0.8 Hz, 1H), 7.26–7.31 (m, 1H), 7.36–7.38 (m, 2H), 7.43–7.52 (m, 3H), 7.64–7.69 (m, 2H), 7.99 (dd, J = 8.0, 1.6 Hz, 1H), 8.05 (dd, J = 8.0, 1.2 Hz, 1H), 11.51 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.1, 163.2, 158.4, 156.2, 153.8, 148.0, 136.9, 132.9, 132.7, 131.8, 131.7, 131.4, 130.6, 130.4, 127.3, 125.0, 123.7, 121.8, 119.0, 118.7, 118.4, 117.7, 112.0, 111.1; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}BrO_5$: 461.0025; found: 461.0023.

2-(2-Hydroxybenzoyl)-3-(2-methoxyphenyl)-4H-furo[3,2-*c*] chromen-4-one (4l): Yellow solid, yield 353 mg (86%); mp 201–

202 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.63 (s, 3H), 6.65 (t, J = 8.0 Hz, 1H), 6.81 (d, J = 8.0 Hz, 1H), 6.97–7.03 (m, 2H), 7.32–7.50 (m, 5H), 7.62 (t, J = 8.0 Hz, 1H), 7.68 (dd, J = 8.4, 2.0 Hz, 1H), 8.04 (dd, J = 7.6, 1.2 Hz, 1H), 11.52 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.5, 162.7, 158.6, 156.5, 153.6, 147.6, 136.5, 132.3, 131.9, 131.6, 131.0, 128.1, 124.8, 121.8, 120.5, 118.7, 117.9, 117.7, 117.5, 112.2, 110.8, 55.1; HMRS *m/z* $[M+H]^+$ calcd for $C_{25}H_{17}O_6$: 413.1025; found: 413.1022.

3-(3-Fluorophenyl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4m): Yellow solid, yield 384 mg (96%); mp 246–248 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.81 (t, J = 8.0 Hz, 1H), 7.03 (dd, J = 7.6, 0.8 Hz, 1H), 7.09–7.14 (m, 1H), 7.28–7.31 (m, 2H), 7.34–7.40 (m, 1H), 7.42–7.52 (m, 3H), 7.66 (t, J = 8.0 Hz, 1H), 7.78 (dd, J = 8.0, 1.6 Hz, 1H), 8.02 (dd, J = 7.6, 1.2 Hz, 1H), 11.58 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.9, 163.4, 158.7, 156.6, 153.7, 147.3, 137.1, 132.8, 131.9, 130.2, 129.8, 129.7, 126.2, 126.1, 125.0, 121.9, 119.1, 118.6, 117.6, 117.5, 117.3, 116.4 (d, $^2J_{C\text{-}F}$ = 21.0 Hz), 111.9, 110.1; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}FO_5$: 401.0825; found: 401.0829.

2-(2-Hydroxybenzoyl)-3-(3-bromophenyl)-4H-furo[3,2-*c*]chromen-4-one (4n): Yellow solid, yield 423 mg (92%); mp 194–195 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.84 (t, J = 8.0 Hz, 1H), 7.07 (dd, J = 8.4, 1.2 Hz, 1H), 7.30 (t, J = 8.0 Hz, 1H), 7.46–7.55 (m, 5H), 7.66–7.71 (m, 2H), 7.82 (dd, J = 8.0, 1.6 Hz, 1H), 8.04 (dd, J = 7.6, 1.6 Hz, 1H), 11.58 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.7, 163.4, 158.6, 153.7, 137.1, 133.1, 132.8, 132.4, 131.9, 130.2, 129.7, 128.9, 125.1, 122.1, 121.9, 119.1, 118.7, 118.6, 117.6, 113.2, 111.8, 110.1; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}BrO_5$: 461.0025; found: 461.0030.

2-(2-Hydroxybenzoyl)-3-(3-nitrophenyl)-4H-furo[3,2-*c*]chromen-4-one (4o): Yellow solid, yield 415 mg (97%); mp 213–215 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.89 (t, J = 8.0 Hz, 1H), 7.05 (dd, J = 8.4, 0.8 Hz, 1H), 7.43–7.53 (m, 3H), 7.60–7.71 (m, 2H), 7.89 (dt, J = 7.6, 1.6 Hz, 1H), 7.94 (dd, J = 8.0, 1.6 Hz, 1H), 8.03 (dd, J = 8.0, 1.6 Hz, 1H), 8.28–8.31 (m, 1H), 8.46 (t, J = 2.0 Hz, 1H), 11.51 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.8, 163.3, 158.3, 156.1, 153.4, 147.6, 147.4, 136.9, 136.0, 132.7, 131.4, 130.7, 129.6, 128.7, 125.2, 124.9, 123.7, 121.5, 118.9, 118.5, 118.3, 117.4, 111.4, 109.8; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{14}NO_7$: 428.0770; found: 428.0761.

3-(2,4-Dichlorophenyl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4p): Yellow solid, yield 413 mg (92%); mp 244–246 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.89–6.93 (m, 1H), 7.04 (dd, J = 8.4, 0.8 Hz, 1H), 7.35 (dd, J = 8.4, 2.4 Hz, 1H), 7.40–7.53 (m, 5H), 7.65–7.70 (m, 1H), 8.04 (dd, J = 8.0, 1.6 Hz, 2H), 11.52 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.7, 163.5, 158.4, 156.1, 153.8, 148.3, 137.1, 132.9, 132.5, 132.1, 131.6, 131.2, 130.7, 130.5, 129.9, 128.9, 125.1, 121.8, 119.1, 118.7, 117.8, 111.9, 111.0; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{13}Cl_2O_5$: 451.0140; found: 451.0133.

3-(2-Fluoro-4-bromophenyl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4q): Yellow solid, yield 430 mg (90%); mp 190–192 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.90 (t, J = 8.0 Hz, 1H), 7.05 (d, J = 8.4 Hz, 1H), 7.33 (dd, J = 9.2, 1.2 Hz, 1H), 7.39–7.55 (m, 5H), 7.66 (td, J = 8.4, 1.2 Hz, 1H), 7.97–8.03 (m, 2H), 11.56 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.1, 163.5, 159.5 (d, $^1J_{C\text{-}F}$ = 252 Hz), 158.6, 156.3, 153.7, 148.0, 137.0, 132.8, 131.6, 127.4, 127.3, 125.4, 125.0, 121.7, 119.4 (d, $^2J_{C\text{-}F}$ = 24.9 Hz), 119.1, 118.6, 117.6, 116.1, 115.9, 111.8, 110.5; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{13}BrFO_5$: 478.9930; found: 478.9939.

2-(2-Hydroxybenzoyl)-3-(3,4-dimethoxyphenyl)-4H-furo[3,2-*c*]chromen-4-one (4r): Yellow solid, yield 384 mg (87%); mp 182–183 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.83 (s, 3H), 3.90 (s, 3H), 6.73 (td, J = 8.0, 1.2 Hz, 1H), 6.87 (d, J = 7.6 Hz, 1H), 7.02 (d, J = 8.4 Hz, 1H), 7.08 (d, J = 2.0 Hz, 1H), 7.14 (dd, J = 8.4, 2.0 Hz, 1H), 7.43–7.51 (m, 3H), 7.63–7.69 (m, 2H), 8.03 (dd, J = 7.6, 1.2 Hz, 1H), 11.61 (s, 1H); ^{13}C NMR (100MHz, $CDCl_3$) δ 187.5, 163.1, 158.7, 156.8, 153.5, 150.0, 148.4, 146.5, 136.8, 132.8, 132.5, 132.1, 124.8, 123.6, 121.8, 120.1, 118.9, 118.7, 118.2, 117.4, 113.8, 111.9, 110.7, 109.9, 55.9, 55.8; HMRS *m/z* $[M+H]^+$ calcd for $C_{26}H_{19}O_7$: 443.1131; found: 443.1117.

2-(2-Hydroxybenzoyl)-3-(2,3-dimethoxyphenyl)-4H-furo[3,2-*c*]chromen-4-one (4s): Yellow solid, yield 375 mg (85%); mp 188–190 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.68 (s, 3H), 3.83 (s, 3H), 6.78 (t, J = 8.0 Hz, 1H), 6.96–7.04 (m, 3H), 7.10 (t, J = 8.0 Hz, 1H), 7.40–7.49 (m, 3H), 7.62 (t, J = 8.0 Hz, 1H), 7.83 (dd, J = 8.0, 1.6 Hz, 1H), 8.02 (dd, J = 8.0, 1.6 Hz, 1H), 11.56 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.3, 163.4, 158.6, 156.8, 153.9, 152.8, 148.3, 147.0, 136.9, 132.6, 132.1, 128.4, 125.1, 124.0, 123.3, 123.1, 122.0, 119.1, 119.0, 118.6, 117.8, 114.5, 112.5, 111.2, 61.1, 56.3; HMRS *m/z* $[M+H]^+$ calcd for $C_{26}H_{19}O_7$: 443.1131; found: 443.1123.

2-(2-Hydroxybenzoyl)-3-(2,3,4-trimethoxyphenyl)-4H-furo[3,2-*c*]chromen-4-one (4t): Yellow solid, yield 425 mg (90%); mp 202–204 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.79 (s, 6H), 3.86 (s, 3H), 6.68 (td, J = 8.0, 1.2 Hz, 1H), 6.77 (s, 2H), 7.01 (dd, J = 8.4, 0.8 Hz, 1H), 7.42–7.46 (m, 2H), 7.50 (d, J = 8.0 Hz, 1H), 7.55 (dd, J = 8.0, 1.6 Hz, 1H), 7.64 (dd, J = 8.4, 1.2 Hz, 1H), 8.05 (dd, J = 8.0, 1.6 Hz, 1H), 11.50 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.7, 162.9, 158.9, 158.8, 153.6, 152.8, 146.7, 139.1, 137.0, 132.6, 132.5, 132.0, 124.9, 122.8, 121.9, 119.0, 118.8, 118.2, 117.4, 111.9, 109.7, 108.3, 60.8, 56.2; HMRS *m/z* $[M+H]^+$ calcd for $C_{27}H_{21}O_8$: 473.1236; found: 473.1236.

3-(Furan-2-yl)-2-(2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4u): Yellow solid, yield 327 mg (88%); mp 252– 254 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.51–6.52 (m, 1H), 6.79 (t, J = 7.6 Hz, 1H), 7.08 (d, J = 8.4 Hz, 1H), 7.29 (s, 1H), 7.42 (t, J = 7.2 Hz, 1H), 7.50–7.64 (m, 5H), 7.98 (d, J = 8.0 Hz, 1H), 11.72 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 189.1, 163.9, 159.6, 157.5, 154.2, 146.3, 144.7, 142.9, 137.7, 133.2, 132.6, 125.7, 122.6, 121.0, 120.2, 119.8, 119.2, 118.1, 116.5, 112.9, 108.8, 100.7; HMRS *m/z* $[M+H]^+$ calcd for $C_{22}H_{13}O_6$: 373.0712; found: 373.0717.

2-(2-Hydroxybenzoyl)-3-(thiophen-2-yl)-4H-furo[3,2-*c*]chromen-4-one (4v): Yellow solid, yield 333 mg (86%); mp 210–212 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.80 (t, J = 7.6 Hz, 1H), 7.04–7.10 (m, 2H), 7.43–7.52 (m, 4H), 7.61–7.65 (m, 2H), 7.72 (d, J = 8.0 Hz, 1H), 7.99 (d, J = 7.6 Hz, 1H), 11.64 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.3, 163.3, 158.6, 156.6, 153.5, 146.7, 137.0, 132.6, 132.0, 131.9, 129.0, 127.5, 127.3, 125.5, 124.9, 121.8, 119.1, 118.9, 118.5, 117.4, 111.8, 109.7; HMRS *m/z* $[M+H]^+$ calcd for $C_{22}H_{13}O_5S$: 389.0484; found: 389.0493.

2-(2-Hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (4w): Yellow solid, yield 291 mg (95%); mp 155–157 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.02 (td, J = 7.2, 0.8 Hz, 1H), 7.12 (dd, J = 8.4, 0.8 Hz, 1H), 7.45 (t, J = 8.0 Hz, 1H), 7.51 (d, J = 8.0 Hz, 1H), 7.58–7.62

(m, 1H), 7.64–7.68 (m, 1H), 7.83 (s, 1H), 8.08 (dd, *J* = 7.6, 1.6 Hz, 1H), 8.16 (dd, *J* = 8.4, 1.6 Hz, 1H), 11.70 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.2, 164.1, 160.5, 157.9, 154.5, 152.7, 137.8, 133.5, 131.5, 125.8, 122.7, 120.2, 119.6, 118.9, 118.4, 112.6, 112.3; HMRS *m/z* $[M+H]^+$ calcd for $C_{18}H_{11}O_5$: 307.0606; found: 307.0604.

2-(2-Hydroxybenzoyl)-3-methyl-4H-furo[3,2-*c*]chromen-4-one (4x): Yellow solid, yield 294 mg (92%); mp 208–210 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.78 (s, 3H), 7.02 (t, *J* = 7.6 Hz, 1H), 7.08 (d, *J* = 8.4 Hz, 1H), 7.42 (t, *J* = 7.6 Hz, 1H), 7.47 (d, *J* = 8.4 Hz, 1H), 7.55 (td, *J* = 8.4, 1.2 Hz, 1H), 7.63 (td, *J* = 8.4, 0.8 Hz, 1H), 7.95 (dd, *J* = 8.0, 1.2 Hz, 1H), 8.26 (dd, *J* = 8.0, 1.2 Hz, 1H), 12.08 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.1, 163.4, 157.6, 157.3, 153.5, 148.1, 136.2, 132.8, 132.2, 131.1, 124.6, 121.4, 118.8, 118.4, 117.3, 111.7, 111.6, 10.7; HMRS *m/z* $[M+H]^+$ calcd for $C_{19}H_{13}O_5$: 321.0763; found: 321.0763.

2-(2-Hydroxybenzoyl)-3-propyl-4H-furo[3,2-*c*]chromen-4-one (4y): Yellow solid, yield 285 mg (82%); mp 201–202 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.05 (t, *J* = 7.6 Hz, 3H), 1.77–1.83 (m, 2H), 3.21 (t, *J* = 7.6 Hz, 2H), 7.02 (td, *J* = 8.0, 1.2 Hz, 1H), 7.09 (dd, *J* = 8.4, 1.6 Hz, 1H), 7.41 (td, *J* = 7.6, 0.8 Hz, 1H), 7.49 (d, *J* = 8.4 Hz, 1H), 7.56 (td, *J* = 8.4, 1.6 Hz, 1H), 7.63 (td, *J* = 8.4, 1.6 Hz, 1H), 7.95 (dd, *J* = 8.0, 1.2 Hz, 1H), 8.25 (dd, *J* = 8.4, 1.6 Hz, 1H), 12.09 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.5, 163.7, 158.0, 157.3, 153.8, 148.2, 137.7, 136.4, 132.4, 131.5, 124.9, 121.6, 119.2, 119.1, 118.7, 117.6, 112.1, 111.5, 26.4, 23.0, 14.0; HMRS *m/z* $[M+H]^+$ calcd for $C_{21}H_{17}O_5$: 349.1076; found: 349.1077.

General procedure for the synthesis of 5

A mixture of 6-substituted 4-hydroxycoumarin **3** (2.0 mmol), aldehydes **2** (1.2 mmol), pyridine (3.0 mmol), and copper bromide (0.1 mmol) in acetonitrile (15 ml) was refluxed for 12 h with magnetic stirring under 1 atm of O_2. After the reaction was completed, the solvent was removed under reduced pressure, and the residue was separated by flash chromatography on a silica gel column with ethyl acetate/ petroleum ether (1:10) as eluent to give products **5**.

3-(4-Chlorophenyl)-2-(2-hydroxy-5-methylbenzoyl)-8-meth-yl-4H-furo[3,2-*c*]chromen-4-one (5a): Yellow solid, yield 398 mg (90%); mp 223–225 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (s, 3H), 2.50 (s, 3H), 6.92 (d, *J* = 7.6 Hz, 1H), 7.26–7.28 (m, 1H), 7.33–7.40 (m, 4H), 7.44–7.47 (m, 3H), 7.81 (d, *J* = 0.8 Hz, 1H), 11.33 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.0, 161.1, 158.9, 156.9, 151.9, 147.0, 138.1, 135.5, 135.0, 133.8, 131.8, 131.7, 131.4, 128.4, 128.2, 126.8, 121.4, 118.1, 118.0, 117.3, 111.6, 109.8, 21.0, 20.2; HMRS *m/z* $[M+H]^+$ calcd for $C_{26}H_{18}ClO_5$: 445.0843; found: 445.0844.

3-(4-Bromophenyl)-2-(2-hydroxy-5-methylbenzoyl)-8-methyl-4H-furo[3,2-*c*]chromen-4-one (5b): Yellow solid, yield 449 mg (92%); mp 238–240 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.10 (s, 3H), 2.50 (s, 3H), 6.92 (d, *J* = 8.4 Hz, 1H), 7.28 (d, *J* = 2.0 Hz, 1H), 7.36–7.40 (m, 4H), 7.44–7.51 (m, 3H), 7.80 (d, *J* = 2.0 Hz, 1H), 11.32 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.1, 161.2, 158.9, 157.0, 151.9, 147.0, 138.2, 135.1, 133.9, 132.0, 131.8, 131.5, 131.4, 128.3, 127.3, 123.9, 121.5, 118.2, 118.1, 117.3, 111.6, 109.8, 21.0, 20.3; HMRS *m/z* $[M+H]^+$ calcd for $C_{26}H_{18}BrO_5$: 489.0338; found: 489.0350.

4-(2-(2-Hydroxy-5-methylbenzoyl)-8-methyl-4-oxo-4H-furo[3,2-*c*]chromen-3-yl)benzonitrile (5c): Yellow solid, yield 421 mg (97%); mp 258–260 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.14 (s, 3H), 2.51 (s, 3H), 6.94 (d, *J* = 8.8 Hz, 1H), 7.30 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.39–7.43 (m, 2H), 7.47 (dd, *J* = 8.4, 2.0 Hz, 1H), 7.63–7.69 (m, 4H), 7.80 (d, *J* = 1.2 Hz, 1H), 11.27 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 187.0, 161.8, 159.4, 157.2, 152.3, 147.8, 138.8, 135.6, 134.5, 133.7, 132.2, 132.0, 131.5, 131.1, 128.7, 121.8, 118.8, 118.5, 117.8, 113.3, 111.8, 110.0, 21.4, 20.7; HMRS *m/z* $[M+H]^+$ calcd for $C_{27}H_{18}NO_5$: 436.1185; found: 436.1184.

3-(2,4-Dichlorophenyl)-2-(2-hydroxy-5-methylbenzoyl)-8-methyl-4H-furo[3,2-*c*]chromen-4-one (5d): Yellow solid, yield 445 mg (93%); mp 138–140 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.20 (s, 3H), 2.51 (s, 3H), 6.91 (d, *J* = 8.4 Hz, 1H), 7.28–7.31 (m, 2H), 7.34 (d, *J* = 1.6 Hz, 1H), 7.39 (dd, *J* = 8.8, 2.0 Hz, 2H), 7.46 (dd, *J* = 8.4, 1.6 Hz, 1H), 7.56 (d, *J* = 1.6 Hz, 1H), 7.82 (d, *J* = 0.8 Hz, 1H), 11.18 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 186.0, 161.0, 158.7, 156.3, 152.0, 148.0, 138.1, 135.0, 133.8, 132.5, 132.2, 131.3, 130.6, 130.4, 130.1, 128.2, 128.1, 121.4, 118.2, 118.1, 117.4, 111.5, 110.7, 21.0, 20.2; HMRS *m/z* $[M+H]^+$ calcd for $C_{26}H_{17}Cl_2O_5$: 479.0453; found: 479.0453.

2-(2-Hydroxy-5-methylbenzoyl)-8-methyl-4H-furo[3,2-*c*]chromen-4-one (5e): Yellow solid, yield 293 mg (88%); mp 196–198 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.39 (s, 3H), 2.50 (s, 3H), 7.01 (d, *J* = 8.8 Hz, 1H), 7.38–7.47 (m, 3H), 7.77 (s, 1H), 7.85 (dd, *J* = 8.0, 1.2 Hz, 2H), 11.46 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 184.2, 160.9, 159.5, 157.2, 151.6, 151.3, 137.8, 134.8, 133.5, 130.0, 128.4, 121.3, 118.3, 117.9, 117.8, 117.1, 111.2, 111.1, 20.6, 20.4; HMRS *m/z* $[M+H]^+$ calcd for $C_{20}H_{15}O_5$: 335.0919; found: 335.0932.

3-(4-Bromophenyl)-8-chloro-2-(5-chloro-2-hydroxybenzoyl)-4H-furo[3,2-*c*]chromen-4-one (5f): Yellow solid, yield 455 mg (86%); mp 223–224 °C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.00 (d, *J* = 8.8 Hz, 1H), 7.38–7.48 (m, 4H), 7.55–7.63 (m, 3H), 7.70 (d, *J* = 2.4 Hz, 1H), 7.99 (d, *J* = 2.4 Hz, 1H), 11.39 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.6, 161.8, 157.7, 155.9, 152.0, 147.0, 137.0, 133.0, 132.8, 131.8, 131.6, 131.0, 130.9, 126.5, 124.4, 124.1, 121.3, 120.2, 119.1, 118.9, 112.8, 110.7; HMRS *m/z* $[M+H]^+$ calcd for $C_{24}H_{12}BrCl_2O_5$: 528.9245, found 528.9258.

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The contributions of Zhang and Yue are equal.

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