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A Regioselective Metal-Free Construction of 3-Aroyl Coumarins by Csp2-H Functionalization

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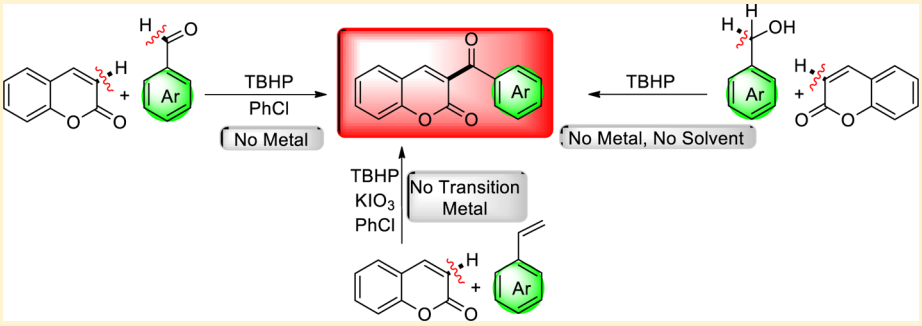
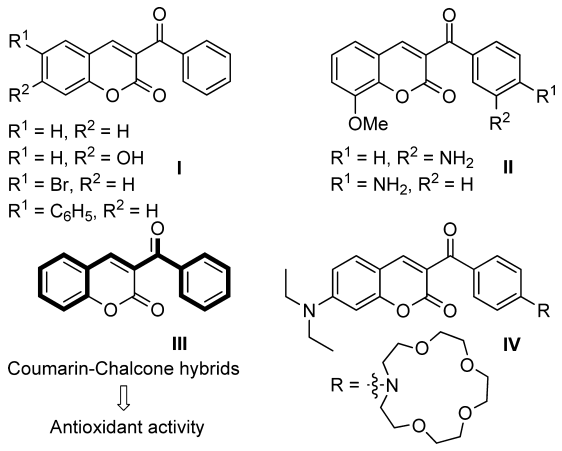
Supporting Information



ABSTRACT: A successive metal-free TBHP-mediated regioselective C−H functionalization of coumarins toward expedient synthesis of 3-aroyl coumarins is unveiled. The ongoing method conducted through the reaction of either coumarins or coumarin-3-carboxylic acids with aromatic aldehydes. The optimized reaction condition also worked well with benzyl alcohols and styrenes as surrogates for aldehydes, which bear latent carbonyl functionality.

Occurrence of 3-carbonyl coumarins in pharmaceutically active compounds justifies their versatility.[1] 3-Aroyl coumarins, in particular, are proved to display varying degrees of α- glucosidase inhibitory and DPPH scavenging activity (Scheme 1, **I**),[1a] antibacterial (**II**),[1b] and as coumarin-chalcone hybrids (**III**), antioxidant activities.[1c] Furthermore, as a fluorescent chemosensor, compound **IV** has shown a high affinity and selectivity for Pb^{2+} which would be helpful in clarifying the cellular role of lead ions in vivo.[1d] Given that, many have made considerable endeavors toward the synthesis of these motifs. Among the traditional methods, Knoevenagel condensation is the most widely used route in which salicylaldehydes and β-ketoesters are exploited as the starting materials.[2] However, despite all virtues the aforementioned reaction suffers from some drawbacks, namely the necessity of basic or acidic conditions and/or a laborious synthetic procedure. Thus, lately efforts have been focused on direct acylation of coumarins through metal-catalyzed C−H functionalization reactions (Scheme 2).

Scheme 1. Interesting Compounds with 3-Aroyl Coumarin Framework



To this end, Zhou et al.[3a] and Yuan et al.[3b] individually reported synthetic procedures in which coumarins were coupled with aromatic aldehydes through metal catalyzed reactions. In another effort, Duan and co-workers showed that 3-aroyl coumarins could be achieved through the reaction of coumarins with phenylglyoxylic acid with the aid of silver catalyst, albeit in low yields.[4] 3-Aroyl coumarins were also prepared by the reaction of benzylether and coumarins promoted by $FeCl_3$ as the catalyst.[5] Nonetheless, a setback relevant to these methods, due to the use of metal catalysts, are incompatibility with instructions issued by Green Chemistry. Instead, metal-free reactions have recently come of age. Plethora of reactions released have now been conducted through metal-free reactions since they offer greener approaches which take advantages of cost-effective reaction-promoters.[6] Despite the growing prevalence of these reactions, to the best of our knowledge, thus far no metal-free cross-dehydrogenative coupling (CDC) reaction for direct functionalization of coumarins has been precedented.[7] Herein, we

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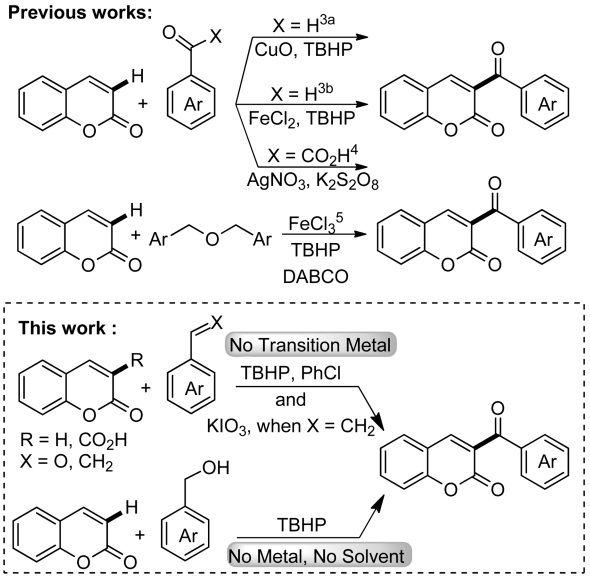
Scheme 2. Methods of Direct 3-Carbonylation of Coumarins

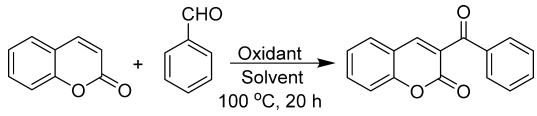


report a state-of-the-art metal-free acylation of this motif via cross-dehydrogenative coupling with aromatic aldehydes as well as benzyl alcohols which obviates the foregoing impediments of metal-catalyzed reactions. This approach benefits from smooth proceedings, is devoid of any kind of metals, and is promoted solely by TBHP. Among metal-free reactions, there are rare examples being promoted merely by TBHP as a catalyst without any contribution of halide salts or other oxidants.[8] This reaction is notable from another aspect since the competing aldehyde oxidation to its benzoic acid fails to outperform coupling procedure.[9]

First, we set out to functionalize coumarin regioselectively at C-3 by benzaldehyde using TBHP which is endowed by the commencement of SET (single electron transfer) reactions. To this end, coumarin was treated with benzaldehyde under TBHP at 100 °C for 20 h as the model reaction. At the outset, the effects of different oxidants were screened as the oxidant seemed to have the key role in conducting the reaction. Hence, an initial reaction was accomplished using 4.0 equivalents of TBHP at 100 °C for 20 h under neat conditions which gave rise to the desired product in 57% yield (Table 1, entry 1). When the oxidant was replaced with DTBP, it still resulted in the favorable product, albeit in a lower yield, but no product was observed when $K_2S_2O_8$ was employed (entries 2 and 3, respectively). In the next step, we added some additives in hope of increasing the reaction efficiency but they had conspicuously deleterious effects on the yields (entries 6−9). In continuation, different solvents were taken into account among which chlorobenzene furnished the best yield (entries 10−14). Finally reducing the amount of TBHP to 2 equivs slightly reduced the yield. We were delighted to find that these conditions, afforded aroylated coumarin regioselectively at C-3 with 70% yield (entry 14). Introduction of coumarin to the optimized conditions in the presence of a radical scavenger like TEMPO (10 equiv), suppressed the formation of the desired aroyl compound markedly which indicated that a radical pathway could be involved (entry 15).

Next, to investigate the scope and limitations of the regioselective direct carbonylation process, various aromatic aldehydes and coumarins were exposed to the reaction condition (Table 2). As we expected, *p*- and *m*-methylbenzaldehydes led to good yields (**3b**,**3c**). Employing highly electron-rich benzaldehyde increased the yield even more (**3d**). Also,

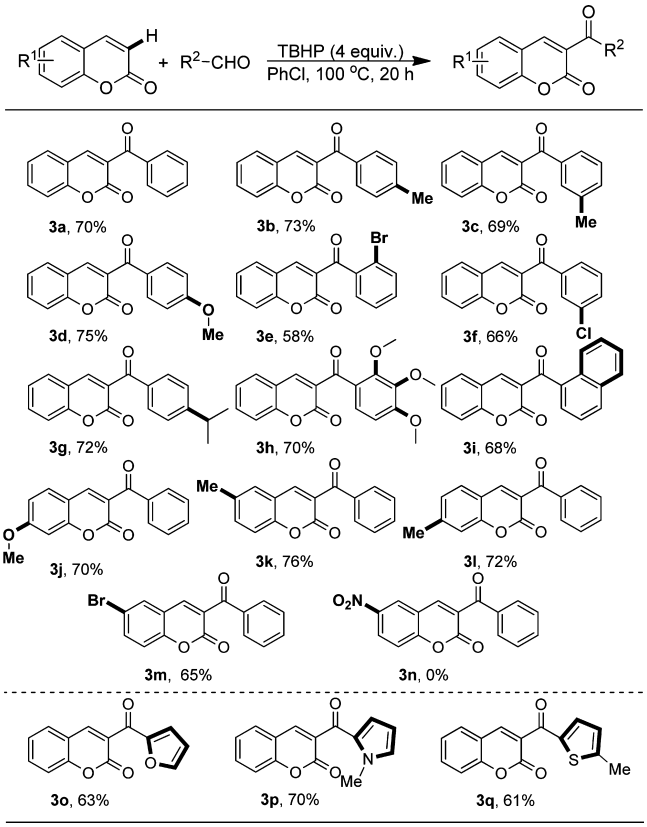
Table 1. Screening Optimal Conditions



entry	oxidant	additive	solvent	yield%[a]
1	TBHP		neat	57
2	DTBP		neat	52
3	$K_2S_2O_8$		neat	0
4	TBHP/DTBP		neat	50
5	AIBN		neat	trace
6	TBHP	TBAI	neat	trace
7	TBHP	TBAB	neat	trace
8	TBHP	TBAC	neat	40
9	TBHP	K_2CO_3	neat	trace
10	TBHP		EtOAc	45
11	TBHP		ACN	48
12	TBHP		DCE	35
13	TBHP		H_2O	25
14	**TBHP**		**PhCl**	**70**
15	TBHP	TEMPO	PhCl	0

[a]Reaction conditions: Coumarin (0.1 mmol), benzaldehyde (4 equiv), and TBHP (4 equiv, 70% in water) were heated in a sealed tube at 100 °C for 20 h.

Table 2. Substrate Scope for Construction of 3-Aroyl Coumarins[a]



[a]All reactions were proceeded through the following conditions: Coumarin **1** (0.1 mmol), arylaldehyde **2** (4.0 equiv), and TBHP (4 equiv, 70% in water) in 0.5 mL PhCl were heated in a sealed tube at 100 °C for 20 h.

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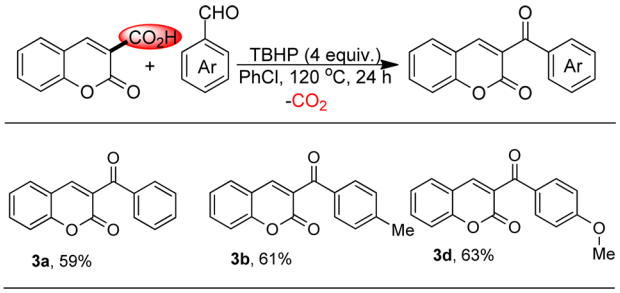
halo substituted arenes were tolerated under these circumstances, making the way for further manipulation (**3e**,**3f**). Cuminaldehyde as a coupling partner also resulted satisfactory yield of the desired product (**3g**). The performance of this approach is also manifested in efficient conversion of sterically encumbered trimethoxy substituted benzaldehyde as well as naphthaldehyde to their desired ketones (**3h**,**3i**). Gratifyingly, various alkyl, alkoxy, and halo substituted coumarins were also tolerated under the optimized conditions and the reactions proceeded smoothly furnishing the desired products in yields exceeding 65% (**3j**−**3m**). Unfortunately, electron-deficient *p*-nitro benzaldehyde did not participate in the cross-coupling reaction.

To our delight, the approach was also viable for some heterocyclic carboxaldehydes. When furan-, pyrrole-, and thiophene-2-carboxaldehydes were exposed to coumarin under reaction conditions, the desired heteroaroyl coumarins **3o**, **3p**, and **3q** were obtained with satisfactory yields, respectively. 1,2-Dihydro derivatives of these motifs, which can be readily prepared from reduction of the corresponding coumarins with sodium borohydride, are proved to show a marked selectivity for the inhibition of SIRT2 over SIRT1 (sirtuins' inhibitors).[10]

Surprisingly, when coumarin-3-carboxylic acid was reacted with arene aldehydes, a tandem decarboxylative/oxidative cross-coupling reaction proceeded and good yields of aroyl coumarins were obtained (Scheme 3). Although lately some

Scheme 3. Reaction of Coumarin-3-carboxylic Acid and Benzaldehydes



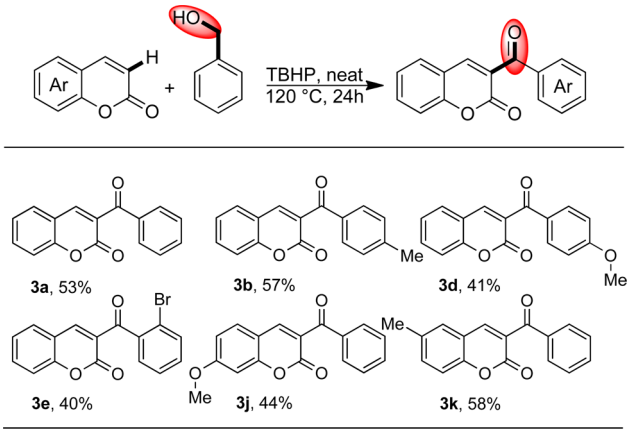
reports on metal-free decarboxylation have been released,[11] this is the first example of decarboxylation of coumarins under metal free conditions. Previous report in this field was also revealed by our group using palladium catalyst.[12]

Next our thoughts were stimulated about other approaches for construction of 3-aroyl coumarins. Gratifyingly, when benzylalcohol was utilized as an acyl source for coupling with coumarin, the corresponding carbonylated coumarin was obtained albeit in low yield. A slightly altered reaction condition with increasing amounts of TBHP and a higher reaction temperature, afforded the desired products in moderate yields (Scheme 4).

As a final step, inspired by Patel, Bhanage, Pan, and Shah's work,[13] we set out to gain the desired product through the reaction of styrene with benzaldehyde (Scheme 5). Using slightly altered reaction conditions the desired ketones were obtained delightfully (see Table S2, Supporting Information). Although the reaction yields are moderate to good, this is the first report of acylation of a heterocyle via reaction with styrene.

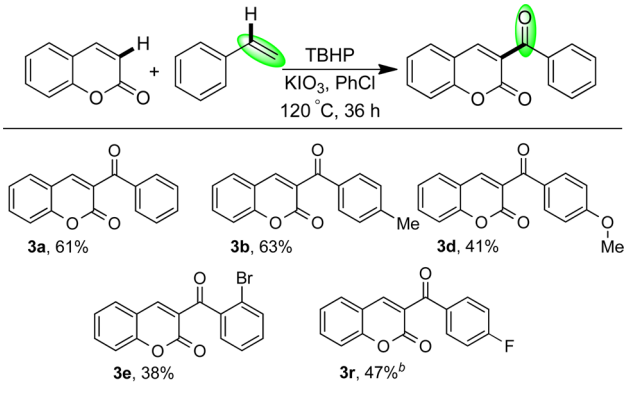
A tentative mechanism of the foregoing reaction has been shown below (Scheme 6). First, the aryl carbonyl radical **A** may

Scheme 4. Oxidative Coupling of Benzylalcohols and Coumarins[a]



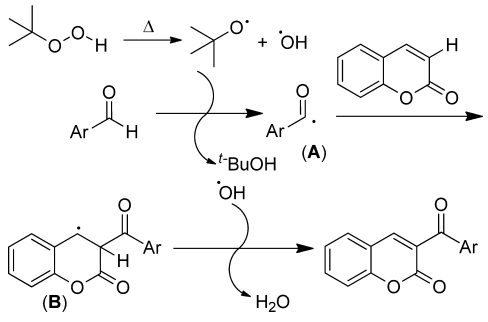
[a]Reaction conditions: Coumarin (0.1 mmol), benzylalcohol (0.1 mL), and TBHP (8 equiv, 70% in water) were heated in a sealed tube at 120 °C for 24 h.

Scheme 5. Acylation of Coumarin via the Reaction with Styrene[a]



[a]Reaction conditions: Coumarin **1** (0.1 mmol), styrene (4.0 equiv), TBHP (8 equiv, 70% in water), and KIO_3 (2 equiv) in 0.5 mL PhCl were heated in a sealed tube at 120 °C for 36 h. [b]Due to difficulties in purification a rough yield is given.

Scheme 6. Plausible Mechanism for Regioselective C-3 Acylation of Coumarins



be generated with the aid of TBHP. Then this radical would selectively attack coumarins at C-3 position and produce intermediate **B** which upon a hydrogen radical loss would deliver the target molecule.

In summary, a regioselective direct carbonylation of coumarins via metal-free cross-dehydrogenative coupling of

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coumarins and aromatic aldehydes has been developed which provides an expedient access to 3-aroyl coumarins. Benzylalcohol and styrene derivatives can also be used in this term enabling one to reach the same products with various reagents. Another privilege offered by this approach is that an in situ decarboxylation takes place simultaneously over the coupling process allowing this procedure to be extended for coumarin-3-carboxylic acids. Good tolerance toward different functional groups renders this method efficient and provides a simple alternative to its precedents.

EXPERIMENTAL SECTION

Typical Experimental Procedure for Metal-Free Direct Carbonylation of Coumarins. A vial equipped with a stir bar was charged with coumarin (0.1 mmol), arylaldehyde (4 equiv), and TBHP (4 equiv). Chlorobenzene (0.5 mL) was added and the vial was capped. The resulting mixture was heated in an oil bath at 100 °C for 20 h. Removal of the solvent gave a crude mixture which was purified by flash column chromatography (hexane/EtOAc gradient) and recrystallization was conducted either using diethyl ether or a mixture of diethyl ether/hexane.

*3-Benzoyl-2H-chromen-2-one (**3a**).* White crystal (18 mg, 70%), mp 131−133 °C (ref 2c, 134−136 °C). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.07 (s, 1H), 7.87 (d, J = 8.1 Hz, 2H), 7.58−7.66 (m, 3H), 7.31−7.49 (m, 4H); $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 191.7, 158.5, 154.7, 145.5, 136.2, 133.9, 133.7, 129.6, 129.2, 128.8, 128.6, 125.0, 118.2, 116.9. Anal. Calcd for $C_{16}H_{10}O_3$: C, 76.79; H, 4.03. Found: C, 77.07; H, 4.16.

*3-(4-Methylbenzoyl)-2H-chromen-2-one (**3b**).* White crystal (19 mg, 73%), mp 127−129 °C (ref 2c, 132−134 °C). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.05 (s, 1H), 8.00 (d, J = 8.1 Hz, 1H), 7.79(d, J = 8.1 Hz, 1H), 7.62 (dd, J = 7.8 Hz, J = 1.5 Hz, 2H), 7.26−7.40 (m, 4H), 2.43 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 191.3, 158.5, 154.7, 145.1, 144.9, 133.6, 133.5, 129.8, 129.4, 129.2, 127.2, 124.9, 118.2, 116.8, 21.8. Anal. Calcd for $C_{17}H_{12}O_3$: C, 77.26; H, 4.58. Found: C, 77.53; H, 4.68.

*3-(3-Methylbenzoyl)-2H-chromen-2-one (**3c**).* White crystal (18 mg, 69%). ^{1}HNMR (300 MHz, $CDCl_3$): δ 8.07 (s, 1H), 7.60−7.74 (m, 4H), 7.27−7.44 (m, 4H), 2.42 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 191.9, 158.5, 154.7, 138.5, 136.2, 134.7, 133.6, 129.9, 129.2, 128.4, 127.9, 127.2, 126.9, 125.0, 118.2, 116.9, 21.3. Anal. Calcd for $C_{17}H_{12}O_3$: C, 77.26; H, 4.58. Found: C, 77.57; H, 4.72.

*3-(4-Methoxybenzoyl)-2H-chromen-2-one (**3d**).* White crystal (21 mg, 75%), mp 174−175 °C (ref 2d, 174−175 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.02 (s, 1H), 7.88 (d, J = 8.8 Hz, 2H), 7.65 (td, J = 8.8 Hz, 1.6 Hz, 1H), 7.58 (dd, J = 8.0 Hz, 1.6 Hz, 1H), 7.40 (d, J = 8.4 Hz, 1H), 7.35 (t, J = 7.6 Hz, 1H), 6.95 (d, J = 8.8 Hz, 2H), 3.88 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ 190.0, 164.3, 157.4, 154.7, 144.6, 133.3, 132.2, 129.0, 127.7, 124.9, 118.3, 116.9, 113.9, 55.6. Anal. Calcd for $C_{17}H_{12}O_4$: C, 72.85; H, 4.32. Found: C, 73.10; H, 4.42.

*3-(2-Bromobenzoyl)-2H-chromen-2-one (**3e**).* White crystal (19 mg, 58%), mp 120−121 °C (ref 3b, 127−128 °C). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.41 (s, 1H), 7.66 (m, 2H), 7.65−7.74 (d, J = 7.8 Hz, 1H), 7.27−7.51 (m, 5H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 191.8, 158.0, 155.3, 147.7, 140.3, 134.5, 133.1, 132.2, 130.0, 129.8, 127.7, 125.5, 125.0, 119.7, 118.4, 117.0. Anal. Calcd for $C_{16}H_9BrO_3$: C, 58.38; H, 2.76. Found: C, 58.66; H, 2.90.

*3-(3-Chlorobenzoyl)-2H-chromen-2-one (**3f**).* White crystal (19 mg, 66%), mp 124−125 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.15 (s, 1H), 7.82 (d, J = 1.5 Hz, 1H), 7.74 (d, J = 7.8 Hz, 1H), 7.66 (t, J = 8.7 Hz, 2H), 7.58 (d, J = 7.8 Hz, 1H), 7.36−7.46 (m, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 190.6, 158.4, 154.9, 146.2, 137.9, 134.9, 134, 133.7, 129.9, 129.4, 129.3, 127.6, 126.3, 125.1, 118.1, 117.0. Anal. Calcd for $C_{16}H_9ClO_3$: C, 67.50; H, 3.19. Found: C, 67.80; H, 3.32.

*3-(4-Isopropylbenzoyl)-2H-chromen-2-one (**3g**).* White crystal (21 mg, 72%), mp 135−136 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.03 (s, 1H), 7.83 (d, J = 7.4 Hz, 2H), 7.58−7.65 (m, 2H), 7.32−7.40 (m, 4H), 2.95−3.00 (m, 1H), 1.27 (d, J = 7.0 Hz, 6 H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ 191.1, 158.5, 155.6, 154.7, 144.9, 134.0, 133.5, 130.0, 129.1, 127.4, 126.8, 125.0, 118.3, 116.9, 34.4, 23.6. Anal. Calcd for $C_{19}H_{16}O_3$: C, 78.06; H, 5.52. Found: C, 78.30; H, 5.63.

*3-(2,3,4-Trimethoxybenzoyl)-2H-chromen-2-one (**3h**).* Red solid (24 mg, 70%), mp 228−230 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.04 (s, 1H), 7.55−7.60 (m, 3H), 7.27−7.37 (m, 2H), 7.76 (d, J = 8.8 Hz, 1H), 3.92 (s, 3H), 3.82 (s, 3 H), 3.72 (s, 3 H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ 189.7, 158.7, 158.4, 154.5, 154.0, 142.1, 141.4, 133.0, 130.2, 129.2, 126.1, 125.0, 124.7, 118.6, 116.8, 107.3, 61.6, 60.9, 56.2. Anal. Calcd for $C_{19}H_{16}O_6$: C, 67.05; H, 4.74. Found: C, 67.33; H, 4.87.

*3-Naphthoyl-2H-chromen-2-one (**3i**).* White crystal (21 mg, 68%), mp 251−252 °C (ref 3b, 252−253 °C). ^{1}H NMR (500 MHz, $CDCl_3$): δ: 8.56 (d, J = 8.5 Hz, 1H), 8.23 (s, 1H), 8.04 (d, J = 8.2 Hz, 1H), 7.93 (d, J = 7.9 Hz, 1H), 7.76 (d, J = 7.1 Hz, 1H), 7.56−7.68 (m, 5H), 7.48 (t, J = 7.5 Hz, 1H), 7.41 (d, J = 8.3 Hz, 1H), 7.36 (t, J = 7.6 Hz, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ: 193.2, 158.1, 155.1, 146.6, 134.6, 134.0, 133.4, 130.7, 129.6, 129.5, 128.6, 128.2, 126.7, 125.5, 124.9, 124.3, 118.3, 116.9. Anal. Calcd for $C_{20}H_{12}O_3$: C, 79.99; H, 4.03. Found: C, 80.31; H, 4.16.

*3-Benzoyl-7-methoxy-2H-chromen-2-one (**3j**).* White crystal (20 mg, 70%), mp 159−160 °C (ref 3b, 150−151 °C).^{1}H NMR (300 MHz, $CDCl_3$): δ 8.11 (s, 1H), 7.88 (d, J = 7.2 Hz, 2H), 7.61 (t, J = 7.2 Hz, 1H), 7.47−7.53 (m, 3H), 6.93 (dd, J = 8.7 Hz, 2.4 Hz, 1H), 6.89 (d, J = 2.4 Hz, 1H), 3.94 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 191.0, 163.6, 157.7, 156.1, 145.4, 135.8, 132.4, 129.4, 128.5, 127.4, 121.9, 112.5, 110.9, 99.7, 55.0. Anal. Calcd for $C_{17}H_{12}O_4$: C, 72.85; H, 4.32. Found: C, 73.12; H, 4.44.

*3-Benzoyl-6-methyl-2H-chromen-2-one (**3k**).* White crystal (21 mg, 76%), mp 163−164 °C (ref 14, 157.7−158.9 °C). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.05 (s, 1H), 7.89 (d, J = 7.5 Hz, 2H), 7.63 (t, J = 7.5 Hz, 1H), 7.28−7.52 (m, 5H), 2.45 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 190.8, 157.6, 151.9, 144.5, 135.3, 133.7, 132.7, 129.9, 128.6, 127.8, 127.6, 125.8, 116.9, 115.6, 19.7. Anal. Calcd for $C_{17}H_{12}O_3$: C, 77.26; H, 4.58. Found: C, 77.55; H, 4.71.

*3-Benzoyl-7-methyl-2H-chromen-2-one (**3l**).* White crystal (19 mg, 72%), mp 156−158 °C (ref 14, 157−158 °C). ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.05 (s, 1H), 7.85 (d, J = 8.1 Hz, 2H), 7.59 (t, J = 8.1 Hz, 1H), 7.44−7.48 (m, 3H), 7.14−7.18 (m, 2H), 2.48 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ 191.8, 158.6, 155.0, 145.7, 136.5, 133.6, 129.5, 128.9, 128.5, 126.3, 125.6, 117.0, 115.8, 22.0. Anal. Calcd for $C_{17}H_{12}O_3$: C, 77.26; H, 4.58. Found: C, 77.58; H, 4.71.

*3-(Furan-2-carbonyl)-2H-chromen-2-one (**3o**).* Brown solid (15 mg, 63%), mp 155−156 °C (ref 3b, 157−158 °C). ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.16 (s, 1H), 7.67−7.60 (m, 3H), 7.40 (d, J = 8.4 Hz, 1H), 7.37−7.33 (m, 2H), 6.61 (dd, J = 3.6 Hz, 1.6 Hz, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ 178.0, 154.8, 151.8, 147.7, 145.5, 133.8, 129.3, 128.8, 126.3, 125.0, 120.7, 118.1, 117.0, 112.7. Anal. Calcd for $C_{14}H_8O_4$: C, 70.00; H, 3.36. Found: C, 70.26; H, 3.47.

*3-(1-Methyl-1H-pyrrole-2-carbonyl)-2H-chromen-2-one (**3p**).* Brown solid (18 mg, 70%), mp 148−150 °C (ref 15, 162−163 °C). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.95 (s, 1H), 7.56−7.65 (m, 2H), 7.28−7.41 (m, 2H), 6.98 (s, 1H), 6.83 (d, J = 2.1 Hz, 1H), 6.19 (d, J = 2.1 Hz, 1H), 4.1 (s, 3H). $^{13}C\{^1H\}$ NMR (75 MHz, $CDCl_3$): δ = 179.8, 158.6, 154.3, 142.6, 133.2, 132.9, 130.9, 128.8, 127.9, 124.8, 123.3, 118.2, 116.9, 108.9, 37.7. Anal. Calcd for $C_{15}H_{11}NO_3$: C, 71.14; H, 4.38; N, 5.53. Found: C, 71.42; H, 4.50; N, 5.70.

*3-(5-Methyl-thiophene−2-carbonyl)-2H-chromen-2-one (**3q**).* Brown solid (16 mg, 61%), mp 150−151 °C (ref 3b, 153−154 °C). ^{1}HNMR (500 MHz, $CDCl_3$): δ 8.05 (s, 1H), 7.64 (t, J = 7.8 Hz, 1H), 7.59 (d, J = 7.6 Hz, 1H), 7.54 (d, J = 3.6 Hz, 1H), 7.39 (d, J = 8.3 Hz, 1H), 7.35 (t, J = 7.6 Hz, 1H), 6.84 (d, J = 3.6 Hz, 1H), 2.6 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ = 182.4, 158.3, 154.6, 152.3, 144.3, 140.6, 136.0, 133.5, 129.1, 127.2, 127.0, 125.0, 118.2, 116.9, 16.2. Anal. Calcd for $C_{15}H_{10}O_3S$: C, 66.65; H, 3.73; S, 11.86. Found: C, 66.94; H, 3.87; S, 12.07.

3-(4-Fluorobenzoyl)-2H-chromen-2-one (3r). White solid (13 mg, 47%), mp 165−166 °C (ref 3b, 167−168 °C). ^{1}HNMR (500 MHz, $CDCl_3$): δ: 8.11- 8.15 (m, 2H), 7.91−7.94 (m, 2H), 7.66−7.68 (m, 1H), 7.61 (d, J = 7.6 Hz, 1H), 7.42 (d, J = 8.3 Hz, 1H), 7.37 (t, J =

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7.5 Hz, 1H), 7.14−7.18 (m, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ: 190.2, 166.2 (d, J_{C-F} = 254.7 Hz), 158.5, 154.9, 145.7, 133.8, 132.3 (d, J_{C-F} = 9.5 Hz), 129.3, 126.9, 125.1, 118.2, 117.0, 115.8 (d, J_{C-F} = 21.9 Hz, CH). Anal. Calcd for $C_{16}H_9FO_3$: C, 71.64; H, 3.38. Found: C, 71.90; H, 3.49.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.6b02051.

Copies of ^1H and ^{13}C spectra of all synthesized compounds. (PDF)

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Notes

The authors declare no competing financial interest.

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