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Synthesis of Isocoumarin Derivatives by Copper-Catalyzed Addition of *o*-Halobenzoic Acids to Active Internal Alkynes

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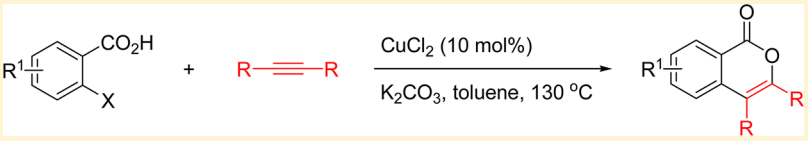
Supporting Information



ABSTRACT: The addition of *o*-halobenzoic acids to active internal alkynes proceeds efficiently in the presence of $CuCl_2$ as a catalyst to give the corresponding isocoumarin derivatives in moderate to good yields. This strategy offers a simple, efficient route to synthesis of the isocoumarin derivatives.

Isocoumarins are important heterocyclic compounds that show a wide range of biological properties.[1] As one of important isocoumarin derivatives, the 3,4-disubstituted isocoumarins show great biological activities,[2] and there are few methods to synthesize of these compounds. However, the reported examples are focused on the use of expensive transition-metal complexes, such as rhodium,[3] palladium,[4] and ruthenium[5] as the catalysts.

Recently, the use of copper salts as catalysts for the formation of carbon−carbon and carbon−heteroatom bonds has attracted considerable attention because of their economic attractiveness and good functional tolerance.[6,7] From the known methods to construct 3,4-disubstituted isocoumarins with copper salts, the reactions suffered the disadvantages of multistep reaction sequences or the need for stoichiometric amounts of copper salts.[8] Very recently, an example of a Cu-catalyzed tandem reaction for the synthesis of 3,4-disubstituted isocoumarins has been reported;[9] in that reaction the starting materials were 2-bromobenzoates and cyclohexane-1,3-diones.

Herein, we report a simple and highly efficient reaction to form 3,4-disubstituted isocoumarin derivatives by copper-catalyzed addition of *o*-halobenzoic acids to internal alkynes. In this reaction, the C−O and C−C bonds are formed simultaneously to afford these important heterocyclic compounds in moderate to good yields.

We became interested in the *o*-halobenzoic acids,[10] which have been used widely as mediates in organic synthesis because of their availability. In our initial study, we chose 2-iodobenzoic acid (**1a**) and dimethyl acetylenedicarboxylate (**2a**) as the model starting materials to examine the reaction. As shown in Table 1, several copper complexes were investigated (entries 1−5). The reaction of compounds **1a** and **2a** in the presence of 10 mol % of CuI in toluene with 2 equiv of K_2CO_3 as the base at 130 °C for 12 h afforded a trace amount of the desired product **3aa** (Table 1, entry 1). The yield was increased to 20% with Cu_2O as a catalyst (Table 1, entry 2). When the catalyst $Cu(OAc)_2·H_2O$ was used, the product **3aa** was obtained in 33% yield (Table 1, entry 3). Under the same reaction conditions, the catalysts $CuBr_2$ and $CuCl_2$ gave the product **3aa** in almost the same yields (Table 1, entries 4 and 5). Screening of catalysts revealed that $CuCl_2$ was a good catalyst in this reaction. We used $CuCl_2$ as the catalyst to optimize other reaction conditions.

It was found that several bases, such as Cs_2CO_3, K_3PO_4, and Na_2CO_3, afforded the product **3aa** in poor yields, and K_2CO_3 provided good yield in this reaction (Table 1, entries 6−8 and entry 5). These results indicated K_2CO_3 was the best base in this reaction. The effect of solvent was investigated. The use of DMF or DMSO gave a trace amount of product **3aa**, and toluene was a good solvent in this reaction (Table 1, entries 9 and 10 and entry 5). We found that the ratio of compound **1a** to **2a** had a great effect on the yield of the product. The product **3aa** was formed in low yield when an excess of compound **1a** was used (Table 1, entries 11 and 12). We were pleased to find that the yield was greatly improved to 83% when 2 equiv of compound **2a** was used (Table 1, entry 14). We also tested the reaction temperature, and we found that 130 °C was the optimized temperature in this reaction (Table 1, entries 14−16). However, the reaction did not give any desired product **3aa** in the absence of the catalyst or the base (Table 1, entries 17 and 18).

With the optimized conditions in hand (Table 1, entry 14), we investigated the scope of the reaction of *o*-halobenzoic acids (**1**) and dimethyl acetylenedicarboxylate (**2a**), and the results are summarized in Table 2. When 2-iodobenzoic acid and its derivatives were applied under the optimized conditions, the compounds with an electron-donating group on the benzene ring gave higher yields than electron-poor counterparts (Table 2, entries 1−4). For example, the compound **1b**, which has a

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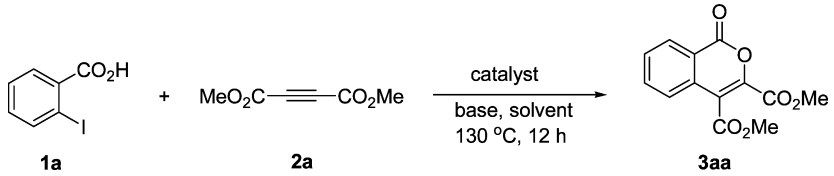
Table 1. Copper-Catalyzed Addition of 2-Iodobenzoic Acid to Dimethyl Acetylenedicarboxylate: Optimization of the Reaction Conditions[a]



1a 2a 3aa

entry	catalyst	base	solvent	yield[b] (%)
1	CuI	K_2CO_3	toluene	trace
2	Cu_2O	K_2CO_3	toluene	20
3	$Cu(OAc)_2·H_2O$	K_2CO_3	toluene	33
4	$CuBr_2$	K_2CO_3	toluene	44
5	$CuCl_2$	K_2CO_3	toluene	45
6	$CuCl_2$	Cs_2CO_3	toluene	trace
7	$CuCl_2$	K_3PO_4	toluene	9
8	$CuCl_2$	Na_2CO_3	toluene	trace
9	$CuCl_2$	K_2CO_3	DMF	trace
10	$CuCl_2$	K_2CO_3	DMSO	trace
11[c]	$CuCl_2$	K_2CO_3	toluene	37
12[d]	$CuCl_2$	K_2CO_3	toluene	21
13[e]	$CuCl_2$	K_2CO_3	toluene	72
14[f]	$CuCl_2$	K_2CO_3	toluene	83 (82)
15[f,g]	$CuCl_2$	K_2CO_3	toluene	76
16[f,h]	$CuCl_2$	K_2CO_3	toluene	80
17		K_2CO_3	toluene	0
18	$CuCl_2$		toluene	0

[a]Unless otherwise noted, the reactions were performed in a sealed tube with 2-iodobenzoic acid (0.3 mmol), dimethyl acetylenedicarboxylate (0.3 mmol), catalyst (0.03 mmol), and base (0.6 mmol) in solvent (2.0 mL) at 130 °C for 12 h under N_2. [b]NMR yields with CH_3NO_2 as an internal standard; the data in parentheses is the yield after column chromatography. [c]1.5 equiv of **1a** was used. [d]2 equiv of **1a** was used. [e]1.5 equiv of **2a** was used. [f]2 equiv of **2a** was used. [g]120 °C. [h]140 °C.

methyl group substituted on the 3-position of the benzene ring, was treated with **2a** in the presence of 10 mol % of $CuCl_2$ with 2 equiv of K_2CO_3 in toluene at 130 °C for 12 h affording the product **3ba** in 66% yield (Table 2, entry 2). The yield of product **3ca** was obtained in 70% yield when compound **1c** with a methyl group substituted on the 5-position of benzene ring was employed in the reaction (Table 2, entry 3). However, the use of compound **1d** with an electron-withdrawing group in the reaction decreased the yield to 34% (Table 2, entry 4). Interestingly, we found that the reactions of 2-bromobenzoic acid derivatives proceeded smoothly giving the corresponding products in moderate to good yields (Table 2, entries 5−10). Under the optimized conditions, the addition of 2-bromobenzoic acid **1e** to **2a** afforded the product **3aa** in 71% yield (Table 2, entry 5). In the cases of the 2-bromobenzoic acid derivatives with a monosubstituted group linked on the 4-position of the benzene ring, the compound with an electron-withdrawing group gave a higher yield than its electron-rich counterpart (Table 2, entries 6 and 7). The products were obtained in good yields when compounds **1h** and **1i** were used in the reaction (Table 2, entries 8 and 9). It was found that the position of substituents on the benzene ring affected the yields. The reaction of compound **1h**, which has a methyl group on the 5-position of benzene ring, with **2a** gave higher yield than that of compound **1g** (Table 2, entry 8 vs entry 7). The compound **1j** with two methoxy groups on the benzene ring can be used as well, and the reaction of compound **1j** and **2a** afforded the product **3ja** in 58% yield (Table 2, entry 10). In order to expand the scope of this reaction, we tested the reaction with 2-chlorobenzoic acid (**1k**), and the reaction of compound **1k** and **2a** proceeded although the yield was low (Table 2, entry 11).

We also examined the scope of internal alkynes. As shown in Table 2, several active internal alkynes can be used in this reaction. The reaction of 2-iodobenzoic acid (**1a**) and dimethyl acetylenedicarboxylate (**2a**) gave the product **3aa** in 82% yield (Table 2, entry 1). Under the same reaction conditions, the product **3ab** was formed in 68% yield when internal alkyne **2b** was employed in the reaction (Table 2, entry 12). It was found that the reaction of compound **1a** and internal alkyne **2c** afforded the product **3ac** in 66% yield (Table 2, entry 13). The product **3ad** was obtained in 69% yield when compound **1a** and internal alkyne **2d** were treated in the reaction (Table 2, entry 14). However, the reactions of 2-iodobenzoic acid (**1a**) with internal alkyne **2e** or **2f**, which is inactive internal alkyne, did not give corresponding substituted isocoumarins at all (Table 2, entries 15−16).

Although the mechanistic details are not clear at this stage, the above experimental results and related literature reports[10b,e,11] suggest that a dimeric copper(II) carboxylate species might be involved in the reaction. 2-Iodobenzoic acid should be rapidly neutralized by the base (K_2CO_3) to give the corresponding potassium carboxylate.[10b,e] The reaction of $CuCl_2$ with the potassium carboxylate might give a dimeric copper(II) carboxylate species,[11] which can be a catalytically active species in the present reaction. Further investigations are needed to elucidate the detailed mechanism.

In conclusion, we demonstrated an efficient method for the synthesis of isocoumarin derivatives based on $CuCl_2$-catalyzed addition of *o*-halobenzoic acids to active internal alkynes. This

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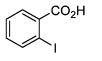
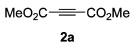
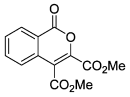
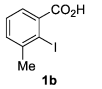
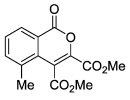
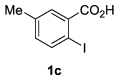
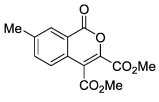
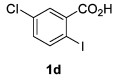
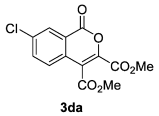
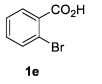
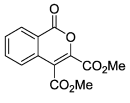
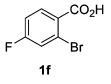
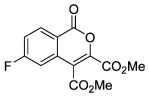
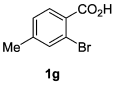
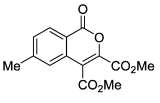
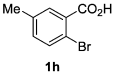
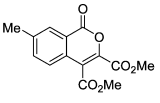
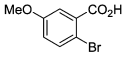
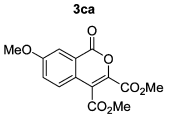
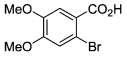
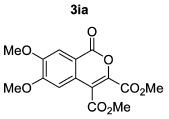
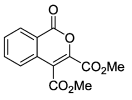
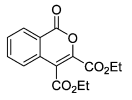
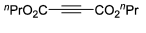
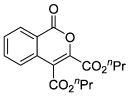
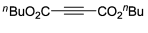
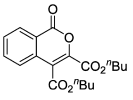
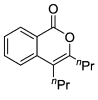
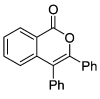
Table 2. Copper-Catalyzed Addition of *o*-Halobenzoic Acids to Internal Alkynes[a]

Entry	*o*-Halobenzoic Acid	Internal Alkyne	Product	Yield (%)
1	 **1a**	 **2a**	 **3aa**	82
2	 **1b**	**2a**	 **3ba**	66
3	 **1c**	**2a**	 **3ca**	70
4	 **1d**	**2a**	 **3da**	34
5	 **1e**	**2a**	 **3aa**	71
6	 **1f**	**2a**	 **3fa**	54
7	 **1g**	**2a**	 **3ga**	42
8	 **1h**	**2a**		60
9	 **1i**	**2a**	 **3ca**	50
10	 **1j**	**2a**	 **3ja**	58
11	 **1k**	**2a**	 **3aa**	23
12	 **1a**	**2b**	 **3ab**	68
13	**1a**	 **2c**	 **3ac**	66
14	**1a**	 **2d**	 **3ad**	69
15	**1a**	**2e**	 **3ae**	0
16	**1a**	**2f**	 **3af**	0

[a]The reactions were performed in a sealed tube with *o*-halobenzoic acid (0.3 mmol), internal alkyne (0.6 mmol), $CuCl_2$ (0.03 mmol), and K_2CO_3 (0.6 mmol) in toluene (2.0 mL) at 130 °C for 12 h under N_2.

method shows good functional group tolerance and the substituted isocoumarins were afforded in moderate to good yields.

EXPERIMENTAL SECTION

General Comments. All of the reactions were carried out with standard Schlenk techniques under predried nitrogen. Toluene was distilled over benzophenone ketyl under N_2. All commercial reagents were used without further purification. Compounds **2c** and **2d** were prepared according to the reported procedure.[12] NMR spectra were recorded on a 400 spectrometer (400 MHz for ^{1}H, 100 MHz for ^{13}C) with deuterated chloroform ($CDCl_3$) as a solvent at 298 K. Chemical shifts are reported in δ ppm referenced to an internal $SiMe_4$ standard for ^{1}H NMR, chloroform-*d* (δ 77.16) for ^{13}C NMR: the following abbreviations are used; s: singlet, d: doublet, t: triplet, q: quartet, m: multiplet. High-resolution mass spectra were obtained with a Q-TOF MS spectrometer.

*Dipropyl acetylenedicarboxylate (**2c**):* colorless liquid; ^{1}H NMR ($CDCl_3$) δ 4.20 (t, J = 8.0 Hz, 4H), 1.68−1.77 (m, 4H), 0.98 (t, J = 8.0 Hz, 6H); ^{13}C NMR ($CDCl_3$) δ 10.3 (2C), 21.8 (2C), 68.6 (2C), 74.8 (2C), 152.0 (2C); HRMS (ESI) calcd for $C_{10}H_{14}O_4Na$ 221.0790 $(M + Na)^+$, found 221.0789.

*Dibutyl acetylenedicarboxylate (**2d**):* colorless liquid; ^{1}H NMR ($CDCl_3$) δ 4.24 (t, J = 8.0 Hz, 4H), 1.64−1.71 (m, 4H), 1.36−1.46 (m, 4H), 0.95 (t, J = 8.0 Hz, 6H); ^{13}C NMR ($CDCl_3$) δ 13.7 (2C), 19.0 (2C), 30.4 (2C), 66.9 (2C), 74.8 (2C), 152.1 (2C); HRMS (ESI) calcd for $C_{12}H_{18}O_4Na$ $(M + Na)^+$ 249.1103, found 249.1110.

General Procedure for the Synthesis of Isocoumarin Derivatives 3. A mixture of $CuCl_2$ (4.0 mg, 0.03 mmol), K_2CO_3 (82.9 mg, 0.6 mmol), 2-iodobenzoic acid (**1a**) (74.4 mg, 0.3 mmol), and dimethyl acetylenedicarboxylate (**2a**) (85.2 mg, 0.6 mmol) in toluene (2.0 mL) was stirred at room temperature under N_2 atmosphere. Then the mixture was heated to 130 °C and it stirred at 130 °C for 12 h. After completion, the mixture was cooled to room temperature and diluted with ethyl acetate. The mixture was passed through a short column of Celite with ethyl acetate as an eluent. After evaporation of the solvent, the residue was subjected to a column chromatography on silica gel (hexane/ethyl acetate, 3/1) to give the product **3aa**.

*3,4-Dimethoxycarbonylisocoumarin (**3aa**, CAS: 89806-27-9):*[13] white solid; 64.5 mg (82% yield); mp 132−133 °C (lit.[13b] mp 130.5−131.7 °C); ^{1}H NMR ($CDCl_3$) δ 8.36 (d, J = 8.6 Hz, 1H), 7.84 (d, J = 8.6 Hz, 1H), 7.70 (d, J = 8.6 Hz, 1H), 7.54 (d, J = 8.6 Hz, 1H), 4.01 (s, 3H), 3.96 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 53.5 (2C), 119.1, 122.0, 125.6, 130.4, 131.4, 132.8, 135.7, 140.9, 159.3, 160.2, 165.1.

*5-Methyl-3,4-dimethoxycarbonylisocoumarin (**3ba**):* white solid; 54.7 mg (66% yield); mp 144−145 °C; ^{1}H NMR ($CDCl_3$) δ 8.31 (d, J = 8.0 Hz, 1H), 7.55−7.63 (m, 2H), 4.01 (s, 3H), 3.96 (s, 3H), 2.51 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 20.1, 53.4 (2C), 118.9, 123.2, 129.1, 130.9,

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131.1, 136.2, 139.1, 140.4, 159.9, 160.5, 167.0; HRMS (ESI) calcd for $C_{14}H_{13}O_6$ $(M + H)^+$ 277.0712, found 277.0706.

*7-Methyl-3,4-dimethoxycarbonylisocoumarin (**3ca**):* white solid; 57.9 mg (70% yield); mp 164−165 °C; ^{1}H NMR ($CDCl_3$) δ 8.18 (s, 1H), 7.65 (d, J = 8.0 Hz, 1H), 7.42 (d, J = 8.0 Hz, 1H), 4.02 (s, 3H), 3.96 (s, 3H), 2.52 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 21.7, 53.4, 53.5, 119.3, 121.9, 125.5, 130.3 (2C), 136.8, 140.1, 142.4, 159.5, 160.3, 165.3; HRMS (ESI) calcd for $C_{14}H_{13}O_6$ $(M + H)^+$ 277.0712, found 277.0699.

*7-Chloro-3,4-dimethoxycarbonylisocoumarin (**3da**):* white solid; 30.0 mg (34% yield); mp 176−179 °C; ^{1}H NMR ($CDCl_3$) δ 8.34 (s, 1H), 7.78 (d, J = 8.0 Hz, 1H), 7.51 (d, J = 8.0 Hz, 1H), 4.02 (s, 3H), 3.97 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 53.6 (2C), 118.2, 123.3, 127.2, 130.0, 131.2, 136.0, 137.7, 141.4, 158.2, 160.1, 164.7; HRMS (ESI) calcd for $C_{13}H_{10}ClO_6$ $(M + H)^+$ 297.0166, found 297.0161.

*6-Fluoro-3,4-dimethoxycarbonylisocoumarin (**3fa**):* white solid; 45.5 mg (54% yield); mp 153−154 °C; ^{1}H NMR ($CDCl_3$) δ 8.41 (dd, J = 8.0 Hz, J = 4.0 Hz, 1H), 7.40 (dt, J = 8.0 Hz, J = 4.0 Hz, 1H), 7.26 (dd, J = 8.0 Hz, J = 4.0 Hz, 1H), 4.02 (s, 3H), 3.98 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 53.6 (2C), 112.1 (d, J_{F-C} = 24.0 Hz), 117.6 (d, J_{F-C} = 2.0 Hz), 118.3 (d, J_{F-C} = 2.0 Hz), 119.4 (d, J_{F-C} = 23.0 Hz), 133.8 (d, J_{F-C} = 10.0 Hz) (2C), 135.6 (d, J_{F-C} = 11.0 Hz), 142.9, 159.2 (d, J_{F-C} = 168.0 Hz), 164.6, 167.0 (d, J_{F-C} = 257.0 Hz); HRMS (ESI) calcd for $C_{13}H_{10}FO_6$ $(M + H)^+$ 281.0461, found 281.0459.

*6-Methyl-3,4-dimethoxycarbonylisocoumarin (**3ga**):* yellow solid; 35.0 mg (42% yield); mp 169−170 °C; ^{1}H NMR ($CDCl_3$) δ 8.25 (d, J = 8.0 Hz, 1H), 7.51 (d, J = 8.0 Hz, 1H), 4.04 (s, 3H), 3.97 (s, 3H), 2.52 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 22.2, 53.4, 53.5, 119.1, 119.5, 125.5, 130.4, 132.6, 132.8, 140.8, 147.2, 159.4, 160.3, 165.3; HRMS (ESI) calcd for $C_{14}H_{13}O_6$ $(M + H)^+$ 277.0712, found 277.0711.

*7-Methoxy-3,4-dimethoxycarbonylisocoumarin (**3ia**):* white solid; 43.9 mg (50% yield); mp 184−185 °C; ^{1}H NMR ($CDCl_3$) δ 7.78 (d, J = 4.0 Hz, 1H), 7.45 (d, J = 8.0 Hz, 1H), 7.38 (dd, J = 8.0 Hz, J = 4.0 Hz, 1H), 4.02 (s, 3H), 3.96 (s, 3H), 3.95 (s, 3H); ^{13}C NMR ($CDCl_3$) δ 53.4, 53.5, 56.1, 111.4, 119.5, 123.8, 124.9, 126.0, 127.3, 138.7, 159.5, 160.3, 162.0, 165.4; HRMS (ESI) calcd for $C_{14}H_{13}O_7$ 293.0661 $(M + H)^+$, found 293.0658.

*6,7-Dimethoxy-3,4-dimethoxycarbonylisocoumarin (**3ja**):* white solid; 56.0 mg (58% yield); mp 221−222 °C; ^{1}H NMR ($CDCl_3$) δ 7.72 (s, 1H), 6.85 (s, 1H), 4.03 (s, 3H), 4.02 (s, 3H), 4.00 (s, 3H), 3.96 (s, 3H). ^{13}C NMR ($CDCl_3$) δ 53.4, 53.5, 56.5, 56.6, 105.9, 110.2, 115.8, 118.8, 127.9, 140.1, 152.0, 155.5, 159.3, 160.4, 165.5; HRMS (ESI) calcd for $C_{15}H_{15}O_8$ 323.0767 $(M + H)^+$, found 323.0764.

*3,4-Diethoxycarbonylisocoumarin (**3ab**, CAS: 101094-24-0):*[14] white solid; 59.1 mg (68% yield); mp 65−66 °C (lit.[14] mp 65−66 °C); ^{1}H NMR ($CDCl_3$) δ 8.39 (d, J = 8.0 Hz, 1H), 7.85 (dd, J = 8.0 Hz, J = 8.0 Hz, 1H), 7.71 (dd, J = 8.0 Hz, J = 8.0 Hz, 1H), 7.57 (d, J = 8.0 Hz, 1H), 4.51 (q, J = 8.0 Hz, 1H), 4.43 (q, J = 8.0 Hz, 1H), 1.43 (t, J = 8.0 Hz, 1H), 1.42 (t, J = 8.0 Hz, 1H); ^{13}C NMR ($CDCl_3$) δ 14.0, 14.2, 62.7, 62.9, 118.9, 122.0, 125.5, 130.3, 131.2, 133.0, 135.6, 141.2, 159.5, 159.7, 164.7.

*3,4-Dipropoxycarbonylisocoumarin (**3ac**):* colorless oil; 62.8 mg (66% yield); ^{1}H NMR ($CDCl_3$) δ 8.39 (d, J = 8.0 Hz, 1H), 7.85 (dd, J = 8.0 Hz, J = 8.0 Hz, 1H), 7.71 (dd, J = 8.0 Hz, J = 8.0 Hz, 1H), 7.57 (d, J = 8.0 Hz, 1H), 4.40 (t, J = 8.0 Hz, 2H), 4.32 (d, J = 8.0 Hz, 2H), 1.77−1.86 (m, 4H), 1.02 (t, J = 8.0 Hz, 6H); ^{13}C NMR ($CDCl_3$) δ 10.4, 10.5, 21.8, 21.9, 68.4, 68.5, 119.0, 122.0, 125.5, 130.4, 131.2, 133.1, 135.6, 141.2, 159.5, 159.9, 164.8; HRMS (ESI) calcd for $C_{17}H_{19}O_6$ $(M + H)^+$ 319.1182, found 319.1175.

*3,4-Dibutylcarbonylisocoumarin (**3ad**):* colorless oil; 71.7 mg (69% yield); ^{1}H NMR ($CDCl_3$) δ 8.39 (d, J = 8.0 Hz, 1H), 7.85 (dd, J = 8.0 Hz, J = 8.0 Hz, 1H), 7.70 (dd, J = 8.0 Hz, J = 8.0 Hz, 1H), 7.56 (d, J = 8.0 Hz, 1H), 4.44 (t, J = 8.0 Hz, 2H), 4.37 (d, J = 8.0 Hz, 2H), 1.73−1.81 (m, 4H), 1.41−1.51 (m, 4H), 0.98 (t, J = 8.0 Hz, 6H); ^{13}C NMR ($CDCl_3$) δ 13.7 (2C), 19.1, 19.2, 30.4, 30.6, 66.6, 66.8, 119.0, 122.0, 125.5, 130.4, 131.1, 133.1, 135.6, 141.3, 159.5, 159.9, 164.8; HRMS (ESI) calcd for $C_{19}H_{22}O_6Na$ $(M + Na)^+$ 369.1314, found 369.1322.

■ ASSOCIATED CONTENT

Supporting Information

^{1}H and ^{13}C NMR spectra for compounds **2c−d**, **3ba−da**, **3fa−ga**, **3ia−ja**, and **3ac−ad**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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