ChemInform Abstract: Rh(III)-Catalyzed Oxidative Coupling of Benzoic Acids with Geminal-Substituted Vinyl Acetates: Synthesis of 3-Substituted Isocoumarins.

ARTICLE *in* THE JOURNAL OF ORGANIC CHEMISTRY · DECEMBER 2014

Impact Factor: 4.72 · DOI: 10.1021/jo502231y · Source: PubMed

JOC The Journal of Organic Chemistry

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Rh(III)-Catalyzed Oxidative Coupling of Benzoic Acids with Geminal-Substituted Vinyl Acetates: Synthesis of 3-Substituted Isocoumarins

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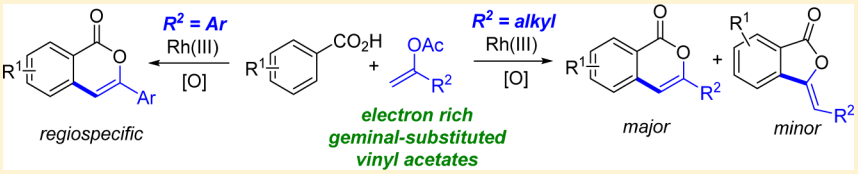
Supporting Information

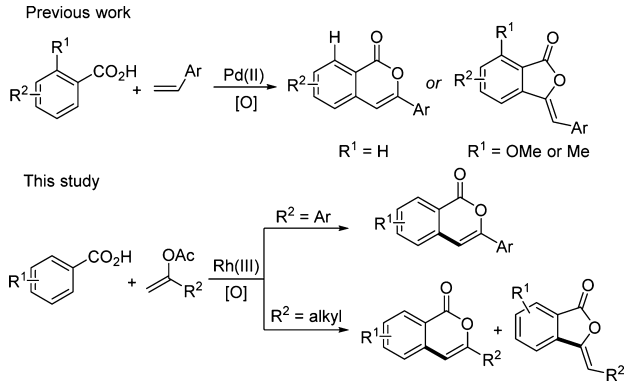


ABSTRACT: The Rh(III)-catalyzed C−H activation initiated cyclization of benzoic acids with electron-rich geminal-substituted vinyl acetates was described. The reaction was employed to prepare a range of 3-aryl and 3-alkyl substituted isocoumarins selectively.

Isocoumarins, especially 3-substituted isocoumarins that have no substituents at the 4-position, are an important class of biologically active scaffolds and present in a large number of pharmaceuticals and natural products.[1,2] Plenty of methods have been developed for the formation of isocoumarin skeletons,[3,4] mainly including the annulation of internal alkynes by halogen- or triflate-containing aromatic esters,[4a,b] the electrophilic cyclization of 2-(alkynyl)benzoic acid derivatives,[4c−e] and the coupling of 2-halo benzoic acid derivatives with terminal alkynes, followed by subsequent cyclization.[4f,g] Recently, several novel routes for the construction of 3-substituted isocoumarins were developed involving the copper-catalyzed sequential cyclization of 2-halobenzoic acids or their derivatives with 1,3-diketones.[4h−k] In addition, Ji et al. disclosed that, starting from 1-(2-halophenyl)-3-phenylpropane-1,3-diones, 3-substituted isocoumarins could be formed through a copper-catalyzed cascade intramolecular Ullmann-type coupling-rearrangement process.[4l] However, most of these strategies were limited by the use of halogenated aromatic carboxylic acid derivatives as substrates.

Recently, direct C−H bond functionalization as an atom- and step-economical process has become a powerful protocol in organic synthesis.[5] In this context, the C−H activation/annulation strategies were applied for the construction of benzo-fused heterocycles including isocoumarins.[6] In 2007, Satoh and Miura et al. disclosed a Rh/Cu-catalyzed oxidative annulation reaction of internal alkynes by benzoic acids for the synthesis of 3,4-disubstituted isocoumarins.[7a,b] Later, Ackermann et al. reported a similar transformation catalyzed by a ruthenium complex.[7c,d] Recently, Miura and Lee et al., respectively, discovered that the palladium-catalyzed direct oxidative coupling of benzoic acids with vinylarenes could afford 3-substituted isocoumarins or 3-benzylidenephthalides (Scheme 1).[8] Lee and his co-workers also found that the substituents on the benzoic acids have a significant effect on the reaction selectivity (Scheme 1). When *ortho*-substituted benzoic acids were treated with vinylarenes, the corresponding 3-benzylidenephthalides were formed selectively, which signified that 7-substituted isocoumarins could not be synthesized using this methodology. Furthermore, other than reactive acrylates[8a] and vinylarenes, electron-rich alkenes, such as vinyl esters and vinyl ethers, were not involved in the transformation.[8] Herein, we report a novel approach to prepare 3-aryl- and 3-alkyl-substituted isocoumarins selectively based on the Rh(III)-catalyzed oxidative coupling between benzoic acid and electron-rich geminal-substituted vinyl acetates (Scheme 1).

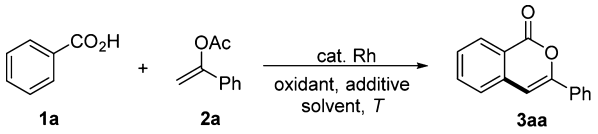
Scheme 1. Synthesis of 3-Substituted Isocoumarins Based on C−H Functionalization



The transition-metal-catalyzed oxidative C−H olefination with electron-deficient and electron-neutral alkenes has been extensively studied.[9] However, there are only a few reports on the oxidative C−H alkenylation with electron-rich alkenes.[10,11] Considering its usability and accessibility, it is of interest to

Received: September 30, 2014
Published: December 1, 2014

Table 1. Reaction Optimization[a]



entry	cat.	oxidant	additive	solvent	yield (%)[b]
1	$[RhCp^*Cl_2]_2$	$Cu(OAc)_2·H_2O$		PhMe	21
2	$[RhCp^*Cl_2]_2$	CuO		PhMe	39
3	$[RhCp^*Cl_2]_2$	CuO		*t*-Am-OH	32
4[c]	$[RhCp^*Cl_2]_2$	CuO		PhMe/*t*-Am-OH (2:1)	31
5	$[RhCp^*Cl_2]_2$	CuO	KOAc	PhMe/*t*-Am-OH	65
6	$[RhCp^*Cl_2]_2$	CuO	KOAc/KI	PhMe/*t*-Am-OH	50
7	$[RhCp^*Cl_2]_2$	CuO	KOAc/LiCl	PhMe/*t*-Am-OH	46
8[d]	$[RhCp^*Cl_2]_2$	CuO	KOAc/LiCl/KI	PhMe/*t*-Am-OH	75
9		CuO	KOAc/LiCl/KI	PhMe/*t*-Am-OH	0
10	$[RhCp^*Cl_2]_2$		KOAc/LiCl/KI	PhMe/*t*-Am-OH	0

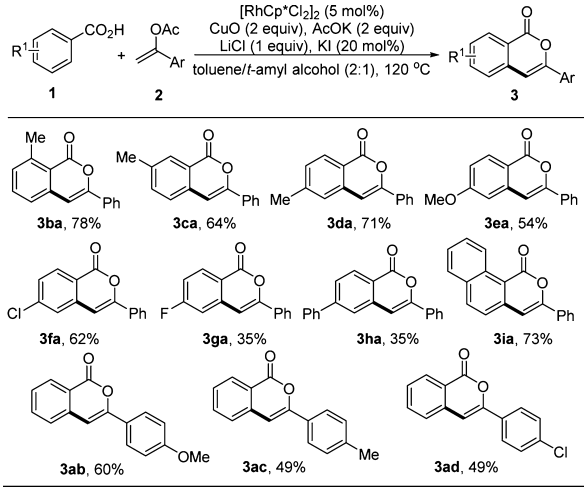
[a]Reaction condtions: **1a** (0.8 mmol), **2a** (2.0 mmol), $[RhCp^*Cl_2]_2$ (0.04 mmol), oxidant (1.6 mmol), additive, solvent (2 or 3 mL), 120 °C. [b]Isolated yield of **3aa**. [c]*tert*-Amyl alcohol (1 mL). [d]KOAc (1.6 mmol), LiCl (0.8 mmol), KI (0.16 mmol).

investigate the direct olefination on aromatic rings with vinyl acetate derivatives.[12,13] Our initial study focused on the reaction between benzoic acid (**1a**) and 1-phenylvinyl acetate (**2a**). To our delight, when **1a** was treated with **2a** in the presence of 5 mol % of $[RhCp^*Cl_2]_2$ and 2 equiv of $Cu(OAc)_2·H_2O$ in toluene at 120 °C, 3-phenylisochromen-1-one (**3aa**) was formed in 21% yield after 48 h (Table 1, entry 1). When $Cu(OAc)_2·H_2O$ was replaced by CuO, the yield of **3aa** was increased to 39% (Table 1, entry 2). Several solvents were tested, and the reactions performed in *tert*-amyl alcohol or toluene/*tert*-amyl alcohol (2:1) gave slightly lower yields (32% and 31%, respectively; Table 1, entries 3 and 4).[14] Interestingly, the addition of KOAc increased the yield of **3aa** up to 65% (Table 1, entry 5).[15] Subsequently, screening of a range of additives suggested that the addition of both KI and LiCl was also effective for the cyclization (Table 1, entries 6–8).[16] The desired product was formed in 75% yield in the presence of KOAc as base and LiCl/KI as additives (Table 1, entry 8). In addition, treatment of benzoic acid (**1a**) with 1-phenylvinyl acetate (**2a**) in the absence of either $[RhCp^*Cl_2]_2$ or CuO did not afford the desired product (entries 9 and 10).

With the optimized conditions in hand, the scope of the benzoic acids and 1-arylvinyl acetates was examined (Table 2). The reactions of all the 2-, 3-, and 4-methylbenzoic acids with **2a** led to the formation of the corresponding isocoumarins in high yields (**3ba**–**3da**). It is noteworthy that the regioselectivity of the transformations was not affected by the substiuents on the benzoic acids, which is different from Lee's work.[8b] Moreover, both electron-rich and electron-deficient benzoic acids were compatible substrates, and moderate to good yields of products (**3ea**–**3ha**) were obtained. When 1-naphthoic acid (**1i**) was treated with **2a**, the corresponding cyclization product **3ia** could be obtained in 73% yield. In addition, several substituted 1-phenylvinyl acetates also reacted with benzoic acid (**1a**) smoothly and gave the corresponding products in moderate yields (**3ab**–**3ad**).

Subsequently, we were delighted to find that 1-alkylvinyl acetates could also react with benzoic acids under the current conditions (Table 3).[17] The cyclization of a range of benzoic acids with isopropenyl acetate produced the corresponding 3-methyl isocoumarins **3ae**–**3he**, accompanied by minor amounts of 3-ethylideneisobenzofuranones **4ae**–**4ie** (entries 1–9).[18] The reactions of 1- and 2-naphthoic acids with isopropenyl acetate also took place smoothly (entry 10 and 11). Notably, starting from 2-naphthoic acids, **3ke** and **4ke** derived from the C–H activation at the C-3 rather than the C-1 position was selectively formed perhaps due to the steric hindrance. Other 1-alkylvinyl acetates, such as hex-1-en-2-yl acetate (**2f**), 4-phenylbut-1-en-2-yl acetate (**2g**), and methyl 2-acetoxyacrylate (**2h**), were also tested, and only the corresponding 3-alkyl isocoumarins **3af**–**3ah** were isolated in low yields (entries 12–14). Notably, the cheap and simple vinyl acetate (**2h**) could also react with benzoic acid (**1a**) under the standard conditions. However, the corresponding isocoumarin **3ai** was produced in only 14% yield (entry 13).[11] Furthermore, cyclohexenyl acetate and 1-propenyl acetate were not suitable substrates for this transformation.

Table 2. Cyclization of Arylcarboxylic Acids with 1-Arylvinyl Acetates[a]

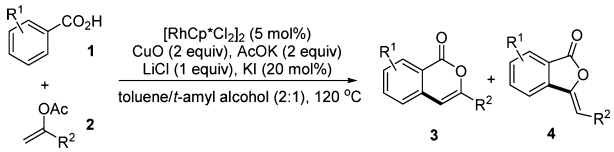


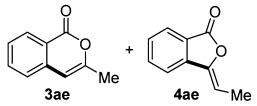
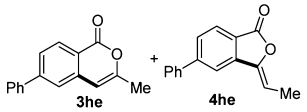
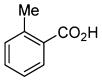
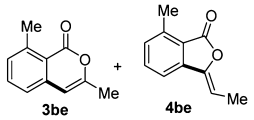
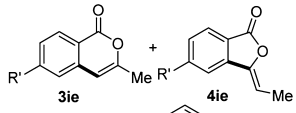
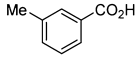
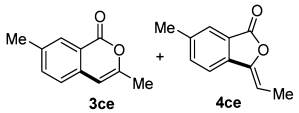
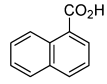
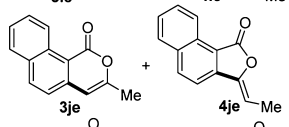
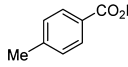
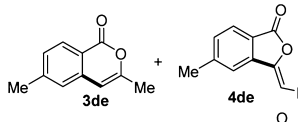
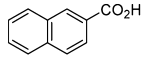
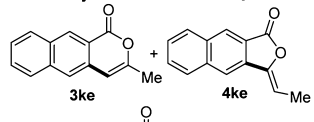
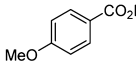
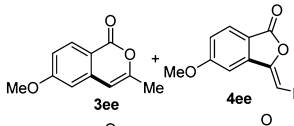
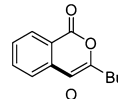
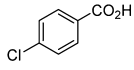
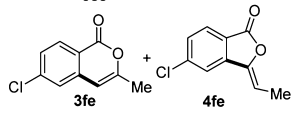
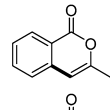
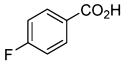
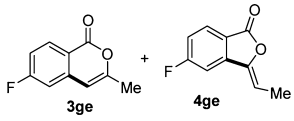
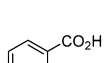
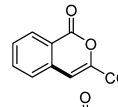
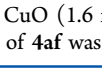
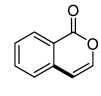
[a]Reaction conditions: **1** (0.8 mmol), **2** (2.0 mmol), $[RhCp^*Cl_2]_2$ (0.04 mmol), CuO (1.6 mmol), KOAc (1.6 mmol), LiCl (0.8 mmol), Kl (0.16 mmol), PhMe/*t*-Am-OH (2:1) (3 mL), 120 °C.

To figure out the mechanism, several experiments were conducted. First, treatment of prop-1-en-2-yl benzoate (**5**) under standard conditions gave only a trace amount of isocoumarin product **3aa** (see the Supporting Information),

dx.doi.org/10.1021/jo502231y | J. Org. Chem. 2015, 80, 620–627

Table 3. Cyclization of Arylcarboxylic Acids with 2-Alkylvinyl Acetates[a,b,c]



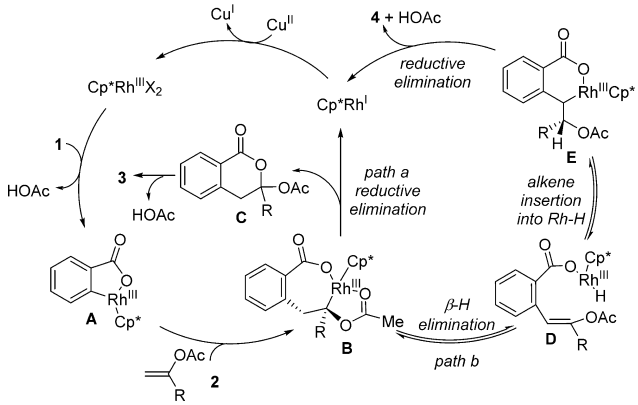
entry	benzoic acids	R^2	product	yield/% (3:4)[b]	entry	benzoic acids	R^2	product	yield/% (3:4)[b]
1		Me	 **3ae** **4ae**	88 (2:1)	8		Me	 **3he** **4he**	66 (4.5:1)
2		Me	 **3be** **4be**	93 (2.7:1)	9	 R' = CO_2Me	Me	 **3ie** **4ie**	28 (3.7:1)
3		Me	 **3ce** **4ce**	90 (2.6:1)	10		Me	 **3je** **4je**	87 (3.6:1)
4		Me	 **3de** **4de**	85 (2.9:1)	11		Me	 **3ke** **4ke**	85 (2.5:1)
5		Me	 **3ee** **4ee**	88 (2.3:1)	12[c]		Bu	 **3af**	20
6		Me	 **3fe** **4fe**	82 (3.1:1)	13		2-phenylethyl	 **3ag**	42
7		Me	 **3ge** **4ge**	88 (3.6:1)	14		CO_2Me	 **3ah**	43
					15		H	 **3ai**	14

[a]Reaction conditions: **1** (0.8 mmol), **2** (2.0 mmol), $[RhCp^*Cl_2]_2$ (0.04 mmol), CuO (1.6 mmol), KOAc (1.6 mmol), LiCl (0.8 mmol), KI (0.16 mmol), PhMe/*t*-Am-OH (2:1) (3 mL), 120 °C. [b]Isolated yield. [c]Trace amount of **4af** was also observed by in situ ^1H NMR.

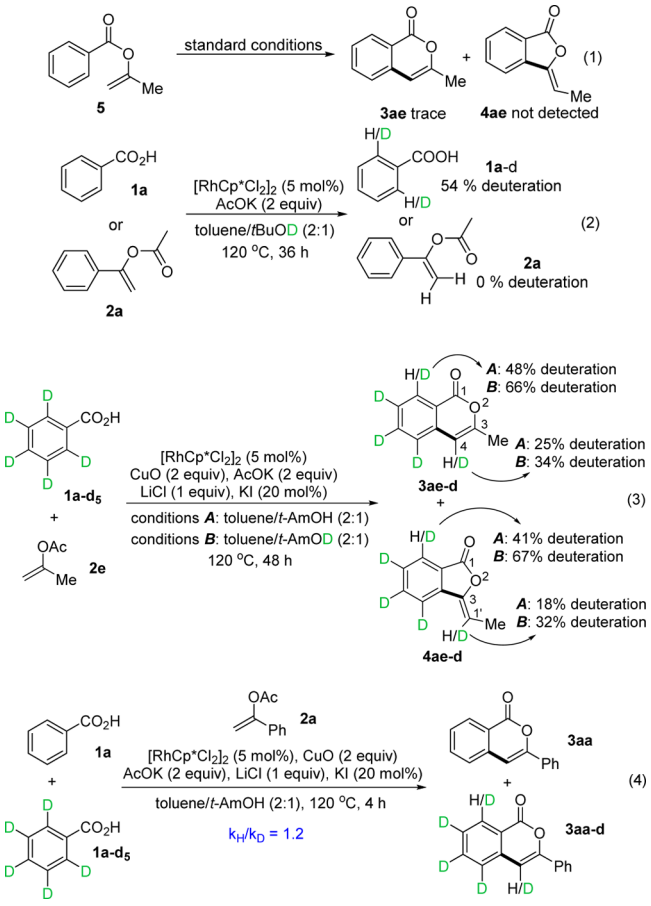
indicating that the transvinylation between **1a** and **2a** might not be involved in the reaction process (eq 1).[19,20] Deuterium labeling experiments of benzoic acid (**1a**) and 1-phenylvinyl acetate (**2a**) were carried out, respectively, under the same reaction conditions (eq 2). Only benzoic acid **1a** was deuterated, indicating the possibility of *ortho*-C−H olefination of benzoic acid with 1-phenylvinyl acetate.[9] Notably, no 4-substituted isocoumarins were observed in all examples shown in Tables 2 and 3, which suggested the highly regioselective insertion of alkenes to arylrhodium intermediates. The formation of 3-ethylideneisobenzofuranones **4** was also consistent with this regiochemistry. Furthermore, the reaction of d_5-benzoic acid **1a-*d*$_5$** with isopropenyl acetate (**2e**) was conducted under standard conditions (eq 3). The incorporation of deuterium at the C-4 position of **3ae-*d*** (25% and 34%) and the C-1′ position of **4ae-*d*** (18% and 32%) was confirmed by ^1H NMR (see the Supporting Information). Moreover, the competing reactions of **1a** and **1a-*d*$_5$** with 1-phenylvinyl acetate (**2a**) were conducted in the same flask (eq 4). The KIE value (k_H/k_D = 1.2) was calculated based on the ratio of products **3aa** and **3aa-*d***, which suggested that the cleavage of the C−H bond maybe not involved in the rate-limiting step.

On the basis of these experiments, a plausible mechanism was proposed (Scheme 2). First, a rhodacycle **A** is formed through the coordination of the carboxylate oxygen of **1** to the Cp*Rh(III) center, followed by *ortho*-rhodation.[9a−d] Subsequently, regioselective insertion of geminal-substituted vinyl acetate **2** into the Rh−C bond leads to the formation of rhodacycle **B**. The phenyl migration from the Rh center to the

Scheme 2. Proposed Catalytic Cycle



dx.doi.org/10.1021/jo502231y | J. Org. Chem. 2015, 80, 620−627



C-2 position of **2** is favored, perhaps due to the coordination between the acetoxy group and the Rh center, which was also proposed by Mardsen and co-workers.[11] When R is an aryl group, the corresponding rhodacycle **B** prefers to undergo reductive elimination to give intermediate **C** and Cp*Rh(I) (path a, in Scheme 2). The resulting Cp*Rh(I) is oxidized by Cu(II) to regenerate Cp*Rh(III). Elimination of acetic acid from **C** affords the final product **3**. This pathway may explain the regiospecific formation of isocoumarin product **3** starting from 1-arylvinyl acetates. When R is the methyl group, besides path a, the corresponding rhodacycle **B** may also undergo reversible β-hydride elimination to afford rhodium hydride intermediate **D** (path b, in Scheme 2). Intramolecular alkene insertion to the Rh−H bond led to the formation of two regioisomeric rhodacycles **B** or **E**. Reductive elimination of intermediate **E**, followed by elimination of acetic acid, produced another isomeric product **4**. The H/D exchange of rhodium hydride intermediate **D** in the presence of *t*-AmOD or in situ formed DOAc may cause the final introduction of deuterium at the C-4 position of **3** and the C-1′ position of **4** selectively (eq 3).[21] Moreover, the reaction between d_5-benzoic acid **1a-*d*$_5$** and 1-phenylvinyl acetate (**2a**) was also conducted under standard conditions, and almost no deuterium was incorporated at the C-4 position of **3aa-*d*** (see the Supporting Information), which is consistent with the proposed catalytic cycle.

In conclusion, we have developed a Rh(III)-catalyzed protocol for the synthesis of 3-substituted isocoumarins by a C−H activation/annulation reaction of electron-rich geminal-substituted vinyl acetates. The reactions starting from 1-aryl vinyl acetates afford the corresponding 3-aryl substituted isocoumarins regiospecifically. However, the reactions of 1-alkyl vinyl acetates with benzoic acids lead to the formation of 3-alkyl substituted isocoumarins as major products. This protocol constitutes an efficient and versatile pathway to a range of isocoumarin derivatives.

EXPERIMENTAL SECTION

General Information. All commercial reagents were used without further purification. ^{1}H and ^{13}C NMR spectra were recorded at 400 or 500 MHz in $CDCl_3$ as solvent. High-resolution mass spectra were recorded on an FT-MS instrument using the ESI technique. IR spectra were recorded on an FT-IR spectrophotometer, with absorptions reported in wavenumbers (cm^{-1}).

General Procedures for Cyclizations of Benzoic Acids with Geminal-Substituted Vinyl Acetates. To a 25 mL tube, benzoic acid **1** (0.8 mmol, 1 equiv), $[RhCp^*Cl_2]_2$ (0.04 mmol, 5 mol %), CuO (1.6 mmol, 2 equiv), AcOK (1.6 mmol, 2 equiv), LiCl (0.8 mmol, 1equiv), KI (0.16 mmol, 0.2 equiv), geminal-substituted vinyl acetate **2** (2 mmol, 2.5 equiv), 1 mL of *tert*-amyl alcohol, and 2 mL of toluene were added. Then, the tube was sealed with a Teflon lined cap, and the reaction mixture was stirred at 120 °C for 48 h. Subsequently, the reaction mixture was concentrated under vacuum. The residue was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 40:1−20:1) to afford the product.

3-Phenyl-1*H*-isochromen-1-one (3aa):[22a] Light yellow solid, mp 88−89 °C, isolated yield 75% (133 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31−8.27 (m, 1H), 7.89−7.83 (m, 2H), 7.72−7.67 (m, 1H), 7.50−7.41 (m, 5H), 6.92 (s, 1H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 162.2, 153.5, 137.4, 134.8, 131.9, 129.9, 129.5, 128.8, 128.1, 126.0, 125.2, 120.4, 101.8; IR (KBr, cm^{-1}) 3060, 2979, 2919, 1727, 1635, 1483, 1232, 1064, 1027, 765, 688.

8-Methyl-3-phenyl-1*H*-isochromen-1-one (3ba):[22b] Light yellow solid; mp 133−135 °C, yield: 78% (147 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.88−7.83 (m, 2H), 7.52 (t, J = 7.6 Hz, 1H), 7.47−7.39 (m, 3H), 7.29 (d, J = 7.7 Hz, 1H), 7.25 (d, J = 7.5 Hz, 1H), 6.85 (s, 1H), 2.85 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 161.5, 153.0, 143.4, 139.0, 133.9, 131.9, 131.0, 129.7, 128.7, 125.1, 124.2, 118.9, 102.2, 23.1; IR (KBr, cm^{-1}) 3099, 3079, 3060, 3027, 2968, 2925, 1720, 1643, 1448, 1074, 1051, 858, 781, 759, 690.

7-Methyl-3-phenyl-1*H*-isochromen-1-one (3ca):[22c] Light yellow solid; mp 138−139 °C, yield: 64% (121 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.12 (s, 1H), 7.88 (dd, J = 5.2, 3.3 Hz, 2H), 7.53 (dd, J = 8.0, 1.3 Hz, 1H), 7.49−7.38 (m, 5H), 6.92 (s, 1H), 2.48 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 162.4, 152.8, 138.4, 136.1, 135.0, 132.1, 129.7, 129.3, 128.7, 125.9, 125.1, 120.4, 101.7, 21.3; IR (KBr, cm^{-1}) 3087, 3052, 3035, 2921, 2856, 1724, 1639, 1498, 1137, 1066, 852, 784, 763, 696, 534.

6-Methyl-3-phenyl-1*H*-isochromen-1-one (3da):[22c] White solid; mp 110−113 °C, yield: 71% (134 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.19 (d, J = 8.1 Hz, 1H), 7.90−7.86 (m, 2H), 7.49−7.41 (m, 3H), 7.33−7.29 (m, 1H), 7.28 (s, 1H), 6.89 (s, 1H), 2.49 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 162.3, 153.6, 145.9, 137.6, 132.1, 129.8, 129.6, 129.5, 128.7, 125.9, 125.2, 118.1, 101.7, 21.9; IR (KBr, cm^{-1}) 3103, 3085, 3054, 3033, 2915, 2852, 1714, 1614, 1450, 1064, 896, 771, 757, 682.

6-Methoxy-3-phenyl-1*H*-isochromen-1-one (3ea):[22c] White solid; mp 143−144 °C, yield: 54% (109 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.22 (d, J = 8.8 Hz, 1H), 7.90−7.85 (m, 2H), 7.49−7.41 (m, 3H), 7.03 (dd, J = 8.8, 2.5 Hz, 1H), 6.88 (s, 1H), 6.87 (d, J = 2.5 Hz, 1H), 3.93 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 164.7, 162.0, 154.1, 139.8, 132.0, 131.8, 129.9, 128.7, 125.2, 116.5, 113.7, 107.9, 101.8, 55.6; IR (KBr, cm^{-1}) 3081, 3035, 2971, 2944, 2840, 1708, 1604, 1452, 1263, 1064, 862, 761, 688.

6-Chloro-3-phenyl-1*H*-isochromen-1-one (3fa):[22d] Light yellow solid; mp 199−203 °C, yield: 62% (127 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.26 (d, J = 8.5 Hz, 1H), 7.92−7.87 (m, 2H), 7.53−7.45 (m, 5H), 6.90 (s, 1H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 161.4, 155.0, 141.5, 138.9, 131.6, 131.3, 130.4, 128.9, 128.5, 125.4, 118.8, 100.7; IR (KBr, cm^{-1}) 3101, 3066, 2921, 2850, 1712, 1633, 1450, 1322, 1236, 1060, 891, 769, 754, 678, 642.

dx.doi.org/10.1021/jo502231y | J. Org. Chem. 2015, 80, 620−627

6-Fluoro-3-phenyl-1*H*-isochromen-1-one (3ga):[22a] Light yellow solid; mp 163−165 °C, yield: 35% (67 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.36 (dd, J = 8.6, 5.6 Hz, 1H), 7.95−7.85 (m, 2H), 7.55−7.45 (m, 3H), 7.24−7.15 (m, 2H), 6.93 (s, 1H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 168.0, 165.4, 161.3, 154.9, 140.2, 140.1, 133.0, 132.9, 131.5, 130.3, 128.9, 125.4, 117.0, 116.9, 116.5, 116.3, 111.6, 111.4, 101.2, 101.2; IR (KBr, cm^{-1}) 3103, 3087, 3072, 3037, 2921, 2852, 1714, 1569, 1454, 1349, 1257, 1066, 883, 771, 682.

3,6-Diphenyl-1*H*-isochromen-1-one (3ha): Light yellow solid; mp 170−173 °C, yield: 35% (84 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.39 (d, J = 8.2 Hz, 1H), 7.97−7.90 (m, 2H), 7.74 (dd, J = 8.2, 1.8 Hz, 1H), 7.72−7.67 (m, 3H), 7.56−7.44 (m, 7H), 7.03 (s, 1H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 162.9, 154.7, 148.4, 140.1, 138.7, 132.7, 130.9, 130.7, 129.7, 129.5, 129.4, 128.1, 127.9, 126.0, 124.8, 119.9, 102.6; IR (KBr, cm^{-1}) 3095, 2919, 2852, 1712, 1608, 1446, 1342, 1068, 892, 756, 690; HRMS (ESI) m/z: calcd. for $C_{21}H_{14}NaO_2$ $[M + Na]^+$ 321.0892, found 321.0894.

3-Phenyl-1*H*-benzo[h]isochromen-1-one (3ia): Light yellow solid; mp 185−188 °C, yield: 73% (159 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.75 (d, J = 8.7 Hz, 1H), 8.11 (d, J = 8.5 Hz, 1H), 8.00−7.94 (m, 2H), 7.90 (d, J = 8.0 Hz, 1H), 7.78 (ddd, J = 8.5, 6.9, 1.4 Hz, 1H), 7.63 (ddd, J = 8.0, 7.0, 1.1 Hz, 1H), 7.54−7.45 (m, 4H), 7.06 (s, 1H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 161.4, 155.0, 140.1, 136.3, 132.9, 131.7, 131.6, 130.2, 129.4, 128.8, 128.6, 126.8, 126.6, 125.4, 123.9, 113.8, 102.6; IR (KBr, cm^{-1}) 3097, 3054, 2962, 2925, 2852, 1708, 1639, 1598, 1047, 1031, 852, 740, 682; HRMS (ESI) m/z: calcd. for $C_{19}H_{12}NaO_2$ $[M + Na]^+$ 295.0735, found 295.0731.

3-(4-Methoxyphenyl)-1*H*-isochromen-1-one (3ab):[22a] Light yellow solid; mp 118−123 °C, yield: 60% (121 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.28 (d, J = 8.2 Hz, 1H), 7.84−7.78 (m, 2H), 7.68 (td, J = 7.8, 1.3 Hz, 1H), 7.45 (ddd, J = 4.7, 3.7, 1.9 Hz, 2H), 6.98−6.95 (m, 2H), 6.81 (s, 1H), 3.86 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 162.4, 161.0, 153.7, 137.9, 134.7, 129.5, 127.6, 126.7, 125.6, 124.5, 120.1, 114.2, 100.2, 55.3; IR (KBr, cm^{-1}) 3076, 2996, 2960, 2931, 2836, 1727, 1633, 1600, 1511, 1255, 1234, 1178, 1064, 1027, 823, 754, 686.

3-(*p*-Tolyl)-1*H*-isochromen-1-one (3ac):[22a] Light yellow solid; mp 117−119 °C, yield: 49% (93 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.28 (dd, J = 8.1, 0.7 Hz, 1H), 7.78−7.73 (m, 2H), 7.72−7.66 (m, 1H), 7.48−7.43 (m, 2H), 7.25 (dd, J = 8.5, 0.6 Hz, 2H), 6.88 (s, 1H), 2.39 (s, 3H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 162.3, 153.7, 140.2, 137.6, 134.8, 129.5, 129.5, 129.1, 127.8, 125.8, 125.1, 120.3, 101.0, 21.3; IR (KBr, cm^{-1}) 3066, 3031, 2952, 2919, 2854, 1731, 1629, 1064, 815, 752, 686, 526.

3-(4-Chlorophenyl)-1*H*-isochromen-1-one (3ad):[22a] Light yellow solid; mp 148−150 °C, yield: 49% (101 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31−8.27 (m, 1H), 7.82−7.78 (m, 2H), 7.75−7.70 (m, 1H), 7.50 (ddd, J = 7.8, 5.4, 1.7 Hz, 2H), 7.45−7.40 (m, 2H), 6.92 (s, 1H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 161.9, 152.4, 137.2, 135.9, 134.9, 130.4, 129.6, 129.0, 128.3, 126.4, 126.0, 120.5, 102.0; IR (KBr, cm^{-1}) 3097, 3035, 2962, 2921, 1722, 1639, 1492, 1068, 1012, 823, 750, 682, 524.

3-Methyl-1*H*-isochromen-1-one (3ae):[23a] White solid, mp 75−77 °C, yield 59% (76 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.22 (d, J = 8.5 Hz, 1H), 7.65 (ddd, J = 8.6, 7.6, 1.3 Hz, 1H), 7.45−7.40 (m, 1H), 7.32 (d, J = 7.9 Hz, 1H), 6.24 (s, 1H), 2.26 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 162.9, 154.5, 137.6, 134.7, 129.4, 127.5, 124.8, 119.8, 103.5, 19.5; IR (KBr, cm^{-1}) 3076, 3029, 2950, 2919, 1720, 1660, 1162, 1068, 757, 688.

3,8-Dimethyl-1*H*-isochromen-1-one (3be): Light yellow solid; mp 91−93 °C, yield: 68% (95 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.47 (t, J = 7.7 Hz, 1H), 7.19 (d, J = 7.5 Hz, 1H), 7.12 (d, J = 7.8 Hz, 1H), 6.16 (d, J = 0.9 Hz, 1H), 2.79 (s, 3H), 2.22 (d, J = 1.0 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 162.2, 154.0, 143.2, 139.1, 133.8, 130.3, 123.0, 118.3, 103.9, 23.1, 19.3; IR (KBr, cm^{-1}) 3091, 3068, 3043, 2969, 2921, 2848, 1724, 1668, 1573, 1475, 1390, 1193, 1162, 1037, 987, 835, 800, 779, 688; HRMS (ESI) m/z: calcd. for $C_{11}H_{10}NaO_2$ $[M + Na]^+$ 197.0579, found 197.0574.

3,7-Dimethyl-1*H*-isochromen-1-one (3ce):[23b] White solid, mp 123−126 °C, yield 65% (91 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 0.8 Hz, 1H), 7.48 (dd, J = 8.0, 1.3 Hz, 1H), 7.23 (d, J = 8.0 Hz, 1H), 6.22 (s, 1H), 2.44 (s, 3H), 2.26 (s, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 163.1, 153.6, 137.6, 135.9, 135.1, 129.1, 124.7, 119.7, 103.3, 21.2, 19.5; IR (KBr, cm^{-1}) 3064, 3031, 2958, 2921, 1729, 1660, 1344, 1153, 1066, 979, 844, 738, 694.

3,6-Dimethyl-1*H*-isochromen-1-one (3de):[23c] Light yellow solid, mp 70−72 °C, yield 63% (88 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.10 (d, J = 8.1 Hz, 1H), 7.23 (d, J = 8.2 Hz, 1H), 7.10 (s, 1H), 6.17 (s, 1H), 2.44 (s, 3H), 2.25 (s, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 163.0, 154.5, 145.7, 137.7, 129.3, 128.8, 124.8, 117.4, 103.4, 21.9, 19.6; IR (KBr, cm^{-1}) 3079, 2958, 2919, 1718, 1660, 1160, 1056, 775, 686.

6-Methoxy-3-methyl-1*H*-isochromen-1-one (3ee):[23a] White solid, mp 100−103 °C, yield 61% (93 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (d, J = 8.8 Hz, 1H), 6.97 (dd, J = 8.8, 2.5 Hz, 1H), 6.70 (d, J = 2.5 Hz, 1H), 6.17 (s, 1H), 3.89 (s, 3H), 2.25 (d, J = 0.9 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 164.6, 162.7, 155.1, 140.0, 131.6, 115.8, 113.0, 106.9, 103.5, 55.5, 19.6; IR (KBr, cm^{-1}) 3074, 3014, 2921, 2842, 1716, 1658, 1602, 1357, 1253, 1222, 1056, 999, 858, 777, 686.

6-Chloro-3-methyl-1*H*-isochromen-1-one (3fe):[23b] White solid, mp 148−150 °C, yield 62% (97 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.16 (d, J = 8.5 Hz, 1H), 7.39 (dd, J = 8.5, 2.0 Hz, 1H), 7.31 (d, J = 2.0 Hz, 1H), 6.19 (s, 1H), 2.29 (d, J = 0.9 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 162.0, 156.0, 141.3, 138.9, 131.1, 128.0, 124.3, 118.2, 102.6, 19.7; IR (KBr, cm^{-1}) 3089, 3064, 3041, 2966, 2927, 1747, 1654, 1598, 1558, 1336, 1159, 1054, 864, 840, 775, 680.

6-Fluoro-3-methyl-1*H*-isochromen-1-one (3ge):[23b] Light yellow solid, mp 88−89 °C, yield 69% (98 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.22 (dd, J = 8.8, 5.6 Hz, 1H), 7.10 (td, J = 8.6, 2.5 Hz, 1H), 6.95 (dd, J = 9.0, 2.5 Hz, 1H), 6.20 (s, 1H), 2.26 (d, J = 0.9 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 167.9, 165.3, 161.8, 156.0, 140.3, 140.2, 132.8, 132.7, 116.3, 116.3, 115.8, 115.6, 110.5, 110.3, 103.0, 103.0, 19.6; IR (KBr, cm^{-1}) 3074, 2975, 2923, 1731, 1662, 1618, 1344, 1168, 1058, 771, 678.

3-Methyl-6-phenyl-1*H*-isochromen-1-one (3he): White solid; mp 142−144 °C, yield: 54% (102 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.31 (d, J = 8.3 Hz, 1H), 7.70−7.63 (m, 3H), 7.54−7.48 (m, 3H), 7.44 (ddd, J = 5.8, 4.4, 2.0 Hz, 1H), 6.31 (s, 1H), 2.31 (d, J = 0.9 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 162.8, 154.9, 147.5, 139.5, 138.1, 130.0, 129.0, 128.6, 127.3, 126.6, 123.0, 118.6, 103.6, 19.6; IR (KBr, cm^{-1}) 3066, 3033, 2958, 2921, 2848, 1720, 1658, 1560, 1160, 1066, 889, 765, 690; HRMS (ESI) m/z: calcd. for $C_{16}H_{12}NaO_2$ $[M + Na]^+$ 259.0735, found 259.0729.

Methyl 3-Methyl-1-oxo-1*H*-isochromene-6-carboxylate (3ie): Light yellow solid; mp 178−181 °C, yield: 22% (38 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.29 (d, J = 8.2 Hz, 1H), 8.03 (d, J = 8.3 Hz, 1H), 8.00 (s, 1H), 6.31 (s, 1H), 3.97 (s, 3H), 2.30 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 165.8, 162.1, 155.4, 137.5, 135.5, 129.7, 127.7, 126.4, 122.8, 103.3, 52.6, 19.6; IR (KBr, cm^{-1}) 3072, 3010, 2960, 2921, 2848, 1737, 1718, 1666, 1338, 1290, 1105, 964, 914, 844, 744, 680; HRMS (ESI) m/z: calcd. for $C_{12}H_{10}NaO_4$ $[M + Na]^+$ 241.0477, found 241.0473.

3-Methyl-1*H*-benzo[*h*]isochromen-1-one (3je):[23d] Light yellow solid; mp 152−154 °C, yield: 68% (114 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 9.64 (d, J = 8.6 Hz, 1H), 7.95 (d, J = 8.5 Hz, 1H), 7.80 (d, J = 8.0 Hz, 1H), 7.69 (ddd, J = 8.5, 6.9, 1.4 Hz, 1H), 7.54 (ddd, J = 8.0, 7.0, 1.1 Hz, 1H), 7.21 (d, J = 8.5 Hz, 1H), 6.24 (s, 1H), 2.27 (d, J = 0.9 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 162.1, 156.3, 140.2, 136.1, 132.5, 131.4, 129.1, 128.5, 126.4, 126.3, 123.1, 112.8, 104.6, 19.5; IR (KBr, cm^{-1}) 3110, 3076, 3014, 2923, 1716, 1589, 1249, 1051, 840, 790, 756, 690; HRMS (ESI) m/z: calcd. for $C_{14}H_{10}NaO_2$ $[M+Na]^+$ 233.0578, found 233.0576.

3-Methyl-1*H*-benzo[*g*]isochromen-1-one (3ke):[23e] Light yellow solid; mp 194−197 °C, yield: 61% (103 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.84 (s, 1H), 7.96 (d, J = 8.7 Hz, 1H), 7.85 (d, J = 8.1 Hz, 1H), 7.69 (s, 1H), 7.60 (ddd, J = 8.3, 6.8, 1.2 Hz, 1H), 7.50 (ddd, J = 8.1, 6.8, 1.2 Hz, 1H), 6.31 (s, 1H), 2.28 (d, J = 0.8 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 163.0, 152.7, 136.5, 132.3, 132.0, 131.7, 129.6, 129.2, 127.5, 126.2, 122.7, 118.5, 103.3, 19.6; IR (KBr, cm^{-1})

dx.doi.org/10.1021/jo502231y | J. Org. Chem. 2015, 80, 620−627

3050, 2956, 2919, 1731, 1666, 1384, 1243, 1157, 1126, 1060, 898, 784, 754, 478.

3-Butyl-1*H*-isochromen-1-one (3af):[23f] Light yellow oil; yield: 20% (32 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.27 (d, J = 8.0 Hz, 1H), 7.68 (td, J = 7.8, 1.3 Hz, 1H), 7.48−7.43 (m, 1H), 7.36 (d, J = 7.8 Hz, 1H), 6.27 (s, 1H), 2.57−2.52 (m, 2H), 1.71 (dt, J = 15.2, 7.5 Hz, 2H), 1.47−1.38 (m, 2H), 0.97 (t, J = 7.4 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 163.1, 158.3, 137.6, 134.6, 129.4, 127.5, 124.9, 120.1, 102.8, 33.2, 28.9, 22.1, 13.7; IR (KBr, cm^{-1}) 3070, 2958, 2929, 2871, 1727, 1656, 1483, 1160, 1103, 1054, 1022, 756, 690.

3-Phenethyl-1*H*-isochromen-1-one (3ag):[23g] Light yellow oil; yield: 42% (84 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.31−8.27 (m, 1H), 7.69 (td, J = 7.6, 1.3 Hz, 1H), 7.50−7.46 (m, 1H), 7.32 (ddd, J = 8.3, 7.5, 5.3 Hz, 3H), 7.23 (dd, J = 10.3, 4.3 Hz, 3H), 6.24 (s, 1H), 3.09−3.03 (m, 2H), 2.89−2.84 (m, 2H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 163.0, 156.9, 140.3, 137.4, 134.7, 129.5, 128.5, 128.3, 127.7, 126.3, 125.1, 120.1, 103.5, 35.4, 33.2; IR (KBr, cm^{-1}) 3060, 3025, 2923, 2856, 1726, 1656, 1483, 1159, 1052, 1024, 970, 754, 688.

Methyl 1-Oxo-1*H*-isochromene-3-carboxylate (3ah):[24] Light yellow solid; mp 167−170 °C, yield: 43% (70 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.38 (d, J = 7.8 Hz, 1H), 7.83 (t, J = 7.6 Hz, 1H), 7.69 (t, J = 7.6 Hz, 1H), 7.63 (d, J = 7.8 Hz, 1H), 7.52 (s, 1H), 3.99 (s, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 160.7, 160.6, 143.2, 135.1, 134.9, 130.8, 130.0, 127.6, 122.7, 112.3, 52.9; IR (KBr, cm^{-1}) 3081, 3045, 3012, 2956, 2917, 2848, 1726, 1716, 1321, 1097, 1052, 1024, 767.

1*H*-Isochromen-1-one (3ai):[25] Light yellow liquid, yield 14% (16 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.31−8.24 (m, 1H), 7.71 (td, J = 7.7, 1.3 Hz, 1H), 7.53−7.48 (m, 1H), 7.42 (d, J = 7.8 Hz, 1H), 7.27 (d, J = 5.6 Hz, 1H), 6.50 (d, J = 5.6 Hz, 1H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 162.1, 144.6, 136.4, 134.7, 129.5, 128.5, 125.5, 121.8, 106.9; IR (KBr, cm^{-1}) 3106, 3085, 3014, 2966, 2925, 1721, 1635, 1486, 1249, 1051, 1002, 790, 690.

(*Z*)-3-Ethylideneisobenzofuran-1(3*H*)-one (4ae):[26a] Light yellow liquid, yield 29% (37 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.89 (dt, J = 7.7, 0.9 Hz, 1H), 7.68 (ddd, J = 8.0, 7.0, 1.0 Hz, 1H), 7.64 (dt, J = 7.8, 1.0 Hz, 1H), 7.54−7.49 (m, 1H), 5.69 (q, J = 7.3 Hz, 1H), 2.04 (d, J = 7.3 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 167.1, 146.3, 139.5, 134.2, 129.3, 125.2, 124.4, 119.5, 104.1, 11.2; IR (KBr, cm^{-1}) 3052, 2917, 2858, 1776, 1693, 1267, 1056, 995, 757, 690.

(*Z*)-3-Ethylidene-7-methylisobenzofuran-1(3*H*)-one (4be):[26b] Light yellow solid; mp 77−81 °C, yield: 25% (35 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.51 (t, J = 7.6 Hz, 1H), 7.42 (d, J = 7.7 Hz, 1H), 7.24 (d, J = 7.4 Hz, 1H), 5.62 (q, J = 7.3 Hz, 1H), 2.68 (s, 3H), 2.01 (d, J = 7.3 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$): δ 167.2, 146.2, 139.9, 139.2, 133.9, 130.8, 122.1, 116.8, 103.2, 17.3, 11.1; IR (KBr, cm^{-1}) 3052, 2919, 2856, 1764, 1687, 1483, 1382, 1209, 999, 784, 692.

(*Z*)-3-Ethylidene-6-methylisobenzofuran-1(3*H*)-one (4ce):[26c] Light yellow solid, mp 71−73 °C, yield 25% (35 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.67 (dt, J = 1.5, 0.8 Hz, 1H), 7.52 (d, J = 7.9 Hz, 1H), 7.48 (ddd, J = 8.0, 1.4, 0.5 Hz, 1H), 5.60 (q, J = 7.2 Hz, 1H), 2.48 (s, 3H), 2.02 (d, J = 7.3 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 167.2, 146.4, 139.8, 137.2, 135.5, 125.0, 124.6, 119.2, 103.1, 21.4, 11.1; IR (KBr, cm^{-1}) 3050, 2919, 2860, 1774, 1691, 1492, 1334, 1272, 1060, 991, 779, 763.

(*Z*)-3-Ethylidene-5-methylisobenzofuran-1(3*H*)-one (4de):[26d] Light yellow liquid, mp 46−49 °C, yield 22% (31 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.76 (d, J = 7.9 Hz, 1H), 7.41 (s, 1H), 7.31 (d, J = 7.9 Hz, 1H), 5.63 (q, J = 7.2 Hz, 1H), 2.50 (s, 3H), 2.02 (d, J = 7.3 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 167.1, 146.4, 145.4, 140.0, 130.6, 124.9, 122.0, 119.6, 103.6, 22.1, 11.2; IR (KBr, cm^{-1}) 3049, 2917, 2860, 1776, 1691, 1618, 1270, 1052, 995, 773, 692.

(*Z*)-3-Ethylidene-5-methoxyisobenzofuran-1(3*H*)-one (4ee):[26e] White solid, mp 99−101 °C, yield 27% (41 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.79 (dd, J = 8.3, 0.6 Hz, 1H), 7.04 (m, 2H), 5.65 (q, J = 7.2 Hz, 1H), 3.93 (s, 3H), 2.03 (d, J = 7.2 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 166.8, 164.9, 146.2, 142.0, 126.7, 117.6, 117.1, 103.9, 102.5, 55.8, 11.2; IR (KBr, cm^{-1}) 3008, 2964, 2917, 2842, 1766, 1606, 1486, 1297, 1110, 1051, 995, 773, 692.

(*Z*)-5-Chloro-3-ethylideneisobenzofuran-1(3*H*)-one (4fe): White solid, mp 116−118 °C, yield 20% (31 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, J = 8.2 Hz, 1H), 7.62 (d, J = 1.5 Hz, 1H), 7.49 (dd, J = 8.2, 1.6 Hz, 1H), 5.71 (q, J = 7.3 Hz, 1H), 2.05 (d, J = 7.3 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$) δ 165.9, 145.3, 141.0, 140.9, 129.9, 126.4, 122.8, 119.7, 105.6, 11.3; IR (KBr, cm^{-1}) 3089, 3062, 2958, 2921, 2854, 1774, 1608, 1432, 1324, 1265, 1068, 997, 829, 773; HRMS (ESI) m/z: calcd. for $C_{10}H_7ClNaO_2$ $[M + Na]^+$ 217.0032, found 217.0031.

(*Z*)-3-Ethylidene-5-fluoroisobenzofuran-1(3*H*)-one (4ge): White solid; mp 90−92 °C, yield 19% (27 mg); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.90 (dd, J = 8.4, 4.8 Hz, 1H), 7.28 (dd, J = 8.1, 1.9 Hz, 1H), 7.21 (td, J = 8.7, 2.2 Hz, 1H), 5.68 (t, J = 7.3 Hz, 1H), 2.04 (d, J = 7.3 Hz, 3H); ^{13}C NMR (400 MHz, $CDCl_3$) δ 168.0, 165.9, 165.5, 145.5, 145.5, 142.0, 141.9, 127.8, 127.6, 120.6, 117.8, 117.6, 106.5, 106.2, 105.6, 11.3; IR (KBr, cm^{-1}) 3089, 3066, 2952, 2923, 2860, 1783, 1766, 1621, 1589, 1477, 1448, 1288, 1054, 999, 775, 688; HRMS (ESI) m/z: calcd. for $C_{10}H_7FNaO_2$ $[M + Na]^+$ 201.0328, found 201.0329.

(*Z*)-3-Ethylidene-5-phenylisobenzofuran-1(3*H*)-one (4he): Light yellow solid; mp 117−121 °C, yield: 12% (23 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (dd, J = 8.0, 0.6 Hz, 1H), 7.79 (s, 1H), 7.71 (dd, J = 8.0, 1.4 Hz, 1H), 7.66−7.62 (m, 2H), 7.54−7.49 (m, 2H), 7.48−7.44 (m, 1H), 5.75 (q, J = 7.2 Hz, 1H), 2.06 (d, J = 7.2 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 166.9, 147.7, 146.4, 140.2, 139.7, 129.0, 128.7, 128.6, 127.4, 125.5, 123.1, 117.9, 104.2, 11.2; IR (KBr, cm^{-1}) 3058, 3033, 2915, 2856, 1777, 1689, 1616, 1425, 1056, 995, 761, 694; HRMS (ESI) m/z: calcd. for $C_{16}H_{12}NaO_2$ $[M + Na]^+$ 259.0735, found 259.0731.

(*Z*)-Methyl 3-Ethylidene-1-oxo-1,3-dihydroisobenzofuran-5-carboxylate (4ie): Light yellow solid; mp 157−160 °C, yield: 6% (11 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.32 (s, 1H), 8.17 (dd, J = 8.0, 1.2 Hz, 1H), 7.96 (dd, J = 8.0, 0.7 Hz, 1H), 5.80 (q, J = 7.3 Hz, 1H), 4.01 (s, 3H), 2.07 (d, J = 7.3 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 166.1, 165.7, 145.8, 139.5, 135.6, 130.1, 127.5, 125.3, 121.1, 105.6, 52.8, 11.3; IR (KBr, cm^{-1}) 3058, 3039, 3008, 2956, 2921, 2853, 1780, 1722, 1591, 1440, 1430, 1249, 995, 754; HRMS (ESI) m/z: calcd. for $C_{12}H_{10}NaO_4$ $[M + Na]^+$ 241.0477, found 241.0463.

(*Z*)-3-Ethylidenenaphtho[1,2-*c*]furan-1(3*H*)-one (4je):[26b] Light yellow solid; mp 117−120 °C, yield: 19% (32 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.92 (d, J = 9.2 Hz, 1H), 8.10 (d, J = 8.5 Hz, 1H), 7.95 (d, J = 8.2 Hz, 1H), 7.74 (ddd, J = 8.3, 7.0, 1.2 Hz, 1H), 7.67−7.60 (m, 2H), 5.80 (q, J = 7.3 Hz, 1H), 2.11 (d, J = 7.3 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 167.2, 146.6, 140.1, 135.4, 133.5, 129.2, 128.8, 128.5, 127.3, 123.9, 118.5, 116.3, 105.6, 11.5; IR (KBr, cm^{-1}) 3066, 3054, 2950, 2904, 2850, 1758, 1685, 1315, 1178, 1087, 997, 964, 804, 794, 750.

(*Z*)-3-Ethylidenenaphtho[2,3-*c*]furan-1(3*H*)-one (4ke):[26b] Light yellow solid; mp 119−122 °C, yield: 24% (40 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.47 (s, 1H), 8.07 (s, 1H), 8.03 (d, J = 8.2 Hz, 1H), 7.97 (d, J = 8.3 Hz, 1H), 7.66 (t, J = 7.5 Hz, 1H), 7.59 (t, J = 7.5 Hz, 1H), 5.79 (q, J = 7.2 Hz, 1H), 2.08 (d, J = 7.2 Hz, 3H); ^{13}C NMR (500 MHz, $CDCl_3$): δ 167.1, 146.3, 136.4, 133.9, 133.2, 130.0, 129.0, 128.5, 127.1, 126.6, 122.4, 118.3, 102.6, 11.1; IR (KBr, cm^{-1}) 3052, 2917, 2852, 1774, 1157, 1105, 997, 887, 777, 746.

■ ASSOCIATED CONTENT

Supporting Information

Text, figures, tables, CIF file giving optimization details, NMR spectra for all new compounds, and crystallographic data for compound **4ie**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

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■ ACKNOWLEDGMENTS

We thank the Natural Science Foundation of China (No. 21302157), the National Basic Research Program of China (973 Program, No. 2012CB821600), the Program for Changjiang Scholars and Innovative Research Team in University (PCSIRT), and the Fundamental Research Funds for the Central Universities (No. 2013121015) for the financial support.

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dx.doi.org/10.1021/jo502231y | *J. Org. Chem.* 2015, 80, 620−627