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CsF-PROMOTED DESILYLATION AND RING-CONTRACTION REACTION OF ELECTRON-DEFICIENT 3-SILYL-2*H*-CHROMENES TO 2-BENZYLBENZOFURANS

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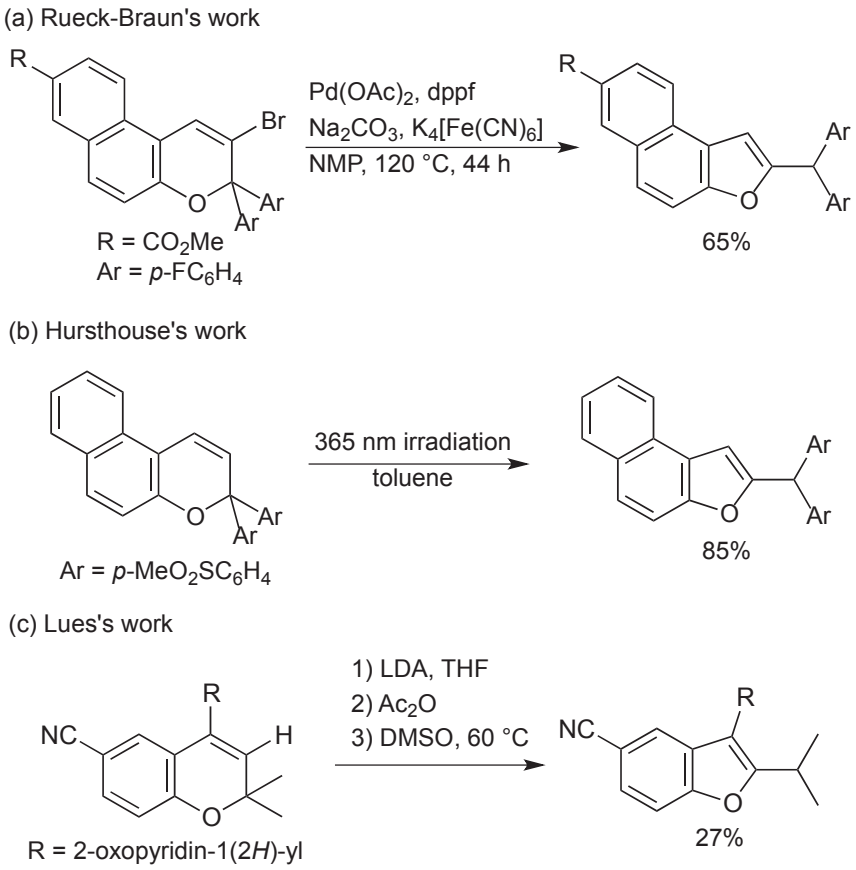
Abstract – The ring-contraction reaction of electron-deficient 3-silyl-2*H*-chromenes to 2-benzylbenzofurans under mild conditions was developed. CsF efficiently promoted the reaction at room temperature or 80 ºC to afford a variety of 2-benzylbenzofurans in good yields. 3-Silyl-2*H*-chromenes having strong electron-withdrawing groups smoothly afforded the desired products. The reaction is proposed to proceed through an allenyl intermediate or dyotropic rearrangement.

INTRODUCTION

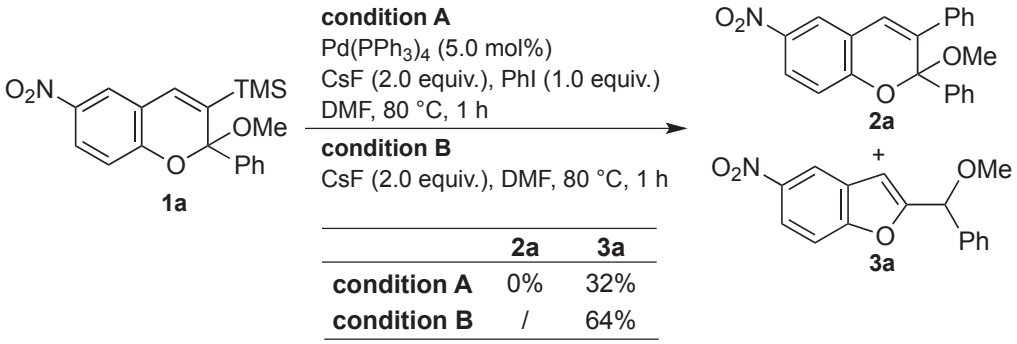
Ring-contraction reaction is a useful synthetic method in organic chemistry and can be used to carry out a wide variety of organic transformations, involving in the total synthesis of natural products.[1] Among some of these attractive transformations, the ring-contraction reaction of six membered ring to five membered ring has been developed by many researchers.[2] However, little work has been done on the synthesis of benzofurans from chromenes via ring-contraction reaction.[3-6] The approaches include the Pd catalyzed ring-contraction reaction of chromene at 120 ºC for 44 h (Scheme 1a),[4] UV light promoted ring-contraction reaction (Scheme 1b).[5] Moreover, in 1992, the transformation from the chromene derivative into benzofuran via an allene intermediate using lithium diisopropylamide as a strong base was reported (Scheme 1c).[6] It was suggested that the proton at the 3-position in chromene was deprotonated by lithium diisopropylamide, which induced a ring opening reaction of chromene to generate allenylphenol. Subsequently, the nucleophilic attack of phenoxide at the C2-position of the allene under heating conditions afforded benzofuran. Despite availability of existing methods, it usually suffers from

necessity of expensive transition metal catalyst, high energy photon source, strong base and/or requirement of the tedious reaction process.



Scheme 1. Ring-contraction reaction of 2*H*-chromenes

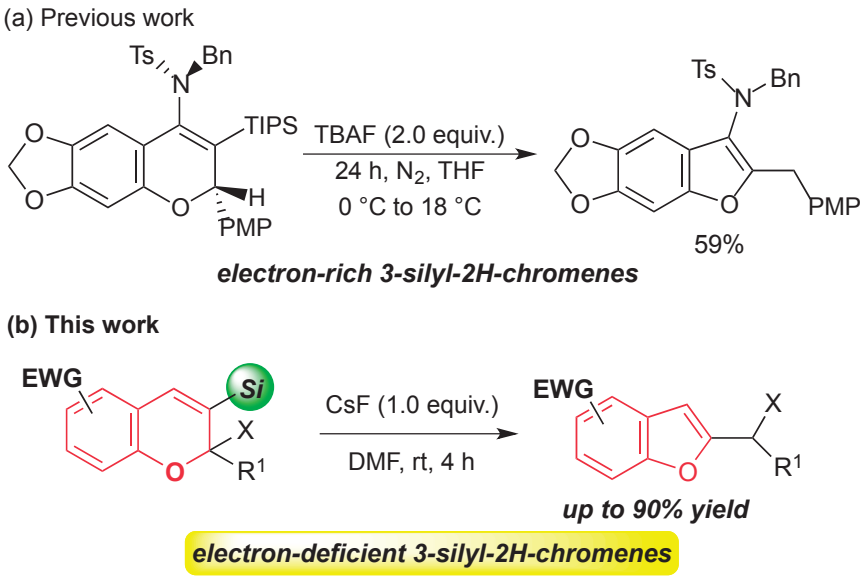
2*H*-Chromene is a significant structural unit in medicinal chemistry and material science.[7] Thus, several research groups developed methodologies to synthesize the polyfunctionalized 2*H*-chromene motifs.[8] During our recent studies on the mild generation of *o*-quinone methide,[9] we developed a direct synthetic method of novel 2,2-disubstituted 3-silyl-2*H*-chromenes via the [4+2] cycloaddition of in situ-generated *o*-quinone methides with electron-rich alkynes.[10] In addition, we demonstrated some transformations of silylchromenes into various polysubstituted chromenes, indicating the usefulness of these compounds. When we attempted to perform the Pd-catalyzed cross-coupling reaction of 3-silyl-2*H*-chromene **1a** with iodobenzene in order to introduce aryl group at the 3-position, surprisingly, the unexpected ring-contracted benzofuran **3a** was obtained in 32% yield instead of the normal cross-coupled product, 3-phenylchromene **2a** (Scheme 2, condition A). Moreover, it was found that the reaction proceeded without a Pd catalyst to afford **3a** in 64% yield (Scheme 2, condition B).



	2a	3a
condition A	0%	32%
condition B	/	64%

Scheme 2. Ring-contraction reaction of 3-silyl-2*H*-chromene

Very recently, the same type of reaction, i.e., four examples of the transformation of 3-(triisopropylsilyl)-4-amino-2*H*-chromenes, which are electron-rich 3-silyl-2*H*-chromene, to 2-alkylbenzofurans or 2-carbonylbenzofurans, was reported (Scheme 3a).[11] To the best our knowledge, this is the only report on the construction of benzofurans from 3-silyl-2*H*-chromene and it used only electron-rich 3-silyl-2*H*-chromenes as substrates. Thus, the development of an efficient transformation from 3-silyl-2*H*-chromene to benzofuran is still desirable, which prompted us to investigate the reaction of electron-deficient 3-silyl-2*H*-chromenes to 2-benzylbenzofurans. Benzofurans having electron withdrawing groups exhibit a variety of useful bioactivities, such as antimicrobial and antitumor.[12] Herein, we report the ring-contraction reaction of electron-deficient 3-silyl-2*H*-chromene to 2-benzylbenzofurans (Scheme 3b). The reaction provides a one-pot ring-contraction reaction of 2*H*-chromenes under mildly basic conditions, which affords versatile access to functionalized 2-benzylbenzofurans that would be a useful tool for the synthesis of biologically active molecules.

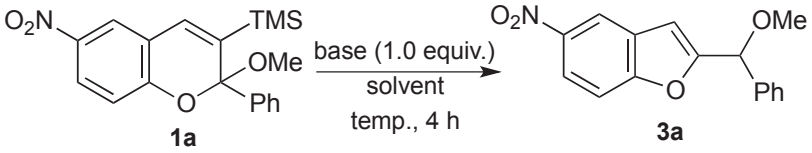


Scheme 3. Previous work and this work

RESULTS AND DISCUSSION

The ring-contraction reaction of 3-trimethylsilyl-2*H*-chromene **1a** in the presence of fluoride source was screened in various conditions (Table 1). At first, fluoride sources such as TBAF, KF, CuF_2, CsF were screened. When TBAF was used, the desired benzofuran **3a** was obtained in 34% (entry 1). While KF gave no product (entry 2), the use in combination with 18-crown-6-ether improved the yield efficiently (53%) (entry 3). CuF_2 was not suitable for the reaction at both room temperature and 80 ºC, recovering the starting material **1a** (entries 4 and 5).

Table 1. Optimization of reaction conditions



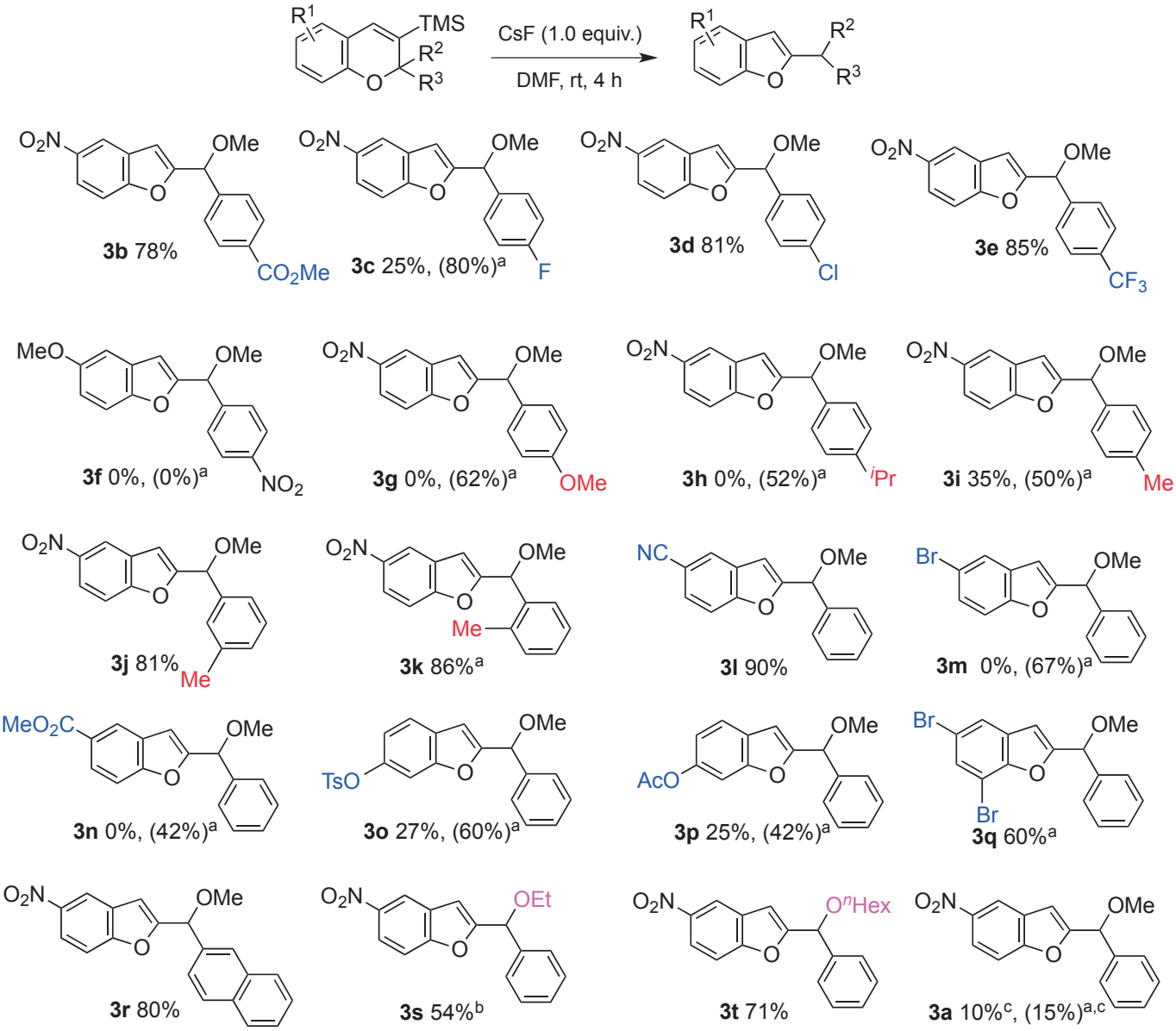
Entry	Solvent	Base	Temp. (ºC)	Yield (%)
1	DMF	TBAF	rt	34
2	DMF	KF	rt	0
3[a]	DMF	KF	rt	53
4	DMF	CuF_2	rt	0
5	DMF	CuF_2	80	0
6	DMF	CsF	rt	**78**
7[b]	DMF	CsF	rt	73
8[c]	DMF	CsF	80	64
9[d]	DMF	CsF	120	66
10	DMF	CsF	0	0
11	DMF	/	rt	0
12	DMSO	CsF	rt	69
13	CH_2Cl_2	CsF	rt	0
14	toluene	CsF	rt	0
15	THF	CsF	rt	0
16	MeOH	CsF	rt	0
17	MeCN	CsF	rt	0

[a] 18-crown-6-ether (1.0 equiv.) was added. [b] CsF (2.0 equiv.). [c] 2 h. [d] 0.5 h.

When CsF was used as a fluoride source, the yield of the product was increased to 78% (entry 6). Increasing the amount of CsF did not improve the product yield (entry 7). In addition, when the reaction of the substrate **1a** was conducted at 80 ºC or 120 ºC, the time of consumption of **1a** was significantly reduced to 2 or 0.5 h, respectively. However, the drastic increase in yield of the product was not observed

(entries 8 and 9). Lowering the temperature to 0 ºC did not afford the desired product (entry 10). Although this temperature effect is not obviously described in the literature, at least room temperature may be needed to generate the silicate intermediate and/or to cyclize to 2-benzylbenzofuran (vide infra). For example, arynes are generally generated from *o*-silylaryl triflates with fluoride source above room temperature.[13-15] The reaction did not proceed without fluoride source (entry 11). Although DMSO led to the formation of the desired benzofuran **3a** in good yield (entries 12), other several common non- or medium-polar solvents such as toluene, CH_2Cl_2, THF, MeOH or MeCN did not afford any products, recovering the starting material **1a** (entries 13-17). From the above investigations, the best reaction condition was obtained using CsF (1.0 equiv.) in DMF for 4 h at room temperature (entry 6).

With the optimal conditions in hand, the scope and limitations on the substrate 3-silyl-2*H*-chromenes were examined (Scheme 4). When 2-(4-methoxycarbonylphenyl)-2*H*-chromene was subjected to the reaction conditions, the desired product was obtained in good yield (**3b**). While (4-fluorophenyl)chromene **1c** afforded a product in low yield at room temperature, the yield of the product was improved to 80% at 80 ºC (**3c**). A chloro functionality afforded the desired product in high yield under standard conditions (rt, 4 h) (**3d**). High yield was observed when a strong electron-withdrawing group such as CF_3 was used (**3e**). Despite the substrate having a strong electron-withdrawing group on the 2*H*-chromene, 6-methoxychromene was found to be unsuitable for this reaction (**3f**). In addition, when the reaction was conducted at 80 ºC, the starting material was consumed within 2 h. But the complex mixture was generated, and no trace of benzofuran compounds was detected. While the electron donating groups such as 4-isopropyl, 4-methoxy and 4-methyl groups on the benzene ring did not lead the reaction to smoothly proceed at room temperature, increased temperature afforded the desired products in good yields (**3g**-**3i**). Moreover, 3- or 2-methyl functionality gave the product in 81% and 86%, respectively (**3j** and **3k**). Excellent yield was obtained when chromene having cyano group, which is a strong electron-withdrawing group, was used (**3l**). The moderate electron-withdrawing groups afforded the desired product in good yields at 80 ºC (**3m**-**3q**). 2-(2-Naphthyl)chromene gave the desired product in good yield of 80% (**3r**). When chromenes possessing alkoxy group such as ethoxy or hexyloxy group instead of methoxy group were used, the desired products were obtained in good yields (**3s** and **3t**). The chromene having sterically hindered silyl group such as *tert*-butyl(dimethyl)silyl group afforded the product in low yield (**3a**). When the temperature was increased to 80 ºC, the reaction was not completed in 27 h (checked by TLC) to give the product in 15% yield.

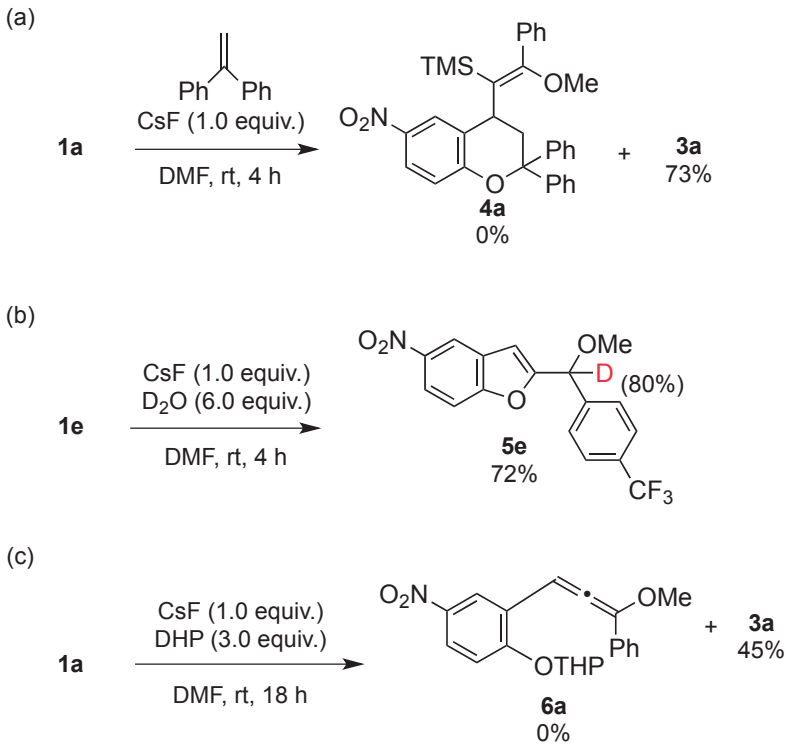


[a] 80 ºC, 2 h. [b] 4.5 h. [c] TBS group was used as a silyl group.

Scheme 4. The generality of the reaction

For study of the reaction mechanism, a trap of intermediates of the reaction was investigated (Scheme 5). The reaction of 3-silyl-2*H*-chromene **1a** with 1,1-diphenylethylene, which is known to be a good dienophile for the Diels–Alder reaction of *o*-quinone methide,[16] did not afford the Diels–Alder cycloadduct **4a** and instead gave the benzofuran **3a** in 73% yield (Scheme 5a). This suggested that *o*-quinone methide should not be generated in the reaction.[3e] A deuterium-labeling experiment of chromene **1e** with D_2O in the presence of CsF provided the desired product **5e** in 72% yield with 80% incorporation of D at the benzyl position (Scheme 5b).[17] Based on this result, the proton source may be H_2O, which is thought to be present in hygroscopic CsF as hydrates. When chromene **1a** was treated with DHP under the ring-contraction conditions, an allenyl intermediate **6a** was not obtained and benzofuran

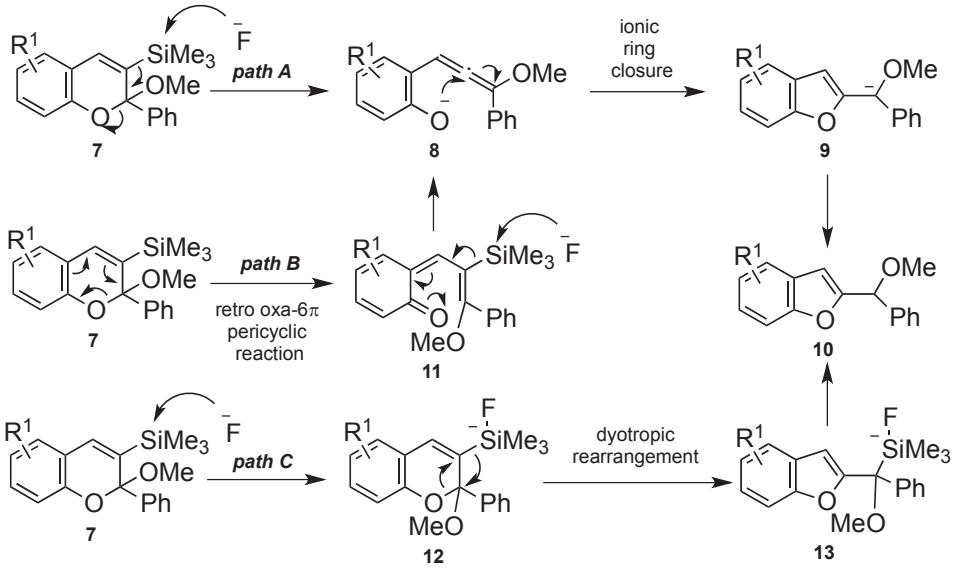
3a was produced in 45% yield along with unknown byproducts. Although the attempt to trap the *o*-allenylphenol failed, the path through the *o*-allenylphenol as a key intermediate is not necessarily ruled out. *o*-Allenylphenol was difficult to trap in the reaction condition because it was not stable at high temperature.[18] In addition, as shown in Table 1 (entry 11), when the reaction temperature was decreased, the reaction did not proceed.



Scheme 5. Investigation of the reaction mechanism

A proposed mechanism for this reaction is shown in Scheme 6. Based on previous reports,[3a,6,19] allenylphenoxide **8** would be efficiently generated by the fluoride anion-promoted elimination of the silyl group in chromene **7** (path A). It is suggested that electron-withdrawing group on chromene ring decrease electron density of pyran oxygen moiety to promote ring-opening reaction. The subsequent nucleophilic attack of phenolate to allene **8** afforded benzofuran **9**. The similar reaction mechanism, which smoothly proceeds through the allenylphenol to give the benzofuran, was suggested by some researchers.[3a,6] Cs of soft metal may activate the allene moiety to promote the cyclization reaction. In addition, according to the deuterium-labeling experiment of chromene **1e** (Scheme 5b), the protonation of benzofuran **9** would afford the desired product **10**. Especially, it is suggested that the electron-withdrawing group on benzene ring at the 4-position makes benzyl anion more stable (Scheme 4, **3b**-**3e**). In the second route (path B), the reaction would commence with a pericyclic retro oxa-6π ring opening.[3e] Then, fluoride source would attack to the silyl group in intermediate **11**, generating the allene intermediate **8**. The addition of a

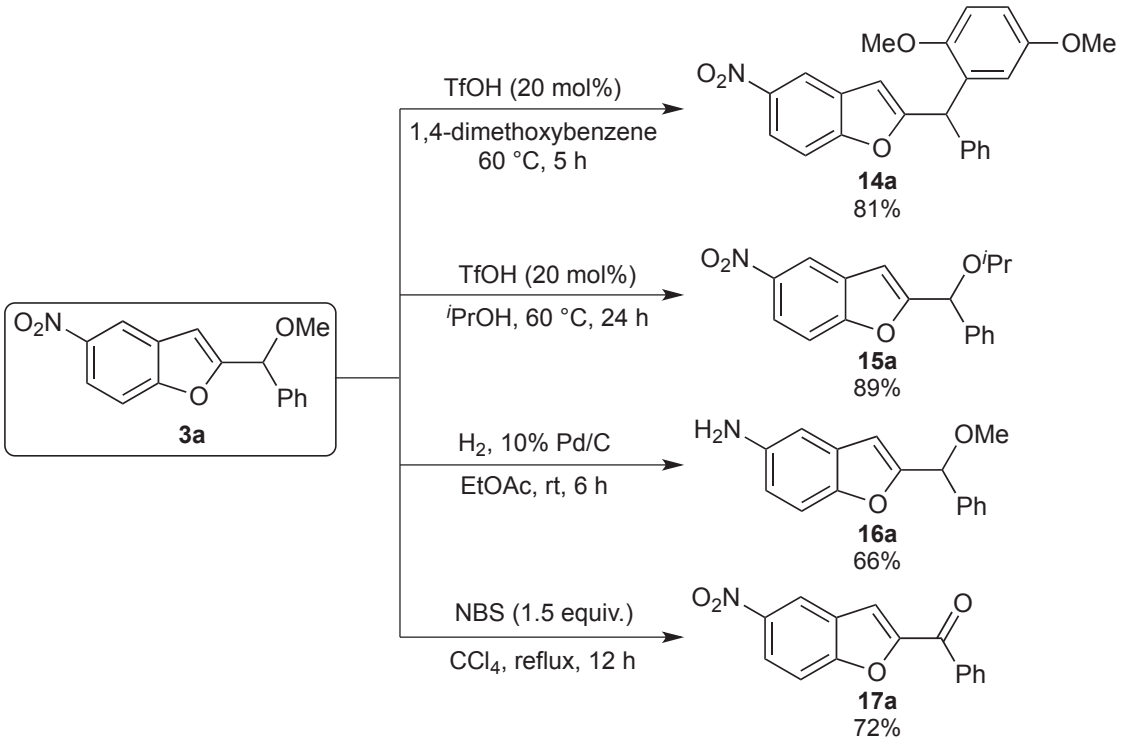
phenolate to the sp-hybridized carbon of the allene and protonation resulted in the production of the desired product **10**. In the third route (path C), the key reaction is the dyotropic rearrangement. Generally, dyotropic rearrangement needs the use of Lewis acid catalysts, such as TMSOTf, $MgBr_2$, and $ZnCl_2$, or high temperature conditions.[20] On the other hand, under the present reaction conditions, the fluoride ion activated the silyl group to generate silicate **12**, followed by concerted dyotropic rearrangement to produce the ring-contraction intermediate **13** at room temperature. Finally, the protonation of intermediate **13** afforded benzofuran **10**. Based on the experiment depicted in Scheme 5a, path A or path C may be more probable than path B because cyclic product **4a** was not obtained in the reaction. Although the attempt to trap the *o*-allenylphenol failed, path A is the most likely pathway to benzylbenzofuran according to previous literature reports. But dyotropic rearrangement is assumed *anti* conformation of the reactive scaffold forces the groups to migrate on opposite sides of the stationary framework, each suprafacially.[21] Then, the formal dyotropic rearrangement, path C, can also not be ruled out.



Scheme 6. The proposed mechanism

Scheme 7 shows examples for demonstrating the useful derivatization of the product **3a**. The reaction of 2-benzylbenzofuran **3a** with 1,4-dimethoxybenzene in the presence of trifluoromethanesulfonic acid afforded triarylmethane **14a** in 81%. In addition, treatment of isopropyl alcohol gave high yield of the product **15a** (89% yield). Hydrogenation of 5-nitrobenzofuran **3a** led to 5-aminobenzofuran **16a** in moderate yield. Some 5-aminobenzofuran derivatives are known to exhibit bioactivities such as antileishmanial and antitubulin.[22] When 2-benzylbenzofuran **3a** was treated with NBS in tetrachloromethane, (5-nitro-2-benzofuranyl)phenylmethanone **17a** was obtained in 72% yield.[12a,23] It is

noted that the present reactions provide new feasible routes for constructing 2-benzylbenzofuran, leading to the effective synthesis of biologically and photochemically active benzofurans.



Scheme 7. The transformation of 2-benzylbenzofuran **3a**

In conclusion, we developed the CsF-promoted one-pot ring-contraction reaction of electron-deficient 3-silyl-2*H*-chromene under mild conditions. 3-Silyl-2*H*-chromenes that have strong electron-withdrawing groups formed the desired products in high yields at room temperature. Chromene possessing electron donating groups on the benzene ring afforded the desired benzofuran at 80 ºC in good yields. The reaction is proposed to proceed via ring opening/closing reactions via allenyl intermediates or dyotropic rearrangement. 2-((Methoxyphenyl)methyl)-5-nitrobenzofuran **3a** can be converted into a variety of benzofuran derivatives, and it provides versatile access to functionalized 2-benzylbenzofurans that would be a useful tool for the synthesis of biologically active molecules.

EXPERIMENTAL

General

Infrared (IR) spectra were recorded on a JASCO FT/IR-4100. ^{1}H NMR spectra were recorded on a Bruker DRX-300 (300 MHz) spectrometer, a JEOL JNM AL-400 (400 MHz) spectrometer or a Bruker DRX-500 (500 MHz) spectrometer with tetramethylsilane (TMS) as an internal standard. Chemical shifts are reported in ppm relative to TMS. Data are reported as follows: chemical shift, multiplicity (s = singlet, d

= doublet, t = triplet, q = quartet, spt = septet, m = multiplet), integration, and coupling constants (Hz). ^{13}C NMR spectra were recorded on a JEOL JNM AL-400 (101 MHz) spectrometer or a Bruker DRX-500 (126 MHz) spectrometer with complete proton decoupling. Chemical shifts are reported in ppm relative to the $CDCl_3$ residual carbon (δ 77.0 for central peak). High resolution mass spectra (HRMS) were determined under conditions of ESI on a NanoFrontierLD. Column chromatography was carried out with Cica-reagent silica gel 60 N (spherical, particle size 63-210 μm). Thin-layer chromatography (TLC) was carried out with Merck TLC plates with silica gel 60 F_{254}. Unless otherwise noted, reagents were commercially available and were used without purification.

General procedure for the synthesis of 2-benzylbenzofurans

Method A

A mixture of 2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (0.50 mmol) and CsF (0.50 mmol) in DMF (5.0 mL) under nitrogen was stirred at room temperature for 4 h. Then the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 40 : 1) to afford product.

Method B

A mixture of 2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (0.50 mmol) and CsF (0.50 mmol) in DMF (5.0 mL) under nitrogen was stirred at 80 ºC for 2 h. Then the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 40 : 1) to afford product.

2-[Methoxy(phenyl)methyl]-5-nitrobenzofuran (3a)

This reaction was carried out in the same manner as method A employing the following materials: **1a** (0.1785 g, 0.50 mmol), CsF (0.0769 g, 0.51 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1114 g (78%) of **3a** as a yellow solid. ^1H NMR (500 MHz, $CDCl_3$): δ 8.44 (d, 1H, J = 2.0 Hz), 8.18 (dd, 1H, J = 9.0, 2.5 Hz), 7.52-7.34 (m, 6H), 6.68 (s, 1H), 5.41 (s, 1H), 3.47 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 160.7, 157.8, 144.0, 137.6, 128.6, 128.6, 128.3, 127.2, 120.0, 117.5, 111.6, 105.1, 79.1, 57.3; IR (ATR): 3031, 2825, 1521, 1450, 1343, 1262, 1088, 1068, 752, 730, 699, 683 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_{14}NO_4$ ($[M+H]^+$): 284.0917, found: 284.0930.

Methyl 4-[5-nitrobenzofuran-2-yl(methoxy)methyl]benzoate (3b)

This reaction was carried out in the same manner as method A employing the following materials: **1b** (0.2056 g, 0.50 mmol), CsF (0.0742 g, 0.49 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1341 g (78%) of **3b** as a white solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.46 (m, 1H), 8.18 (m, 1H), 8.08 (d, 2H, *J* = 8.3 Hz), 7.56 (d, 2H, *J* = 8.3 Hz), 7.51 (d, 1H, *J* = 9.0 Hz), 6.72 (s, 1H), 5.48 (s, 1H), 3.93 (s, 3H), 3.49 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 166.6, 159.8, 157.9, 144.2, 142.6, 130.5, 130.0, 128.2, 127.1, 120.3, 117.7, 111.7, 105.6, 78.7, 57.6, 52.2; IR (ATR): 3005, 1716, 1524, 1450, 1344, 1268, 1082, 1064, 820 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{17}H_{12}NO_5$ ($[M\text{-}OMe]^+$): 310.0710, found: 310.0700.

2-[4-Fluorophenyl(methoxy)methyl]-5-nitrobenzofuran (3c)

This reaction was carried out in the same manner as method B employing the following materials: **1c** (0.1871 g, 0.50 mmol), CsF (0.0748 g, 0.49 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1195 g (80%) of **3c** as a yellow solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.41 (s, 1H), 8.14 (d, 1H, *J* = 8.6 Hz), 7.48-7.44 (m, 3H), 7.10-7.07 (m, 2H), 6.70 (s, 1H), 5.41 (s, 1H), 3.46 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 162.7 (d, *J* = 247.8 Hz), 160.4, 157.8, 144.1, 133.6 (d, *J* = 3.7 Hz), 129.0 (d, *J* = 8.2 Hz), 128.3, 120.1, 117.5, 115.5 (d, *J* = 21.0 Hz), 111.6, 105.1, 78.5, 57.2; IR (ATR): 2827, 1522, 1448, 1344, 1262, 1222, 1084, 1069, 813 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_9NO_3F$ ($[M\text{-}OMe]^+$): 270.0561, found: 270.0575.

2-[4-Chlorophenyl(methoxy)methyl]-5-nitrobenzofuran (3d)

This reaction was carried out in the same manner as method A employing the following materials: **1d** (0.1939 g, 0.50 mmol), CsF (0.0740 g, 0.49 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1273 g (81%) of **3d** as a yellow solid. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.45 (d, 1H, *J* = 2.3 Hz), 8.19 (1H, dd, *J* = 9.0, 2.3 Hz), 7.51 (d, 1H, *J* = 9.0 Hz), 7.44-7.36 (m, 4H), 6.70 (s, 1H), 5.39 (s, 1H), 3.47 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 160.2, 157.9, 144.3, 136.3, 134.6, 128.9, 128.6, 128.3, 120.3, 117.6, 111.7, 105.3, 78.6, 57.4; IR (ATR): 2822, 1520, 1447, 1340, 1266, 1138, 1079, 816 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_9NO_3Cl$ ($[M\text{-}OMe]^+$): 286.0266, found: 286.0275.

2-[4-Trifluoromethylphenyl(methoxy)methyl]-5-nitrobenzofuran (3e)

This reaction was carried out in the same manner as method A employing the following materials: **1e** (0.2115 g, 0.50 mmol), CsF (0.0759 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1491 g (85%) of **3e** as a yellow solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ8.45 (s, 1H), 8.18 (d, 1H, *J* = 8.5 Hz), 7.61-7.62 (m, 4H), 6.76 (s, 1H), 5.50 (s, 1H), 3.51 (s, 3H). ^{13}C NMR (126 MHz,

$CDCl_3$): δ 159.6, 157.9, 144.2, 141.8, 131.2 (q, J = 93.9 Hz), 128.2, 127.5, 125.6 (q, J = 3.7 Hz), 123.9 (q, J = 272.7 Hz), 120.3, 117.6, 111.7, 105.6, 78.5, 57.5. IR (ATR): 2830, 1523, 1449, 1345, 1322, 1263, 1091, 1065, 819 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{21}H_{13}NO_3$ ($[M+H]^+$): 352.0791, found: 352.0791.

2-[Methoxy(4-methoxyphenyl)methyl]-5-nitrobenzofuran (3g)

This reaction was carried out in the same manner as method B employing the following materials: **1g** (0.1919 g, 0.50 mmol), CsF (0.0742 g, 0.49 mmol), and DMF (5 mL) at 80 ºC. The usual workup and chromatography gave 0.0960 g (62%) of **3g** as a yellow solid. ^1H NMR (500 MHz, $CDCl_3$): δ 8.41 (d, 1H, J = 2.5 Hz), 8.15 (dd, 1H, J = 9.0, 2.0 Hz), 7.48 (d, 1H, J = 9.1 Hz), 7.39-7.38 (m, 2H), 6.95-6.93 (m, 2H), 6.66 (s, 1H), 5.36 (s, 1H), 3.82 (s, 3H), 3.44 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 161.0, 159.9, 157.8, 144.1, 129.6, 128.6, 128.4, 120.0, 117.5, 114.1, 111.6, 104.9, 78.8, 57.1, 55.2; IR (ATR): 2830, 1521, 1446, 1346, 1259, 1243, 1098, 1035, 815 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_{12}NO_4$ ($[M\text{-}OMe]^+$): 314.1023, found: 282.0769.

2-[4-Isopropylphenyl(methoxy)methyl]-5-nitrobenzofuran (3h)

This reaction was carried out in the same manner as method B employing the following materials: **1h** (0.1961 g, 0.49 mmol), CsF (0.0748 g, 0.49 mmol), and DMF (5 mL) at 80 ºC. The usual workup and chromatography gave 0.0825 g (52%) of **3h** as a brown oil. ^1H NMR (500 MHz, $CDCl_3$): δ 8.44 (d, 1H, J = 2.5 Hz), 8.18 (dd, 1H, J = 9.0, 2.0 Hz), 7.51 (d, 1H, J = 9.1 Hz), 7.41-7.40 (m, 2H), 7.29-7.28 (m, 2H), 6.70 (s, 1H), 5.40 (s, 1H), 3.48 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 160.9, 157.8, 149.4, 144.1, 134.9, 128.4, 127.3, 126.7, 120.0, 117.5, 111.6, 105.0, 79.1, 57.3, 33.8, 23.9; IR (ATR): 2960, 2824, 1523, 1448, 1343, 1262, 1086, 1068, 818 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{18}H_{12}NO_3$ ($[M\text{-}OMe]^+$): 294.1125, found: 294.1129.

2-[Methoxy(4-methylphenyl)methyl]-5-nitrobenzofuran (3i)

This reaction was carried out in the same manner as method B employing the following materials: **1i** (0.1853 g, 0.50 mmol), CsF (0.0757 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.0743 g (50%) of **3i** as an orange oil. ^1H NMR (500 MHz, $CDCl_3$): δ 8.42 (d, 1H, J = 2.0 Hz), 8.16 (dd, 1H, J = 9.2, 2.5 Hz), 7.49 (d, 2H, J = 9.5 Hz), 7.36-7.35 (m, 2H), 7.23-7.21 (m, 2H), 6.66 (s, 1H), 5.37 (s, 1H), 3.45 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 161.1, 157.9, 144.1, 138.6, 134.6, 129.4, 128.4, 127.3, 120.1, 117.5, 111.7, 105.0, 79.1, 57.3, 21.2; IR (ATR): 3103, 2930, 1520, 1343, 1262, 1068, 811, 752 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_{12}NO_3$ ($[M\text{-}OMe]^+$): 266.0812, found: 266.0823.

2-[Methoxy(3-methylphenyl)methyl]-5-nitrobenzofuran (3j)

This reaction was carried out in the same manner as method A employing the following materials: **1j** (0.1845 g, 0.50 mmol), CsF (0.0761 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1199 g (81%) of **3j** as an orange oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.44 (d, 1H, *J* = 2.5 Hz), 8.16 (dd, 1H, *J* = 9.3, 2.5 Hz), 7.49 (d, 1H, *J* = 8.5 Hz), 7.31-7.27 (m, 3H), 7.18-7.17 (m, 1H), 6.68 (s, 1H), 5.37 (s, 1H), 3.47 (s, 3H), 2.38 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 160.8, 157.9, 144.1, 138.5, 137.5, 129.4, 128.6, 128.4, 127.9, 124.4, 120.0, 117.5, 111.7, 105.1, 79.3, 57.4, 21.4; IR (ATR): 2932, 2820, 1512, 1346, 1262, 1066, 799, 752 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_{12}NO_3$ ([M-OMe]$^+$): 266.0812, found: 266.0822.

2-[Methoxy(2-methylphenyl)methyl]-5-nitrobenzofuran (3k)

This reaction was carried out in the same manner as method B employing the following materials: **1k** (0.1817 g, 0.49 mmol), CsF (0.0738 g, 0.49 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1256 g (86%) of **3k** as a yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.41 (d, 1H, *J* = 2.0 Hz), 8.17 (dd, 1H, *J* = 9.0, 2.0 Hz), 7.55-7.53 (m, 1H), 7.50 (d, 1H, *J* = 9.0 Hz), 7.29-7.27 (m, 2H), 7.21-7.20 (m, 1H), 6.58 (s, 1H), 5.62 (s, 1H), 3.48 (s, 3H), 2.36 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 160.4, 157.9, 144.1, 136.0, 135.5, 130.7, 128.4, 128.3, 127.0, 126.4, 120.1, 117.5, 111.7, 105.4, 76.3, 57.5, 19.1; IR (ATR): 2932, 2824, 1521, 1343, 1262, 1068, 748 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_{12}NO_3$ ([M-OMe]$^+$): 266.0812, found: 266.0815.

2-[Methoxy(phenyl)]methyl]benzofuran-5-carbonitrile (3l)

This reaction was carried out in the same manner as method A employing the following materials: **1l** (0.1680 g, 0.50 mmol), CsF (0.0755 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1185 g (90%) of **3l** as a white solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.82 (s, 1H), 7.48-7.46 (m, 4H), 7.42-7.39 (m, 2H), 7.37-7.34 (m, 1H), 6.59 (s, 1H), 5.40 (s, 1H), 3.46 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 159.7, 156.6, 137.6, 128.6, 128.6, 128.5, 127.8, 127.2, 125.9, 119.2, 112.4, 106.6, 104.2, 79.1, 57.3; IR (ATR): 3450, 2953, 2225, 1615, 1373, 1248, 1177, 836, 545 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_{10}NO$ ([M-OMe]$^+$): 232.0757, found: 232.0751.

5-Bromo-2-[(methoxy(phenyl))methyl]benzofuran (3m)

This reaction was carried out in the same manner as method B employing the following materials: **1m** (0.1947 g, 0.50 mmol), CsF (0.0753 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1055 g (67%) of **3m** as an orange oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.61 (d, 1H, *J* = 1.5 Hz), 7.46-7.44 (m, 2H), 7.40-7.28 (m, 5H), 6.47 (s, 1H), 5.36 (s, 1H), 3.44 (s, 3H); ^{13}C NMR (126

MHz, $CDCl_3$): δ 158.5, 153.9, 138.1, 129.9, 128.6, 128.4, 12.3, 127.1, 123.7, 115.8, 112.8, 104.2, 79.3, 57.3; IR (ATR): 2930, 2822, 1443, 1258, 1088, 797, 698 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_{10}OBr$ ($[M\text{-}OMe]^+$): 284.9910, found: 284.9920.

Methyl 2-[methoxy(phenyl)methyl]benzofuran-5-carboxylate (3n)

This reaction was carried out in the same manner as method B employing the following materials: **1n** (0.1842 g, 0.50 mmol), CsF (0.0757 g, 0.50 mmol), and DMF (5 mL) at 80 ºC. The usual workup and chromatography gave 0.0616 g (42%) of **3n** as a yellow oil. ^1H NMR (500 MHz, $CDCl_3$): δ 8.24 (d, 1H, *J* = 2.0 Hz), 7.97 (d, 1H, *J* = 8.5, 3.5 Hz), 7.49-7.43 (m, 3H), 7.42-7.37 (m, 2H), 7.36-7.33 (m, 1H), 6.59 (s, 1H), 5.39 (s, 1H), 3.91 (s, 3H), 3.45 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 167.1, 158.5, 157.6, 138.0, 128.5, 128.4, 127.9, 127.2, 126.0, 125.1, 123.5, 111.2, 105.1, 79.3, 57.3, 52.0; IR (ATR): 2824, 1715, 1442, 1264, 1085, 699 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{17}H_{13}O_3$ ($[M\text{-}OMe]^+$): 265.0859, found: 265.0867.

2-[Methoxy(4-methylphenyl)methyl]-6-(4-methylbenzenesulfonyloxy)benzofuran (3o)

This reaction was carried out in the same manner as method B employing the following materials: **1o** (0.2411 g, 0.50 mmol), CsF (0.0755 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1224 g (60%) of **3o** as a brown oil. ^1H NMR (500 MHz, $CDCl_3$): δ 7.69 (d, 2H, *J* = 8.5 Hz), 7.45 (m, 2H), 7.38 (m, 4H), 7.29 (d, 2H, *J* = 8.5 Hz), 7.11 (s, 1H), 6.84 (dd, 1H, *J* = 8.3, 2.0 Hz), 6.46 (s, 1H), 5.35 (s, 1H) 3.44 (s 3H), 2.44 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 158.8, 154.5, 146.6, 145.3, 138.0, 132.2, 129.7, 128.5, 128.5, 128.4, 127.2, 126.8, 121.0, 117.6, 106.2, 104.6, 79.2, 57.2, 21.6; IR (ATR): 3087, 1599, 1475, 1172, 1088, 964, 845, 661, 539 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{22}H_{17}O_4S$ ($[M\text{-}OMe]^+$): 3770842, found: 377.0845.

6-Acetyloxy-2-[methoxy(phenyl)methyl]benzofuran (3p)

This reaction was carried out in the same manner as method B employing the following materials: **1p** (0.1847 g, 0.50 mmol), CsF (0.0746 g, 0.49 mmol), and DMF (5 mL) at 80 ºC. The usual workup and chromatography gave 0.0658 g (42%) of **3p** as a brown oil. ^1H NMR (300 MHz, $CDCl_3$): δ 7.45 (d, 3H, *J* = 8.1 Hz), 7.43-7.30 (m, 3H), 7.21 (s, 1H), 6.93 (dd, 1H, *J* = 8.4, 2.1 Hz), 6.52 (s, 1H), 5.37 (s, 1H), 3.44 (s, 3H), 2.29 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 169.6, 158.0, 154.9, 147.8, 138.3, 128.5, 128.3, 127.2, 125.8, 121.0, 116.9, 105.3, 104.7, 79.3, 57.2, 21.0; IR (ATR): 2929, 2824, 1761, 1619, 1197, 1087, 1074, 724 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{17}H_{13}O_3$ ($[M\text{-}OMe]^+$): 265.0859, found: 265.0866.

5,7-Dibromo-2-[methoxy(phenyl)methyl]benzofuran (3q)

This reaction was carried out in the same manner as method B employing the following materials: **1q** (0.1170 g, 0.25 mmol), CsF (0.0383 g, 0.25 mmol), and DMF (2.5 mL). The usual workup and chromatography gave 0.0594 g (60%) of **3q** as a brown oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.55-7.53 (m, 3H), 7.48-7.46 (m, 2H), 7.41-7.38 (m, 2H), 7.37-7.33 (m, 1H), 6.51 (s, 1H), 5.40 (s, 1H), 3.46 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 159.7, 151.3, 137.9, 130.6, 129.5, 128.7, 128.6, 127.3, 122.9, 115.9, 104.8, 104.7, 79.2, 57.5; IR (ATR): 2823, 1566, 1438, 1088, 846, 736, 697 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_9OBr_2$ ($[M\text{-}OMe]^+$): 362.9015, found: 362.9019.

2-[Methoxy(2-naphthyl)methyl]-5-nitrobenzofuran (3r)

This reaction was carried out in the same manner as method A employing the following materials: **1r** (0.2015 g, 0.50 mmol), CsF (0.0782 g, 0.51 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1329 g (80%) of **3r** as a yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.41 (s, 1H), 8.15 (d, 1H, *J* = 8.9 Hz), 7.95 (s, 1H), 7.90-7.83 (m, 3H), 7.57-7.24 (m, 4H), 6.70 (s, 1H), 5.57 (s, 1H), 3.51 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 160.6, 157.8, 144.1, 134.9, 133.4, 133.1, 128.7, 128.3, 128.0, 127.7, 126.7, 126.5, 226.4, 124.5, 120.1, 117.5, 111.6, 105.3, 79.3, 57.4; IR (ATR): 2825, 1521, 1447, 1342, 1262, 1085, 1068, 751 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{19}H_{12}NO_3$ ($[M\text{-}OMe]^+$): 302.0812, found: 302.0807.

2-[Ethoxy(phenyl)methyl]-5-nitrobenzofuran (3s)

This reaction was carried out in the same manner as method A for 4.5 h employing the following materials: **1s** (0.1845 g, 0.50 mmol), CsF (0.0755 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.0804 g (54%) of **3s** as a yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.41 (d, 1H, *J* = 2.0 Hz), 8.15 (dd, 1H, *J* = 9.5, 2.0 Hz), 7.49-7.4662 (m, 3H), 7.41-7.38 (m, 2H), 7.36-7.33 (m, 1H), 6.67 (s, 1H), 6.52 (s, 1H), 3.66-3.60 (m, 2H), 1.30 (t, 3H, *J* = 7.0 Hz); ^{13}C NMR (126 MHz, $CDCl_3$): δ 161.2, 157.9, 144.1, 138.2, 128.6, 128.5, 128.4, 127.2, 120.0, 117.5, 111.6, 105.0, 77.4, 65.2, 15.2; IR (ATR): 2973, 2871, 1521, 1343, 1262, 1068, 699 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_{10}NO_3$ ($[M\text{-}OEt]^+$): 252.0655, found: 302.0644.

2-[Hexyloxy(phenyl)methyl]-5-nitrobenzofuran (3t)

This reaction was carried out in the same manner as method A employing the following materials: **1t** (0.1923 g, 0.50 mmol), CsF (0.0760 g, 0.50 mmol), and DMF (5 mL). The usual workup and chromatography gave 0.1257 g (71%) of **3t** as a yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.43 (d, 1H, *J* = 2.5 Hz), 8.17 (dd, 1H, *J* = 9.5, 2.5 Hz), 7.50-7.46 (m, 3H), 7.42-7.39 (m, 2H), 7.37-7.33 (m, 1H), 6.68

(s, 1H), 5.49 (s, 1H), 3.59-3.52 (m, 2H), 1.70-1.64 (m, 2H), 1.41-1.36 (m, 2H), 1.33-1.26 (m, 4H), 0.88 (t, 3H, J = 7.0 Hz); ^{13}C NMR (126 MHz, $CDCl_3$): δ 161.3, 157.9, 144.1, 138.3, 128.6, 128.5, 128.5, 127.2, 120.0, 117.5, 111.7, 105.0, 77.6, 70.0, 31.6, 29.7, 25.8, 22.6, 14.0; IR (ATR): 2929, 1523, 1451, 1344, 1262, 1068, 805, 729, 699 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_{10}NO_3$ ([M-O^{n}Hex]$^+$): 252.0655, found: 252.0661.

Investigation of the reaction mechanism (Scheme 5)

The reaction of 1a in the presence of 1,1-diphenylethylene

A mixture of 2-methoxy-3-trimethylsilyl-6-nitro-2-phenyl-2*H*-1-benzopyran (**1a**, 0.1776 g, 0.50 mmol), CsF (0.0767 g, 0.50 mmol), and 1,1-diphenylethylene (0.438 mL, 2.5 mmol) in DMF (5.0 mL) under nitrogen was stirred at room temperature for 4 h. After that, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 50 : 1). Any intermediates were obtained, but **3a** was produced in 73% (0.1041 g).

Procedure for the synthesis of 2-[methoxy(phenyl)(D)methyl]-5-nitrobenzofuran 5e

In an oven-dried round-bottom flask, CsF (0.0764 g, 0.50 mmol) was added, heated by heatgun for 30 min in vacuo. D_2O (3.0 mmol, 54 mL) and a solution of 3-silyl-2*H*-chromene (0.2116 g, 0.50 mmol) in dry DMF (5.0 mL) were added, then stirred at room temperature for 4 h. After being stirred, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layer were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 50 : 1) to afford the product in 72% (0.1257 g) as a yellow oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.44 (s, 1H), 8.17 (d, 1H, J = 9.0 Hz), 7.68-7.62 (m, 4H), 7.50 (d, 1H, J = 9.0 Hz), 6.76 (s, 1H), 5.49 (s, 0.20H) 3.50 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 159.5, 157.9, 144.2, 141.7, 130.8 (q, J = 32.1 Hz), 128.2, 127.5, 125.7 (q, J = 3.8 Hz), 123.9 (d, J = 272.7 Hz), 122.8, 120.4, 117.7, 111.8, 105.6, 78.5, 57.6; IR (ATR): 2828, 1523, 1449, 1345, 1322, 1262, 1094, 1065, 818 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{16}H_8DF_3NO_3$ ([M-OMe]$^+$): 321.0592, found: 321.0603.

Investigation of the reaction of 2-benzylbenzofuran 3a with DHP

A mixture of 2-methoxy-3-trimethylsilyl-6-nitro-2-phenyl-2*H*-1-benzopyran (**1a**, 0.1767 g, 0.50 mmol), CsF (0.0749 g, 0.49 mmol) and DHP (0.14 mL, 3.0 equiv.) in DMF (5.0 mL) under nitrogen was stirred at room temperature for 18 h. After that, the reaction mixture was quenched with H_2O. The organic layer

was separated and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 50 : 1). The 2-benzylbenzpfuran **3a** was obtained in 45% (0.0636 g) instead of an allenyl intermediate **6a**.

Transformation of 2-[methoxy(phenyl)methyl]-5-nitrobenzofuran (3a) to 2-[(2,5-dimethoxyphenyl)(phenyl)methyl]-5-nitrobenzofuran (14a)

A mixture of 2-(methoxy(phenyl)methyl)-5-nitrobenzofuran (**3a**, 0.0280 g, 0.10 mmol) and 1,4-dimethoxybenzene (0.5010 g, 3.6 mmol) under nitrogen was heated to 60 ºC, then trifluoromethanesulfonic acid (20 mol%, 0.0018 mL) was added. After being stirred at 60 ºC for 5 h, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 50 : 1) to afford product (**14a**) in 81% (0.0310 g) as yellow solid; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.37 (d, 1H, J = 2.3 Hz), 8.15 (dd, 1H, J = 9.2, 2.3 Hz), 7.45 (d, 1H, J = 9.2 Hz), 7.36-7.27 (m, 3H), 7.24-7.20 (m, 2H), 6.88-6.84 (m, 1H), 8.82-6.77 (m, 1H), 6.60 (d, 1H, J = 2.8 Hz), 6.40-6.36 (m, 1H), 6.00 (s, 1H), 3.74 (s, 3H), 3.69 (s, 3H); ^{13}C NMR (101 MHz, $CDCl_3$): δ 163.7, 157.9, 153.5, 151.1, 144.0, 139.7, 129.8, 128.9, 128.8, 128.6, 127.2, 119.6, 117.0, 116.5, 111.9, 111.7, 111.4, 106.0, 56.2, 55.6, 44.2; IR (ATR): 2971, 1523, 1343, 1263, 1044, 730, 697, 683 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{23}H_{19}NO_5$ ($[M+H]^+$): 390.1336, found: 390.1320.

Transformation of 2-[methoxy(phenyl)methyl]-5-nitrobenzofuran (3a) to 2-[isopropoxy(phenyl)methyl]-5-nitrobenzofuran (15a)

To a mixture of 2-(methoxy(phenyl)methyl)-5-nitrobenzofuran (**3a**, 0.0282 g, 0.10 mmol) in isopropyl alcohol (1.5 mL) under nitrogen, trifluoromethanesulfonic acid (20 mol%, 0.0018 mL) was added. After being stirred at 60 ºC for 24 h, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layers were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 40 : 1) to afford product (**15a**) in 89% (0.0276 g) as yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ 8.42 (d, 1H, J = 2.3 Hz), 8.17 (dd, 1H, J = 9.2, 2.3 Hz), 7.51-7.46 (m, 3H), 7.43-7.32 (m, 3H), 6.66 (s, 1H), 5.62 (s, 1H), 3.78 (spt, 1H, J = 6.1 Hz), 1.29 (d, 3H, J = 6.0 Hz), 1.24 (d, 3H, J = 6.0 Hz); ^{13}C NMR (101 MHz, $CDCl_3$): δ 161.8, 157.9, 144.1, 138.8, 128.6, 128.5, 128.4, 127.2, 120.0, 117.5, 111.7, 104.9, 74.8, 70.5, 22.6, 21.8; IR (ATR): 2971,

1523, 1343, 1263, 1119, 1067, 753, 727, 699, 683 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{15}H_{10}NO_3$ ($[M\text{-}OCH_3CHCH_3]^+$): 252.0655, found: 252.0647.

Transformation of 2-[methoxy(phenyl)methyl]-5-nitrobenzofuran (3a) to 5-amino-2-[Methoxy(phenyl)methyl]benzofuran (16a)

To a mixture of 2-(methoxy(phenyl)methyl)-5-nitrobenzofuran (**3a**, 0.0270 g, 0.10 mmol) in EtOAc (1 mL), palladium on charcoal (10%, 0.0127 g) was added. After being stirred under hydrogen for 6 h, the reaction mixture was filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 2 : 1) to afford product (**16a**) in 66% (0.0158 g) as orange oil; ^{1}H NMR (400 MHz, $CDCl_3$): δ 7.49-7.43 (m, 2H), 7.41-7.30 (m, 3H), 7.22 (d, 1H, *J* = 8.7 Hz), 6.77 (d, 1H, *J* = 2.3 Hz), 6.62 (dd, 1H, *J* = 8.7, 2.3 Hz), 6.37 (s, 1H), 5.34 (s, 1H), 3.44 (s, 1H), 3.35-2.69 (br s, 2H); ^{13}C NMR (101 MHz, $CDCl_3$): 157.4, 149.8, 141.9, 138.6, 128.8, 128.5, 128.2, 127.3, 113.5, 111.6, 105.9, 104.6, 79.5, 57.2; IR (ATR): 3366, 2931, 1452, 1206, 1090, 939, 846, 817, 760, 722, 696, 565; HRMS (ESI+): *m/z* calcd for $C_{16}H_{59}NO_2$ ($[M+H]^+$): 254.1176, found: 254.1183.

Transformation of 2-[methoxy(phenyl)methyl]-5-nitrobenzofuran (3a) to 2-benzoyl-5-nitrobenzofuran (17a)

A mixture of 2-(methoxy(phenyl)methyl)-5-nitrobenzofuran (**3a**, 0.0283 g, 0.10 mmol) and NBS (0.0267 g, 0.15 mmol) in CCl_4 (2.0 mL) under nitrogen was stirred at reflux for 12 h. After that, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with CH_2Cl_2. The combined organic layers were dried over Na_2SO_4, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 20 : 1) to afford product (**17a**) in 72% (0.0189 g) as a white solid; ^{1}H NMR (300 MHz, $CDCl_3$): δ 8.70 (d, 1H, *J* = 2.3 Hz), 8.42 (dd, 1H, *J* = 9.4, 2.3 Hz, 8.07 (m, 2H), 7.77 (d, 1H, *J* = 9.0 Hz), 7.73-7.67 (m, 1H), 7.66 (s, 1H), 7.61-7.55 (m, 1H). ^{13}C NMR (126 MHz, $CDCl_3$): δ 183.6, 158.2, 154.9, 145.0, 136.5, 133.6, 129.5, 128.8, 127.3, 123.5, 119.9, 115.9, 113.2. IR (ATR): 3089, 2962, 2926, 2852, 1658, 1620, 1600, 1552, 1521, 1448, 1346, 1322, 1261, 1220, 1173, 1129, 1070, 966, 937, 895, 831, 802, 753, 723, 687, 592, 577 cm^{-1}. (ESI+): *m/z* calcd for $C_{15}H_{10}NO_4$ ($[M+H]^+$): 268.0604, found: 268.0601.

General procedure for the synthesis of 3-trimethylsilyl-2H-1-benzopyran[10]

To a mixture of 5-nitrosalicylaldehyde (30.0 mmol), trimethylsilylethynylbenzene (60.0 mmol) and trimethyl orthoformate (30.0 mmol) in dry CH_2Cl_2 (80 mL) under nitrogen, boron trifluoride etherate (20 mol%) was added. After being stirred at reflux for 16 h, the reaction mixture was quenched with 5% aq. $NaHCO_3$. The organic layer was separated and the aqueous layer was extracted with EtOAc. The

combined organic layer were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 20 : 1) to afford product.

2-Methoxy-3-trimethylsilyl-6-nitro-2-phenyl-2*H*-1-benzopyran (1a)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (5.01 g, 30.0 mmol), acetylene (11.8 mL, 60.0 mmol), trimethyl orthoformate (3.28 mL, 30.0 mmol), boron trifluoride etherate (0.75 mL, 20 mol%), and dry CH_2Cl_2 (80 mL). The usual workup and chromatography gave 5.22 g (49%) of **1a** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14-8.11 (m, 2H), 7.51-7.49 (m, 2H), 7.40-7.32 (m, 3H), 7.14 (s, 1H), 6.95 (d, 1H, *J* = 9.0 Hz), 3.34 (s, 3H), -0.10 (s, 9H).

Methyl 4-(2-Methoxy-6-nitro-3-trimethylsilyl-2*H*-1-benzopyran-2-yl)benzoate (1b)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (1.503 g, 9.0 mmol), acetylene (4.156 g, 18 mmol), trimethyl orthoformate (0.98 mL, 9.0 mmol), boron trifluoride etherate (0.23 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 0.647 g (17%) of **1b** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.16-8.10 (m, 2H), 8.05 (d, 2H, *J* = 9.0 Hz), 7.56 (d, 2H, *J* = 9.0 Hz), 7.15 (s, 1H), 6.94 (d, 1H, *J* = 7.5 Hz), 3.93 (s, 3H), 3.33 (s, 3H), -0.10 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 166.3, 157.7, 146.4, 141.5, 137.0, 134.0, 130.4, 129.3, 126.3 125.7, 122.7, 118.1, 115.6, 105.1, 51.9, 50.6, -1.0; IR (ATR): 2834, 1720, 1519, 1340, 1248, 1109, 1068, 824 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{20}H_{20}NO_5Si$ ($[M\text{-}OMe]^+$): 382.1105, found: 382.1115.

2-Methoxy-6-nitro-2-(4-fluoromethylphenyl)-3-trimethylsilyl-2*H*-1-benzopyran (1c)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.14 g, 13 mmol), acetylene (4.93 g, 26 mmol), trimethyl orthoformate (1.40 mL, 13 mmol), boron trifluoride etherate (0.32 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 1.25 g (26%) of **1c** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.13-8.10 (m, 2H), 7.49-7.46 (m, 2H), 7.13 (s, 1H), 7.05 (t, 2H, *J* = 8.3 Hz), 3.31 (s, 3H), -0.07 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 163.8, 161.9, 158.0, 141.5, 138.3, 137.6, 133.8, 128.3, 128.2, 125.9, 122.8, 118.1, 115.7, 115.0, 114.9, 105.2, 50.7, -0.9: IR (ATR): 2835, 1509, 1340, 1245, 1232, 1116, 1092, 1065, 822 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{18}H_{17}NO_3FSi$ ($[M\text{-}OMe]^+$): 342.0956, found: 342.0957.

2-Methoxy-6-nitro-2-(4-chlorophenyl)-3-trimethylsilyl-2*H*-1-benzopyran (1d)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.28 g, 14 mmol), acetylene (5.5 g, 26 mmol), trimethyl orthoformate (1.51 mL, 14 mmol), boron trifluoride etherate (0.35 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 1.35 g (25%) of **1d** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.09 (d, 1H, *J* = 2.5 Hz), 8.04 (dd, 1H, *J* = 8.5, 2.5 Hz), 7.44-7.39 (m, 2H), 7.33-7.29 (m, 2H), 7.15 (s, 1H), 6.89 (d, 1H, *J* = 8.5 Hz), 3.29 (s, 3H), -0.08 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 157.7, 141.3, 140.7, 137.1, 134.6, 133.9, 128.1, 127.7, 125.7, 122.7, 118.0, 115.5, 105.0, 50.5, -1.0; IR (ATR): 2835, 1515, 1337, 1248, 1117, 1092, 1065, 818 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{18}H_{17}NO_3SiCl$ ([M-OMe]$^+$): 358.0661, found: 358.0668.

2-Methoxy-6-nitro-2-(4-trifluoromethylphenyl)-3-trimethylsilyl-2*H*-1-benzopyran (1e)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.84 g, 17 mmol), acetylene (7.05 mL, 30 mmol), trimethyl orthoformate (3.72 mL, 34 mmol), boron trifluoride etherate (0.43 mL, 20 mol%), and dry CH_2Cl_2 (50 mL). The usual workup and chromatography gave 2.81 g (39%) of **1e** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14-8.12 (m, 2H), 7.66-7.61 (m, 4H), 7.17 (s, 1H), 6.94 (d, 1H, *J* = 9.0 Hz), 3.33 (s, 3H), -0.09 (s, 9H).

2-Methoxy-2-(4-methoxyphenyl)-6-nitro-3-trimethylsilyl-2*H*-1-benzopyran (1g)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.51 g, 15 mmol), acetylene (6.38 mL, 30 mmol), trimethyl orthoformate (3.28 mL, 30 mmol), boron trifluoride etherate (0.38 mL, 20 mol%), and dry CH_2Cl_2 (40 mL). The usual workup and chromatography gave 0.67 g (12%) of **1g** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.11-8.09 (m, 2H), 7.40-7.38 (m, 2H), 7.10 (s, 1H), 6.93 (d, 1H, *J* = 9.1 Hz), 6.89-6.87 (m, 2H), 3.82 (s, 3H), 3.30 (s, 3H), -0.08 (s, 9H).

2-Methoxy-6-nitro-2-(4-isopropylphenyl)-3-trimethylsilyl-2*H*-1-benzopyran (1h)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (1.00 g, 6.0 mmol), acetylene (2.70 mL, 11 mmol), trimethyl orthoformate (0.66 mL, 6.0 mmol), boron trifluoride etherate (0.15 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 0.98 g (41%) of **1h** as a yellow oil; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.12-8.08 (m, 2H), 7.40-7.38 (m, 2H), 7.23-7.21 (m, 2H), 7.10 (s, 1H), 6.94 (d, 1H, *J* = 8.5 Hz), 3.31 (s, 3H), 2.92 (spt, 1H, *J* = 7.0 Hz), 1.24 (d, 6H, *J* = 7.0 Hz), -0.10 (s, 9H).

2-(4-Methylphenyl)-2-methoxy-6-nitro-3-trimethylsilyl-2*H*-1-benzopyran (1i)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (0.978 g, 5.9 mmol), acetylene (2.203 g, 12 mmol), trimethyl orthoformate (0.64 mL, 5.9 mmol), boron trifluoride etherate (0.14 mL, 20 mol%), and dry CH_2Cl_2 (30 mL). The usual workup and chromatography gave 0.6534 g (30%) of **1i** as a brown oil; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14-8.12 (m, 2H), 7.66-7.61 (m, 4H), 7.17 (s, 1H), 6.94 (d, 1H, J = 9.0 Hz), 3.33 (s, 3H), -0.09 (s, 9H).

2-(3-Methylphenyl)-2-methoxy-6-nitro-3-trimethylsilyl-2*H*-1-benzopyran (1j)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (0.5171 g, 3.1 mmol), acetylene (1.168 g, 6.2 mmol), trimethyl orthoformate (0.34 mL, 3.1 mmol), boron trifluoride etherate (0.078 mL, 20 mol%), and dry CH_2Cl_2 (15 mL). The usual workup and chromatography gave 0.4589 g (40%) of **1j** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14-8.12 (m, 2H), 7.66-7.61 (m, 4H), 7.17 (s, 1H), 6.94 (d, 1H, J = 9.0 Hz), 3.33 (s, 3H), -0.09 (s, 9H).

2-(2-Methylphenyl)-2-methoxy-6-nitro-3-trimethylsilyl-2*H*-1-benzopyran (1k)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (0.7922 g, 4.7 mmol), acetylene (1.7893 g, 9.5 mmol), trimethyl orthoformate (0.52 mL, 4.8 mmol), boron trifluoride etherate (0.12 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 0.2054 g (12%) of **1k** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.14-8.12 (m, 2H), 7.66-7.61 (m, 4H), 7.17 (s, 1H), 6.94 (d, 1H, J = 9.0 Hz), 3.33 (s, 3H), -0.09 (s, 9H).

2-Methoxy-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran-6-carbonitrile (1l)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (0.71 g, 4.8 mmol), acetylene (1.96 mL, 10 mmol), trimethyl orthoformate (0.55 mL, 5.0 mmol), boron trifluoride etherate (0.13 mL, 20 mol%), and dry CH_2Cl_2 (30 mL). The usual workup and chromatography gave 0.58 g (35%) of **1l** as a yellow solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.56 (m, 4H), 7.36 (m, 3H), 7.03 (s, 1H), 7.36 (d, 2H, J = 9.0 Hz), 3.31 (s, 3H), -0.12 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 156.2, 142.1, 137.3, 133.6, 133.0, 130.9, 128.6, 127.8, 126.2, 119.0, 119.0, 116.1, 104.8, 103.9, 50.4, -1.1, 52.2; IR (ATR): 2959, 1615, 1245, 1066, 1000, 831, 753, 694 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{19}H_{18}NOSi$ ($[M\text{-}OMe]^+$): 304.1152, found: 304.1162.

6-Bromo-2-methoxy-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (1m)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.02 g, 10 mmol), acetylene (3.92 mL, 20 mmol), trimethyl orthoformate

(1.09 mL, 10 mmol), boron trifluoride etherate (0.25 mL, 20 mol%), and dry CH_2Cl_2 (50 mL). The usual workup and chromatography gave 1.05 g (27%) of **1m** as an orange oil. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.50-7.48 (m, 2H), 7.37-7.27 (m, 5H), 6.97 (s, 1H), 6.78 (d, 1H, *J* = 8.5 Hz), 3.29 (s, 3H), -0.14 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 152.1, 142.7, 136.6, 133.7, 132.6, 129.3, 128.5, 128.0, 126.6, 120.5, 117.1, 112.6, 104.1, 50.5; IR (ATR): 2955, 1474, 1245, 1000, 834, 755, 697 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{18}H_{18}OSiBr$ ([M-OMe]$^+$): 357.0305, found: 357.0296.

Methyl 2-methoxy-6-nitro-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran-6-carboxylate (1n)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (1.08 g, 6.0 mmol), acetylene (2.35 mL, 12 mmol), trimethyl orthoformate (0.66 mL, 6.0 mmol), boron trifluoride etherate (0.15 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 0.86 g (39%) of **1n** as a yellow oil; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.94-7.89 (m, 2H), 7.52-7.49 (m, 2H), 7.35-7.28 (m, 3H), 7.12 (s, 1H), 6.90 (d, 1H, *J* = 8.3 Hz), 3.86 (s, 3H), 3.29 (s, 3H), -0.11 (s, 9H).

2-Methoxy-7-(4-methylbenzenesulfonate)-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (1o)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (1.46 g, 5.0 mmol), acetylene (1.96 mL, 10 mmol), trimethyl orthoformate (0.55 mL, 5 mmol), boron trifluoride etherate (0.13 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 0.71 g (30%) of **1o** as a yellow solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.69 (d, 2H, *J* = 8.5 Hz), 7.46 (m, 2H), 7.33 (m, 3H), 7.26 (m, 2H), 7.09 (d, 1H, *J* = 8.5 Hz), 6.99 (s, 1H), 6.68 (dd, 1H, *J* = 8.5, 2.5 Hz), 6.46 (s, 1H) 3.23 (s 3H), 2.40 (s, 3H), -0.15 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 153.4, 150.3, 145.3, 142.3, 135.7, 133.8, 132.3, 129.7, 128.5, 128.4, 127.9, 127.5, 126.6, 117.8, 115.0, 109.5, 104.0, 50.5, 21.5, -0.92; IR (ATR): 3439, 2955, 1615, 1489, 1372, 1248, 1177, 835, 549 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{25}H_{25}O_4SiS$ ([M-OMe]$^+$): 449.1237, found: 449.1244.

2-Methoxy-7-acetyloxy-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (1p)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (1.08 g, 6.0 mmol), acetylene (2.35 mL, 12 mmol), trimethyl orthoformate (0.66 mL, 6.0 mmol), boron trifluoride etherate (0.15 mL, 20 mol%), and dry CH_2Cl_2 (25 mL). The usual workup and chromatography gave 0.40 g (18%) of **1p** as a yellow solid; ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.52-7.49 (m, 2H), 7.37-7.33 (m, 3H), 7.15 (d, 1H, *J* = 7.9 Hz), 7.03 (s, 1H), 6.70-6.65 (m, 2H), 3.31 (s, 3H), 2.27 (s, 3H), -0.15 (s, 9H).

6,8-Dibromo-2-methoxy-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (1q)

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.4209 g, 8.6 mmol), acetylene (3.38 mL, 17 mmol), trimethyl orthoformate (0.95 mL, 8.6 mmol), boron trifluoride etherate (0.22 mL, 20 mol%), and dry CH_2Cl_2 (45 mL). The usual workup and chromatography gave 0.1659 g (4%) of **1q** as a brown oil; ^{1}H NMR (500 MHz, $CDCl_3$): δ 7.57 (d, 1H, *J* = 2.4 Hz), 7.51-7.48 (m, 2H), 7.40-7.35 (m, 3H), 7.27 (d, 1H, *J* = 2.4 Hz), 6.88 (s, 1H), 3.31 (s, 3H), -0.14 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 148.7, 141.4, 138.9, 135.1, 132.8, 128.6, 128.5, 128.1, 127.0, 122.1, 112.8, 110.3, 105.0, 51.0, -0.9; IR (ATR): 2956, 1443, 1247, 1002, 837, 695 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{18}H_{17}OSiBr_2$ ([M-OMe]$^+$): 434.9410, found: 434.9415.

2-Methoxy-6-nitro-2-naphthyl-3-trimethylsilyl-2*H*-1-benzopyran (1r)[10]

This reaction was carried out in the same manner as general procedure employing the following materials: salicylaldehyde (2.09 g, 13 mmol), acetylene (5.53 mL, 25 mmol), trimethyl orthoformate (2.76 mL, 25 mmol), boron trifluoride etherate (0.31 mL, 20 mol%), and dry CH_2Cl_2 (30 mL). The usual workup and chromatography gave 0.98 g (19%) of **1r** as a yellow solid; ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.16 (d, 1H, *J* = 2.5 Hz), 8.12 (dd, 1H, *J* = 8.5, 2.5 Hz), 8.04 (s, 1H), 7.89-7.82 (m, 3H), 7.52-7.48 (m, 3H), 7.18 (s, 1H), 6.95 (d, 1H, *J* = 8.5 Hz), 3.39 (s, 3H), -0.12 (s, 9H).

2-Ethoxy-6-nitro-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (1s)

In an oven-dried round-bottom flask, benzopyran **1a** (0.4859 g, 1.4 mmol), boron trifluoride etherate (0.034 mL, 20 mol%) and EtOH (7 mL) were added, then stirred at 60 ºC for 8 h. After being stirred, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layer were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 100 : 1) to afford **1s** in 65% (0.3299 g) as a yellow solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.13-8.10 (m, 2H), 7.51-7.49 (m, 2H), 7.40-7.34 (m, 3H), 7.07 (s, 1H), 6.93 (d, 1H, *J* = 12.5 Hz), 3.50 (q, 1H, *J* = 8.5 Hz), 1.23 (t, 1H, *J* = 8.5 Hz), -0.11 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ158.2, 142.3, 141.3, 138.3, 132.9, 128.9, 128.1, 126.4, 125.8, 122.8, 118.3, 115.7, 105.1, 58.7, 14.9, -0.9; IR (ATR): 2896, 1609, 1516, 1338, 1249, 1059, 989, 829, 750, 698 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{20}H_{24}NO_4Si$ ([M+H]$^+$): 370.1470, found: 370.1485.

2-Hexyloxy-6-nitro-2-phenyl-3-trimethylsilyl-2*H*-1-benzopyran (1t)

In an oven-dried round-bottom flask, benzopyran **1a** (0.7072 g, 2.0 mmol), boron trifluoride etherate (0.050 mL, 20 mol%) and *n*-hexanol (10 mL) were added, then stirred at 60 ºC for 11 h. After being

stirred, the reaction mixture was quenched with H_2O. The organic layer was separated and the aqueous layer was extracted with EtOAc. The combined organic layer were washed with brine, dried over $MgSO_4$, and filtered. The filtrate was concentrated in vacuo. The resulting residue was purified by column chromatography on silica gel (hexane / EtOAc = 100 : 1) to afford **1t** in 79% (0.6017 g) as a yellow solid. ^{1}H NMR (500 MHz, $CDCl_3$): δ 8.12-8.09 (m, 2H), 7.50-7.48 (m, 2H), 7.39-7.33 (m, 3H), 7.07 (s, 1H), 6.91 (d, 1H, *J* = 10.0 Hz), 3.47-3.37 (m, 2H), 1.70-1.59 (m, 2H), 1.40-1.34 (m, 2H), 1.33-1.24 (m, 4H), 0.87 (t, 3H, *J* = 7.0 Hz), -0.11 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$): δ 158.3, 142.5, 141.3, 132.9, 128.8, 128.1, 126.5, 125.8, 122.8, 118.4, 115.7, 105.1, 63.2, 31.6, 29.6, 25.9, 22.5, 14.0, -0.8; IR (ATR): 2953, 1611, 1518, 1337, 1269, 1006, 830, 748, 698 cm^{-1}; HRMS (ESI+): *m/z* calcd for $C_{24}H_{32}NO_4Si$ ($[M+H]^+$): 426.2095, found: 426.2080.

REFERENCES AND NOTES

1. F. Luiz and J. Silva, *Tetrahedron,* 2002, **58**, 9137.
2. For selected reports on ring contraction reactions of six membered ring to five membered ring, see: (a) Z. Xiang, Z. Guangshuai, Z. Yong, Z.-N. Daisy, D. Yunfei, and Z. Kang, *J. Org. Chem.*, 2016, **81**, 11397; (b) A. Ahmad and L. F. S. Júnior, *J. Braz. Chem. Soc.*, 2016, **27**, 1820; (c) G. B. Evans, S. A. Cameron, S. R. Culbert, and P. K. Grant, *Tetrahedron Lett.*, 2014, **55**, 6227; (d) K. O. Eyong, S. P. Kumar, V. Kuete, G. N. Folefoc, H. Langmi, M. J. J. Meyer, N. Lall, and S. Baskaran, *Med. Chem. Res.*, 2012, **21**, 2117; (e) L. E. Bourque, P. E. Haile, and K. A. Woerpel, *J. Org. Chem.*, 2009, **74**, 7180; (f) W. G. Dauben and R. A. Bunce, *J. Org. Chem.*, 1982, **47**, 5042.
3. (a) C. D. Gabbutt, B. M. Heron, C. Kilner, and S. B. Kolla, *Dyes Pigm.*, 2012, **92**, 825; (b) I. D. Jurberg, K. Ikeda, D. Antwi-Omane, and F. Gagosz, *Isr. J. Chem.*, 2013, **53**, 915; (c) K. Bowden and S. Battah, *J. Chem. Soc., Perkin Trans. 2*, 1998, 1603; (d) K.-S. C. Marriott, R. Bartee, A. Z. Morrison, L. Stewart, and J. Wesby, *Tetrahedron Lett.*, 2012, **53**, 3319; (e) M. N. V. Sastry, S. Claessens, P. Habonimana, and N. De Kimpe, *J. Org. Chem.*, 2010, **75**, 2274; (f) M. Khoobi, F. Molaverdi, F. Jafarpour, M. Abbasnia, M. Kubicki, and A Shafiee, *Chem. Commun.*, 2015, **51**, 11713.
4. C. Böttcher, G. Zeyat, S. A. Ahmed, E. Irran, T. Cordes, C. Elsner, W. Zinth, and K. Rueck-Braun, *Beilstein J. Org. Chem.*, 2009, **5**, 1.
5. C. D. Gabbutt, B. M. Heron, S. B. Kolla, C. Kilner, S. J. Coles, P. N. Horton, and M. B. Hursthouse, *Org. Biomol. Chem.*, 2008, **6**, 3096.
6. R. Gericke and I. Lues, *Tetrahedron Lett.*, 1992, **33**, 1871.
7. (a) S. Gauthier, B. Caron, J. Cloutier, Y. L. Dory, A. Favre, D. Larouche, J. Mailhot, C. Ouellet, A. Schwerdtfeger, G. Leblanc, C. Martel, J. Simard, Y. Merand, A. Belanger, C. Labrie, and F. Labrie,

J. Med. Chem., 1997, **40**, 2117; (b) K. Arai, Y. Kobayashi, and J. Abe, *Chem. Commun.*, 2015, **51**, 3057.

8. N. Majumdar, N. D. Paul, S. Mandal, B. Bruin, and W. D. Wulff, *ACS Catal*., 2015, **5**, 2329.
9. (a) K. Tanaka, M. Kishimoto, Y. Hoshino, and K. Honda, *Tetrahedron Lett.*, 2018, **59**, 1841; (b) K. Tanaka, M. Sukekawa, Y. Shigematsu, Y. Hoshino, and K. Honda, *Tetrahedron*, 2017, **73**, 6456; (c) K. Tanaka, Y. Shigematsu, M. Sukekawa, Y. Hoshino, and K. Honda, *Tetrahedron Lett.*, 2016, **57**, 5914; (d) H. Miyazaki, Y. Honda, K. Honda, and S. Inoue, *Tetrahedron Lett.*, 2000, **41**, 2643; (e) H. Miyazaki, K. Honda, M. Asami, and S. Inoue, *J. Org. Chem.*, 1999, **64**, 9507; (f) S. Inoue, P. Wang, M. Nagao, Y. Hoshino, and K. Honda, *Synlett*, 2005, 469; (g) K. S. Shrestha, K. Honda, M. Asami, and S. Inoue, *Bull. Chem. Soc. Jpn*., 1999, **72**, 73.
10. (a) K. Tanaka, Y. Hoshino, and K. Honda, *Tetrahedron Lett*., 2016, **57**, 2448; (b) K. Tanaka, Y. Hoshino, and K. Honda, *Heterocycles*, 2017, **95**, 474; transformation of 3-silyl-2*H*-chromenes, see: (c) K. Tanaka, M. Sukekawa, Y. Hoshino, and K. Honda *Chem. Lett.*, 2018, **47**, 440.
11. Y. Yang, H. Liu, C. Peng, J. Wu, J. Zhang, Y. Qiao, X.-N. Wang, and J. Chang, *Org. Lett*., 2016, **18**, 5022.
12. (a) R. S. Kulkarni, S. Kumara, T. Hanumanthappa, N. Gopalpur, S. H. B. V. Kumar, and S. S. More *Synth. Commun.*, 2014, **44**, 331; (b) N. S. H. N. Moorthy, S. F. Sousa, M. J. Ramos, and P. A. Fernandes, *J. Enzyme Inhib. Med. Chem.*, 2011, **26**, 777; (c) K. Asoh, M. Kohchi, I. Hyoudoh, T. Ohtsuka, M. Masubuchi, K. Kawasaki, H. Ebiike, Y. Shiratori, T. A. Fukami, O. Kondoh, T. Tsukaguchi, N. Ishii, Y. Aoki, N. Shimma, and M. Sakaitani, *Bioorg. Med. Chem. Lett.*, 2009, **19**, 1753; (d) M. R. Saberi, T. K. Vinh, S. W. Yee, B. J. N. Griffiths, P. J. Evans, and C. Simons, *J. Med. Chem.*, 2006, **49**, 1016.
13. (a) R. A. Dhokale and S. B. Mhaske, *J. Org. Chem*., 2017, **82**, 4875; (b) V. G. Pandya and S. B. Mhaske, *Org. Lett.*, 2014, **16**, 3836; (c) D. Hong, Z. Chen, X. Lin, and Y. Wang, *Org. Lett.*, 2010, **12**, 4608; (d) F. Shi, J. P. Waldo, Y. Chen, and R. C. Larock, *Org. Lett.*, 2008, **10**, 2409.
14. For an example of the reaction performed at 0 ºC, see: M. M. Ahire, R. Khan, and S. B. Mhaske, *Org. Lett.*, 2017, **19**, 2134.
15. For a related study of this temperature effect, the preparation of both *cis*- and *trans*-β-fluorostyrene derivatives from (*Z*)-1-aryl-2-fluoro-1-(trimethylsilyl)ethenes through fast anti elimination would be helpful. See: G. Landelle, M.-O. Turcotte-Savard, L. Angers, and J.-F. Paquin, *Org. Lett.*, 2011, **13**, 1568.
16. (a) K. Mal, S. Das, N. C. Maiti, R. Natarajan, and I. Das, *J. Org. Chem.*, 2015, **80**, 2972; (b) E. E. Allen, C. Zhu, J. S. Panek, and S. E. Schaus, *Org Lett.*, 2017, **19**, 1878; (c) J. Liu, X. Wang, L. Xu, Z. Hao, L. Wang, and J. Xiao, *Tetrahedron*, 2016, **72**, 7642.

17. For synthesis of the deuterium product **5e**, see supplementary data.
18. (a) M. Ishiguro, N. Ikeda, and H. Yamamoto, *Chem. Lett.*, 1982, **11**, 1029; (b) A. Alexakis, A. Commercon, C. Coulentianos, and J. F. Normant, *Tetrahedron*, 1984, **40**, 715; (c) X. Teng, T. Wada, S. Okamoto, and F. Sato, *Tetrahedron Lett.*, 2001, **42**, 5501; (d) T. Hsi-Hwa and T. Hongru, *Tetrahedron Lett.*, 1997, **38**, 6869.
19. (a) M. R. Attwood, I. Churcher, R. M. Dunsdon, D. N. Hurst, and P. N. Jones, *Tetrahedron Lett.*, 1991, **32**, 811; (b) B. A. Otter, S. S. Saluja, and J. J. Fox, *J. Org. Chem.*, 1972, **37**, 2858.
20. (a) M. T. Reetz, *Angew. Chem.*, *Int. Ed. Engl.*, 1972, **11**, 129; (b) I. Fernandez, F. P. Cossío, and M. A. Sierra, *Chem. Rev.*, 2009, **109**, 6687; (c) O. Gutierrez and D. J. Tantillo, *J. Org. Chem.*, 2012, **77**, 8845.
21. M. T. Reetz, *Tetrahedron*, 1972, **29**, 2189.
22. (a) R. Romagnoli, P. G. Baraldi, C. Lopez-Cara, O. Cruz-Lopez, M. D. Carrion, M. K. Salvador, J. Bermejo, S. Estevez, F. Estevez, J. Balzarini, A. Brancale, A. Ricci, L. Chen, J. G. Kim, and E. Hamel, *ChemMedChem*, 2011, **6**, 1841; (b) H. Hao, W. Chen, J. Zhu, C. Lu, and Y. Shen, *Eur. J. Med. Chem.*, 2015, **102**, 277; (c) L. Antonino, G. Carla, M. Francesco, P. P. Antonio, B. Roberta, D. Riccardo, B. Silvestre, and M. Annamaria, *Chem. Biol. Drug Des.*, 2018, **91**, 39; (d) S. R. Patil, S. Bollikonda, R. H. Patil, J. N. Sangshetti, A. S. Bobade, A. Asrondkar, P. P. Reddy, and D. B. Shinde *Bioorg. Med. Chem. Lett.*, 2018, **28**, 482.
23. (a) C. Aswathanarayanappa, E. Bheemappa, Y. D. Bodke, V. K. Bhovi, R. Ningegowda, M. C. Shivakumar, S. K. Peethambar, and S. Telkar, *Med. Chem. Res.*, 2013, **22**, 78; (b) K. Chanda, Rajeshwari, A. Hiremathad, M. Singh, M. A. Santos, and R. S. Keri, *Pharmacol. Rep.*, 2017, **69**, 281.