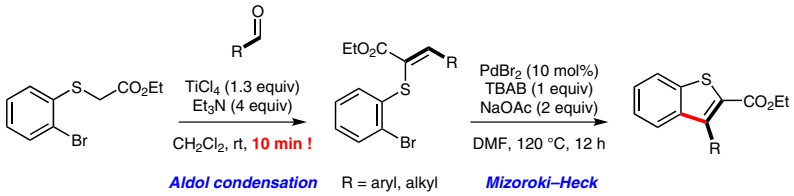
Synthesis S. H. Kwak et al. Paper

# Intramolecular Mizoroki–Heck Reaction of 2-Thiosubstituted Acrylates for the Synthesis of 3-Substituted Benzo[*b*]thiophene-2-carboxylates

**Se Hun Kwak**
**Su-Jeong Lim**
**Hyun-Jeong Yoo**
**Ji-Eun Ha**
**Young-Dae Gong***

Center for Innovative Drug Library Research, Department of Chemistry, College of Science, Dongguk University, 26, 3-ga, Pil-dong Jung-gu, Seoul 100-715, Korea
ydgong@dongguk.edu

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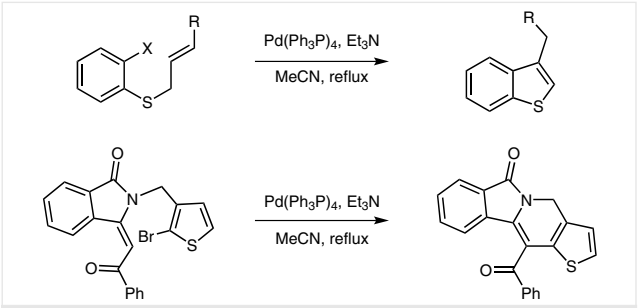
**Abstract** 3-Substituted 2-(phenylthio)acrylates prepared from aldol condensation using titanium tetrachloride were employed to synthesize benzo[*b*]thiophenes. The acrylates containing aryls and alkyls generated the desired benzo[*b*]thiophenes in reasonable yields under the optimized Heck condition, but acrylates having heteroaryls gave the desired products in poor yields or no products under the condition.

**Key words** Heck reaction, acrylate, benzo[*b*]thiophene, heterocycles, $TiCl_4$




**Scheme 1** Examples of fused thiophene synthesis via intramolecular Heck reaction

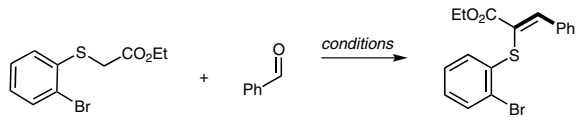
Mizoroki–Heck reaction is a valuable tool for the formation of C–C bond between organohalides (or triflates) and olefins. Along with application of the intermolecular Heck reaction, the transformation have been widely used intramolecularly to construct rings, providing access to a number of natural products and heterocycles.[1] Although a range of synthetic routes using this protocol for the target molecules have been developed, an unexplored route involving the Heck protocol with efficient and convenient means remains to be studied. In this regard, our interest was to find a new way to heterocycles, especially benzo[*b*]thiophenes, via intramolecular Heck reaction.

Benzo[*b*]thiophenes[2] are biologically prominent heterocycles like other similar skeletons such as benzofurans[3] and indoles.[4] A few study for the approach to benzo[*b*]thiophenes[5] or fused thiophenes[6] via Heck cyclization have been reported (Scheme 1); however, intermediates for the synthesis of 2,3-disubstituted benzo[*b*]thiophenes via intramolecular Heck cyclization have not previously been explored. Herein, we report the preparation of 2-thiosubstituted acrylates and the corresponding benzo[*b*]thiophenes via intramolecular Heck reaction.

At first, Knoevenagel condensation with piperidine at refluxing temperature was attempted in order to obtain the desired acrylate **2a** from ethyl (2-bromophenyl)thioacetate (**1a**) (Table 1, entry 1). However, we failed to obtain the acrylate **2a**. Addition of acetic acid under the same condition above was also not effective for the condensation (entry 2). When the ester **1a** was treated with ethanolic sodium ethoxide at room temperature, the acrylate **2a** was obtained in poor yield (29%) (entry 3). The acrylate could be produced via condensation of aldol adduct generated using LDA at –78 °C, but this procedure was not preferred as it requires inconvenient two steps.[7] After scrutinizing conditions for the condensation, we found that $TiCl_4$ with triethylamine in dichloromethane could be applied to our substrate and eventually acquired the acrylate **2a** in a good yield (80%) within a short reaction time (10 min).[8]

Aryl aldehydes bearing various functional groups, heteroaryl, and alkyl aldehydes were reacted in the titanium-mediated aldol condensation with the acetate **1a**, which readily gave acrylates **2a**–**p** (Table 2, entries 1–16). 2-(Pyridinethio)acetate **1b**, 2-(phenylsulfonyl)acetate **1c**, 2-(benzylthio)acetate **1d**, and 2-(phenylthio)acetonitrile **1e** were

**Table 1** Aldol Condensation of Ethyl 2-Phenylthioacetate (**1a**)[a]




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

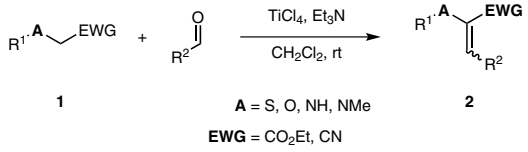
| Entry | Conditions | Yield (%) |
|---|---|---|
| 1[b] | piperidine, toluene, 120 °C, 24 h | – |
| 2[b,c] | piperidine, AcOH, toluene, 120 °C, 24 h | – |
| 3[d] | NaOEt, EtOH, r.t., 3 h | 29 |
| 4[e] | $TiCl_4$, $Et_3N$, $CH_2Cl_2$, r.t., 10 min | 80 |

[a] Ester **1a** (0.4 mmol), benzaldehyde (1.05 equiv).
[b] Piperidine (0.5 equiv).
[c] AcOH (0.5 equiv).
[d] NaOEt (1.5 equiv).
[e] $TiCl_4$ (1.3 equiv), $Et_3N$ (4 equiv).

also investigated with benzaldehyde, which gave acrylates **2q–s** and acrylonitrile **2t** (entries 17–20). Unlike the ester **1a**, the acetonitrile **1e** provided *E*- and *Z*-isomers, separable via flash column chromatography (entry 20). This is probably because nitrile group has smaller steric interactions than ethyl ester. In case of the ethyl aryl glycinate **1f**, an aldol product **2u** was isolated as a major product rather than the corresponding 2-(phenylamino)acrylate, which could be used for the synthesis of indole (entry 21).[9] Finally, 2-(phenyloxy)acrylates **1g** and **1h** were prepared to investigate whether they could be employed for the synthesis of benzofuran (entries 22 and 23).[3] The geometry of acrylates **2** were assumed to be *Z* by comparing β-vinyl proton signals of **2** with those of *E*- and *Z*-isomers in the literature.[10]

We initiated the optimization of Heck reaction with the acrylate **2a** under the conditions either with a phosphine ligand or with no ligand (Jeffery conditions) (Table 3, entries 1 and 2).[11] Both gave unsatisfactory results. However, in these experiments, we observed that the Jeffery conditions gave a cleaner product **3a**,[12] either without purification or after short column chromatography, than the conditions using triphenylphosphine. Therefore, optimization studies were carried out under Jeffery conditions by changing bases, solvents, reaction temperature, additives and palladium catalysts. Control experiments showed that the suitable base is sodium acetate (entries 2, 3 and 6), reaction temperature below 120 °C is not enough for complete consumption of the acrylate **2a** (entries 5 and 6), DMF as solvent was better than MeCN and NMP (entries 4–6 and 15), palladium(II) bromide as catalyst was the best (entries 6, 8, 9, 17, and 18), and TBAB (tetrabutylammonium bromide) is the most appropriate additive among others (entries 6 and 10–14).

**Table 2** Preparation of Acrylates **2**[a]




**1** **A** = S, O, NH, NMe **2**
**EWG** = $CO_2Et$, CN

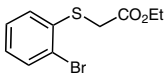
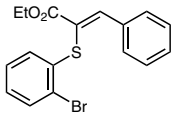
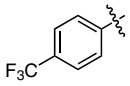
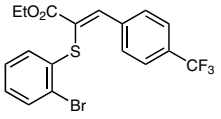
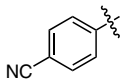
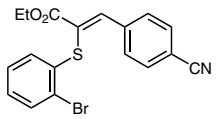
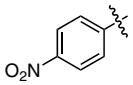
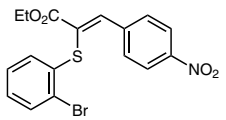
| Entry | $R^1$-X-EWG | | $R^2$ | Product | | Yield (%) |
|---|---|---|---|---|---|---|
| 1 |  | **1a** |  |  | **2a** | 80 |
| 2 | | |  |  | **2b** | 88 |
| 3 | | |  |  | **2c** | 76 |
| 4 | | |  |  | **2d** | 81 |

Table 2 (continued)

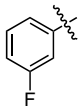
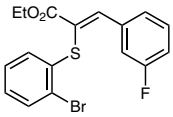
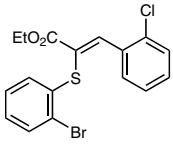
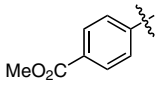
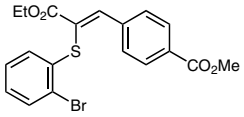
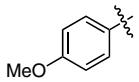
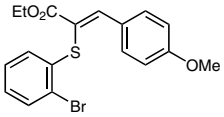
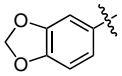
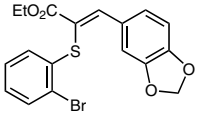
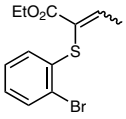
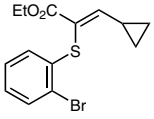
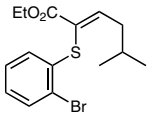
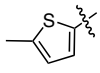
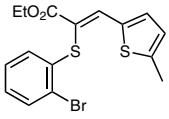
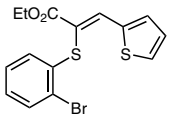
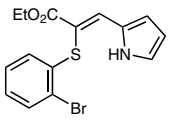
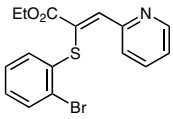
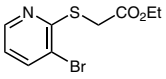
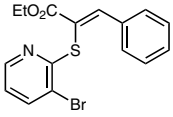
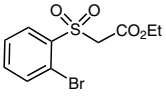
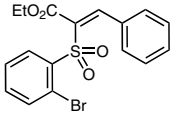
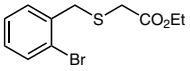
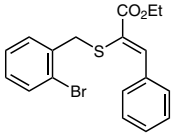
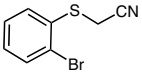
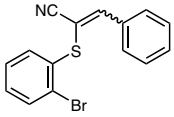
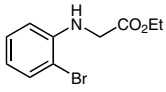
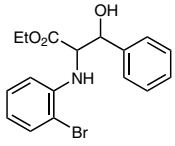
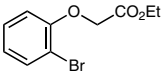
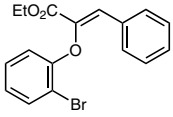
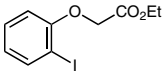
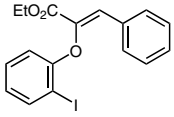
| Entry | $R^1$ X EWG | $R^2$ | Product | | Yield (%) |
|---|---|---|---|---|---|
| 5 | |  |  | **2e** | 86 |
| 6 | |  |  | **2f** | 85 |
| 7 | |  |  | **2g** | 88 |
| 8 | |  |  | **2h** | 85 |
| 9 | |  |  | **2i** | 53 |
| 10 | |  |  | **2j** | 46[b] |
| 11 | |  |  | **2k** | 93 |
| 12 | |  |  | **2l** | 54 |
| 13 | |  |  | **2m** | 73 |
| 14 | |  |  | **2n** | 61 |
| 15 | |  |  | **2oa** | 50 |

Table 2 (continued)

| Entry | $R^1$, X, EWG | | $R^2$ | Product | | Yield (%) |
|---|---|---|---|---|---|---|
| 16 | | |  |  | **2p** | 58 |
| 17 |  | **1b** |  |  | **2q** | 61 |
| 18 |  | **1c** | |  | **2r** | 63 |
| 19 |  | **1d** | |  | **2s** | 87 |
| 20 |  | **1e** | |  | **2t** | 91 |
| 21 |  | **1f** | |  | **2u** | 36 |
| 22 |  | **1g** | |  | **2v** | 62 |
| 23 |  | **1h** | |  | **2w** | 59 |

[a] Ester **1** (2 mmol), aldehyde (1.05 equiv), $TiCl_4$ (1.3 equiv), and $Et_3N$ (4 equiv).
[b] Slightly impure product, which slowly decomposed.

With the optimal conditions in hand, the substrate scope and limitations of the conditions were next explored (Table 4). The reactions proceeded well whether acrylates **2** have an electron-donating or electron-withdrawing group on the phenyl ring ($R^2$) to afford **3a–i**. Furthermore, acrylates **2** having alkyl groups ($R^2$) under the conditions gave the corresponding benzo[*b*]thiophenes **3k** and **3l** except for ethyl (2-arylthio)crotonate **2j**. The instability of **2j** could explain this failure. Unfortunately, acrylates **2m–p** involving heterocycles ($R^2$) gave poor yields (**3ma**, **3n**, **3ob**) or no products (**2oa** and **2p**). 3-(5-Methylthiophen-2-yl)acrylate **2m** also underwent cyclization to yield both the tricycle **3mb** and a thiol detached by-product **3mc**. Attempts to synthesize the thieno[2,3-*b*]pyridine from **2q** failed. The sulfonyl acrylate **2r** gave only the vinyl sulfone **3r**.[13] 2-(Benzylthio)acrylate **2s** under the optimized condition gave a complex mixture. Acrylonitrile **2t** was not a suitable substrate for the construction of benzo[*b*]thiophene under the Heck condition. This result was unexpected because replacement of ethyl ester with nitrile would not be a signifi-

cant change. Also, attempts to synthesize the benzofuran from 2-(phenyloxy)acrylate **2v** failed even though the more reactive iodide **2w** than the bromide **2v** was used.

**Table 3** Optimization of Intramolecular Heck Reaction of **2a**[a]


**2a** **3a**

| Entry | [Pd] | Additive | Base | Temp (°C) Time (h) | Yield (%)[b] |
|---|---|---|---|---|---|
| 1 | $Pd(OAc)_2$ | $Ph_3P$[c] | $K_2CO_3$ | 120/12 | –[d] |
| 2 | $Pd(OAc)_2$ | TBAB | $K_2CO_3$ | 120/12 | 13 |
| 3 | $Pd(OAc)_2$ | TBAB | $Et_3N$ | 120/12 | 34 |
| 4[e] | $Pd(OAc)_2$ | TBAB | NaOAc | 100/24 | 15[f] |
| 5 | $Pd(OAc)_2$ | TBAB | NaOAc | 100/24 | 30[g] |
| 6 | $Pd(OAc)_2$ | TBAB | NaOAc | 120/3 | 75 |
| 7[h] | $Pd(OAc)_2$ | TBAB | NaOAc | 120/24 | 64 |
| 8 | $PdCl_2$ | TBAB | NaOAc | 120/16 | 74 |
| 9 | $Pd_2dba_3$ | TBAB | NaOAc | 120/24 | 60 |
| 10 | $Pd(OAc)_2$ | TBAOAc | NaOAc | 120/3 | 62 |
| 11 | $Pd(OAc)_2$ | TBACl | NaOAc | 120/3 | 65 |
| 12 | $Pd(OAc)_2$ | TBAF | NaOAc | 120/24 | 25 |
| 13 | $Pd(OAc)_2$ | TBAI | NaOAc | 120/24 | 50[i] |
| 14 | $Pd(OAc)_2$ | LiBr | NaOAc | 120/24 | 69 |
| 15[j] | $Pd(OAc)_2$ | TBAB | NaOAc | 120/24 | 56 |
| 16 | $Pd(OAc)_2$ | TBAB | – | 120/24 | 15[k] |
| **17** | **$PdBr_2$** | **TBAB** | NaOAc | **120/12** | **78 (75)**[l] |
| 18 | $Pd(TFA)_2$ | TBAB | NaOAc | 120/12 | 78 |

[a] Acrylate **2a** (0.2 mmol), Pd cat. (10 mol%), additive (1 equiv), base (2 equiv), and DMF (1 mL).
[b] Yield determined by $^1$H NMR spectroscopy.
[c] $Ph_3P$: 20 mol%.
[d] Intractable mixtures and **3a**.
[e] MeCN as solvent instead of DMF.
[f] Unreacted **2a**: 67%.
[g] Unreacted **2a**: 20%.
[h] $Pd(OAc)_2$: 5 mol%.
[i] Unreacted **2a**: 15%.
[j] NMP as solvent instead of DMF.
[k] Unreacted **2a**: 66%.
[l] Isolated yield.

In conclusion, we have reported on the new route for the 1,2-disubstituted benzo[*b*]thiophenes. The advantages of this route are that the preparation of acrylates is easy and a number of them can be prepared. However, the optimized Heck condition was not effective to the substrates for the synthesis of thieno[2,3-*b*]pyridine, isothiochromene, 2-cyanobenzo[*b*]thiophene, benzo[*b*]thiophenes having heteroaryls at the 3-position, and benzofuran. Further studies in order to achieve intramolecular Heck reaction for the unreactive substrates are in progress.

All commercial reagents and solvents were used as received without further purification. The reactions were monitored by TLC. Column chromatography was performed with silica gel (230–400 mesh). $^1$H and $^{13}$C NMR spectra were recorded on a 500 MHz spectrometer referenced to TMS at δ = 0.00 as an internal standard. HRMS were obtained using a TOF LC/MS system.

### Acrylates 2; General Procedure

To a solution of the respective aldehyde (1.05 mmol) and the appropriate 2-(arylthio)acetate **1** (1 mmol) in $CH_2Cl_2$ (4 mL) was added dropwise $TiCl_4$ (1.3 mmol, 1.0 M in $CH_2Cl_2$). The mixture was stirred for 5 min, then $Et_3N$ (4 mmol) was added dropwise. After 10 min, $H_2O$ was added to the mixture and extracted with $CH_2Cl_2$. The combined organic layers were dried ($MgSO_4$) and filtered. After removal of the solvent under vacuum, the residue was purified by column chromatography to afford the desired product **2** (Table 2).

### Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-phenylacrylate (2a)

Pale yellow solid; yield: 581 mg (80%); mp 79–81 °C.

IR (ATR): 3053, 2981, 2901, 1712, 1487, 1271, 1226, 1174, 841, 754 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.23 (s, 1 H), 7.87–7.79 (m, 2 H), 7.54 (dd, *J* = 7.9, 1.2 Hz, 1 H), 7.43–7.34 (m, 3 H), 7.20–7.13 (m, 1 H), 7.11 (dd, *J* = 7.9, 1.7 Hz, 1 H), 7.04–6.97 (m, 1 H), 4.14 (q, *J* = 7.1 Hz, 2 H), 1.09 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.83, 147.13, 137.29, 134.06, 132.99, 130.83, 130.21, 128.76, 128.42, 127.74, 127.22, 124.54, 122.71, 61.95, 13.86.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{16}BrO_2S$: 363.0049; found: 363.0049.

### Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-[4-(trifluoromethyl)phenyl]acrylate (2b)

Yellow oil; yield: 759 mg (88%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.16 (s, 1 H), 7.87 (d, *J* = 8.1 Hz, 2 H), 7.65 (d, *J* = 8.2 Hz, 2 H), 7.55 (dd, *J* = 7.9, 1.1 Hz, 1 H), 7.22–7.16 (m, 1 H), 7.13 (dd, *J* = 7.9, 1.5 Hz, 1 H), 7.09–7.01 (m, 1 H), 4.14 (q, *J* = 7.1 Hz, 2 H), 1.09 (t, *J* = 7.2 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.33, 144.17, 137.48, 136.44, 133.16, 131.35 (q, *J* = 32.7 Hz), 130.67, 129.43, 127.92, 127.84, 127.79, 125.30 (q, *J* = 3.6 Hz), 123.79 (q, *J* = 272.5 Hz), 123.31, 62.20, 13.82.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{15}BrF_3O_2S$: 430.9923; found: 430.9909.

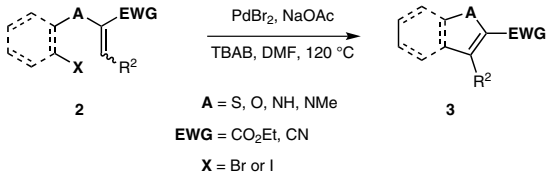
### Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(4-cyanophenyl)acrylate (2c)

Pale yellow solid; yield: 590 mg (76%); mp 98–100 °C.

IR (ATR): 3053, 2903, 2217, 1711, 1272, 1228, 1176, 755 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.08 (s, 1 H), 7.85 (d, *J* = 8.2 Hz, 2 H), 7.67 (d, *J* = 8.4 Hz, 2 H), 7.55 (dd, *J* = 8.0, 1.1 Hz, 1 H), 7.22–7.16 (m, 1 H), 7.14 (dd, *J* = 7.9, 1.5 Hz, 1 H), 7.06 (td, *J* = 8.0, 1.7 Hz, 1 H), 4.14 (q, *J* = 7.1 Hz, 2 H), 1.08 (t, *J* = 7.2 Hz, 3 H).

**Table 4** Intramolecular Heck Reaction of Acrylates and Acrylonitrile[a]




2 3

**A** = S, O, NH, NMe
**EWG** = $CO_2Et$, CN
**X** = Br or I

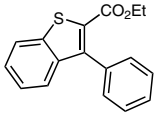
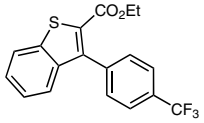
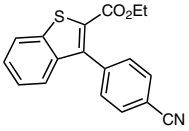
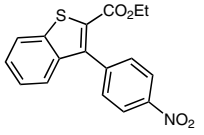
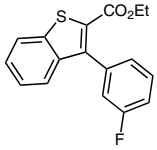
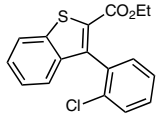
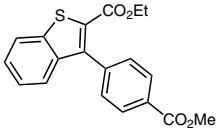
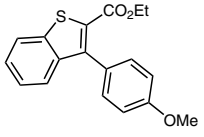
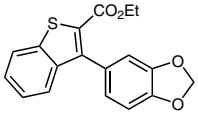
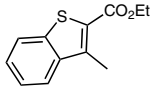
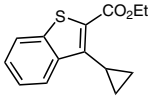
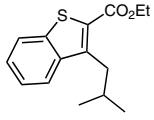
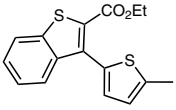
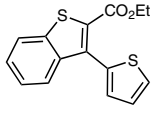
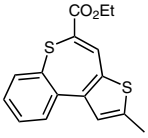
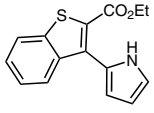
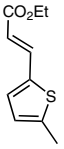
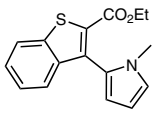
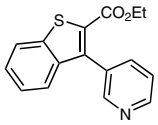
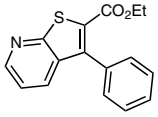
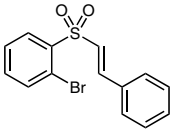
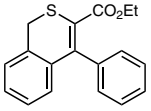
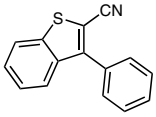
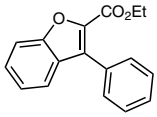
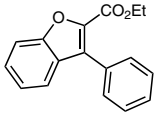
| Precursor **2** | Product **3** | Yield (%) | Precursor **2** | Product **3** | Yield (%) |
|---|---|---|---|---|---|
| **2a** |  | **3a** (75) | **2b** |  | **3b** (53) |
| **2c** |  | **3c** (58) | **2d** |  | **3d** (53) |
| **2e** |  | **3e** (62) | **2f** |  | **3f** (70) |
| **2g** |  | **3g** (73) | **2h** |  | **3h** (56) |
| **2i** |  | **3i** (68) | **2j** |  | –[d] |
| **2k** |  | **3k** (51) | **2l** |  | **3l** (46) |
| **2m**[b] |  | **3ma** (11)[c] | **2n**[b] |  | **3n** (12)[c] |
| |  | **3mb** (6)[c] | **2oa** |  | –[d] |
| |  | **3mc** (6)[c] | **2ob**[b] |  | **3ob** (4) |

Table 4 (continued)

| Precursor **2** | Product **3** | Yield (%) | Precursor **2** | Product **3** | Yield (%) |
|---|---|---|---|---|---|
| **2p** |  | –[d] | **2q** |  | –[e] |
| **2r** |  | **3r** (27%)[f] | **2s** |  | –[d] |
| **2t** |  | –[d] | **2v** |  | –[d] |
| **2w** |  | –[d] | | | |

[a] Acrylate **2** (0.5 mmol), $PdBr_2$ (10 mol%), TBAB (1 equiv), NaOAc (2 equiv), and DMF (2.5 mL) at 120 °C for 12 h.
[b] Toluene was used as the solvent instead of DMF.
[c] The product was isolated by preparative TLC.
[d] Not detected.
[e] No reaction.
[f] Unreacted **2r**: 8%.

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.10, 142.93, 138.46, 136.05, 133.23, 132.05, 130.81, 129.77, 129.25, 128.05, 127.88, 123.60, 118.39, 112.96, 62.30, 13.79.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{14}BrNO_2S$: 388.0001; found: 387.9978.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(4-nitrophenyl)acrylate (2d)**

Yellow solid; yield: 661 mg (81%); mp 102–103 °C.

IR (ATR): 2991, 1702, 1513, 1340, 1251, 1199, 1012, 846 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.24 (d, *J* = 8.9 Hz, 2 H), 8.11 (s, 1 H), 7.91 (d, *J* = 8.7 Hz, 2 H), 7.56 (dd, *J* = 8.0, 1.1 Hz, 1 H), 7.23–7.14 (m, 2 H), 7.07 (td, *J* = 7.9, 1.8 Hz, 1 H), 4.14 (q, *J* = 7.2 Hz, 2 H), 1.09 (t, *J* = 7.2 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.02, 147.85, 142.24, 140.33, 135.87, 133.27, 131.09, 129.99, 129.93, 128.18, 127.91, 123.74, 123.54, 62.36, 13.79.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{15}BrNO_4S$: 407.9900; found: 407.9872.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(3-fluorophenyl)acrylate (2e)**

Pale yellow oil; yield: 656 mg (86%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.58 (dd, *J* = 8.0, 1.2 Hz, 1 H), 7.46 (dd, *J* = 7.9, 1.5 Hz, 1 H), 7.32–7.23 (m, 3 H), 7.14–7.08 (m, 3 H), 7.06–6.99 (m, 2 H), 4.07 (q, *J* = 7.1 Hz, 2 H), 1.03 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.71, 162.58 (d, *J* = 246.4 Hz), 138.63 (d, *J* = 2.3 Hz), 136.94 (d, *J* = 7.9 Hz), 134.74, 133.34, 132.04, 129.94 (d, *J* = 8.4 Hz), 128.83, 128.40, 127.93, 124.99, 124.42 (d, *J* = 2.9 Hz), 115.87 (d, *J* = 21.2 Hz), 115.21 (d, *J* = 22.4 Hz), 61.83, 13.66.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{15}BrFO_2S$: 380.9955; found: 380.9943.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(2-chlorophenyl)acrylate (2f)**

Pale yellow oil; yield: 676 mg (85%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.36 (s, 1 H), 7.72 (dd, *J* = 7.2, 2.1 Hz, 1 H), 7.51 (dd, *J* = 7.9, 1.1 Hz, 1 H), 7.40 (dd, *J* = 7.7, 1.6 Hz, 1 H), 7.34–7.24 (m, 2 H), 7.22–7.11 (m, 2 H), 7.02 (td, *J* = 7.9, 1.8 Hz, 1 H), 4.17 (q, *J* = 7.1 Hz, 2 H), 1.11 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.16, 143.27, 136.78, 134.55, 133.02, 132.87, 130.83, 130.64, 129.43, 129.31, 128.17, 127.77, 127.51, 126.41, 123.13, 62.08, 13.85.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{15}BrClO_2S$: 396.9659; found: 396.9658.

**Methyl (*Z*)-4-{2-[(2-Bromophenyl)thio]-3-ethoxy-3-oxoprop-1-en-1-yl}benzoate (2g)**

Pale yellow solid; yield: 741 mg (88%); mp 85–87 °C.

IR (ATR): 3003, 2980, 2955, 1705, 1590, 1428, 1279, 1241, 1193, 1107, 1016, 770 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.16 (s, 1 H), 8.04 (d, *J* = 8.4 Hz, 2 H), 7.83 (d, *J* = 8.3 Hz, 2 H), 7.53 (dd, *J* = 8.0, 1.2 Hz, 1 H), 7.17 (td, *J* = 7.7, 1.3 Hz, 1 H), 7.12 (dd, *J* = 7.9, 1.6 Hz, 1 H), 7.03 (td, *J* = 7.9, 1.7 Hz, 1 H), 4.13 (q, *J* = 7.1 Hz, 2 H), 3.91 (s, 3 H), 1.07 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 166.44, 165.45, 144.75, 138.35, 136.64, 133.13, 130.96, 130.47, 129.54, 129.39, 127.83, 127.70, 127.56, 123.25, 62.16, 52.31, 13.84.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{19}H_{18}BrO_4S$: 421.0104; found: 421.0093.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(4-methoxyphenyl)acrylate (2h)**

Pale yellow oil; yield: 668 mg (85%).

IR (ATR): 2976, 1709, 1603, 1509, 1249, 1173, 1020, 829, 749 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.24 (s, 1 H), 7.89 (d, *J* = 8.7 Hz, 2 H), 7.53 (d, *J* = 7.9 Hz, 1 H), 7.15 (t, *J* = 7.6 Hz, 1 H), 7.07 (d, *J* = 7.8 Hz, 1 H), 7.00 (t, *J* = 7.6 Hz, 1 H), 6.91 (d, *J* = 8.9 Hz, 2 H), 4.16 (q, *J* = 7.1 Hz, 2 H), 1.11 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 166.24, 161.43, 147.84, 137.59, 133.20, 132.94, 128.08, 127.72, 126.88, 126.70, 122.25, 120.62, 113.96, 61.80, 55.37, 13.95.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{18}BrO_3S$: 393.0155; found: 393.0156.

**Ethyl (*Z*)-3-(Benzo[*d*][1,3]dioxol-5-yl)-2-[(2-bromophenyl)thio]acrylate (2i)**

Pale yellow solid; yield: 432 mg (53%); mp 90–91 °C.

IR (ATR): 2994, 2906, 1678, 1573, 1485, 1372, 1235, 1195, 1099, 1016, 928, 809 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.17 (s, 1 H), 7.65 (d, *J* = 1.3 Hz, 1 H), 7.53 (d, *J* = 7.9 Hz, 1 H), 7.28 (dd, *J* = 8.1, 1.2 Hz, 1 H), 7.15 (d, *J* = 7.6, Hz, 1 H), 7.06 (dd, *J* = 7.8, 1.1 Hz, 1 H), 7.00 (td, *J* = 7.6, 1.1 Hz, 1 H), 6.83 (d, *J* = 8.1 Hz, 1 H), 5.99 (s, 2 H), 4.13 (q, *J* = 7.1 Hz, 2 H), 1.09 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 166.10, 149.60, 147.79, 147.58, 137.36, 132.97, 128.19, 127.85, 127.74, 127.02, 122.36, 121.22, 110.03, 108.31, 101.62, 61.88, 13.92.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{16}BrO_4S$: 406.9947; found: 406.9937.

**Ethyl 2-[(2-Bromophenyl)thio]but-2-enoate (2j)**

Brown oil; yield: 277 mg (46%).

$^1$H NMR (500 MHz, $CDCl_3$): δ (major isomer) = 7.63 (q, *J* = 7.0 Hz, 1 H), 7.52 (dd, *J* = 7.9, 1.2 Hz, 1 H), 7.20–7.14 (m, 1 H), 7.02–6.94 (m, 2 H), 4.14 (q, *J* = 7.1 Hz, 2 H), 2.10 (d, *J* = 7.0 Hz, 3 H), 1.13 (t, *J* = 7.1 Hz, 3 H).

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{12}H_{14}BrO_2S$: 300.9892; found: 300.9897.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-cyclopropylacrylate (2k)**

Pale yellow oil; yield: 609 mg (93%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.49 (dd, *J* = 7.9, 1.2 Hz, 1 H), 7.20–7.15 (m, 1 H), 7.01–6.95 (m, 2 H), 6.94 (d, *J* = 10.7 Hz, 1 H), 4.13 (q, *J* = 7.1 Hz, 2 H), 2.25–2.16 (m, 1 H), 1.12 (t, *J* = 7.1 Hz, 3 H), 1.08–1.04 (m, 2 H), 0.83–0.78 (m, 2 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.22, 161.51, 137.92, 132.85, 127.59, 127.26, 126.39, 121.47, 121.36, 61.52, 14.59, 14.07, 9.83.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{14}H_{16}BrO_2S$: 327.0049; found: 327.0045.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-5-methylhex-2-enoate (2l)**

Pale yellow oil; yield: 371 mg (54%).

IR (ATR): 2956, 2869, 1711, 1446, 1243, 1041, 1019, 745 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.60–7.48 (m, 2 H), 7.17 (td, *J* = 7.8, 1.4 Hz, 1 H), 7.03–6.95 (m, 2 H), 4.13 (q, *J* = 7.1 Hz, 2 H), 2.43 (t, *J* = 7.2 Hz, 2 H), 1.85 (dq, *J* = 13.4, 6.7 Hz, 1 H), 1.10 (t, *J* = 7.2 Hz, 3 H), 0.96 (d, *J* = 6.6 Hz, 6 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.04, 154.20, 137.64, 132.90, 127.89, 127.58, 126.69, 126.45, 122.05, 61.60, 39.78, 28.32, 22.55, 13.92.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{15}H_{20}BrO_2S$: 343.0362; found: 343.0365.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio)-3-(5-methylthiophen-2-yl)acrylate (2m)**

Brown oil; yield: 560 mg (73%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.46 (s, 1 H), 7.52 (d, *J* = 7.8 Hz, 1 H), 7.33 (d, *J* = 3.7 Hz, 1 H), 7.12 (t, *J* = 7.6 Hz, 1 H), 6.98 (t, *J* = 8.1 Hz, 2 H), 6.77 (d, *J* = 3.7 Hz, 1 H), 4.18 (q, *J* = 7.1 Hz, 2 H), 2.48 (s, 3 H), 1.15 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 166.02, 149.41, 143.57, 137.30, 137.28, 135.93, 132.94, 127.74, 126.96, 126.76, 125.64, 122.14, 116.35, 61.77, 15.92, 14.11.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{16}BrO_2S_2$: 382.9770; found: 382.9772.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(thiophen-2-yl)acrylate (2n)**

Pale yellow solid; yield: 451 mg (61%); mp 97–98 °C.

IR (ATR): 3103, 2990, 1703, 1582, 1253, 1200, 1036, 1019, 748, 719 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.54 (s, 1 H), 7.57–7.51 (m, 3 H), 7.15–7.08 (m, 2 H), 7.02–6.96 (m, 2 H), 4.19 (q, *J* = 7.1 Hz, 2 H), 1.16 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 165.78, 142.75, 137.85, 136.92, 136.34, 133.37, 132.97, 127.75, 127.14, 126.92, 126.90, 122.32, 118.64, 61.89, 14.05.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{15}H_{14}BrO_2S_2$: 368.9613; found: 368.9610.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(1*H*-pyrrol-2-yl)acrylate (2oa)**

Yellow solid; yield: 352 mg (50%); mp 71–72 °C.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 12.10 (s, 1 H), 7.51 (d, *J* = 5.9 Hz, 2 H), 7.18 (t, *J* = 7.5 Hz, 1 H), 7.10 (d, *J* = 7.3 Hz, 2 H), 6.99 (t, *J* = 7.5 Hz, 1 H), 6.63 (s, 1 H), 6.33 (s, 1 H), 4.15 (q, *J* = 7.1 Hz, 2 H), 1.08 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 167.74, 143.32, 139.75, 132.79, 128.25, 127.56, 127.09, 126.47, 124.92, 122.11, 121.14, 111.15, 109.46, 61.78, 13.83.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{15}H_{15}BrNO_2S$: 352.0001; found: 351.9999.

**Ethyl (*Z*)-2-[(2-Bromophenyl)thio]-3-(pyridin-3-yl)acrylate (2p)**

Yellow solid; yield: 423 mg (58%); mp 58–59 °C.

IR (ATR): 3056, 2990, 1699, 1413, 1239, 1220, 1036, 1016, 808, 758 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 8.53 (s, 1 H), 7.56–7.50 (m, 3 H), 7.15–7.08 (m, 2 H), 7.01–6.94 (m, 2 H), 4.19 (q, *J* = 7.1 Hz, 2 H), 1.16 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 165.80, 142.73, 137.89, 136.96, 136.33, 133.36, 133.00, 127.77, 127.20, 126.94, 126.92, 122.37, 118.72, 61.90, 14.07 (one carbon is missing due to overlapping).

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{15}BrNO_2S$: 364.0001; found: 364.0024.

**Ethyl (*Z*)-2-[(3-Bromopyridin-2-yl)thio]-3-phenylacrylate (2q)**

Pale brown solid; yield: 444 mg (61%); mp 97–98 °C.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 8.31 (dd, *J* = 4.7, 1.4 Hz, 1 H), 8.19 (s, 1 H), 7.72 (td, *J* = 6.0, 1.4 Hz, 6 H), 7.41–7.35 (m, 3 H), 6.89 (dd, *J* = 7.9, 4.7 Hz, 1 H), 4.20 (q, *J* = 7.1 Hz, 2 H), 1.14 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 166.12, 158.08, 147.67, 145.70, 139.57, 134.25, 130.64, 129.77, 128.32, 124.12, 120.84, 118.40, 61.74, 14.01.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{15}BrNO_2S$: 364.0001; found: 364.0011.

**Ethyl (*Z*)-2-[(2-Bromophenyl)sulfonyl]-3-phenylacrylate (2r)**

White solid; yield: 498 mg (63%); mp 101–102 °C.

IR (ATR): 2989, 1716, 1615, 1320, 1216, 1152, 1035, 855, 749 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 8.27 (dd, *J* = 7.9, 1.7 Hz, 1 H), 7.73 (dd, *J* = 7.9, 1.2 Hz, 1 H), 7.55–7.49 (m, 3 H), 7.48–7.44 (m, 2 H), 7.42–7.38 (m, 2 H), 4.12 (q, *J* = 7.1 Hz, 2 H), 1.03 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.51, 148.27, 138.38, 135.45, 134.66, 132.84, 131.96, 131.63, 131.55, 130.12, 128.80, 127.69, 121.07, 62.24, 13.50.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{16}BrO_4S$: 394.9947; found: 394.9941.

**Ethyl (*Z*)-2-[(2-Bromobenzyl)thio]-3-phenylacrylate (2s)**

Pale yellow oil; yield: 656 mg (87%).

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.68–7.64 (m, 2 H), 7.45 (d, *J* = 7.7 Hz, 1 H), 7.32–7.28 (m, 3 H), 7.16–7.11 (m, 2 H), 7.03–6.98 (m, 1 H), 4.34 (q, *J* = 7.1 Hz, 2 H), 4.13 (s, 2 H), 1.39 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 166.32, 146.12, 136.85, 134.46, 132.94, 130.98, 130.82, 129.57, 128.79, 128.08, 127.31, 125.60, 124.59, 61.95, 39.05, 14.40.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{18}BrO_2S$: 377.0205; found: 377.0193.

**2-[(2-Bromophenyl)thio]-3-phenylacrylonitrile (2t)**

**Major Isomer 2t**

White solid; yield: 348 mg (55%); mp 48–49 °C.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.83 (dd, *J* = 7.3, 2.0 Hz, 2 H), 7.63 (dd, *J* = 7.9, 1.2 Hz, 1 H), 7.57 (s, 1 H), 7.51–7.43 (m, 4 H), 7.35 (td, *J* = 7.7, 1.2 Hz, 1 H), 7.19 (td, *J* = 7.8, 1.5 Hz, 1 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 151.25, 133.61, 133.55, 132.87, 131.63, 131.55, 129.42, 129.25, 129.13, 128.33, 125.08, 116.16, 102.62.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{15}H_{11}BrNS$: 315.9790; found: 315.9760.

**Minor Isomer 2t**

White solid; yield: 228 mg (36%); mp 46–47 °C.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.77–7.70 (m, 2 H), 7.67 (dd, *J* = 7.9, 1.4 Hz, 1 H), 7.56 (dd, *J* = 7.8, 1.5 Hz, 1 H), 7.53 (s, 1 H), 7.49–7.40 (m, 3 H), 7.36 (td, *J* = 7.6, 1.2 Hz, 1 H), 7.24 (td, *J* = 7.8, 1.7 Hz, 1 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 146.81, 133.70, 133.62, 133.34, 132.28, 130.69, 130.49, 130.30, 128.75, 128.37, 126.94, 116.79, 107.30.

**Ethyl 2-[(2-Bromophenyl)amino]-3-hydroxy-3-phenylpropanoate (2u)**

Colorless oil; yield: 262 mg (36%).

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.41 (td, *J* = 7.0, 1.4 Hz, 3 H), 7.39–7.26 (m, 4 H), 7.05 (td, *J* = 7.8, 1.2 Hz, 1 H), 6.59 (td, *J* = 7.8, 1.4 Hz, 1 H), 6.43 (dd, *J* = 8.2, 1.0 Hz, 1 H), 5.22 (d, *J* = 8.7 Hz, 1 H), 5.12 (t, *J* = 4.3 Hz, 1 H), 4.24 (dd, *J* = 8.7, 4.6 Hz, 1 H), 4.12 (q, *J* = 7.1 Hz, 2 H), 3.00 (d, *J* = 4.1 Hz, 1 H), 1.13 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 171.54, 143.78, 139.53, 132.66, 128.50, 128.37, 128.36, 126.34, 119.40, 112.52, 111.04, 74.34, 63.49, 61.72, 14.02.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{19}BrNO_3$: 364.0543; found: 364.0534.

**Ethyl (*Z*)-2-(2-Bromophenoxy)-3-phenylacrylate (2v)**

White solid; yield: 431 mg (62%); mp 80–81 °C.

IR (ATR): 2994, 2903, 1712, 1471, 1224, 1096, 1096, 924, 767, 753 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.74–7.71 (m, 2 H), 7.61 (d, *J* = 7.9 Hz, 1 H), 7.37–7.31 (m, 3 H), 7.14 (t, *J* = 7.8 Hz, 1 H), 6.91 (t, *J* = 7.6 Hz, 1 H), 6.79 (d, *J* = 8.2 Hz, 1 H), 4.19 (q, *J* = 7.1 Hz, 2 H), 1.18 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 163.18, 153.11, 139.90, 133.72, 132.27, 130.46, 129.83, 128.80, 128.34, 127.37, 123.79, 114.91, 111.99, 61.59, 14.03.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{16}BrO_3$: 347.0277; found: 347.0282.

**Ethyl (*Z*)-2-(2-Iodophenoxy)-3-phenylacrylate (2w)**

White solid; yield: 465 mg (59%); mp 92–93 °C.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.84 (dd, *J* = 7.8, 1.4 Hz, 1 H), 7.72 (dd, *J* = 7.5, 1.9 Hz, 2 H), 7.37–7.31 (m, 3 H), 7.18 (td, *J* = 8.2, 1.4 Hz, 1 H), 6.78 (td, *J* = 7.7, 1.2 Hz, 1 H), 6.73 (dd, *J* = 8.2, 1.1 Hz, 1 H), 4.18 (q, *J* = 7.1 Hz, 2 H), 1.17 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 163.18, 155.50, 140.08, 139.78, 132.29, 130.50, 129.81, 129.35, 128.79, 127.27, 124.35, 113.95, 85.77, 61.57, 14.06.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{16}IO_3$: 395.0139; found: 395.0129.

**Benzo[*b*]thiphenes 3; General Procedure**

To a solution of acrylate **2** (0.5 mmol) in DMF (2.5 mL) in an 8 mL screw-capped vial were added $PdBr_2$ (10 mol %), NaOAc (2 equiv), and TBAB (1 equiv). The mixture was heated at 120 °C for 12 h. After cool-

ing to r.t., $H_2O$ was added to the mixture and extracted with $Et_2O$. The combined organic layers were dried ($MgSO_4$) and filtered. After removal of the solvent under vacuum, the residue was purified by column chromatography to afford the desired product **3** (Table 4).

**Ethyl 3-Phenylbenzo[*b*]thiophene-2-carboxylate (3a)**

Pale yellow solid; yield: 106 mg (75%); mp 48–49 °C.

IR (ATR): 3054, 2983, 2903, 1713, 1503, 1488, 1272, 1227, 1175, 1060, 1026, 754 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.88 (d, *J* = 8.1 Hz, 1 H), 7.53 (d, *J* = 8.2 Hz, 1 H), 7.51–7.42 (m, 4 H), 7.41–7.37 (m, 2 H), 7.34 (t, *J* = 7.6 Hz, 1 H), 4.22 (q, *J* = 7.1 Hz, 2 H), 1.19 (t, *J* = 7.2 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.64, 143.77, 140.40, 140.17, 134.72, 129.68, 128.68, 127.98, 127.10, 125.27, 124.75, 122.46, 61.23, 13.96 (one carbon is missing due to overlapping).

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{15}O_2S$: 283.0787; found: 283.0781.

**Ethyl 3-[4-(Trifluoromethyl)phenyl]benzo[*b*]thiophene-2-carboxylate (3b)**

Yellow solid; yield: 93 mg (53%); mp 57–58 °C.

IR (ATR): 2939, 1706, 1321, 1272, 1236, 1157, 1106, 1058, 850 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.90 (d, *J* = 8.2 Hz, 1 H), 7.75 (d, *J* = 8.1 Hz, 2 H), 7.52 (d, *J* = 8.0 Hz, 2 H), 7.50–7.45 (m, 2 H), 7.37 (td, *J* = 7.6, 0.7 Hz, 2 H), 4.23 (q, *J* = 7.1 Hz, 2 H), 1.20 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.36, 142.00, 140.48, 139.69, 138.63, 130.19 130.16 (q, *J* = 32.5 Hz), 129.36, 127.41, 125.10, 125.01 (q, *J* = 3.7 Hz), 124.85, 124.21 (q, *J* = 272.1 Hz), 122.63, 61.50, 13.94.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{14}F_3O_2S$: 351.0661; found: 351.0658.

**Ethyl 3-(4-Cyanophenyl)benzo[*b*]thiophene-2-carboxylate (3c)**

White solid; yield: 89 mg (58%); mp 134–135 °C.

IR (ATR): 2994, 2228, 1709, 1272, 1236, 1175, 831, 757 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.91 (d, *J* = 8.2 Hz, 1 H), 7.83–7.76 (m, 2 H), 7.56–7.49 (m, 3 H), 7.44 (d, *J* = 7.9 Hz, 1 H), 7.42–7.35 (m, 1 H), 4.25 (q, *J* = 7.2 Hz, 2 H), 1.23 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.17, 141.32, 140.51, 139.82, 139.31, 131.83, 130.66, 129.54, 127.51, 125.23, 124.57, 122.71, 118.78, 111.91, 61.60, 14.00.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{14}NO_2S$: 308.0740; found: 308.0712.

**Ethyl 3-(4-Nitrophenyl)benzo[*b*]thiophene-2-carboxylate (3d)**

Yellow solid; yield: 86 mg (53%); mp 119–120 °C.

IR (ATR): 3106, 2981, 1683, 1506, 1343, 1288, 1250, 1086, 854, 838 762 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 8.35 (td, *J* = 8.7, 2.0 Hz, 3 H), 7.91 (d, *J* = 8.2 Hz, 1 H), 7.58 (td, *J* = 8.8, 2.2 Hz, 3 H), 7.52 (td, *J* = 7.6, 1.1 Hz, 2 H), 7.44 (d, *J* = 7.9 Hz, 1 H), 7.38 (td, *J* = 7.5, 0.8 Hz, 2 H), 4.24 (q, *J* = 7.1 Hz, 2 H), 1.23 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.15, 147.61, 141.82, 140.98, 140.55, 139.27, 130.89, 129.69, 127.59, 125.33, 124.54, 123.32, 122.76, 61.69, 14.05.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{14}NO_4S$: 328.0638; found: 328.0613.

**Ethyl 3-(3-Fluorophenyl)benzo[*b*]thiophene-2-carboxylate (3e)**

Yellow solid; yield: 93 mg (62%); mp 58–59 °C.

IR (ATR): 3071, 2989, 2902, 1711, 1278, 1216 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.88 (d, *J* = 8.1 Hz, 1 H), 7.51 (d, *J* = 8.2 Hz, 1 H), 7.48 (td, *J* = 7.6, 1.4 Hz, 2 H), 7.46–7.40 (m, 1 H), 7.36 (td, *J* = 7.6, 1.0 Hz, 2 H), 7.20–7.14 (m, 2 H), 7.13–7.08 (m, 1 H), 4.23 (q, *J* = 7.1 Hz, 2 H), 1.20 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.47 (d, *J* = 246.0 Hz), 162.44, 142.06, 142.04, 140.11 (d, *J* = 72.3 Hz), 136.88, 136.81, 129.53 (d, *J* = 8.4 Hz), 129.24, 127.28, 125.55 (d, *J* = 2.9 Hz), 125.00 (d, *J* = 4.8 Hz), 122.56, 116.89 (d, *J* = 22.1 Hz), 114.95 (d, *J* = 21.0 Hz), 61.41, 13.96.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{14}FO_2S$: 301.0693; found: 301.0684.

**Ethyl 3-(2-Chlorophenyl)benzo[*b*]thiophene-2-carboxylate (3f)**

Yellow oil; yield: 111 mg (70%).

IR (ATR): 2905, 1706, 1537, 1469, 1273, 1243, 1185, 1053, 841, 755 $cm^{-1}$.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 7.88 (d, *J* = 8.2 Hz, 1 H), 7.52 (dd, *J* = 7.6, 1.5 Hz, 1 H), 7.48–7.43 (m, 1 H), 7.41–7.26 (m, 5 H), 4.26–4.15 (m, 2 H), 1.14 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.28, 140.37, 140.17, 139.43, 134.15, 133.75, 131.02, 130.28, 129.40, 129.36, 127.16, 126.42, 124.88, 124.81, 122.56, 61.29, 13.84.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{17}H_{14}ClO_2S$: 317.0398; found: 317.0397.

**Ethyl 3-[4-(Methoxycarbonyl)phenyl]benzo[*b*]thiophene-2-carboxylate (3g)**

Pale yellow solid; yield: 124 mg (73%); mp 108–109 °C.

$^1H$ NMR (500 MHz, $CDCl_3$): δ = 8.16 (d, *J* = 8.2 Hz, 2 H), 7.89 (d, *J* = 8.1 Hz, 1 H), 7.50–7.45 (m, 4 H), 7.35 (t, *J* = 7.6 Hz, 1 H), 4.22 (q, *J* = 7.1 Hz, 2 H), 3.96 (s, 3 H), 1.18 (t, *J* = 7.1 Hz, 3 H).

$^{13}C$ NMR (126 MHz, DMSO-$d_6$): δ = 166.11, 161.63, 141.76, 139.59, 139.12, 138.98, 130.19, 129.19, 128.87, 128.79, 127.74, 125.61, 124.54, 123.13, 61.29, 52.31, 13.73.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{19}H_{17}O_4S$: 341.0842; found: 341.0867.

**Ethyl 3-(4-Methoxyphenyl)benzo[*b*]thiophene-2-carboxylate (3h)**

Pale yellow solid; yield: 87 mg (56%); mp 142–143 °C.

IR (ATR): 3059, 3004, 2840, 1709, 1234, 1171, 1026, 848, 756 $cm^{-1}$.

$^1H$ NMR (500 MHz,$CDCl_3$): δ = 7.87 (d, *J* = 8.1 Hz, 1 H), 7.58 (d, *J* = 8.2 Hz, 1 H), 7.51–7.43 (m, 1 H), 7.39–7.32 (m, 3 H), 7.06–6.99 (m, 2 H), 4.25 (q, *J* = 7.1 Hz, 2 H), 3.89 (s, 3 H), 1.24 (t, *J* = 7.2 Hz, 3 H).

$^{13}C$ NMR (126 MHz, $CDCl_3$): δ = 162.68, 159.44, 143.69, 140.36, 140.29, 131.01, 128.16, 127.08, 126.70, 125.32, 124.68, 122.46, 113.47, 61.20, 55.29, 14.09.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{17}O_3S$: 313.0893; found: 313.0896.

**Ethyl 3-[Benzo[*d*][1,3]dioxol-5-yl]benzo[*b*]thiophene-2-carboxylate (3i)**

Pale yellow solid; yield: 111 mg (68%); mp 98–99 °C.

IR (ATR): 2986, 2899, 2796, 1715, 1483, 1229, 1032, 758 $cm^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.86 (d, *J* = 8.1 Hz, 1 H), 7.58 (d, *J* = 8.2 Hz, 1 H), 7.46 (t, *J* = 7.6 Hz, 1 H), 7.35 (t, *J* = 7.6 Hz, 1 H), 6.93 (d, *J* = 7.9 Hz, 1 H), 6.89–6.84 (m, 2 H), 6.04 (s, 2 H), 4.26 (q, *J* = 7.1 Hz, 2 H), 1.26 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 162.56, 147.46, 147.36, 143.38, 140.31, 140.18, 128.48, 128.07, 127.17, 125.25, 124.78, 123.37, 122.49, 110.43, 108.10, 101.20, 61.29, 14.11.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{18}H_{15}O_4S$: 326.0686; found: 327.0691.

**Ethyl 3-Cyclopropylbenzo[*b*]thiophene-2-carboxylate (3k)**

Colorless oil; yield: 63 mg (51%).

IR (ATR): 2981, 1713, 1693, 1226, 1058, 758, 734 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 8.06 (d, *J* = 8.0 Hz, 1 H), 7.79 (d, *J* = 8.0 Hz, 1 H), 7.44–7.35 (m, 2 H), 4.40 (q, *J* = 7.1 Hz, 2 H), 2.32 (tt, *J* = 8.7, 5.6 Hz, 1 H), 1.41 (t, *J* = 7.1 Hz, 3 H), 1.18–1.14 (m, 2 H), 0.89–0.85 (m, 2 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 163.03, 144.79, 140.27, 140.19, 129.88, 126.74, 124.72, 124.24, 122.68, 61.26, 14.36, 9.83, 7.48.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{14}H_{15}O_2S$: 247.0787; found: 247.0785.

**Ethyl 3-Isobutylbenzo[*b*]thiophene-2-carboxylate (3l)**

Colorless oil; yield: 60 mg (46%).

IR (ATR): 2957, 2868, 1711, 1525, 1242, 1217, 1098, 1062, 909, 758, 732 cm$^{-1}$.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.83 (dd, *J* = 12.3, 7.9 Hz, 2 H), 7.49–7.33 (m, 2 H), 4.38 (q, *J* = 7.2 Hz, 2 H), 3.19 (d, *J* = 7.3 Hz, 2 H), 2.15–2.02 (m, 1 H), 1.41 (t, *J* = 7.2 Hz, 3 H), 0.97 (d, *J* = 6.6 Hz, 6 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 163.35, 145.10, 140.56, 140.13, 127.51, 126.90, 124.21, 124.13, 122.60, 61.12, 35.82, 30.02, 22.76, 14.32.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{15}H_{19}O_2S$: 263.1100; found: 263.1100.

**Ethyl 3-(5-Methylthiophen-2-yl)benzo[*b*]thiophene-2-carboxylate (3ma)**

Pale yellow solid; yield: 17 mg (11%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.85 (d, *J* = 8.1 Hz, 1 H), 7.81 (d, *J* = 8.1 Hz, 1 H), 7.50–7.45 (m, 1 H), 7.42–7.35 (m, 1 H), 6.98 (d, *J* = 3.4 Hz, 1 H), 6.83 (dd, *J* = 3.4, 1.2 Hz, 1 H), 4.30 (q, *J* = 7.1 Hz, 2 H), 1.31 (d, *J* = 7.1 Hz, 2 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 162.33, 141.37, 140.28, 139.90, 136.21, 131.48, 129.80, 128.74, 127.22, 125.34, 125.11, 124.92, 122.39, 61.39, 15.37, 14.08.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{15}O_2S_2$: 303.0508; found: 303.0493.

**Ethyl 2-Methylbenzo[*b*]thieno[3,2-*d*]thiophene-5-carboxylate (3mb)**

Light yellow solid; yield: 9 mg (6%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 9.10–9.01 (m, 1 H), 8.35–8.23 (m, 1 H), 7.67 (s, 1 H), 7.64–7.57 (m, 2 H), 4.49 (q, *J* = 7.1 Hz, 2 H), 2.73 (s, 3 H), 1.48 (t, *J* = 7.2 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 167.56, 145.02, 140.12, 134.86, 129.07, 128.93, 126.70, 126.36, 126.34, 125.44, 123.93, 122.99, 120.52, 61.01, 16.52, 14.46.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{15}O_2S_2$: 303.0508; found: 303.0467.

**Ethyl (*E*)-3-(5-Methylthiophen-2-yl)acrylate (3mc)**[14]

Yellow oil; yield: 6 mg (6%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.69 (d, *J* = 15.6 Hz, 1 H), 7.05 (d, *J* = 3.6 Hz, 1 H), 6.70 (dd, *J* = 3.6, 1.2 Hz, 1 H), 6.10 (d, *J* = 15.6 Hz, 1 H), 4.24 (q, *J* = 7.1 Hz, 2 H), 2.49 (s, 3 H), 1.32 (t, *J* = 7.1 Hz, 3 H).

**Ethyl 3-(Thiophen-2-yl)benzo[*b*]thiophene-2-carboxylate (3n)**

Brown solid; yield: 17 mg (12%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.87 (d, *J* = 8.1 Hz, 1 H), 7.74 (d, *J* = 8.2 Hz, 1 H), 7.53 – 7.45 (m, 2 H), 7.39 (ddd, *J* = 8.1, 7.1, 1.0 Hz, 1 H), 7.21–7.14 (m, 2 H), 4.28 (q, *J* = 7.1 Hz, 2 H), 1.26 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 162.30, 140.31, 139.90, 135.60, 134.05, 130.54, 128.61, 127.26, 126.80, 126.69, 125.23, 125.01, 122.42, 61.43, 14.01.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{15}H_{13}O_2S_2$: 289.0351; found: 289.0340.

**Ethyl 3-(1-Methyl-1*H*-pyrrol-2-yl)benzo[*b*]thiophene-2-carboxylate (3ob)**

Brown oil; yield: 6 mg (4%).

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.89 (dd, *J* = 8.1, 1.0 Hz, 1 H), 7.73 (dd, *J* = 8.1, 1.1 Hz, 1 H), 7.51 (ddd, *J* = 8.2, 7.1, 1.2 Hz, 1 H), 7.44–7.38 (m, 1 H), 6.86 (t, *J* = 2.1 Hz, 1 H), 6.36–6.30 (m, 1 H), 6.26 (dd, *J* = 3.6, 1.7 Hz, 1 H), 4.38–4.24 (m, 2 H), 3.45 (s, 3 H), 1.30 (t, *J* = 7.1 Hz, 3 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 162.31, 140.64, 140.23, 135.01, 130.51, 127.29, 125.72, 125.25, 124.89, 123.08, 122.41, 110.19, 107.72, 61.36, 34.27, 14.15.

HRMS (APCI): *m*/*z* [M + H]$^+$ calcd for $C_{16}H_{16}NO_2S$: 286.0896; found: 286.0892.

**(*E*)-1-Bromo-2-(styrylsulfonyl)benzene (3r)**[13]

Yellow solid; yield: 44 mg (27%); mp 115–117 °C.

$^1$H NMR (500 MHz, $CDCl_3$): δ = 7.81 (d, *J* = 8.5 Hz, 2 H), 7.70 (d, *J* = 8.5 Hz, 2 H), 7.67 (d, *J* = 15.4 Hz, 1 H), 7.48 (d, *J* = 6.6 Hz, 2 H), 7.40 (q, *J* = 6.6 Hz, 3 H), 6.83 (d, J = 15.4 Hz, 1 H).

$^{13}$C NMR (126 MHz, $CDCl_3$): δ = 143.1, 139.8, 132.6, 132.2, 131.4, 129.2, 129.1, 128.6, 126.8.

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## Supporting Information

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## References

(1) (a) Li, J. J.; Gribble, G. W. *Palladium in Heterocyclic Chemistry*, 2nd ed.; Pergamon: Oxford, **2009**. (b) Dounay, A. B.; Overman, L. E. *Chem. Rev.* **2003**, *103*, 2945. (c) Whitcombe, N. J.; Hii, K. K.; Gibson, S. E. *Tetrahedron* **2001**, *57*, 7449. (d) Beletskaya, I. P.; Cheprakov, A. V. *Chem. Rev.* **2000**, *100*, 3009. (e) Crisp, G. T. *Chem. Soc. Rev.* **1998**, *27*, 427.

(2) (a) Kim, Y.-S.; Kwak, S. H.; Gong, Y.-D. *ACS Comb. Sci.* **2015**, *17*, 365. (b) Tréguier, B.; Lawson, M.; Bernadat, G.; Bignon, J.; Dubois, J.; Brion, J.-D.; Alami, M.; Hamze, A. *ACS Comb. Sci.* **2014**, *16*, 702. (c) Hou, C.; He, Q.; Yang, C. *Org. Lett.* **2014**, *16*, 5040. (d) Chonan, T.; Wakasugi, D.; Yamamoto, D.; Yashiro, M.; Oi, T.; Tanaka, H.; Ohoka-Sugita, A.; Io, F.; Koretsune, H.; Hiratate, A. *Bioorg. Med. Chem.* **2011**, *19*, 1580. (e) Yuan, H.; Bi, K.; Li, B.; Yue, R.; Ye, J.; Shen, Y.; Shan, L.; Jin, H.-Z.; Sun, Q.-Y.; Zhang, W.-D. *Org. Lett.* **2013**, *15*, 4742. (f) Hari, D. P.; Hering, T.; König, B. *Org. Lett.* **2012**, *14*, 5334.

(3) Yuan, H.; Bi, K.; Li, B.; Yue, R.; Ye, J.; Shen, Y.; Shan, L.; Jin, H.-Z.; Sun, Q.-Y.; Zhang, W.-D. *Org. Lett.* **2013**, *15*, 4742.

(4) Vicente, R. *Org. Biomol. Chem.* **2011**, *9*, 6469.

(5) Arnau, N.; Moreno-Mañas, M.; Pleixats, R. *Tetrahedron* **1993**, *49*, 11019.

(6) (a) Coya, E.; Sotomayor, N.; Lete, E. *Adv. Synth. Catal.* **2014**, *356*, 1853. (b) Pigeon, P.; Decroix, B. *Tetrahedron Lett.* **1996**, *37*, 7707.

(7) Hoye, T. R.; Kurth, M. J. *J. Org. Chem.* **1980**, *45*, 3549.

(8) Periasamy, M. *ARKIVOC* **2002**, *(vii)*, 151.

(9) Palmieri, A.; Gabrielli, S.; Maggi, R.; Ballini, R. *Synlett* **2014**, *25*, 128.

(10) (a) Tidei, C.; Sancineto, L.; Bagnoli, L.; Battistelli, B.; Marini, F.; Santi, C. *Eur. J. Org. Chem.* **2014**, 5968. (b) Yadav, J. S.; Reddy, B. V. S.; Raju, A.; Ravindar, K.; Baishya, G. *Chem. Lett.* **2007**, *36*, 1474. (c) Lewandowska, E. *Tetrahedron* **2006**, *62*, 4879. (d) Seneci, P.; Leger, I.; Souchet, M.; Nadler, G. *Tetrahedron* **1997**, *53*, 17097. (e) Haigh, D. *Tetrahedron* **1994**, *50*, 3177.

(11) (a) Fuwa, H.; Sasaki, M. *J. Org. Chem.* **2009**, *74*, 212. (b) Svennebring, A.; Nilsson, P.; Larhed, M. *J. Org. Chem.* **2007**, *72*, 5851. (c) Jeffery, T. *Tetrahedron Lett.* **2000**, *41*, 8445. (d) Jeffery, T. *Tetrahedron Lett.* **1985**, *26*, 2667.

(12) (a) Yan, K.; Yang, D.; Zhang, M.; Wei, W.; Liu, Y.; Tian, L.; Wang, H. *Synlett* **2015**, *26*, 1890. (b) Yang, D.; Yan, K.; Wei, W.; Tian, L.; Li, Q.; You, J.; Wang, H. *RSC Adv.* **2014**, *4*, 48547.

(13) Wei, W.; Li, J.; Yang, D.; Wen, J.; Jiao, Y.; You, J.; Wang, H. *Org. Biomol. Chem.* **2014**, *12*, 1861.

(14) Schmodt, R. R.; Hirsenkorn, R. *Tetrahedron* **1983**, *39*, 2043.