HETEROCYCLES, Vol. 104, No. 2, 2022, pp. 379 - 388. © 2022 The Japan Institute of Heterocyclic Chemistry
Received, 18th October, 2021, Accepted, 8th November, 2021, Published online, 11th November, 2021
DOI: 10.3987/COM-21-14575

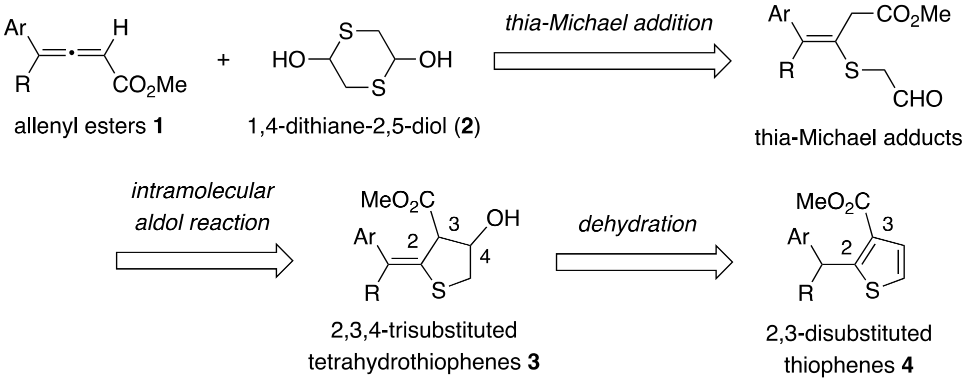
SYNTHESIS OF NOVEL 2,3-DISUBSTITUTED THIOPHENES VIA TANDEM THIA-MICHAEL/ALDOL REACTION OF ALLENYL ESTERS

Michiyasu Nakao, Munehisa Toguchi, Ken Horikoshi, Syuji Kitaike, and Shigeki Sano*

Graduate School of Pharmaceutical Sciences, Tokushima University, Sho-machi, Tokushima 770-8505, Japan. E-mail: ssano@tokushima-u.ac.jp

Abstract – A tandem thia-Michael/aldol reaction of allenyl esters and mercaptoacetaldehyde in the presence of triethylamine provided 2,3,4-trisubstituted tetrahydrothiophenes. Novel 2,3-disubstituted thiophenes were obtained in high yield by the subsequent dehydration of the 2,3,4-trisubstituted tetrahydrothiophenes using *p*-toluenesulfonic acid monohydrate as an effective catalyst.

Thiophenes are an important class of heterocyclic compounds due to their wide range of biological activities[1–6] and applications to functional materials.[7–9] Therefore, many synthetic approaches for substituted thiophenes have been developed.[10–12] Recently we reported a novel tandem thia-Michael/Dieckmann condensation of allenyl esters with methyl mercaptoacetate for the regioselective synthesis of 2,3,5-trisubstituted thiophenes and 2,3,4-trisubstituted thiophenes.[13] As part of our ongoing effort towards the synthesis of polysubstituted thiophenes, we describe a tandem thia-Michael/aldol reaction of allenyl esters **1**[14] with 1,4-dithiane-2,5-diol (**2**) for the construction of 2,3,4-trisubstituted tetrahydrothiophenes **3** via the ester enolates of thia-Michael adducts bearing a formyl group (Scheme 1).

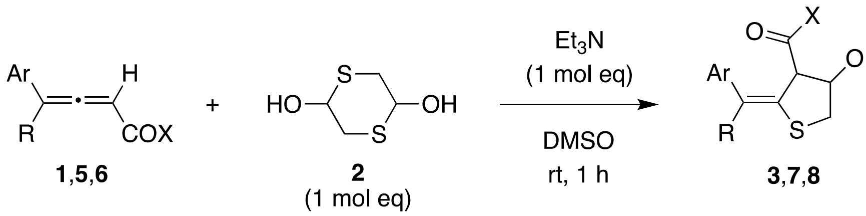


Scheme 1. Tandem thia-Michael/aldol reaction of allenyl esters **1** with 1,4-dithiane-2,5-diol (**2**) for the synthesis of 2,3-disubstituted thiophenes **4**

Novel 2,3-disubstituted thiophenes **4** were obtained in high yield by the subsequent dehydration of the 2,3,4-trisubstituted tetrahydrothiophenes **3** using *p*-toluenesulfonic acid monohydrate as an effective catalyst.

The tandem thia-Michael/aldol reaction of allenyl esters **1a**–**f** with 1,4-dithiane-2,5-diol (**2**) was investigated in the presence of 1 equiv of triethylamine as shown in Table 1. 1,4-Dithiane-2,5-diol (**2**) is useful for the synthesis of various kinds of sulfur-containing heterocyclic compounds.[15,16] The reaction of allenyl ester **1a** and 1,4-dithiane-2,5-diol (**2**) in DMSO at room temperature for 1 h was found to afford 2,3,4-trisubstituted tetrahydrothiophene **3a** with *E*-geometry at the *exo*-double bond in 86% yield as an inseparable mixture of diastereomers (*cis*-**3a**/*trans*-**3a** = 62:38) (Entry 1). The molar ratio of *cis*-**3a** and *trans*-**3a** was determined by integrating the appropriate proton absorptions obtained by ^{1}H NMR (400 or 500 MHz, $CDCl_3$) analysis. The reaction of allenyl esters **1b**–**d** bearing a *para*-substituted phenyl group provided 2,3,4-trisubstituted tetrahydrothiophenes **3b**–**d** in 71–92% yields with a *cis*/*trans* ratio in the range of 55:45 to 63:37 (Entries 2–4). These reactions also constructed only the *exo*-double bond with *E*-geometry.

Table 1. Tandem thia-Michael/aldol reaction of allenyl esters **1a**–**f**, allenyl amide **5**, and allenyl ketone **6** with 1,4-dithiane-2,5-diol (**2**) in the presence of Et_3N

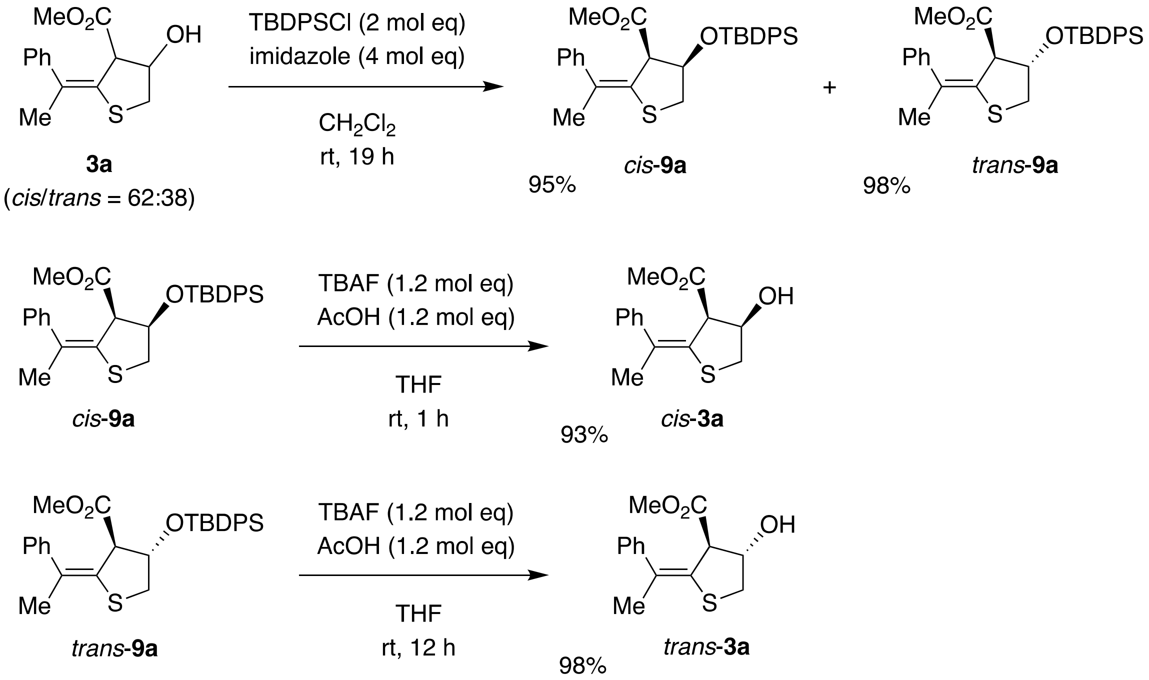


Entry	**1**,**5**,**6**	Ar	R	X	Yield of **3**,**7**,**8** (%) [a]	*E*/*Z*	*cis*/*trans* of *E* isomer
1	**1a**	Ph	Me	OMe	86 (**3a**)	100:0 [b]	62:38 [b]
2	**1b**	4-$MeOC_6H_4$	Me	OMe	92 (**3b**)	100:0 [b]	63:37 [b]
3	**1c**	4-MeC_6H_4	Me	OMe	90 (**3c**)	100:0 [b]	62:38 [b]
4	**1d**	4-ClC_6H_4	Me	OMe	71 (**3d**)	100:0 [c]	55:45 [c]
5	**1e**	Ph	Et	OMe	95 (**3e**)	92:8 [c]	61:39 [c]
6	**1f**	Ph	Ph	OMe	56 (**3f**)	—	69:31 [c]
7	**5**	Ph	Me	N(OMe)Me	92 (**7**)	100:0 [c]	68:32 [c]
8	**6**	Ph	Me	Ph	94 (**8**)	100:0 [c]	50:50 [c]

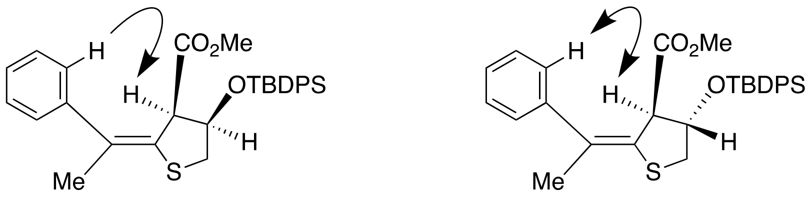
a) Isolated yields.
b) Determined by ^{1}H NMR (400 MHz, $CDCl_3$) analysis.
c) Determined by ^{1}H NMR (500 MHz, $CDCl_3$) analysis.

In the case of allenyl ester **1e** bearing ethyl substituent (R = Et), tetrahydrothiophene **3e** was obtained in 95% yield with the generation of a small amount of *Z*-isomer (*E*/*Z* = 92:8) (Entry 5). On the other hand, the reaction of allenyl ester **1f** with phenyl substituent (R = Ph) furnished tetrahydrothiophene **3f** in moderate yield (56%) (Entry 6). The tandem thia-Michael/aldol reaction of allenyl amide **5** and allenyl ketone **6** also afforded 2,3,4-trisubstituted tetrahydrothiophenes **7** and **8** with *E*-geometry in 92–94% yields (Entries 7 and 8).

The chemical structure of 2,3,4-trisubstituted tetrahydrothiophene **3a** was unequivocally demonstrated, as shown in Scheme 2, Figure 1, and Figure 2. The silylation of an inseparable diastereomer mixture of the tetrahydrothiophene **3a** (*cis*-**3a**/*trans*-**3a** = 62:38) in the presence of *tert*-butyldiphenylsilyl chloride (TBDPSCl) and imidazole furnished the corresponding silyl ethers *cis*- and *trans*-**9a**, which were isolated and purified by column chromatography on silica gel (Scheme 2). The geometry of *cis*- and *trans*-**9a** was determined to be *E* based on the ^{1}H–^{1}H nuclear Overhauser effects (NOEs) between the *ortho*-protons of the benzene ring in the phenylethylidene moiety and the 3-H of the tetrahydrothiophene ring (Figure 1). Then, deprotection of the silyl group of *cis*- and *trans*-**9a** using tetra-*n*-butylammonium fluoride (TBAF) in the presence of acetic acid afforded *cis*- and *trans*-**3a**, respectively. The relative stereochemistry of *cis*-**3a** was established by single crystal X-ray diffraction analysis (Figure 2).[17] Therefore, *trans*-**3a** was determined to be the other isomer of **3a**.



Scheme 2. Separation of diastereomers of 2,3,4-trisubstituted tetrahydrothiophene **3a**



cis-**9a** *trans*-**9a**

Figure 1. ^{1}H–^{1}H NOE correlations for *cis*- and *trans*-**9a**

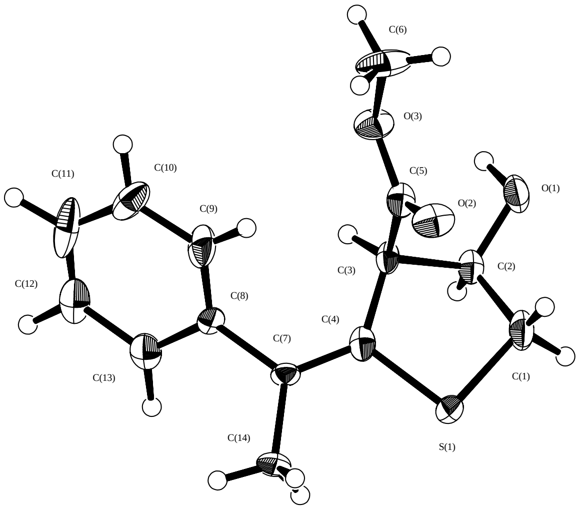
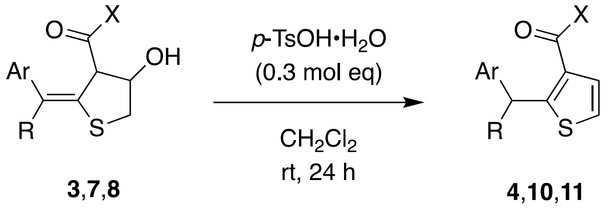


Figure 2. The X-ray crystal structure of 2,3,4-trisubstituted tetrahydrothiophene *cis*-**3a**

To achieve the synthesis of polysubstituted thiophenes, we investigated the dehydration of 2,3,4-trisubstituted tetrahydrothiophenes **3**,**7**,**8** using an acid catalyst (Table 2). In the presence of 0.3 equiv of *p*-toluenesulfonic acid monohydrate, tetrahydrothiophenes **3a**–**e** and **8** were stirred in CH_2Cl_2 at room temperature for 24 h. As a result, dehydration of **3a**–**e** and **8** was followed by aromatization to give 2,3-disubstituted thiophenes **4a**–**e** and **11** in 81–93% yields (Entries 1–5, 8). Although the dehydration of tetrahydrothiophenes **3f** and **7** did not proceed in the same reaction conditions, 2,3-disubstituted thiophenes **4f** and **10** were obtained in 93% and 85% yields with an equimolar amount of *p*-toluenesulfonic acid monohydrate (Entries 6 and 7).

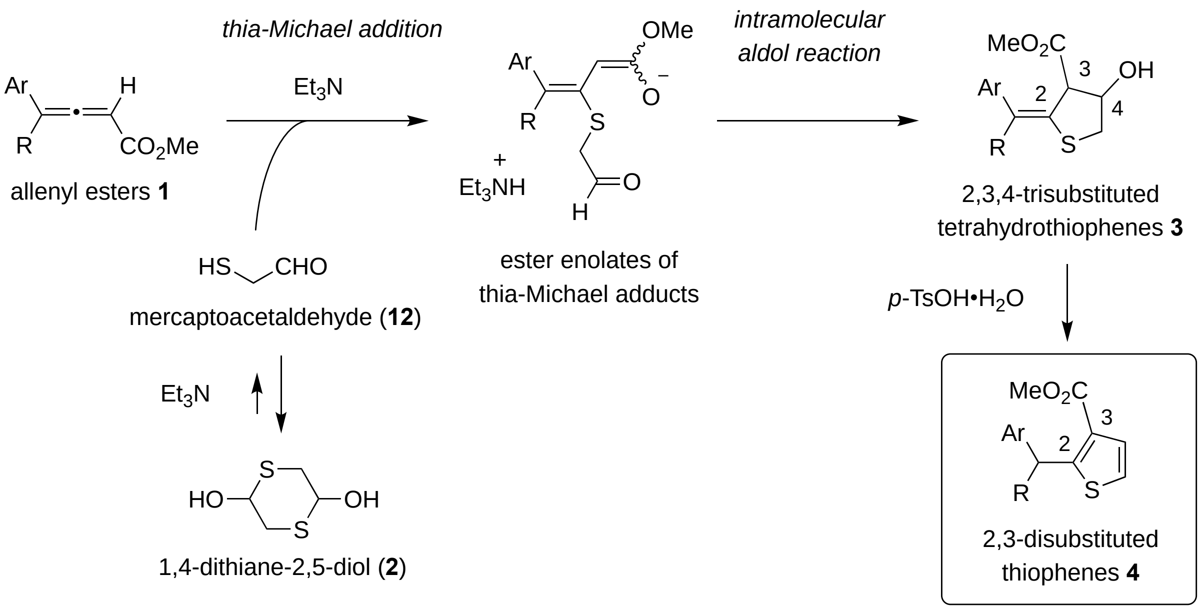
A plausible reaction pathway for the tandem thia-Michael/aldol reaction of allenyl esters **1** with 1,4-dithiane-2,5-diol (**2**) is shown in Scheme 3. 1,4-Dithiane-2,5-diol (**2**) is the stable dimer of mercaptoacetaldehyde (**12**). In the presence of triethylamine, mercaptoacetaldehyde (**12**) was generated *in situ* from 1,4-dithiane-2,5-diol (**2**). Then, the thia-Michael addition of mercaptoacetaldehyde (**12**) to allenyl esters **1** afforded the ester enolates of thia-Michael adducts, which were intramolecularly cyclized to give 2,3,4-trisubstituted tetrahydrothiophenes **3**. The *E*-selectivity in the formation of tetrahydrothiophenes **3a**–**e**

Table 2. Dehydration of 2,3,4-trisubstituted tetrahydrothiophenes **3**,**7**,**8** in the presence of *p*-toluenesulfonic acid monohydrate



Entry	**3**,**7**,**8**	Ar	R	X	Yield of **4**,**10**,**11** (%) [a)]
1	**3a**	Ph	Me	OMe	82 (**4a**)
2	**3b**	4-MeOC$_6$H$_4$	Me	OMe	88 (**4b**)
3	**3c**	4-MeC$_6$H$_4$	Me	OMe	93 (**4c**)
4	**3d**	4-ClC$_6$H$_4$	Me	OMe	90 (**4d**)
5	**3e**	Ph	Et	OMe	88 (**4e**)
6 [b)]	**3f**	Ph	Ph	OMe	93 (**4f**)
7 [c)]	**7**	Ph	Me	N(OMe)Me	85 (**10**)
8	**8**	Ph	Me	Ph	81 (**11**)

a) Isolated yields.
b) *p*-TsOH•H$_2$O (1 mol eq) was used at 40 °C.
c) *p*-TsOH•H$_2$O (1 mol eq) was used.



Scheme 3. Plausible reaction pathway for the formation of 2,3-disubstituted thiophenes **4**

suggested that mercaptoacetaldehyde (**12**) attacked preferentially at the less-hindered allene face of allenyl esters **1a**–**e**. Finally, dehydration of the tetrahydrothiophenes **3** followed by aromatization afforded 2,3-disubstituted thiophenes **4**. A similar reaction pathway is plausible in the reactions of allenyl amide **5** and allenyl ketone **6**.

In summary, we have demonstrated a tandem thia-Michael/aldol reaction of allenyl esters **1**, allenyl amide **5**, and allenyl ketone **6** using mercaptoacetaldehyde (**12**) for the construction of 2,3,4-trisubstituted tetrahydrothiophenes **3**,**7**,**8**. Novel 2,3-disubstituted thiophenes **4**,**10**,**11** were obtained by the subsequent dehydration of 2,3,4-trisubstituted tetrahydrothiophenes **3**,**7**,**8**.

EXPERIMENTAL

All melting points were determined on a Yanagimoto micro melting point apparatus and are uncorrected. IR spectra were obtained with a JASCO FT/IR-6200 IR Fourier transform spectrometer. ^{1}H NMR (400 MHz) spectra were recorded with a Bruker AV400N spectrometer. ^{1}H NMR (500 MHz) and ^{13}C NMR (125 MHz) spectra were recorded with a Bruker AV500 spectrometer. Chemical shifts are given in δ values (ppm) using TMS as an internal standard. HRMS (ESI) data were recorded with a Waters LCT Premier spectrometer. Elemental combustion analyses were performed with a J-SCIENCE LAB JM10. Single crystal X-ray diffraction experiment was performed using a Rigaku RAXIS-RAPID diffractometer. All reactions were monitored by TLC employing 0.25 mm silica gel plates (Merck 5715; 60 F_{254}). Column chromatography was carried out on silica gel [Silica Gel PSQ 60B (Fuji Silysia Chemical)]. Anhydrous DMSO was used as purchased from FUJIFILM Wako Pure Chemical Corporation. Anhydrous CH_2Cl_2 and THF were used as purchased from Kanto Chemical. Triethylamine was distilled prior to use. All other reagents were used as purchased.

Methyl (*E*)-4-Hydroxy-2-(1-phenylethylidene)tetrahydrothiophene-3-carboxylate (3a)

To a solution of allenyl ester **1a** (68.6 mg, 0.364 mmol) and 1,4-dithiane-2,5-diol (**2**) (55.5 mg, 0.364 mmol) in anhydrous DMSO (3 mL) was added triethylamine (50.9 μL, 0.364 mmol) at room temperature under argon. After stirring for 1 h, the reaction mixture was treated with 1N HCl aq (3 mL) and then extracted with AcOEt (30 mL x 1). The extract was washed with H_2O (20 mL x 3), dried over anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The oily residue was purified by column chromatography [Silica Gel PSQ 60B: *n*-hexane–AcOEt (2:1)] to afford **3a** (82.8 mg, 86%, *cis*/*trans* = 62:38) as a colorless oil.

Methyl (*E*)-*cis*-4-Hydroxy-2-(1-phenylethylidene)tetrahydrothiophene-3-carboxylate (*cis*-3a)

Colorless needles ($CHCl_3$–*n*-hexane); mp 79–80 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.07 (d, *J* = 1.2 Hz, 3H), 3.02 (d, *J* = 7.6 Hz, 1H), 3.21 (dd, *J* = 6.3, 10.8 Hz, 1H), 3.22 (dd, *J* = 7.2, 10.8 Hz, 1H), 3.51 (s, 3H), 3.76 (dd, *J* = 1.1, 6.0 Hz, 1H), 4.50–4.57 (m, 1H), 7.08–7.12 (m, 2H), 7.20–7.24 (m, 1H), 7.27–7.32 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.4, 37.0, 52.0, 53.8, 75.0, 126.8, 127.5, 128.2, 130.0, 130.2, 142.8, 171.4; IR (KBr) 2948, 2895, 1712, 1439, 1360, 1208, 1176 cm^{-1}; HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{14}H_{16}O_3SNa$: 287.0718; found: 287.0706. Anal. Calcd for $C_{14}H_{16}O_3S$: C, 63.61; H, 6.10. Found: C, 63.45; H, 6.09%.

Methyl (*E*)-*trans*-4-Hydroxy-2-(1-phenylethylidene)tetrahydrothiophene-3-carboxylate (*trans*-3a)

Colorless oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.13 (s, 3H), 2.54 (brs, 1H), 3.07 (d, *J* = 11.7 Hz, 1H), 3.43 (dd, *J* = 3.6, 11.7 Hz, 1H), 3.50 (s, 3H), 3.68 (brs, 1H), 4.58 (brs, 1H), 7.07–7.15 (m, 2H), 7.18–7.40 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 24.3, 39.9, 52.1, 58.8, 76.2, 126.8, 127.6, 128.3, 131.4, 131.5, 142.9, 171.1; IR (neat) 2949, 2850, 1727, 1434 cm^{-1}; HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{14}H_{16}O_3SNa$: 287.0718; found: 287.0741. Anal. Calcd for $C_{14}H_{16}O_3S$: C, 63.61; H, 6.10. Found: C, 63.32; H, 6.25%.

Methyl 2-(1-Phenylethyl)thiophene-3-carboxylate (4a)

To a solution of tetrahydrothiophene **3a** (51.2 mg, 0.194 mmol, *cis*/*trans* = 62:38) in anhydrous CH_2Cl_2 (2 mL) was added *p*-toluenesulfonic acid monohydrate (10.0 mg, 0.0581 mmol) at room temperature. After stirring for 24 h, the reaction mixture was treated with H_2O (3 mL) and then extracted with $CHCl_3$ (30 mL x 3). The extract was dried over anhydrous $MgSO_4$, filtered, and concentrated *in vacuo*. The oily residue was purified by column chromatography [Silica Gel PSQ 60B: *n*-hexane–AcOEt (4:1)] to afford **4a** (39.2 mg, 82%) as a colorless oil.

Colorless oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.69 (d, *J* = 7.2 Hz, 3H), 3.81 (s, 3H), 5.39 (q, *J* = 7.2 Hz, 1H), 7.06 (d, *J* = 5.3 Hz, 1H), 7.18–7.22 (m, 1H), 7.27–7.34 (m, 4H), 7.37 (d, *J* = 5.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.5, 38.9, 51.4, 122.0, 126.5, 127.1, 127.4, 128.4, 129.1, 145.3, 160.6, 163.7; IR (neat) 3026, 2968, 1711, 1528, 1443, 1253, 1151, 700 cm^{-1}; HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{14}H_{14}O_2SNa$: 269.0612; found: 269.0592.

Methyl 2-[1-(4-Methoxyphenyl)ethyl]thiophene-3-carboxylate (4b)

Colorless needles ($CHCl_3$–*n*-hexane); mp 49–50 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.67 (d, *J* = 7.2 Hz, 3H), 3.78 (s, 3H), 3.83 (s, 3H), 5.33 (q, *J* = 7.2 Hz, 1H), 6.81–6.86 (m, 2H), 7.05 (d, *J* = 5.4 Hz, 1H), 7.23–7.27 (m, 2H), 7.37 (d, *J* = 5.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.6, 38.2, 51.4, 55.2, 113.7, 121.9, 126.9, 128.4, 129.1, 137.5, 158.2, 161.4, 163.8; IR (KBr) 3114, 2977, 1708, 1509, 1286, 1256, 1181, 1025, 828, 718 cm^{-1}; HRMS (ESI): *m*/*z* [M + Na]$^+$ calcd for $C_{15}H_{16}O_3SNa$: 299.0718; found: 299.0692.

Methyl 2-[1-(4-Methylphenyl)ethyl]thiophene-3-carboxylate (4c)

Colorless oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.68 (d, *J* = 7.2 Hz, 3H), 2.31 (s, 3H), 3.82 (s, 3H), 5.35 (q, *J* = 7.2 Hz, 1H), 7.05 (d, *J* = 5.4 Hz, 1H), 7.08–7.12 (m, 2H), 7.20–7.24 (m, 2H), 7.37 (d, *J* = 5.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 21.0, 23.5, 38.6, 51.4, 121.9, 127.0, 127.3, 129.08, 129.11, 136.0, 142.4, 161.0, 163.8; IR (neat) 2948, 1711, 1528, 1512, 1443, 1253, 1151, 1089 cm^{-1}; HRMS (ESI): *m*/*z* $[M + Na]^+$ calcd for $C_{15}H_{16}O_2SNa$: 283.0769; found: 283.0769. Anal. Calcd for $C_{15}H_{16}O_2S$: C, 69.20; H, 6.19. Found: C, 69.00; H, 6.22%.

Methyl 2-[1-(4-Chlorophenyl)ethyl]thiophene-3-carboxylate (4d)

Colorless oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.67 (d, *J* = 7.2 Hz, 3H), 3.81 (s, 3H), 5.36 (q, *J* = 7.2 Hz, 1H), 7.09 (d, *J* = 5.4 Hz, 1H), 7.25 (s, 4H), 7.39 (d, *J* = 5.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.5, 38.3, 51.5, 122.1, 127.3, 128.5, 128.7, 129.2, 132.2, 143.8, 159.7, 163.6; IR (neat) 2946, 1711, 1529, 1492, 1442, 1255, 1152, 1091 cm^{-1}; HRMS (ESI): *m*/*z* $[M + Na]^+$ calcd for $C_{14}H_{13}ClO_2SNa$: 303.0222; found: 303.0249. Anal. Calcd for $C_{14}H_{13}ClO_2S$: C, 59.89; H, 4.67. Found: C, 59.89; H, 4.76%.

Methyl 2-(1-Phenylpropyl)thiophene-3-carboxylate (4e)

Colorless oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.92 (t, *J* = 7.3 Hz, 3H), 2.03–2.15 (m, 2H), 3.83 (s, 3H), 5.16 (t, *J* = 7.8 Hz, 1H), 7.06–7.09 (m, 1H), 7.17–7.22 (m, 1H), 7.26–7.31 (m, 2H), 7.34–7.39 (m, 3H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.7, 31.1, 46.3, 51.4, 122.1, 126.5, 127.5, 128.0, 128.4, 129.0, 143.7, 159.5, 163.9; IR (neat) 3026, 2963, 2873, 1712, 1528, 1443, 1271, 1251 cm^{-1}; HRMS (ESI): *m*/*z* $[M + Na]^+$ calcd for $C_{15}H_{16}O_2SNa$: 283.0769; found: 283.0786. Anal. Calcd for $C_{15}H_{16}O_2S$: C, 69.20; H, 6.19. Found: C, 69.06; H, 6.20%.

Methyl 2-Benzhydrylthiophene-3-carboxylate (4f)

Colorless needles ($CHCl_3$–*n*-hexane); mp 82–84 °C; ^{1}H NMR (500 MHz, $CDCl_3$) δ 3.73 (s, 3H), 6.63 (s, 1H), 7.12 (d, *J* = 5.4 Hz, 1H), 7.15–7.19 (m, 4H), 7.21–7.25 (m, 2H), 7.26–7.31 (m, 4H), 7.46 (d, *J* = 5.4 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 50.5, 51.4, 123.3, 126.7, 128.2, 128.3, 128.9, 129.3, 143.5, 157.8, 163.4; IR (KBr) 3025, 1716, 1529, 1268, 1255, 1148, 1009 cm^{-1}; HRMS (ESI): *m*/*z* $[M + Na]^+$ calcd for $C_{19}H_{16}O_2SNa$: 331.0769; found: 331.0783.

***N*-Methoxy-*N*-methyl-2-(1-phenylethyl)thiophene-3-carboxamide (10)**

Brown oil; yield: ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.70 (d, *J* = 7.2 Hz, 3H), 3.13 (s, 3H), 3.28 (s, 3H), 4.85 (q, *J* = 7.2 Hz, 1H), 7.04 (d, *J* = 5.2 Hz, 1H), 7.09 (d, *J* = 5.2 Hz, 1H), 7.14–7.19 (m, 1H), 7.24–7.32 (m, 4H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.2, 33.4, 38.7, 60.8, 121.8, 126.4, 127.2, 127.4, 128.3, 130.6, 145.5, 153.2, 166.1; IR (neat) 2967, 2931, 1641, 1451, 1379, 1350, 1226, 1163 cm^{-1}; HRMS (ESI): *m/z* [M + Na]$^+$ calcd for $C_{15}H_{17}NO_2SNa$: 298.0878; found: 298.0858. Anal. Calcd for $C_{15}H_{17}NO_2S$: C, 65.43; H, 6.22; N, 5.09. Found: C, 65.13; H, 6.24; N, 4.83%.

Phenyl[2-(1-phenylethyl)thiophen-3-yl]methanone (11)

Colorless oil; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.73 (d, *J* = 7.2 Hz, 3H), 5.08 (q, *J* = 7.2 Hz, 1H), 7.06 (d, *J* = 5.3 Hz, 1H), 7.11 (d, *J* = 5.3 Hz, 1H), 7.14–7.20 (m, 1H), 7.24–7.33 (m, 4H), 7.41–7.46 (m, 2H), 7.52–7.57 (m, 1H), 7.72–7.76 (m, 2H); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.6, 38.8, 121.9, 126.5, 127.3, 128.2, 128.4, 129.5, 129.7, 132.4, 135.5, 139.2, 145.2, 158.8, 192.2; IR (neat) 3059, 3026, 2968, 1650, 1597, 1512, 1447, 1255, 1175, 699 cm^{-1}; HRMS (ESI): *m/z* [M + K]$^+$ calcd for $C_{19}H_{16}OSK$: 331.0559; found: 331.0531. Anal. Calcd for $C_{19}H_{16}OS$: C, 78.05; H, 5.52. Found: C, 77.76; H, 5.54%.

ACKNOWLEDGEMENTS

This work was partially supported by JSPS KAKENHI Grant Number JP20K06940.

REFERENCES AND NOTES

1. R. Shah and P. K. Verma, *Chem. Cent. J.*, 2018, **12**, 137, https://doi.org/10.1186/s13065-018-0511-5.
2. R. Mishra, N. Sachan, N. Kumar, I. Mishra, and P. Chand, *J. Heterocycl. Chem.*, 2018, **55**, 2019.
3. S. Pathania, R. K. Narang, and R. K. Rawal, *Eur. J. Med. Chem.*, 2019, **180**, 486.
4. A. Singh, G. Singh, and P. M. S. Bedi, *J. Heterocycl. Chem.*, 2020, **57**, 2658.
5. Archna, S. Pathania, and P. A. Chawla, *Bioorg. Chem.*, 2020, **101**, 104026.
6. R. M. D. Da Cruz, F. J. B. Mendonça-Junior, N. B. de Mélo, L. Scotti, R. S. A. de Araújo, R. N. de Almeida, and R. O. de Moura, *Pharmaceuticals*, 2021, **14**, 692, https://doi.org/10.3390/ph14070692.
7. B. Amna, H. M. Siddiqi, A. Hassan, and T. Ozturk, *RSC Adv.*, 2020, **10**, 4322.
8. F. Di Maria, M. Zangoli, and G. Barbarella, *Org. Mater.*, 2021, **3**, 321.
9. R. S. Fernandes, N. S. Shetty, P. Mahesha, and S. L. Gaonkar, *J. Fluoresc.*, 2021, https://doi.org/10.1007/s10895-021-02833-x.
10. F. Abedinifar, E. B. Rezaei, M. Biglar, B. Larijani, H. Hamedifar, S. Ansari, and M. Mahdavi, *Mol. Divers.*, 2021, **25**, 2571, https://doi.org/10.1007/s11030-020-10128-9.
11. M. E. Khalifa, *Synth. Commun.*, 2020, **50**, 2590.
12. D. D. Xuan, *Mini-Rev. Org. Chem.*, 2021, **18**, 110.
13. M. Nakao, M. Toguchi, Y. Shimabukuro, and S. Sano, *Tetrahedron Lett.*, 2020, **61**, 152271.
14. S. Sano, T. Matsumoto, T. Yano, M. Toguchi, and M. Nakao, *Synlett*, 2015, **26**, 2135.
15. F. Zamberlan, A. Fantinati, and C. Trapella, *Eur. J. Org. Chem.*, 2018, 3248.
16. S. S. Sajadikhah and M. T. Maghsoodlou, *Chem. Heterocycl. Compd.*, 2018, **54**, 581.

17. Crystal data for *cis*-**3a**: $C_{14}H_{16}O_3S$, *M* = 264.34, monoclinic, *P*2$_1$/*c* (No. 14), a = 14.3417(7) Å, b = 9.5516(5) Å, c = 9.9422(4) Å, β = 94.589(1) °, V = 1357.6(2) Å^3, *Z* = 4, D_{calc} = 1.293 g/m^3, μ(Mo-Kα) = 2.357 cm^{-1}, R1 = 0.0905, wR2 = 0.2963. Deposition number CCDC-2106528 for compound *cis*-**3a** contains the supplementary crystallographic data. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre at www.ccdc.cam.ac.uk/data_request/cif.