Electronic Supplementary Information

Synthesis of 2,3-Disubstituted Thiophenes from 2-Aryl-3-Nitro-Cyclopropane-1,1-Dicarboxylates and 1,4-Dithiane-2,5-Diol

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A. EXPERIMENTAL PROCEDURES AND CHARACTERIZATION DATA

General Methods: Melting point was determined by the open capillary tube method and is uncorrected. The NMR spectra were recorded on a 400 MHz NMR spectrometer. High resolution mass spectra (ESI) were recorded on a Q-TOF mass spectrometer. Low resolution mass spectra (ESI) were recorded on a LC mass spectrometer. Elemental analyses were performed on a CHN analyzer. The IR spectra were recorded on a FT-IR spectrometer. Thin layer chromatography (TLC) was performed on pre-coated alumina sheets and detected under UV light. Silica gel (100-200 mesh) was used for column chromatography.

General procedure for the synthesis of tetrahydrothiophenes 4a-i: To a solution of nitrocyclopropane 1 (1 mmol) in dichloromethane (5 mL) was added BF$_3$·OEt$_2$ (0.13 mL; 1 mmol) at room temperature. The reaction mixture was stirred until the starting material disappeared completely (2-24 h; as judged by TLC). To the same reaction flask, 1,4-dithiane-2,5-diol (0.08 mg; 0.5 mmol) and Et$_3$N (0.28 mL; 2.0 mmol) were added and the reaction mixture was stirred at room temperature. After completion of the reaction (1-6 h), it was quenched with water. The organic layer was separated, washed with water, dried (anhdyrous Na$_2$SO$_4$) and the solvent was removed under reduced pressure. The crude product 4 was purified by column chromatography using 8-15% ethyl acetate/hexane. (Note: All the products were chromatographically homogeneous diastereomeric mixtures. However, in case of 4d, the liquid diastereomeric mixture when kept at room temperature for 3-4 days formed crystals of one of the diastereomers. The impure crystals were collected and further recrystallized from CHCl$_3$/MeOH (1:1 v/v) to obtain the diastereomer 4d in pure form).

Diethyl 2-benzoyl-4-hydroxy-dihydro-thiophene-3,3-dicarboxylate (4a):
Yellow semisolid; Yield: 292 mg (83%); dr = 1:1.5; $^1$H NMR (400 MHz, CDCl$_3$): δ 7.91 (d, $J = 7.6$ Hz, H8 min), 7.81 (d, $J = 7.6$ Hz, H8 maj), 7.54 (t, $J = 9.2$ Hz, H10 both isomers), 7.45-7.39 (m, H9 both isomers), 5.39 (d, $J = 10.0$ Hz, H3 min), 5.19 (s, H5 min), 5.18-5.15 (m, H3 & H5 maj), 4.26-4.23 (m, H12 both isomers), 4.14-4.07 (m, H12 both isomers), 3.39-3.35 (m, H2 min & -OH both isomers), 3.19 (dd, $J = 6.4$, 10.4 Hz, H2 maj), 3.09 (dd, $J = 1.6$, 12.0 Hz, H2 min), 2.98 (t, $J = 9.8$ Hz, H2 maj), 1.27-1.18 (m, H13 both isomers), 1.11 (t, $J = 7.2$ Hz, H13 min), 1.04 (t, $J = 7.2$ Hz, H13 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): δ 198.3, 194.3, 169.8, 167.48, 167.48, 166.5, 135.6, 134.6, 133.9, 133.7, 129.1, 128.9, 128.8, 128.7, 77.8, 77.0, 73.5, 65.9, 63.0, 62.5, 62.4, 61.8, 51.4, 49.8, 40.5, 34.7, 14.1, 14.0, 13.9, 13.7 ppm; IR (KBr): 3328 (O-H), 1745 (C=O, ester), 1679 (C=O) cm$^{-1}$; HRMS (ESI) calcd for C$_{17}$H$_{20}$O$_6$S: 353.1053 [M + H$^+$], found: 353.1060.

**Diethyl 4-hydroxy-2-(4-methyl-benzoyl)-dihydro-thiophene-3,3-dicarboxylate (4b):**

![Diethyl 4-hydroxy-2-(4-methyl-benzoyl)-dihydro-thiophene-3,3-dicarboxylate (4b) structure](image)

Yellow semisolids; Yield: 293 mg (80%); dr = 1:1.6; $^1$H NMR (400 MHz, CDCl$_3$): δ 7.84 (d, $J = 8.4$ Hz, H8 min), 7.79 (d, $J = 8.0$ Hz, H8 maj), 7.27 (t, $J = 9.2$ Hz, H9 both isomers), 5.67 (d, $J = 9.6$ Hz, H3 min), 5.48 (s, H5 min), 5.26 (brs, H3, H5 maj), 4.33-4.29 (m, H12 both isomers), 4.20-4.12 (m, H12 both isomers), 3.68 (brs, -OH both isomers), 3.43 (dd, $J = 5.6$, 12.0 Hz, H2 min), 3.25 (dd, $J = 6.4$, 10.0 Hz, H2 maj), 3.14 (dd, $J = 1.2$, 11.6 Hz, H2 min), 3.05 (t, $J = 9.8$ Hz, H2 maj), 2.41 (s, H14 min), 2.39 (s, H14 maj), 1.33-1.24 (m, H13 both isomers), 1.17 (t, $J = 7.0$ Hz, H13 min), 1.09 (t, $J = 7.0$ Hz, H13 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): δ 197.9, 193.9, 169.6, 167.5, 167.4, 166.4, 145.0, 144.7, 132.9, 132.1, 129.51, 129.47, 129.1,
128.7, 77.7, 77.1, 73.3, 66.0, 62.9, 62.3, 62.2, 61.6, 51.2, 49.8, 40.5, 34.9, 21.63, 21.60, 14.0, 13.9, 13.8, 13.7 ppm; MS (ESI): \textit{m/z} 367 [M + H$^+$]. Anal. calcd. C$_{18}$H$_{22}$O$_6$S: C 59.00, H 6.05; found: C 59.16, H 6.08.

**Diethyl 2-(3,4-dimethyl-benzoyl)-4-hydroxy-dihydro-thiophene-3,3-dicarboxylate (4c):**

![Chemical Structure](image)

Yellow semisolid; Yield: 323 mg (85%); dr = 1:2.2; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 7.84-7.80 (m, H8 min), 7.76-7.70 (m, H8 maj), 7.66-7.60 (m, H12 both isomers), 7.29-7.19 (m, H9 both isomers), 5.70 (d, $J = 9.6$ Hz, H3 min), 5.46 (s, H5 min), 5.28-5.20 (m, H3 & H5 maj), 4.34-4.29 (m, H14 both isomers), 4.18-4.11 (m, H14 both isomers), 3.56 (s, -OH both isomers), 3.42 (dd, $J = 5.6$, 11.6 Hz, H2 min), 3.23 (dd, $J = 6.6$, 10.2 Hz, H2 maj), 3.14 (dd, $J = 1.8$, 11.8 Hz, H2 min), 3.04 (t, $J = 10.0$ Hz, H2 maj), 2.33 (s, H16 both isomers), 2.32 (s, H16 both isomers), 1.34-1.24 (m, H15 both isomers), 1.18 (t, $J = 7.2$ Hz, H15 min), 1.11 (t, $J = 7.0$ Hz, H15 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 198.2, 194.2, 171.2, 169.8, 167.6, 166.4, 143.9, 143.5, 137.3, 132.4, 130.2, 130.1, 130.0, 129.7, 126.8, 126.4, 77.7, 77.0, 73.3, 65.8, 62.9, 62.4, 62.3, 61.7, 51.2, 49.7, 40.6, 34.6, 20.10, 20.06, 19.81, 19.77, 14.1, 14.0, 13.9, 13.7 ppm; MS (ESI): \textit{m/z} 381 [M + H$^+$]. Anal. calcd. C$_{19}$H$_{24}$O$_6$S: C 59.98, H 6.36; found: C 60.16, H 6.48.

**Diethyl 4-hydroxy-2-(4-methoxy-benzoyl)-dihydro-thiophene-3,3-dicarboxylate (4d):**

![Chemical Structure](image)
Yellow semisolid; Yield: 309 mg (81%); dr = 1:1.1; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 7.98 (d, $J$ = 8.8 Hz, H8 maj), 7.86 (d, $J$ = 8.8 Hz, H8 min), 6.96 (t, $J$ = 9.8 Hz, H9 both isomers), 5.77 (d, $J$ = 9.6 Hz, H3 min), 5.45 (s, H5 min), 5.26-5.19 (m, H3 & H5 maj), 4.35-4.30 (m, H12 both isomers), 4.20-4.14 (m, H12 both isomers), 3.89 (s, H14 min), 3.88 (s, H14 maj), 3.45-3.41 (m, H2 min & -OH both isomers), 3.25 (dd, $J$ = 6.4, 10.0 Hz, H2 maj), 3.16 (d, $J$ = 11.6 Hz, H2 min), 3.04 (t, $J$ = 9.8 Hz, H2 maj), 1.34-1.26 (m, H13 both isomers), 1.17 (t, $J$ = 7.0 Hz, H13 min), 1.10 (t, $J$ = 7.0 Hz, H13 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 196.9, 193.1, 169.7, 167.6, 167.5, 166.3, 164.3, 164.0, 132.5, 131.5, 130.9, 130.3, 128.2, 127.4, 77.7, 77.1, 73.4, 66.0, 62.9, 62.3, 62.2, 61.6, 55.6, 55.5, 50.9, 49.6, 40.6, 34.8, 14.1, 13.9, 13.8, 13.7 ppm; HRMS (ESI) calcd for C$_{18}$H$_{22}$O$_7$S: 383.1159 [M + H$^+$], found: 383.1156. Data for pure diastereomer of 4d: White solid; M.p.: 110-112 °C; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 7.87 (d, $J$ = 8.8 Hz, 2H, H8), 6.95 (d, $J$ = 8.8 Hz, 2H, H9), 5.24 (t, $J$ = 8.0 Hz, 1H, H3), 5.20 (s, 1H, H5), 4.34-4.29 (m, 2H, H12), 4.18-4.13 (m, 2H, H12), 3.87 (s, 3H, H14), 3.50 (s, 1H, -OH), 3.04 (t, $J$ = 9.8 Hz, 1H, H2), 1.31 (t, $J$ = 7.2 Hz, 3H, H13), 1.10 (t, $J$ = 7.2 Hz, 3H, H13) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 193.1, 169.8, 167.6, 164.1, 131.0, 127.4, 114.1, 77.0, 65.9, 62.4, 61.7, 55.6, 49.5, 34.6, 14.1, 13.7 ppm; HRMS (ESI) calcd for C$_{18}$H$_{22}$O$_7$S: 383.1159 [M + H$^+$], found: 383.1156.

**Diethyl 2-(3,4-dimethoxy-benzoyl)-4-hydroxy-dihydro-thiophene-3,3-dicarboxylate (4e):**

Yellow semisolid; Yield: 358 mg (87%); dr = 1:1.5; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 7.62 (dd, $J$ = 1.8, 8.6 Hz, H8 min), 7.57 (d, $J$ = 1.9 Hz, H8 maj), 7.49-7.48 (m, H12 both isomers), 6.95-6.90 (m, H9 both isomers), 5.71 (d, $J$ = 8.4 Hz, H3 min), 5.49 (s, H5 min), 5.26-5.22 (m, H3 & H5 maj), 4.35-4.30 (m, H14 both isomers), 4.22-4.15 (m, H14 both isomers), 3.97 (s, H16 min), 3.96 (s, H16 maj), 3.95 (s, H16 min), 3.93 (s, H16 maj), 3.55 (brs, -OH both isomers), 3.44
(dd, $J = 5.5$, 11.8 Hz, H2 min), 3.26 (dd, $J = 6.5$, 10.2 Hz, H2 maj), 3.17 (dd, $J = 1.6$, 11.8 Hz, H2 min), 3.02 (t, $J = 9.9$ Hz, H2 maj), 1.35-1.30 (m, H15 both isomers), 1.19 (t, $J = 7.0$ Hz, H15 min), 1.12 (t, $J = 7.0$ Hz, H15 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): δ 196.8, 193.2, 169.8, 167.6, 167.5, 166.4, 154.2, 153.9, 149.33, 149.30, 128.3, 127.6, 124.0, 123.2, 111.1, 110.7, 110.2, 110.1, 77.8, 77.0, 73.3, 65.9, 62.9, 62.4, 62.3, 61.7, 56.2, 56.1, 56.0, 50.8, 40.6, 34.7, 14.1, 13.9, 13.8, 13.7 ppm; MS (ESI): $m/z$ 435.12 [M + Na$^+$]. Anal. calcd. for C$_{19}$H$_{24}$O$_8$S: C 55.33, H 5.87; found: C 55.46, H 5.91.

**Diethyl 2-(4-chloro-benzoyl)-4-hydroxy-dihydro-thiophene-3,3-dicarboxylate (4f):**

![Diagram of 4f](image)

Yellow semisolid; Yield: 286 mg (74%); dr = 1:1.1; $^1$H NMR (400 MHz, CDCl$_3$): δ 7.94 (d, $J = 8.4$ Hz, H8 min), 7.87 (d, $J = 8.0$ Hz, H8 maj), 7.48-7.44 (m, H9 both isomers), 5.47 (s, H5 maj), 5.41 (brs, H5 min), 5.30-5.26 (m, H3 both isomers), 4.34-4.21 (m, H12 both isomers), 4.19-4.10 (m, H12 both isomers), 3.92 (brs, -OH both isomers) 3.45 (dd, $J = 5.8$, 11.4 Hz, H2 min), 3.32 (dd, $J = 6.4$, 10.0 Hz, H2 maj), 3.16 (d, $J = 11.6$ Hz, H2 min), 3.09 (t, $J = 9.4$ Hz, H2 maj), 1.32-1.24 (m, H13 both isomers), 1.19 (t, $J = 6.8$ Hz, H13 min), 1.11 (t, $J = 6.8$ Hz, H13 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): δ 196.7, 192.9, 169.1, 167.3, 167.2, 166.3, 140.1, 139.9, 133.9, 133.0, 130.3, 130.0, 129.01, 128.95, 77.6, 77.1, 73.1, 66.3, 62.9, 62.2, 61.8, 61.5, 51.2, 50.0, 40.2, 35.4, 13.9, 13.8, 13.7, 13.6 ppm; HRMS (ESI) calcd for C$_{17}$H$_{19}$ClO$_6$S: 387.0664 [M + H$^+$], found: 387.0672.
Diethyl 4-hydroxy-2-(naphthalene-1-carbonyl)-dihydro-thiophene-3,3-dicarboxylate (4h):

Yellow semisolid; Yield: 326 mg (81%); dr = 1:1.2; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 8.51 (d, $J = 8.0$ Hz, H14 both isomers), 8.03-7.95 (m, H8 min & H10 both isomers), 7.88-7.80 (m, H8 maj & H11 both isomers), 7.62-7.47 (m, H9, H12 & H13 both isomers), 5.71 (d, $J = 9.6$ Hz, H3 min), 5.43-5.34 (m, H3 maj & H5 both isomers), 4.35-4.22 (m, H16 maj & H16 both isomers), 4.18-4.10 (m, H16 min), 3.51 (dd, $J = 6.0$, 11.6 Hz, H2 min), 3.45 (brs, -OH both isomers), 3.33 (dd, $J = 6.8$, 9.2 Hz, H2 maj), 3.23 (d, $J = 12.0$ Hz, H2 min), 3.08 (t, $J = 9.4$ Hz, H2 maj), 1.34-1.29 (m, H17 both isomers), 1.24 (t, $J = 6.6$ Hz, H17 min), 1.14 (t, $J = 7.0$ Hz, H17 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 201.1, 197.1, 169.8, 167.5, 167.4, 166.7, 135.2, 133.93, 133.87, 133.4, 133.2, 137.0, 130.8, 128.4, 128.3, 128.19, 128.15, 127.9, 127.6, 126.7, 125.83, 125.76, 124.2, 77.8, 77.2, 73.8, 66.4, 62.9, 62.5, 62.0, 55.6, 53.4, 40.4, 34.9, 14.1, 13.9, 13.8 ppm. HRMS (ESI) calcd for C$_{21}$H$_{22}$O$_6$S: 403.1210 [M + H$^+$], found: 403.1206.

Diethyl 4-hydroxy-2-(thiophene-2-carbonyl)-dihydro-thiophene-3,3-dicarboxylate (4i):

Brown semisolid; Yield: 90 mg (25%); dr = 1:1.1; $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 7.82 (t, $J = 8.4$ Hz, H8 both isomers), 7.74-7.68 (t, $J = 3.6$ Hz, H10 both isomers), 7.20-7.16 (m, H9 both isomers), 5.75 (d, $J = 10.0$ Hz, H3 min), 5.31-5.25 (m, H3 maj & H5 min), 5.13 (brs, H5 maj), 4.36-4.29 (m, H12 both isomers), 4.19-4.14 (m, H12 both isomers), 3.60 (s, -OH both isomers),
3.49 (dd, $J = 5.8, 11.8$ Hz, H2 min), 3.30 (dd, $J = 6.4, 10.4$ Hz, H2 maj), 3.18 (dd, $J = 1.6, 12.0$ Hz, H2 min), 3.06 (t, $J = 9.8$ Hz, H2 maj), 1.34-1.29 (m, H13 both isomers), 1.17 (t, $J = 7.2$ Hz, H13 min), 1.10 (t, $J = 7.0$ Hz, H13 maj) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 191.3, 188.1, 169.2, 167.3, 167.2, 166.0, 142.3, 141.8, 136.3, 135.3, 134.0, 132.9, 128.7, 128.5, 77.5, 77.2, 73.8, 66.3, 63.0, 62.42, 62.38, 61.8, 52.5, 50.8, 40.8, 35.1, 14.0, 13.9, 13.8, 13.7 ppm; MS (ESI): $m/z$ 359 [M + H$^+$]. Anal. calcd. C$_{15}$H$_{18}$O$_6$S$_2$: C 50.26, H 5.06; found: C 50.20, H 5.08.

**General procedure for the synthesis of thiophenes 5:** To a solution of tetrahydrothiophene 4 (1 mmol) in toluene (5 mL) was added $p$-toluenesulphonic acid (0.172 mg; 1 mmol). The reaction mixture was heated under stirring at 90 ºC for 15-24 h. After completion of the reaction, it was cooled to room temperature and the solvent was removed under reduced pressure. The residue was extracted with ethyl acetate, the organic layer was washed with water, dried (anhydrous Na$_2$SO$_4$) and the solvent was removed under reduced pressure. The crude product 5 was purified by column chromatography using 5-10% ethyl acetate/hexane.

**Ethyl 2-benzoyl-thiophene-3-carboxylate (5a):**

![Structure of 5a]

Yellow oil; Yield: 187 mg (72%); $^1$H NMR (400 MHz, CDCl$_3$): $\delta$ 7.82 (d, $J = 7.2$ Hz, 2H), 7.57 (d, $J = 7.2$ Hz, 1H), 7.51-7.44 (m, 4H), 3.93 (q, $J = 7.2$ Hz, 2H), 0.90 (t, $J = 7.0$ Hz, 3H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$): $\delta$ 189.7, 162.5, 145.2, 137.8, 134.0, 133.4, 129.3, 129.0, 128.6, 127.8, 61.2, 13.5 ppm; MS (ESI): $m/z$ 283.03 [M + Na$^+$]. Anal. calcd. C$_{14}$H$_{12}$O$_3$S: C 64.60, H 4.65; found: C 64.66, H 4.79.
Ethyl 2-(4-methyl-benzoyl)-thiophene-3-carboxylate (5b):

Yellow oil; Yield: 186 mg (68%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 7.72 (d, \(J = 7.6\) Hz, 2H), 7.53-7.45 (m, 2H), 7.25 (d, \(J = 7.6\) Hz, 2H), 3.96 (q, \(J = 7.2\) Hz, 2H), 2.41 (s, 3H), 0.94 (t, \(J = 7.0\) Hz, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 189.4, 162.5, 145.6, 144.4, 135.2, 133.6, 129.6, 129.3, 128.8, 127.4, 61.1, 21.7, 13.5 ppm; MS (ESI): \(m/z\) 297.04 [M + Na\(^+\)]. Anal. calcd. C\(_{15}\)H\(_{14}\)O\(_3\)S: C 65.67, H 5.14; found: C 65.76, H 5.28.

Ethyl 2-(3,4-dimethyl-benzoyl)-thiophene-3-carboxylate (5c):

Brown oil; Yield: 228 mg (79%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta\) 7.62 (s, 1H), 7.52-7.49 (m, 2H), 7.45 (d, \(J = 4.4\) Hz, 1H), 7.19 (d, \(J = 7.6\) Hz, 1H), 3.97 (q, \(J = 7.2\) Hz, 2H), 2.32 (s, 3H), 2.29 (s, 3H), 0.95 (t, \(J = 7.0\) Hz, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta\) 189.6, 162.6, 145.7, 143.2, 137.0, 135.5, 133.6, 130.3, 129.8, 128.7, 127.39, 127.37, 61.1, 20.1, 19.7, 13.5 ppm; MS (ESI): \(m/z\) 289 [M + H\(^+\)]. Anal. calcd. C\(_{16}\)H\(_{16}\)O\(_3\)S: C 66.64, H 5.59; found: C 66.76, H 5.64.

Ethyl 2-(4-methoxy-benzoyl)-thiophene-3-carboxylate (5d):
Yellow oil; Yield: 255 mg (88%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta 7.80\) (d, \(J = 8.8\) Hz, 2H), \(7.50\) (d, \(J = 4.8\) Hz, 1H), \(7.44\) (d, \(J = 4.8\) Hz, 1H), \(6.92\) (d, \(J = 8.8\) Hz, 2H), \(3.99\) (q, \(J = 7.2\) Hz, 2H), \(3.87\) (s, 3H), \(0.96\) (t, \(J = 7.2\) Hz, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta 188.5, 164.0, 162.5, 145.8, 133.2, 131.9, 130.7, 128.7, 127.0, 113.8, 61.1, 55.6, 13.6\) ppm; MS (ESI): \(m/z\) 291 [M + H\(^+\)]. Anal. calcd. C\(_{15}\)H\(_{14}\)O\(_4\)S: C 62.05, H 4.86; found: C 62.16, H 4.88.

**Ethyl 2-(3,4-dimethoxy-benzoyl)-thiophene-3-carboxylate (5e):**

\[\text{5e} \]

Yellow oil; Yield: 259 mg (81%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta 7.52\) (d, \(J = 1.6\) Hz, 1H), \(7.49\) (d, \(J = 5.2\) Hz, 1H), \(7.44\) (d, \(J = 4.8\) Hz, 1H), \(7.28\) (dd, \(J = 1.6 \& 8.4\) Hz, 1H), \(6.83\) (d, \(J = 8.4\) Hz, 1H), \(4.00\) (q, \(J = 7.2\) Hz, 2H), \(3.924\) (s, 3H), \(3.919\) (s, 3H), \(0.98\) (t, \(J = 7.2\) Hz, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta 188.4, 162.6, 153.8, 149.2, 145.6, 133.5, 130.8, 128.7, 127.1, 125.2, 110.8, 110.0, 61.1, 56.12, 56.05, 13.7\) ppm; MS (ESI): \(m/z\) 321 [M + H\(^+\)]. Anal. calcd. C\(_{16}\)H\(_{16}\)O\(_5\)S: C 59.99, H 5.03; found: C 60.06, H 5.18.

**Ethyl 2-(4-chloro-benzoyl)-thiophene-3-carboxylate (5f):**

\[\text{5f} \]

Yellow oil; Yield: 185 mg (63%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta 7.76\) (d, \(J = 8.4\) Hz, 2H), \(7.50\) (q, \(J = 5.2\) Hz, 2H), \(7.43\) (d, \(J = 8.4\) Hz, 2H), \(3.99\) (q, \(J = 7.2\) Hz, 2H), \(0.98\) (t, \(J = 7.0\) Hz, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta 188.6, 162.3, 144.8, 139.9, 136.1, 133.9, 130.7, 129.0, 128.9, 127.9, 61.3, 13.6\) ppm; MS (ESI): \(m/z\) 295.0 [M + H\(^+\)]. Anal. calcd. C\(_{14}\)H\(_{11}\)ClO\(_3\)S: C 57.05, H 3.76; found: C 57.26, H 3.88.
**Ethyl 2-(thiophene-2-carbonyl)-thiophene-3-carboxylate (5i):**

![Chemical structure of 5i]

Yellow oil; Yield: 162 mg (61%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta 7.60 \text{ (d, } J = 8.8 \text{ Hz, 1H)}, 7.38-7.32 \text{ (m, 3H)}, 6.98 \text{ (d, } J = 3.6 \text{ Hz, 1H)}, 3.98 \text{ (d, } J = 7.2 \text{ Hz, 2H)}, 0.91 \text{ (t, } J = 7.0 \text{ Hz, 3H) ppm}; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta 181.5, 162.5, 144.5, 144.4, 135.1, 134.8, 133.8, 128.9, 128.2, 127.3, 61.3, 13.6 \text{ ppm}; MS (ESI): m/z 288.9 [M + Na\(^+\)]. Anal. calcd. C\(_{12}\)H\(_{10}\)O\(_3\)S\(_2\): C 54.12, H 3.78; found: C 54.36, H 3.90.

**Diethyl 5,5'-bis-(4-methyl-benzoyl)-[2,2']bithiophenyl-4,4'-dicarboxylate (6):**

To a solution of thiophene 5b (1 mmol) in DMSO (5 mL) was added PdCl\(_2\)(PPh\(_3\))\(_2\) (0.021 mg; 3 mol%) followed by AgOAc (0.334 mg; 2 mmol) The reaction mixture was heated at 60 °C for 24 h. After completion of the reaction, it was diluted with water. The organic layer was separated, washed with water, dried (anhydrous Na\(_2\)SO\(_4\)) and the solvent was removed under reduced pressure. The crude product 6 was purified by column chromatography using 10-20% ethyl acetate/hexane.

![Chemical structure of 6]

Yellow semisolid; Yield: 142 mg (52%); \(^1\)H NMR (400 MHz, CDCl\(_3\)): \(\delta 7.77 \text{ (d, } J = 8.0 \text{ Hz, 2H)}, 7.62 \text{ (s, 1H)}, 7.28 \text{ (d, } J = 8.0 \text{ Hz, 2H)}, 3.99 \text{ (q, } J = 7.2 \text{ Hz, 2H)}, 2.44 \text{ (s, 3H)}, 0.96 \text{ (t, } J = 7.2 \text{ Hz, 3H) ppm}; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)): \(\delta 188.4, 162.0, 145.0, 144.8, 137.2, 134.9, 134.4, 129.6, 129.4, 126.3, 61.5, 21.8, 13.5 \text{ ppm}; MS (ESI): m/z 547.1 [M + H\(^+\)]. Anal. calcd. C\(_{30}\)H\(_{26}\)O\(_6\)S\(_2\): C 65.91, H 4.79; found: C 65.98, H 4.92.
B. NMR SPECTRA FOR ALL COMPOUNDS

Figure 1. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4a
Figure 2. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4a
Figure 3. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4b
Figure 4. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4b
Figure 5. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4c
Figure 6. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4c
Figure 7. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4d
Figure 8. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4d
Figure 9. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of pure diastereomer of 4d
Figure 10. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of pure diastereomer of 4d
Figure 11. The DEPT-135 spectrum of pure diastereomer of 4d in CDCl₃ solvent
Figure 12. The COSY spectrum of pure diastereomer of 4d in CDCl$_3$ solvent
Figure 13. The HMBC spectrum of pure diastereomer of 4d in CDCl₃ solvent
Figure 14. The NOESY spectrum of pure diastereomer of 4d in CDCl$_3$ solvent
Figure 15. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4e
Figure 16. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4e
Figure 17. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4f
Figure 18. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4f
Figure 19. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4h
Figure 20. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4h.
Figure 21. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 4i
Figure 22. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 4i
Figure 23. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 5a
Figure 24. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 5a.
Figure 25. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 5b
Figure 26. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 5b
Figure 27. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 5c
Figure 28. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 5c
Figure 29. The \(^1\)H NMR (400 MHz, CDCl\(_3\)) spectrum of 5d
Figure 30. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 5d
Figure 31. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 5e
Figure 32. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 5e
Figure 33. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 5f
Figure 34. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of $5f$
Figure 35. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 5i
Figure 36. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 5i
Figure 37. The $^1$H NMR (400 MHz, CDCl$_3$) spectrum of 6
Figure 38. The $^{13}$C NMR (100 MHz, CDCl$_3$) spectrum of 6