

**Difference in  $\alpha$ -thiocyanation of malonates,  $\beta$ -oxo esters and  $\beta$ -diketones with sodium thiocyanate and cerium(IV) ammonium nitrate**

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**General**

NMR spectra were recorded on a commercial instrument (300.13 MHz for  $^1\text{H}$ , 75.48 MHz for  $^{13}\text{C}$ ) in  $\text{CDCl}_3$  or  $\text{DMSO-d}_6$ . High resolution mass spectra (HRMS) were measured using electrospray ionization (ESI).<sup>1</sup> The measurements were performed in positive ion mode (interface capillary voltage 4500 V); the mass ratio was from  $m/z$  50 to 3000 Da; external/internal calibration was done with Electrospray Calibrant Solution. A syringe injection was used for solutions in MeCN (flow rate 3  $\mu\text{L}/\text{min}$ ). Nitrogen was applied as a dry gas; the interface temperature was set at 180  $^\circ\text{C}$ . The TLC analysis was carried out on standard silica gel chromatography plates. Chromatography was performed on silica gel (0.060-0.200 mm, 60 A, CAS 7631-86-9). Acetone, hexane, ethyl acetate (EA), AcOH,  $\text{CH}_2\text{Cl}_2$ , CAN, NaSCN, **1a-f, q** were purchased from Acros.

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$\beta$ -Dicarbonyl compounds **1g-p,r** were prepared as referenced below.

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**1i**: J.P. Michael, C.B. Koning, C.W. van der Westhuyzen and M.A. Fernandes, *J. Chem. Soc., Perkin Trans. 1*, 2001, 2055.

**1j**: H.O. House and W.F. Gannon, *J. Org. Chem.*, 1958, **23**, 879.

**1k:** J. Marquet, M. Moreno-Manas, P. Pacheco, M. Prat, A. R. Katritzky and B. Brycki, *Tetrahedron*, 1990, **46**, 5333.

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**1o:** W. B. Renfrow and A. Renfrow, *J. Am. Chem. Soc.*, 1946, **68**, 1801.

**1p:** A. Kathuria, A. Gupta, N. Priya, P. Singh and H.G. Raj, *Bioorg. Med. Chem.*, 2009, **17**, 1550.

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### Representative experimental procedures.

Diethyl malonate **1a** (0.50 g, 2.0 mmol) and NaSCN (0.162–0.648 g, 2.0–8.0 mmol) were mixed with the solvent (10 ml; EtOAc, AcOH, acetone), and then CAN (1.096–4.386 g, 2.0–8.0 mmol) was added with stirring. The reaction mixture was stirred for 3 h at 20–25°C, then CH<sub>2</sub>Cl<sub>2</sub> (10 ml) was added, and the mixture was poured into water (30 ml) and extracted with CH<sub>2</sub>Cl<sub>2</sub> (3×15 ml). The combined organic extracts were successively washed with a saturated NaHCO<sub>3</sub> solution (30 ml) and water (30 ml), dried over MgSO<sub>4</sub>, and filtered. The solvent was evaporated under water-jet pump vacuum. Product **2a** was isolated by column chromatography on silica gel using gradient 0→20% EtOAc in light petroleum.

Similarly, 3-benzylpentane-2,4-dione **1j** (0.38 g, 2.0 mmol) and NaSCN (0.486 g, 6.0 mmol) were mixed with the solvent (10 mL; AcOH, acetone, EtOH, EtOAc), and then CAN (3.288 g, 6.0 mmol) was added with stirring. The reaction mixture was stirred for 3 h at 20–25°C, then CH<sub>2</sub>Cl<sub>2</sub> (10 ml) was added, and the mixture was poured into water (30 ml) and extracted with CH<sub>2</sub>Cl<sub>2</sub> (3×15 ml). Combined organic extracts were successively washed with a saturated NaHCO<sub>3</sub> solution (30 ml) and water (30 ml), dried over MgSO<sub>4</sub>, and filtered. The solvent was evaporated under water-jet pump vacuum. Product **2j** was isolated by column chromatography on silica gel using gradient 0→20% EtOAc in light petroleum.

### General procedure for the synthesis of thiocyanates **2b–r**

Compound **1b–r** (2.0 mmol) and NaSCN (0.486 g, 6.0 mmol) were mixed with the solvent (10 mL; EtOAc (**2b–f**, **j–n**), AcOH (**2g–i**, **o–r**)), and then CAN (3.288 g, 6.0 mmol) was added with

stirring. The reaction mixture was stirred for 3 h at 20-25°C, then CH<sub>2</sub>Cl<sub>2</sub> (10 ml) was added, and the mixture was poured into water (30 ml) and extracted with CH<sub>2</sub>Cl<sub>2</sub> (3×15 ml). Combined organic extracts were successively washed with a saturated NaHCO<sub>3</sub> solution (30 ml) and water (30 ml), dried over MgSO<sub>4</sub>, and filtered. The solvent was evaporated under water-jet pump vacuum. Product **2b-r** was isolated by column chromatography on silica gel.

#### **Diethyl 2-benzyl-2-thiocyanatomalonate 2a**

Colourless oil; R<sub>f</sub> = 0.33 (hexane/EtOAc = 10:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, CDCl<sub>3</sub>): 1.35 (t, *J* = 7.1, 6 H – 2CH<sub>3</sub>), 3.67 (s, 2 H – CH<sub>2</sub>), 4.21-4.46 (m, 4 H – 2CH<sub>2</sub>), 7.25 – 7.38 (m, 5 H – Ph).

<sup>13</sup>C NMR (75.47 MHz, CDCl<sub>3</sub>): 14.0, 39.5, 63.8, 67.2, 110.0, 128.2, 128.7, 130.3, 133.2, 165.9.

HRMS (ESI): *m/z* [M+Na]<sup>+</sup>: calculated for [C<sub>15</sub>H<sub>17</sub>NNaO<sub>4</sub>S]<sup>+</sup>: 330.0770; found: 330.0769.

Anal. Calcd for C<sub>15</sub>H<sub>17</sub>NO<sub>4</sub>S (%): C, 58.61, H, 5.57, N, 4.56, S, 10.43; found (%): C, 58.56, H, 5.60, N, 4.48, S, 10.55.

#### **Diethyl 2-methyl-2-thiocyanatomalonate 2b**

Colourless oil; R<sub>f</sub> = 0.38 (hexane/EtOAc = 10:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, CDCl<sub>3</sub>): 1.29 (t, *J* = 7.1, 6 H – 2CH<sub>3</sub>), 1.95 (s, 3 H – CH<sub>3</sub>), 4.29 (q, *J* = 7.1, 4 H – 2CH<sub>2</sub>).

<sup>13</sup>C NMR (75.47 MHz, CDCl<sub>3</sub>): 13.9, 22.5, 60.8, 63.7, 109.5, 166.6.

HRMS (ESI): *m/z* [M+Na]<sup>+</sup>: calculated for [C<sub>9</sub>H<sub>13</sub>NNaO<sub>4</sub>S]<sup>+</sup>: 254.0457; found: 254.0460.

[M+K]<sup>+</sup>: calculated for [C<sub>9</sub>H<sub>13</sub>NKO<sub>4</sub>S]<sup>+</sup>: 270.0197; found: 270.0196.

Anal. Calcd for C<sub>9</sub>H<sub>13</sub>NO<sub>4</sub>S (%): C, 46.74, H, 5.67, N, 6.06, S, 13.87; found (%): C, 46.72, H, 5.74, N, 6.14, S, 13.79.

#### **Diethyl 2-ethyl-2-thiocyanatomalonate 2c**

Colourless oil; R<sub>f</sub> = 0.40 (hexane/EtOAc = 10:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, CDCl<sub>3</sub>): 1.03 (t, *J* = 7.3, 3 H – CH<sub>3</sub>), 1.30 (t, *J* = 7.1, 6 H – 2CH<sub>3</sub>), 2.35 (q, *J* = 7.3, 2 H – CH<sub>2</sub>), 4.30 (q, *J* = 7.1, 4 H – 2CH<sub>2</sub>).

<sup>13</sup>C NMR (75.47 MHz, CDCl<sub>3</sub>): 8.6, 14.0, 27.5, 63.6, 67.3, 109.5, 166.2.

HRMS (ESI): *m/z* [M+Na]<sup>+</sup>: calculated for [C<sub>10</sub>H<sub>15</sub>NNaO<sub>4</sub>S]<sup>+</sup>: 268.0614; found: 268.0609.

[M+K]<sup>+</sup>: calculated for [C<sub>10</sub>H<sub>15</sub>NKO<sub>4</sub>S]<sup>+</sup>: 284.0353; found: 284.0352. [M+NH<sub>4</sub>]<sup>+</sup>: calculated for [C<sub>10</sub>H<sub>15</sub>NNH<sub>4</sub>O<sub>4</sub>S]<sup>+</sup>: 263.1060; found: 263.1058.

Anal. Calcd for C<sub>10</sub>H<sub>15</sub>NO<sub>4</sub>S (%): C, 48.96, H, 6.16, N, 5.71, S, 13.07; found (%): C, 49.14, H, 6.19, N, 5.83, S, 12.98.

### Diethyl 2-butyl-2-thiocyanatomalonate 2d

Colourless oil;  $R_f = 0.46$  (hexane/EtOAc = 10:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 0.92 (t,  $J = 6.8$ , 3 H –  $\text{CH}_3$ ), 1.29 (t,  $J = 7.1$ , 6 H –  $2\text{CH}_3$ ), 1.34-1.45 (m, 4 H –  $2\text{CH}_2$ ), 2.21-2.34 (m, 2 H –  $\text{CH}_2$ ), 4.29 (q,  $J = 7.1$ , 4 H –  $2\text{CH}_2$ ).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 13.8, 13.9, 22.3, 26.3, 33.6, 63.6, 66.5, 109.5, 166.3.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{12}\text{H}_{19}\text{NNaO}_4\text{S}]^+$ : 296.0927; found: 296.0925.

$[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{12}\text{H}_{19}\text{NKO}_4\text{S}]^+$ : 312.0666; found: 312.0661.  $[\text{M}+\text{NH}_4]^+$ : calculated for  $[\text{C}_{12}\text{H}_{19}\text{NNH}_4\text{O}_4\text{S}]^+$ : 291.1373; found: 291.1370.

Anal. Calcd for  $\text{C}_{12}\text{H}_{19}\text{NO}_4\text{S}$  (%): C, 52.73, H, 7.01, N, 5.12, S, 11.73; found (%): C, 52.60, H, 7.12, N, 5.11, S, 11.71.

### Diethyl 2-allyl-2-thiocyanatomalonate 2e

Colourless oil;  $R_f = 0.40$  (hexane/EtOAc = 10:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 1.31 (t,  $J = 7.1$ , 6 H –  $2\text{CH}_3$ ), 3.05 (d,  $J = 7.1$ , 2 H –  $\text{CH}_2$ ), 4.31 (q,  $J = 7.1$ , 4 H –  $2\text{CH}_2$ ), 5.26 (d,  $J = 10.0$ , 1H,  $=\text{CH}_2$ ), 5.30 (d,  $J = 17.0$ , 1H,  $=\text{CH}_2$ ), 5.72 (ddt,  $J_1 = 17.0$ ,  $J_2 = 10.0$ ,  $J_3 = 7.1$ , 1H, CH).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 14.0, 38.5, 63.8, 65.4, 109.5, 121.8, 129.5, 165.9.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{11}\text{H}_{15}\text{NNaO}_4\text{S}]^+$ : 280.0614; found: 280.0617.

$[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{11}\text{H}_{15}\text{NKO}_4\text{S}]^+$ : 296.0353; found: 296.0356.

Anal. Calcd for  $\text{C}_{11}\text{H}_{15}\text{NO}_4\text{S}$  (%): C, 51.35, H, 5.88, N, 5.44, S, 12.46; found (%): C, 51.17, H, 5.85, N, 5.43, S, 12.49.

### Diethyl 2-phenyl-2-thiocyanatomalonate 2f

Colourless oil;  $R_f = 0.46$  (hexane/EtOAc = 95:5).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 1.32 (t,  $J = 7.1$ , 6 H –  $2\text{CH}_3$ ), 4.28-4.47 (m, 4 H –  $2\text{CH}_2$ ), 7.40 – 7.55 (m, 5 H – Ph).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 13.9, 64.1, 69.6, 110.0, 128.3, 128.9, 129.7, 132.9, 166.0.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{14}\text{H}_{15}\text{NNaO}_4\text{S}]^+$ : 316.0614; found: 316.0610.

$[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{14}\text{H}_{15}\text{NKO}_4\text{S}]^+$ : 332.0353; found: 332.0345.  $[\text{M}+\text{NH}_4]^+$ : calculated for  $[\text{C}_{14}\text{H}_{15}\text{NNH}_4\text{O}_4\text{S}]^+$ : 311.1060; found: 311.1058.

Anal. Calcd for  $\text{C}_{14}\text{H}_{15}\text{NO}_4\text{S}$  (%): C, 57.32, H, 5.15, N, 4.77, S, 10.93; found (%): C, 57.55, H, 5.01, N, 4.80, S, 10.53.

### 3-Hexyl-3-thiocyanatopentane-2,4-dione 2g

Colourless oil;  $R_f = 0.32$  (hexane/EtOAc = 5:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, CDCl<sub>3</sub>): 0.88 (t, *J* = 6.6, 3 H – CH<sub>3</sub>), 1.19-1.47 (m, 8 H – 4 CH<sub>2</sub>), 2.29 (s, 6 H – 2CH<sub>3</sub>), 2.24-2.32 (m, 2H - CH<sub>2</sub>).

<sup>13</sup>C NMR (75.47 MHz, CDCl<sub>3</sub>): 14.1, 22.6, 23.9, 26.1, 29.1, 31.4, 32.2, 82.8, 110.3, 199.1.

HRMS (ESI): *m/z* [M+K]<sup>+</sup>: calculated for [C<sub>12</sub>H<sub>19</sub>NKO<sub>2</sub>S]<sup>+</sup>: 280.0768; found: 280.0776.

Anal. Calcd for C<sub>12</sub>H<sub>19</sub>NO<sub>2</sub>S (%): C, 59.72, H, 7.93, N, 5.80, S, 13.29; found (%): C, 59.76, H, 7.91, N, 5.80, S, 13.20.

### **3-Acetyl-3-thiocyanatoheptane-2,6-dione 2h**

Colourless oil; R<sub>f</sub> = 0.38 (hexane/EtOAc = 5:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, CDCl<sub>3</sub>): 1.25 (t, *J* = 7.1, 3 H – CH<sub>3</sub>), 2.32 (s, 6 H – 2CH<sub>3</sub>), 2.34-2.43 (m, 2 H – CH<sub>2</sub>), 2.62-2.71 (m, 2 H – CH<sub>2</sub>), 4.13 (q, *J* = 7.1, 2 H – CH<sub>2</sub>CH<sub>3</sub>).

<sup>13</sup>C NMR (75.47 MHz, CDCl<sub>3</sub>): 14.2, 26.2, 27.3, 29.1, 61.3, 81.9, 109.6, 171.5, 198.5.

HRMS (ESI): *m/z* [M+H]<sup>+</sup>: calculated for [C<sub>11</sub>H<sub>15</sub>NHO<sub>4</sub>S]<sup>+</sup>: 258.0795; found: 258.0792.

[M+NH<sub>4</sub>]<sup>+</sup>: calculated for [C<sub>11</sub>H<sub>15</sub>NNH<sub>4</sub>O<sub>4</sub>S]<sup>+</sup>: 275.1060; found: 275.1053. [M+Na]<sup>+</sup>: calculated for [C<sub>11</sub>H<sub>15</sub>NNaO<sub>4</sub>S]<sup>+</sup>: 280.0614; found: 280.0603. [M+K]<sup>+</sup>: calculated for [C<sub>11</sub>H<sub>15</sub>NKO<sub>4</sub>S]<sup>+</sup>: 296.0353; found: 296.0338.

Anal. Calcd for C<sub>11</sub>H<sub>15</sub>NO<sub>4</sub>S (%): C, 51.35, H, 5.88, N, 5.44, S, 12.46; found (%): C, 51.41, H, 5.80, N, 5.31, S, 12.35.

### **4-Acetyl-5-oxo-4-thiocyanatohexanenitrile 2i**

White crystals; mp=77-79 °C.

R<sub>f</sub> = 0.30 (hexane/acetone = 3:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, CDCl<sub>3</sub>): 2.36 (s, 6 H – 2 CH<sub>3</sub>), 2.50 (t, *J* = 7.2, 2 H – CH<sub>2</sub>), 2.70 (t, *J* = 7.2, 2 H – CH<sub>2</sub>).

<sup>13</sup>C NMR (75.47 MHz, CDCl<sub>3</sub>): 12.8, 26.2, 28.0, 81.3, 108.9, 117.4, 197.5.

HRMS (ESI): *m/z* [M+NH<sub>4</sub>]<sup>+</sup>: calculated for [C<sub>9</sub>H<sub>10</sub>N<sub>2</sub>NH<sub>4</sub>O<sub>2</sub>S]<sup>+</sup>: 228.0801; found: 228.0795.

[M+Na]<sup>+</sup>: calculated for [C<sub>9</sub>H<sub>10</sub>N<sub>2</sub>NaO<sub>2</sub>S]<sup>+</sup>: 233.0355; found: 286.0350.

Anal. Calcd for C<sub>9</sub>H<sub>10</sub>N<sub>2</sub>O<sub>2</sub>S (%): C, 51.41, H, 4.79, N, 13.32, S, 15.25; found (%): C, 51.11, H, 4.45, N, 13.64, S, 15.20.

### **3-Benzyl-3-thiocyanatopentane-2,4-dione 2j**

White crystals; mp=53-54 °C.

R<sub>f</sub> = 0.58 (hexane/EtOAc = 10:1).

<sup>1</sup>H NMR (300 MHz, δ ppm, *J* Hz, DMSO-d<sub>6</sub>): 2.44 (s, 6 H – 2 CH<sub>3</sub>), 3.60 (s, 2 H – CH<sub>2</sub>), 7.09 – 7.32 (m, 5H – Ph).

$^{13}\text{C}$  NMR (75.47 MHz, DMSO- $d_6$ ): 26.6, 36.3, 81.9, 111.0, 127.6, 128.5, 129.7, 133.6, 199.0.  
HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{13}\text{NNaO}_2\text{S}]^+$ : 270.0559; found: 270.0568.  
 $[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{13}\text{NKO}_2\text{S}]^+$ : 286.0299; found: 286.0306.  
Anal. Calcd for  $\text{C}_{13}\text{H}_{13}\text{NO}_2\text{S}$  (%): C, 63.13, H, 5.30, N, 5.66, S, 12.97; found (%): C, 63.11, H, 5.29, N, 5.60, S, 12.93.

### **3-(4-Chlorobenzyl)-3-thiocyanatopentane-2,4-dione 2k**

White crystals; mp=62-64 °C.

$R_f$  = 0.53 (hexane/EtOAc = 5:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 2.37 (s, 6 H – 2 $\text{CH}_3$ ) 3.60 (s, 2 H –  $\text{CH}_2$ ), 7.11 (d,  $J$  = 8.4, 2 H – 2CH), 7.28 (d,  $J$  = 8.4, 2 H – 2CH).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 26.7, 37.3, 82.8, 110.2, 129.1, 131.2, 131.7, 134.3, 198.0.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{12}\text{NCINaO}_2\text{S}]^+$ : 304.0169; found: 304.0170.  
 $[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{12}\text{NCIKO}_2\text{S}]^+$ : 319.9909; found: 319.9908.  $[\text{M}+\text{NH}_4]^+$ : calculated for  $[\text{C}_{13}\text{H}_{12}\text{NCINH}_4\text{O}_2\text{S}]^+$ : 299.0616; found: 299.0615.

Anal. Calcd for  $\text{C}_{13}\text{H}_{12}\text{NClO}_2\text{S}$  (%): C, 55.42, H, 4.29, N, 4.97, S, 11.38, Cl, 12.58; found (%): C, 55.25, H, 4.18, N, 4.98, S, 11.23, Cl, 12.42.

### **3-(4-Bromobenzyl)-3-thiocyanatopentane-2,4-dione 2l**

Colourless oil;  $R_f$  = 0.31 (hexane/EtOAc = 5:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 2.37 (s, 6 H - 2 $\text{CH}_3$ ), 3.59 (s, 2 H -  $\text{CH}_2$ ), 7.05 (d,  $J$  = 8.2, 2 H – 2CH), 7.44 (d,  $J$  = 8.2, 2 H – 2CH).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 26.7, 37.4, 82.7, 110.2, 122.4, 131.5, 132.1, 132.3, 198.0.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{12}\text{NBrNaO}_2\text{S}]^+$ : 347.9664; found: 347.9667.

Anal. Calcd for  $\text{C}_{13}\text{H}_{12}\text{NBrO}_2\text{S}$  (%): C, 47.86, H, 3.71, N, 4.29, S, 9.83, Br, 24.49; found (%): C, 47.91, H, 3.69, N, 4.21, S, 9.92, Br, 24.73.

### **Ethyl 2-(4-nitrobenzyl)-3-oxo-2-thiocyanatobutanoate 2m**

White crystals; mp=92-94 °C.

$R_f$  = 0.64 (hexane/EtOAc = 3:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 1.32 (t,  $J$  = 7.1, 3 H –  $\text{CH}_3$ ), 2.42 (s, 3H –  $\text{CH}_3$ ), 3.58 (d,  $J$  = 15.0, 1H –  $\text{CH}_2$ ), 3.72 (d,  $J$  = 15.0, 1H –  $\text{CH}_2$ ), 4.22-4.43 (m, 2 H –  $\text{CH}_2\text{CH}_3$ ), 7.40 (d,  $J$  = 8.6, 2 H – 2CH), 8.18 (d,  $J$  = 8.6, 2 H – 2CH).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 14.0, 25.6, 38.1, 64.7, 72.5, 109.2, 123.9, 131.2, 141.1, 147.9, 165.8, 194.6.

HRMS (ESI):  $m/z$   $[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{14}\text{H}_{14}\text{N}_2\text{KO}_5\text{S}]^+$ : 361.0255; found: 361.0245.

Anal. Calcd for  $\text{C}_{14}\text{H}_{14}\text{N}_2\text{O}_5\text{S}$  (%): C, 52.17, H, 4.38, N, 8.69, S, 9.95; found (%): C, 52.15, H, 4.44, N, 8.63, S, 10.00.

### **Ethyl 2-(4-methylbenzyl)-3-oxo-2-thiocyanatobutanoate 2n**

White crystals; mp=87-90 °C.

$R_f$  = 0.29 (hexane/EtOAc = 10:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 1.32 (t,  $J$  = 7.1, 3 H –  $\text{CH}_3$ ), 2.33 (s, 3H –  $\text{CH}_3\text{Ph}$ ), 2.39 (s, 3H –  $\text{CH}_3\text{CO}$ ), 3.47 (d,  $J$  = 15.2, 1H –  $\text{CH}_2$ ), 3.60 (d,  $J$  = 15.2, 1H –  $\text{CH}_2$ ), 4.16-4.46 (m, 2 H –  $\text{CH}_2\text{CH}_3$ ), 7.03 – 7.17 (m, 4 H – Ph).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 14.0, 21.2, 25.9, 38.2, 64.1, 73.6, 109.9, 129.5, 130.0, 130.3, 137.9, 166.4, 195.8.

HRMS (ESI):  $m/z$   $[\text{M}+\text{H}]^+$ : calculated for  $[\text{C}_{15}\text{H}_{17}\text{NHO}_3\text{S}]^+$ : 292.1008; found: 292.1002.

$[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{15}\text{H}_{17}\text{NNaO}_3\text{S}]^+$ : 314.0823; found: 314.0821.  $[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{15}\text{H}_{17}\text{NKO}_3\text{S}]^+$ : 330.0564; found: 330.0561.

Anal. Calcd for  $\text{C}_{15}\text{H}_{17}\text{NO}_3\text{S}$  (%): C, 61.83, H, 5.88, N, 4.81, S, 11.01; found (%): C, 62.01, H, 5.87, N, 4.85, S, 10.99.

### **Ethyl 2-acetyl-2-thiocyanatohexanoate 2o**

Colourless oil;  $R_f$  = 0.40 (hexane/EtOAc = 5:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 0.94 (t,  $J$  = 7.0, 3 H –  $\text{CH}_3$ ), 1.32 (t,  $J$  = 7.0, 3 H –  $\text{CH}_3$ ), 1.20-1.54 (m, 4 H –  $2\text{CH}_2$ ), 2.14-2.44 (m, 2 H –  $\text{CH}_2$ ), 2.30 (s, 3 H –  $\text{CH}_3$ ), 4.33 (q,  $J$  = 7.0, 2 H –  $\text{CH}_2\text{O}$ ).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 13.8, 14.0, 22.5, 25.4, 26.2, 32.7, 63.9, 73.5, 109.8, 166.9, 197.0.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{11}\text{H}_{17}\text{NNaO}_3\text{S}]^+$ : 266.0821; found: 266.0826.

$[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{11}\text{H}_{17}\text{NKO}_3\text{S}]^+$ : 282.0561; found: 282.0562.  $[\text{M}+\text{NH}_4]^+$ : calculated for  $[\text{C}_{11}\text{H}_{17}\text{NNH}_4\text{O}_3\text{S}]^+$ : 261.1267; found: 261.1273.

Anal. Calcd for  $\text{C}_{11}\text{H}_{17}\text{NO}_3\text{S}$  (%): C, 54.30, H, 7.04, N, 5.76, S, 13.18; found (%): C, 54.62, H, 7.62, N, 5.85, S, 12.98.

### **Ethyl 2-acetyl-2-thiocyanatooctanoate 2p**

Colourless oil;  $R_f$  = 0.59 (hexane/EtOAc = 5:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 0.88 (t,  $J = 7.1$ , 3 H –  $\text{CH}_3$ ), 1.2-1.45 (m, 11 H), 2.15-2.28 (m, 2 H –  $\text{CH}_2$ ), 2.31 (s, 3 H –  $\text{CH}_3\text{CO}$ ), 4.33 (q,  $J = 7.1$ , 2 H –  $\text{CH}_2\text{O}$ ).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 14.1, 22.6, 24.1, 25.4, 29.0, 31.5, 33.0, 63.9, 73.6, 109.8, 166.9, 197.1.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{21}\text{NNaO}_3\text{S}]^+$ : 294.1134; found: 294.1146.

$[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{13}\text{H}_{21}\text{NKO}_3\text{S}]^+$ : 310.0874; found: 310.0884.  $[\text{M}+\text{NH}_4]^+$ : calculated for  $[\text{C}_{13}\text{H}_{21}\text{NNH}_4\text{O}_3\text{S}]^+$ : 289.1580; found: 289.1590.

Anal. Calcd for  $\text{C}_{13}\text{H}_{21}\text{NO}_3\text{S}$  (%): C, 57.54, H, 7.80, N, 5.16, S, 11.82; found (%): C, 57.46, H, 7.71, N, 5.08, S, 11.30.

### **Ethyl 2-oxo-1-thiocyanatocyclohexanecarboxylate 2q**

Colourless oil;  $R_f = 0.52$  (hexane/EtOAc = 5:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{DMSO-d}_6$ ): 1.23 (t,  $J = 7.1$ , 3 H –  $\text{CH}_3$ ), 1.48-2.17 (m, 5 H –  $\text{CH}_2$ ), 2.45-2.70 (m, 2 H –  $\text{CH}_2$ ), 2.76-2.90 (m, 1 H –  $\text{CH}_2$ ), 4.20-4.38 (m, 2 H –  $\text{CH}_2\text{O}$ ).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{DMSO-d}_6$ ): 13.6, 22.6, 26.0, 37.2, 39.8, 63.2, 68.0, 110.0, 166.0, 201.6.

HRMS (ESI):  $m/z$   $[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{10}\text{H}_{13}\text{NnaO}_3\text{S}]^+$ : 250.0508; found: 250.0512.

$[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{10}\text{H}_{13}\text{NKO}_3\text{S}]^+$ : 266.0248; found: 266.0291.  $[\text{M}+\text{NH}_4]^+$ : calculated for  $[\text{C}_{10}\text{H}_{13}\text{NNH}_4\text{O}_3\text{S}]^+$ : 245.0954; found: 245.0957.

Anal. Calcd for  $\text{C}_{10}\text{H}_{13}\text{NO}_3\text{S}$  (%): C, 52.85, H, 5.77, N, 6.16, S, 14.11; found (%): C, 52.91, H, 5.70, N, 6.21, S, 14.23.

### **Ethyl 2-(2-cyanoethyl)-3-oxo-2-thiocyanatobutanoate 2r**

Colourless oil;  $R_f = 0.41$  (hexane/acetone = 3:1).

$^1\text{H}$  NMR (300 MHz,  $\delta$  ppm,  $J$  Hz,  $\text{CDCl}_3$ ): 1.31 (t,  $J = 7.1$ , 3 H –  $\text{CH}_3$ ), 2.34 (s, 3 H –  $\text{CH}_3$ ), 2.46-2.74 (m, 4 H –  $2\text{CH}_2$ ), 4.29-4.38 (m, 2 H –  $\text{CH}_2\text{O}$ ).

$^{13}\text{C}$  NMR (75.47 MHz,  $\text{CDCl}_3$ ): 12.9, 13.8, 25.2, 28.8, 64.9, 71.0, 108.3, 117.5, 165.6, 194.8.

HRMS (ESI):  $m/z$   $[\text{M}+\text{K}]^+$ : calculated for  $[\text{C}_{10}\text{H}_{22}\text{N}_2\text{KO}_3\text{S}]^+$ : 279.0165; found: 279.0165.

$[\text{M}+\text{Na}]^+$ : calculated for  $[\text{C}_{10}\text{H}_{22}\text{N}_2\text{NaO}_3\text{S}]^+$ : 263.0426; found: 263.0426.

Anal. Calcd for  $\text{C}_{10}\text{H}_{22}\text{N}_2\text{O}_3\text{S}$  (%): C, 49.99, H, 5.03, N, 11.66, S, 13.35; found (%): C, 49.36, H, 4.93, N, 11.65, S, 13.23.