Lewis acid-catalyzed one-pot thioalkenylation of donor-acceptor cyclopropanes using in situ generated dithiocarbamates and propiolates

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Supporting Information

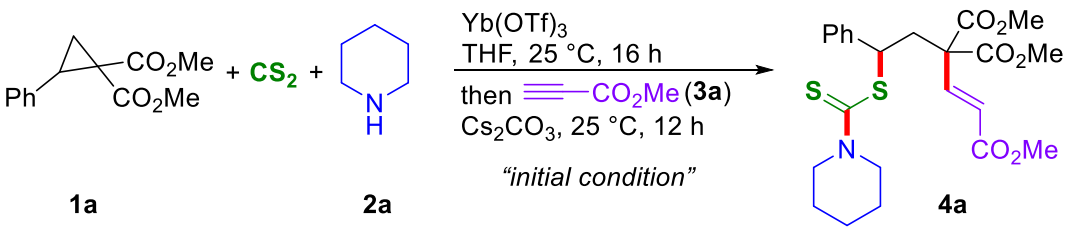
1. General Information

Unless otherwise specified, all reactions were carried out under an atmosphere of argon in flame-dried reaction vessels with Teflon screw caps. 25 °C corresponds to the room temperature of the lab when the experiments were carried out. THF was freshly purified by distillation over Na-benzophenone and was transferred under argon. $Yb(OTf)_3$ and Cs_2CO_3 were purchased from commercial sources and were stored in nitrogen filled Glove-box. All the amines, and CS_2 were purchased from Alfa Aesar, TCI, Sigma-Aldrich or Spectrochem and used directly as received. All D-A cyclopropane derivatives[1] were synthesized following known literature procedures.

Analytical thin layer chromatography was performed on TLC Silica gel 60 F_{254}. Visualization was accomplished with short wave UV light or $KMnO_4$ staining solutions followed by heating. Unless and otherwise specified flash chromatography was performed on silica gel (100-200 mesh) by standard techniques eluting with Pet. Ether-EtOAc solvent system.

All compounds were fully characterized. ^1H and ^{13}C NMR spectra were recorded on Bruker Ultrashield spectrometer in $CDCl_3$ as solvent. Chemical shifts (δ) are given in ppm. The residual solvent signals were used as references and the chemical shifts converted to the TMS scale ($CDCl_3$: δ_H = 7.26 ppm, δ_C = 77.16 ppm). Infrared (FT-IR) spectra were recorded on a Bruker Alfa FT-IR, ν-max in cm^{-1}. HRMS (ESI) data were recorded on a Waters Xevo G2-XS Q-TOF instrument.

2. General Procedure for the Optimization of the Reaction Conditions



1a **2a** **4a**

[1] (*a*) A. U. Augustin, M. Busse, P. G. Jones and D. B. Werz, *Org. Lett.*, 2018, **20**, 820; (*b*) A. F. G. Goldberg, N. R. O'Connor, R. A. Craig II and B. M. Stoltz, *Org. Lett.*, 2012, **14**, 5314; (*c*) P. D. Pohlhaus, S. D. Sanders, A. T. Parsons, W. Li and J. S. Johnson, *J. Am. Chem. Soc.*, 2008, **130**, 8642.

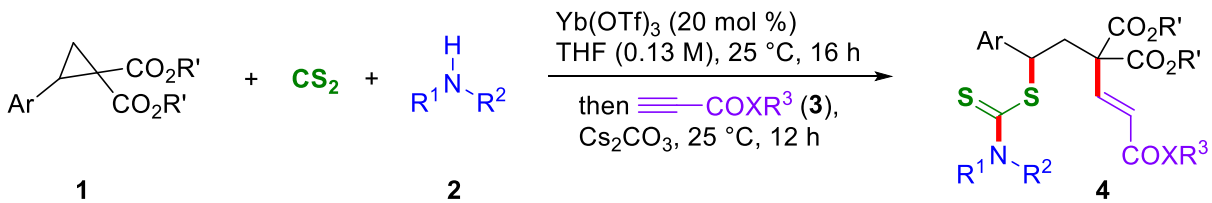
To a flame-dried screw-capped test tube equipped with a magnetic stir bar was added piperidine **2a** and CS_2 in 1.5 mL THF under argon atmosphere. The reaction mixture was stirred for 5 minutes and to the stirring solution dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.047 g, 0.2 mmol) and $Yb(OTf)_3$ were added and then the reaction mixture was allowed to stir at 25 °C for 16 h. After 16 h, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) were added and then stirred for 12 h. After 12 h, the reaction was stopped, the solvent was evaporated, and the crude mixture was passed through a pad of silica gel and eluted with EtOAc (3x10 mL). The reaction mixture was concentrated under reduced pressure and then the yield of **4a** was determined by the ^{1}H NMR analysis of the crude reaction products using CH_2Br_2 as the internal standard.

Table S1. Optimization Studies

entry	variation of the initial conditions[a]	yield of **4a** (%)[b]	E/Z ratio[c]
1	*none*	*78 (77)*	*5:1*
2	1.5 equiv of CS_2	63	4:1
3	1.5 equiv of **2a**	68	4:1
4	1.5 equiv of **3a**	65	4:1
5	DCE instead of THF	70	5:1
6	CH_2Cl_2 instead of THF	16	4:1
7	10 mol % of $Yb(OTf)_3$	30	4:1
8	$Sc(OTf)_3$ instead of $Yb(OTf)_3$	18	5:1
9	$Sn(OTf)_2$ instead of $Yb(OTf)_3$	10	4:1
10	DBU instead of Cs_2CO_3	<5	Nd
11	DABCO instead of Cs_2CO_3	<5	Nd
12	K_2CO_3 instead of Cs_2CO_3	24	4:1

[a] Initial conditions: **1a** (0.2 mmol), CS_2 (0.4 mmol), **2a** (0.4 mmol), $Yb(OTf)_3$ (20 mol%), THF (1.5 mL) for 16 h, then base (2.5 equiv), **3a** (2.0 equiv) for 12 h. [b] Yield was determined on the basis of the ^{1}H NMR of the crude reaction mixture using CH_2Br_2 as the internal standard. The isolated yield of **4a** was given in parentheses. [c] E/Z Ratio was determined from the ^{1}H NMR of the crude reaction mixture. Nd indicates not determined.

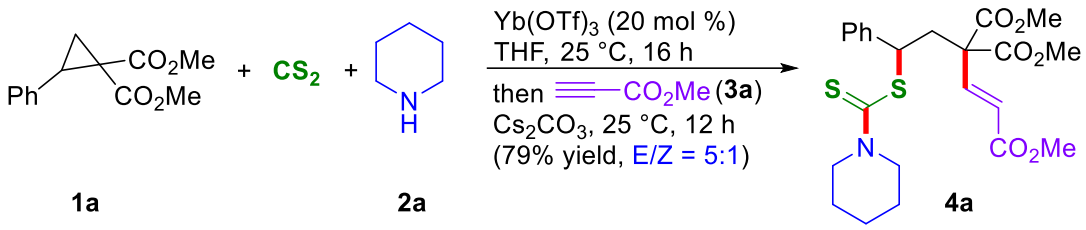
3. General Procedure for 1,3-Thioalkenylation of D-A Cyclopropanes



1 **2** **4**

To a flame-dried screw-capped test tube equipped with a magnetic stir bar were added amine **2** (0.4 mmol) and CS_2 (0.030 g, 24 μL, 0.4 mmol) in 1.5 mL of THF under argon atmosphere. The reaction mixture was stirred for 5 min, and to the stirring solution were added D-A cyclopropane **1** (0.2 mmol) and $Yb(OTf)_3$ (0.025 g, 0.04 mmol). The reaction mixture was stirred at 25 °C for 16 h. After 16 h, Cs_2CO_3 (0.5 mmol) and alkyl propiolate **3** (0.4 mmol) were added and stirred for 12 h. After 12 h, the solvent was evaporated, and the crude residue was pre-adsorbed on silica gel and purified by flash column chromatography on silica gel (Pet. Ether-EtOAc as the eluent) to afford the corresponding 1,3-carbothiolated product **4** in moderate-to good yields.

Procedure for the 2.0 mmol Scale Reaction for the Synthesis of 4a

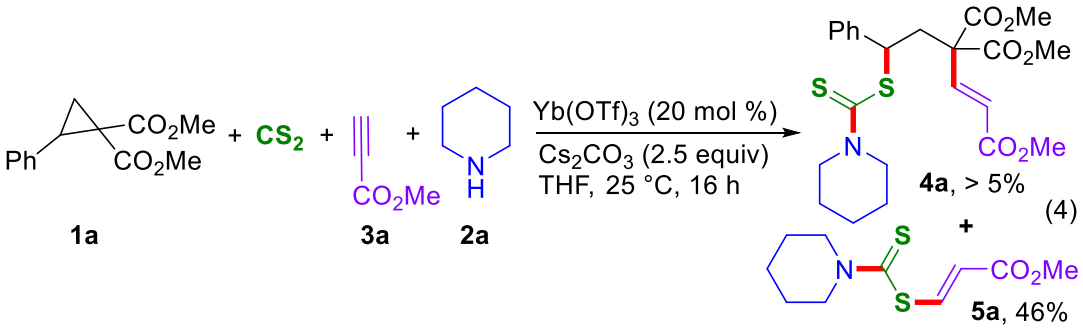


1a **2a** **4a**

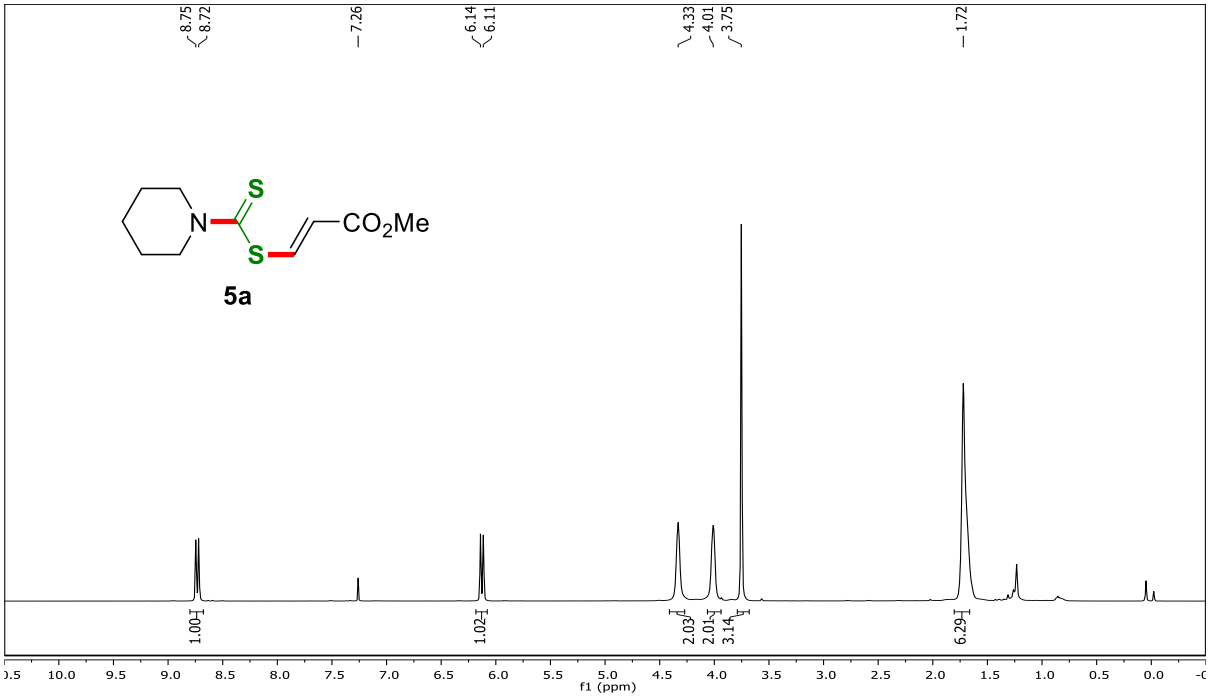
To a flame-dried screw-capped test tube equipped with a magnetic stir bar was added piperidine **2a** (0.341 g, 4.0 mmol), and CS_2 (0.304 g, 4.0 mmol) in 15 mL THF under argon atmosphere. The reaction mixture was stirred for 5 minutes and to the stirring solution dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.468 g, 2.0 mmol) and $Yb(OTf)_3$ (0.248 g, 0.2 mmol) were added and then the reaction mixture was allowed to stir at 25 °C for 16 h. After 16 h, Cs_2CO_3 (1.6 g, 5.0 mmol) and methyl propiolate **3a** (0.336 g, 4.0 mmol) and then stir for 12 h. After 12 h, the reaction was stopped, the solvent was evaporated and the crude residue was pre-adsorbed on silica gel and purified by flash column chromatography on silica gel (Pet. ether /EtOAc = 84/16) to afford trimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio) pent-1-ene-1,3,3-tricarboxylate **4a** as yellow oil (0.758 g, 79% yield with E/Z ratio of 5:1).

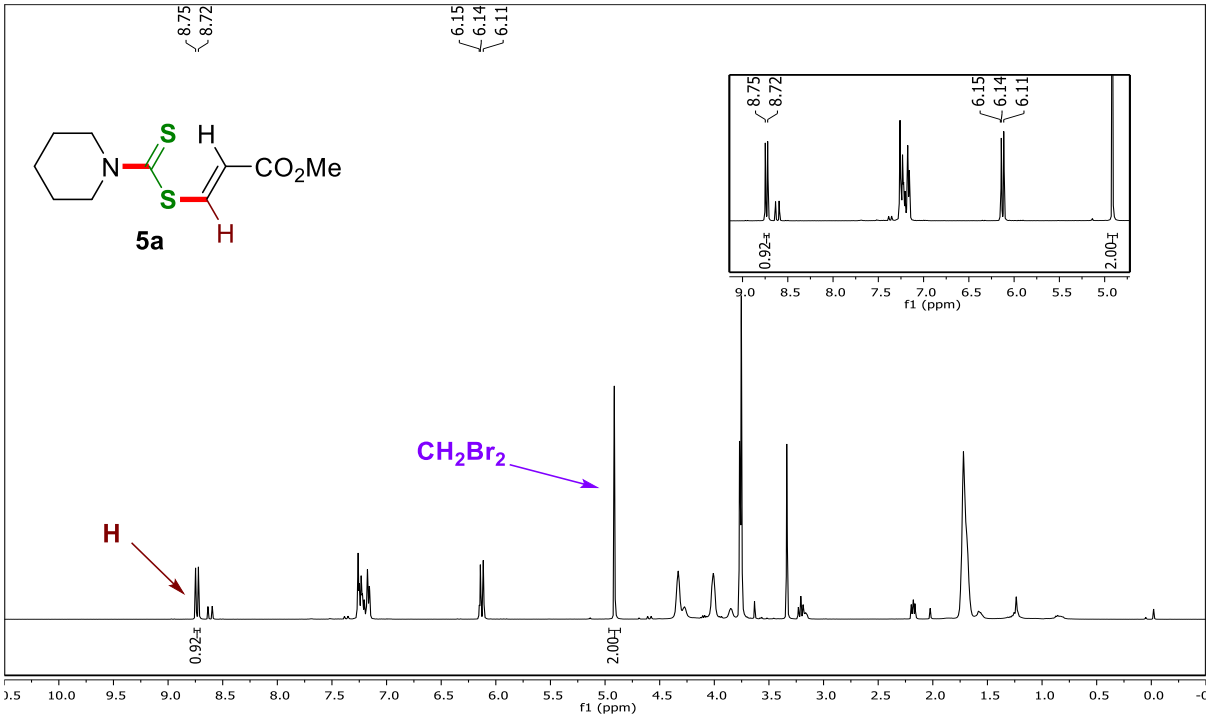
4. Mechanistic Experiments

(a) *Envisioned Four-Component Approach*



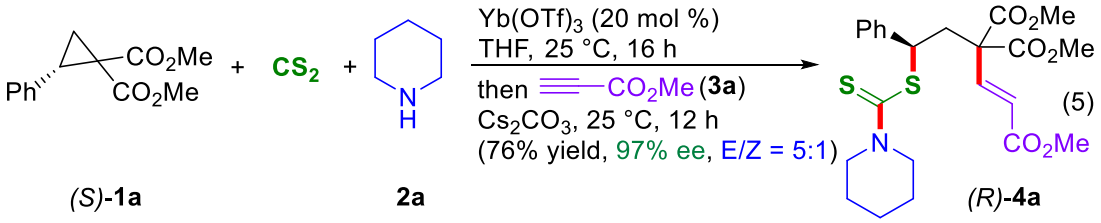
To a flame-dried screw-capped test tube equipped with a magnetic stir bar was added piperidine **2a** (0.034 g, 40 µL, 0.4 mmol), and CS_2 (0.030 g, 24 µL, 0.4 mmol) in 1.5 mL THF under argon atmosphere. The reaction mixture was stirred for 5 minutes and to the stirring solution dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.047 g, 0.2 mmol) and $Yb(OTf)_3$ (0.025 g, 0.04 mmol) were added followed by the addition of Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) and then stirring for 16 h. After 16 h, the reaction was stopped, the solvent was evaporated, and the crude mixture was passed through a pad of silica gel and eluted with EtOAc (3x10 mL). The reaction mixture was concentrated under reduced pressure and then the yield of **4a** and **5a** was determined by the ^1H NMR analysis of the crude reaction products using CH_2Br_2 (0.035 g, 14 µL, 0.2 mmol) as the internal standard.





This study indicates that the nucleophilic ring-opening of D-A cyclopropanes using dithiocarbamates was less facile than the direct dithiocarbamate addition to methyl propiolate thus making the four-component coupling not feasible.

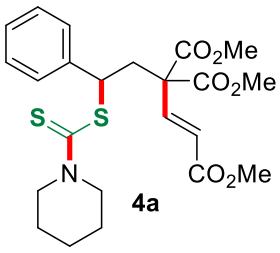
(b) ***Enantiospecific Study***



To a flame-dried screw-capped test tube equipped with a magnetic stir bar was added piperidine **2a** (0.034 g, 40 µL, 0.4 mmol), and CS_2 (0.030 g, 24 µL, 0.4 mmol) in 1.5 mL THF under argon atmosphere. The reaction mixture was stirred for 5 minutes and to the stirring solution enantiopure cyclopropane (*S*)-**1a** (0.047 g, 0.2 mmol) and $Yb(OTf)_3$ (0.025 g, 0.04 mmol) were added and then the reaction mixture was allowed to stir at 25 °C for 16 h. After 16 h, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) were added and then stir for 12 h. After 12 h, the solvent was evaporated, and the crude residue was pre-adsorbed on silica gel and purified by flash column chromatography on silica gel (Pet. ether /EtOAc = 84/16) to afford (*R*)-**4a** in 76% yield, 97% ee and E/Z ratio of 5:1. (*The absolute stereochemistry of the chiral center was not unequivocally determined*). *This study provides insights into the S_N2-type addition of in situ generated dithiocarbamates to D-A cyclopropane.*

5. Synthesis and Characterization of 1,3-Thioalkenylated Products

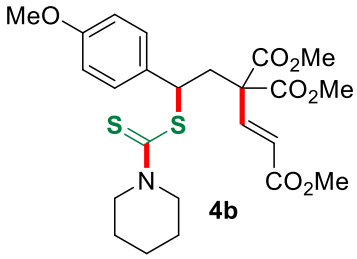
Trimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4a)



Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.047 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 84/16) of the crude reaction mixture afforded trimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4a** as yellow oil (0.074 g, 77% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.33; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.27-7.17 (m, 6H), 5.96 (d, *J* = 16.4 Hz, 1H), 5.15-5.11 (m, 1H), 4.21-4.14 (m, 2H), 3.75-3.70 (m, 2H), 3.70 (s, 3H), 3.68 (s, 3H), 3.32 (s, 3H), 3.11-3.07 (m, 1H), 2.93-2.86 (m, 1H), 1.63 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.2, 169.2, 169.0, 166.1, 142.8, 139.0, 129.0, 128.6, 127.9, 123.3, 59.0, 53.2, 52.7, 52.5, 51.7, 51.3, 42.5, 26.0, 25.5, 24.3. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{23}H_{29}NNaO_6S_2$ 502.1329; found 502.1331. **FTIR (cm^{-1})** 2943, 1735, 1652, 1434, 1231, 1124.

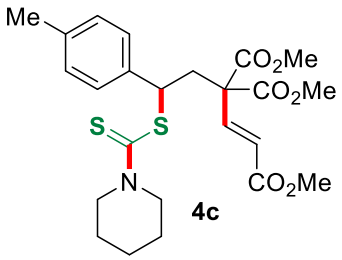
Trimethyl (*E*)-5-(4-methoxyphenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4b)



Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(4-methoxyphenyl)cyclopropane-1,1-dicarboxylate **1b** (0.053 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-(4-methoxyphenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4b** as yellow oil (0.073 g, 72% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.31; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.26-7.20 (m, 3H), 6.80 (d, *J* = 8.2 Hz, 2H), 5.96 (d, *J* = 16.4 Hz, 1H), 5.1-5.07 (m, 1H), 4.26-4.08 (m, 2H), 3.83-3.80 (m, 2H), 3.76 (s, 3H), 3.74 (s, 3H), 3.70 (s, 3H), 3.39 (s, 3H), 3.14-3.09 (m, 1H), 2.91-2.84 (m, 1H), 1.65 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.4, 169.2, 169.1, 166.1, 159.3, 142.8, 130.8, 130.1, 123.1, 113.9, 60.4, 59.0, 55.3, 53.2, 52.8, 52.0, 51.7, 42.7, 26.0, 24.3, 21.1. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{24}H_{31}NNaO_7S_2$ 532.1434; found 532.1440. **FTIR (cm^{-1})** 2945, 1735, 1609, 1434, 1242, 1024.

Trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(*p*-tolyl)pent-1-ene-1,3,3-tricarboxylate (4c)



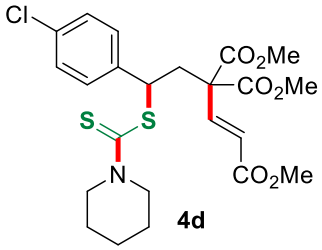
4c

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(*p*-tolyl)cyclopropane-1,1-dicarboxylate **1c** (0.050 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(*p*-tolyl)pent-1-ene-1,3,3-tricarboxylate **4c** as yellow oil (0.068 g, 69% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.34; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.30-7.26 (m, 1H), 7.20-7.18 (m, 2H), 7.10-7.08 (m, 2H), 5.98 (d, *J* = 16.6 Hz, 1H), 5.14-5.10 (m, 1H), 4.26-4.15 (m, 2H), 3.90-3.79 (m, 2H), 3.74 (s, 3H), 3.72 (s, 3H), 3.37 (s, 3H), 3.15-3.10 (m, 1H), 2.94-2.88 (m, 1H), 2.30 (s,3H), 1.66 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.4, 169.3, 169.1, 166.1, 142.8, 137.8, 135.8, 129.2, 128.9, 123.6, 59.0, 53.2, 52.7, 52.3, 51.7, 51.4, 42.9, 26.0, 25.6, 24.4, 21.2. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{24}H_{31}NNaO_6S_2$ 516.1485; found 516.1493. **FTIR (cm^{-1})** 2944, 1735, 1650, 1433, 1230, 1123.

Trimethyl (*E*)-5-(4-chlorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4d)

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(4-chlorophenyl)cyclopropane-1,1-dicarboxylate **1d** (0.054 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at

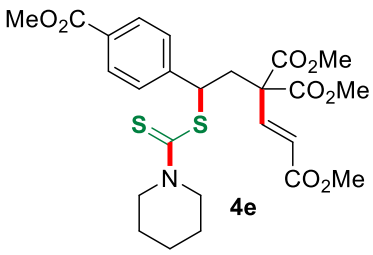


4d

25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-(4-chlorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4d** as yellow oil (0.056 g, 54% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.33; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.26-7.18 (m, 5H), 5.91 (d, *J* = 16.4 Hz, 1H), 5.16-5.12 (m, 1H), 4.20-4.14 (m, 2H), 3.84-3.77 (m, 2H), 3.75 (s, 3H), 3.72 (s, 3H), 3.44 (s, 3H), 3.10-3.05 (m, 1H), 2.88-2.82 (m, 1H), 1.66 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 192.6, 169.2, 169.0, 166.0, 142.7, 138.0, 133.8, 130.4, 128.7, 123.3, 58.9, 53.4, 53.0, 51.9, 51.7, 51.4, 42.6, 26.1, 25.4, 24.3. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{23}H_{28}ClNNaO_6S_2$ 536.0939; found 536.0944. **FTIR (cm^{-1})** 2949, 1731, 1651, 1429, 1223, 1091.

Trimethyl (*E*)-5-(4-(methoxycarbonyl)phenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4e)



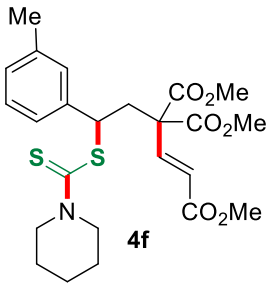
4e

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(4-(methoxycarbonyl)phenyl)cyclopropane-1,1-dicarboxylate **1e** (0.058 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 78/22) of the crude reaction mixture afforded trimethyl (*E*)-5-(4-(methoxycarbonyl)phenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4e** as yellow oil (0.075 g, 70% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.28; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.94 (d, *J* = 8 Hz, 2H), 7.38 (d, *J*=7.85, 2H),7.24 (d, *J*=16.95 Hz, 1H), 5.94 (d, *J* = 16.2 Hz, 1H), 5.27-5.23 (m, 1H), 4.19-4.19 (m, 2H), 3.88 (m, 3H), 3.88-3.79 (m, 2H), 3.74 (s, 3H), 3.69 (s, 3H), 3.40 (s, 3H), 3.10-3.06 (m, 1H), 2.93-2.87 (m, 1H), 1.66 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 192.8, 169.1, 168.9, 166.8, 166.0, 144.9, 142.6, 129.9, 129.6, 129.0, 123.5, 59.0, 53.7, 53.0, 52.2,

52.1, 51.8, 51.5, 42.3, 26.1, 25.4, 24.4. **HRMS (ESI)** m/z: $[M+H]^+$ calcd for $C_{24}H_{32}NO_8S_2$ 538.1564; found 538.1569. **FTIR (cm^{-1})** 2946, 1731, 1611, 1434, 1277, 1113.

Trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(*m*-tolyl)pent-1-ene-1,3,3-tricarboxylate (4f)

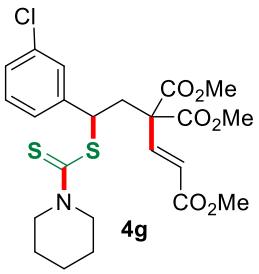


4f

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(*m*-tolyl)cyclopropane-1,1-dicarboxylate **1f** (0.050 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(*m*-tolyl)pent-1-ene-1,3,3-tricarboxylate **4f** as yellow oil (0.068 g, 69% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.34; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.30-7.03 (m, 5H), 5.98 (d, *J* = 16.23 Hz, 1H), 5.16-5.12 (m, 1H), 4.27-4.18 (m, 2H), 3.99-3.82 (m, 2H), 3.76 (s, 3H), 3.72 (s, 3H), 3.39 (s, 3H), 3.15-3.11 (m, 1H), 2.96-2.90 (m, 1H), 2.33 (s, 3H) 1.67 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.4, 169.3, 169.1, 166.1, 142.9, 138.8, 138.3, 129.6, 128.7, 128.5, 126.1, 123.2, 59.0, 53.2, 52.9, 52.7, 52.5, 51.7, 42.5, 26.0, 26.0, 24.4, 21.4. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{24}H_{31}NaNO_6S_2$ 516.1485; found 516.1491. **FTIR (cm^{-1})** 2944, 1735, 1651, 1433, 1230, 1012.

Trimethyl (*E*)-5-(3-chlorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4g)



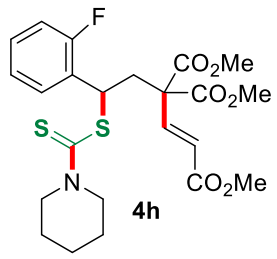
4g

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(3-chlorophenyl)cyclopropane-1,1-dicarboxylate **1g** (0.054 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl

(*E*)-5-(3-chlorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4g** as yellow oil (0.062 g, 60% yield with E/Z ratio 4:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.33; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.31-7.23 (m, 5H) 5.99 (d, *J* = 16.92 Hz, 1H), 5.22-5.18 (m, 1H), 4.23-4.10 (m, 2H), 3.94-3.81 (m, 2H), 3.77 (s, 3H), 3.75 (s, 3H), 3.48 (s, 3H), 3.12-3.07 (m, 1H), 2.93-2.87 (m, 1H), 1.69 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 192.5, 169.1, 168.9, 166.0, 142.7, 141.5, 134.3, 129.9, 128.8, 128.1, 127.4, 123.5, 58.9, 53.4, 53.0, 52.9, 52.5, 51.8, 51.4, 42.3, 26.1, 25.5, 24.3. **HRMS (ESI)** m/z: $[M+H]^+$ calcd for $C_{23}H_{29}ClNO_6S_2$ 514.1119; found 514.1125. **FTIR (cm^{-1})** 2945, 1735, 1652, 1433, 1231, 1126.

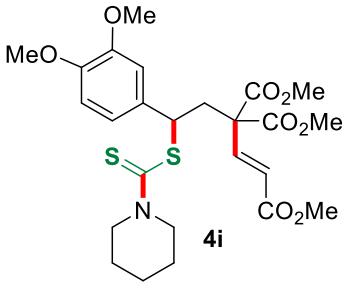
Trimethyl (*E*)-5-(2-fluorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4h)



Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(2-fluorophenyl)cyclopropane-1,1-dicarboxylate **1h** (0.050 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-(2-fluorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4h** as yellow oil (0.060 g, 60% yield with E/Z ratio 6:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.34; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.33-7.21 (m, 3H), 7.07-6.96 (m, 2H), 6.00 (d, *J* = 16.6 Hz, 1H), 5.49-5.45 (m, 1H), 4.22-4.11 (m, 2H), 3.96-3.81 (m, 2H), 3.75 (s, 3H), 3.71 (s, 3H), 3.43 (s, 3H), 3.05-3.03 (m, 2H), 1.64 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.3, 169.2, 169.0, 166.1, 161.1 (d, *J* = 249.2 Hz), 142.6, 131.1 (d, *J* = 4.4 Hz), 129.7 (d, *J* = 8.4 Hz), 126.8 (d, *J* = 14.2 Hz), 124.2 (d, *J* = 3.3 Hz), 123.4, 115.9 (d, *J* = 21.7 Hz), 59.0, 53.3, 52.9, 51.8, 51.6, 47.8, 41.4, 26.0, 25.6, 24.4. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{23}H_{28}FNNaO_6S_2$ 520.1234; found 520.1243. **FTIR (cm^{-1})** 2944, 1736, 1651, 1436, 1231, 1013.

Trimethyl (*E*)-5-(3,4-dimethoxyphenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4i)

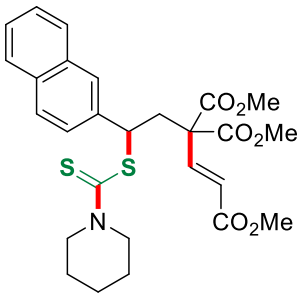


4i

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(3,4-dimethoxyphenyl)cyclopropane-1,1-dicarboxylate **1i** (0.059 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-(2-fluorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylatetrimethyl (*E*)-5-(3,4-dimethoxyphenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4i** as yellow oil (0.055 g, 51% yield with E/Z ratio 4:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.21; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.26-7.21 (m, 1H), 6.87-6.75 (m, 3H), 5.93 (d, *J* = 16.4 Hz, 1H), 5.09-5.05 (m, 1H), 4.28-4.17 (m, 2H), 4.00-3.90 (m, 2H), 3.88 (s, 3H), 3.84 (s, 3H), 3.76 (s, 3H), 3.70 (s, 3H), 3.42 (s, 3H), 3.15-3.10 (m, 1H) 2.91-2.85 (m, 1H),1.66 (bs, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.5, 169.3, 169.2, 166.2, 149.0, 148.9, 142.8, 131.2, 123.0, 121.4, 112.2, 111.1, 59.0, 56.1, 56.0, 53.3, 52.9, 52.7, 52.5, 51.8, 51.5, 42.9, 26.1, 25.5, 24.4. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{25}H_{33}NNaO_8S_2$ 562.1540; found 562.1547. **FTIR (cm^{-1})** 2942, 1735, 1651, 1514, 1436, 1239.

Trimethyl (*E*)-5-(naphthalen-2-yl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4j)



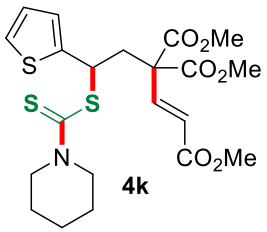
4j

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(naphthalen-2-yl)cyclopropane-1,1-dicarboxylate **1j** (0.057 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) were added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 80/20) of the crude reaction

mixture afforded trimethyl (*E*)-5-(naphthalen-2-yl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4j** as yellow oil (0.063 g, 60% yield with E/Z ratio 6:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.33; **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.81-7.76 (m, 4H),7.48-7.39 (m, 3H), 7.26-7.20 (m, 1H), 5.91 (d, *J* = 16.4 Hz, 1H), 5.36-5.32 (m, 1H), 4.25-4.19 (m, 2H), 3.87-3.79 (m, 2H), 3.76 (s, 3H), 3.47 (s, 3H), 3.23 (s, 3H), 3.21-3.17 (m, 1H), 3.07-3.01 (m, 1H), 1.65 (bs, 6H). **^{13}C NMR (100 MHz, CDCl$_3$)** δ 193.0, 169.3, 169.1, 165.9, 142.9, 136.3, 133.2, 133.0, 128.4, 128.1, 128.0, 127.6, 126.6, 126.4, 126.3, 123.0, 59.0, 53.3, 52.8, 52.7, 51.6, 51.3, 42.6, 26.1, 25.5, 24.3. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{27}H_{31}NNaO_6S_2$ 552.1485; found 552.1490. **FTIR (cm^{-1})** 2947, 1733, 1651, 1429, 1224, 1130.

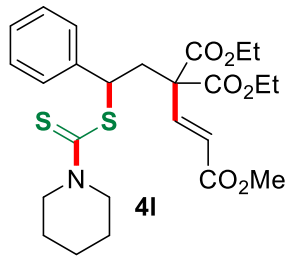
Trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(thiophen-2-yl)pent-1-ene-1,3,3-tricarboxylate (4k)



Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 μL, 0.4 mmol), CS_2 (0.030 g, 24 μL, 0.4 mmol), and dimethyl 2-(thiophen-2-yl)cyclopropane-1,1-dicarboxylate **1k** (0.048 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 μL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(thiophen-2-yl)pent-1-ene-1,3,3-tricarboxylatee **4k** as yellow oil (0.069 g, 71% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.29; **^{1}H NMR (400 MHz, CDCl$_3$)** δ 7.33 (d, *J*=16.4, 1H), 7.18 (d, *J* = 5.6 Hz, 1H), 7.09 (d, *J* = 4.2 Hz, 1H), 6.89-6.87 (m, 1H), 5.97 (d, *J* = 16.4 Hz, 1H), 5.53- 5.50 (m, 1H), 4.26-4.10 (m, 2H), 3.97-3.78 (m, 2H), 3.75 (s, 3H), 3.72 (s, 3H), 3.52 (s, 3H), 3.16-3.12 (m, 1H), 2.95- 2.88(m, 1H) 1.65 (bs, 6H). **^{13}C NMR (100 MHz, CDCl$_3$)** δ 192.7, 169.2, 169.1, 166.1, 142.6, 142.4, 127.0, 126.7, 125.6, 123.2, 59.0, 53.3, 53.0, 52.9, 51.8, 51.6, 47.8, 43.8, 26.2, 25.6, 24.4. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{21}H_{27}NNaO_6S_3$ 508.0893; found 508.0897. **FTIR (cm^{-1})** 2944, 1735, 1650, 1434, 1232, 1010.

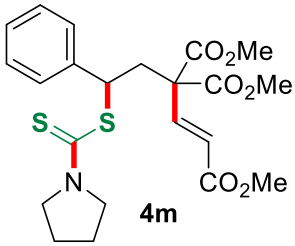
3,3-Diethyl 1-methyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4l)



Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and diethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1l** (0.052 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded 3,3-diethyl 1-methyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4l** as yellow oil (0.071 g, 70% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.34; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.34-7.29 (m, 5H), 7.27-7.22 (m, 1H), 6.00 (d, *J* = 16.4 Hz, 1H), 5.21-5.17 (m, 1H), 4.26-4.21 (m, 4H), 3.85-3.75 (m, 4H), 3.73 (s, 3H), 3.16-3.11 (m, 1H), 2.97-2.91 (m, 1H), 1.68 (bs, 6H), 1.30-1.24 (m, 3H), 1.15-1.12 (m, 3H),. **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.2, 168.8, 168.6, 166.2, 143.2, 139.1, 129.0, 128.5, 127.9, 123.1, 62.3, 61.9, 59.0, 52.7, 52.5, 51.8, 51.4, 42.5, 26.1, 25.5, 24.4, 14.0, 13.8. **HRMS (ESI)** m/z: $[M+H]^+$ calcd for $C_{25}H_{34}NO_6S_2$ 508.1822; found 508.1834. **FTIR (cm^{-1})** 2926, 2855, 1728, 1428, 1221, 1185.

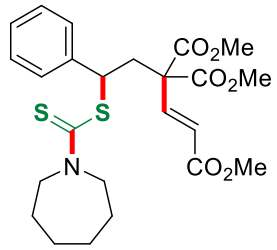
Trimethyl (*E*)-5-phenyl-5-((pyrrolidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4m)



Following the general procedure, a mixture of pyrrolidine **2b** (0.028 g, 33 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-phenyl-5-((pyrrolidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4m** as yellow oil (0.068 g, 73% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.33; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.31-7.19 (m, 6H), 5.98 (d, *J* = 16.5 Hz, 1H), 5.21- 5.17 (m, 1H), 3.92-3.81 (m, 2H), 3.73 (s, 3H), 3.71 (s, 3H), 3.57-3.48 (m, 2H) ,3.37 (s, 3H), 3.12-3.08(m, 1H), 2.97-2.94 (m, 1H), 2.06-1.88 (m, 4H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 190.4, 169.2, 169.0, 166.1, 142.8, 139.2, 128.9, 128.6, 127.9, 123.4, 58.9, 55.0, 53.3, 52.8, 51.8, 51.6, 50.6, 42.5, 26.1, 24.3. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{22}H_{27}NNaO_6S_2$ 488.1172; found 488.1178. **FTIR (cm^{-1})** 2955, 1735, 1652, 1436, 1261, 1010.

Trimethyl (*E*)-5-((azepane-1-carbonothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4n)



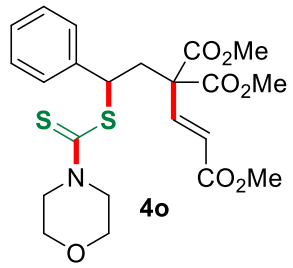
4n

Following the general procedure, a mixture of azepane **2c** (0.039 g, 45 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. Then, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 80/20) of the crude reaction mixture afforded Trimethyl (*E*)-5-((azepane-1-carbonothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate **4n** as yellow oil (0.038 g, 66% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.33; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.32-7.28 (m, 5H),7.26-7.24 (m, 1H), 6.02 (d, *J* = 16.4 Hz, 1H), 5.19-5.15 (m, 1H), 4.23-4.16 (m, 1H), 4.12-4.07 (m, 1H), 3.88-3.79 (m, 2H), 3.76 (s, 3H), 3.73 (s, 3H), 3.39 (s, 3H), 3.17-3.12 (m, 1H), 2.98-2.91 (m, 1H), 1.79-1.56 (m, 8H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 194.0, 169.3, 169.1, 166.1, 142.8, 139.0, 129.0, 128.6, 127.9, 123.4, 59.0, 55.6, 53.3, 52.8, 52.3, 51.8, 42.4, 27.6, 26.7, 26.6, 26.3, 25.6. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{24}H_{31}NNaO_6S_2$ 516.1485; found 516.1490. **FTIR (cm^{-1})** 2929, 1731, 1604, 1434, 1415, 1196.

Trimethyl (*E*)-5-((morpholine-4-carbonothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4o)

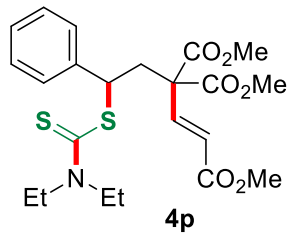
Following the general procedure, a mixture of morpholine **2d** (0.035 g, 35 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate



3a (0.034 g, 36 μL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-((morpholine-4-carbonothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate **4o** as yellow oil (0.039 g, 41% yield with E/Z ratio 4:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.29; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.31-7.23 (m, 6H), 5.98 (d, *J* = 16.5 Hz, 1H), 5.21- 5.17 (m, 1H), 4.30-4.06 (m, 2H), 3.91-3.79 (m, 2H), 3.73 (s, 3H), 3.72 (s, 3H), 3.64-3.55 (m, 4H), 3.36 (s, 3H), 3.12-3.07 (m, 1H), 2.97-2.91 (m, 1H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 195.1, 169.2, 169.0, 166.1, 142.7, 138.8, 129.0, 128.7, 128.1, 123.4, 66.3, 58.9, 53.3, 52.8, 52.4, 51.8, 50.9, 50.8, 42.4, 29.8. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{21}H_{27}NNaO_7S_2$ 504.1121; found 504.1127. **FTIR (cm^{-1})** 2953, 1743, 1650, 1429, 1224, 1116.

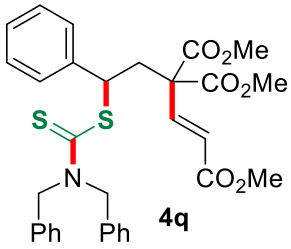
Trimethyl (*E*)-5-((diethylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4p)



Following the general procedure, a mixture of diethylamine **2e** (0.029 g, 29 μL, 0.4 mmol), CS_2 (0.030 g, 24 μL, 0.4 mmol), and dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 μL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded trimethyl (*E*)-5-((diethylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate **4p** as yellow oil (0.064 g, 69% yield with E/Z ratio 4:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.32; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.31-7.19 (m, 6H), 5.98 (d, *J* = 16.5 Hz, 1H), 5.15- 5.11 (m, 1H), 4.02-3.90 (m, 2H), 3.73 (s, 3H), 3.71 (s, 3H), 3.67-3.62 (m, 2H) ,3.36 (s, 3H), 3.14-3.09 (m, 1H), 2.95-2.89 (m, 1H), 1.24-1.20 (m, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.2, 169.3, 169.1, 166.1, 142.8, 139.0, 129.0, 128.6, 127.9, 123.4, 59.0, 53.3, 52.8, 52.4, 51.8, 49.4, 46.7, 42.5, 12.7, 11.7. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{22}H_{29}NNaO_6S_2$ 490.1329; found 490.1334. **FTIR (cm^{-1})** 2950, 1735, 1651, 1433, 1267, 1006.

Trimethyl (*E*)-5-((dibenzylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4q)

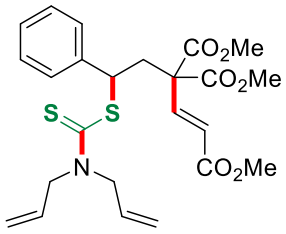


4q

Following the general procedure, a mixture of dibenzylamine **2f** (0.079 g, 77 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that , Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded Trimethyl (*E*)-5-((dibenzylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate **4q** as yellow oil (0.092 g, 78 % yield with E/Z ratio 7:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.35; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.35-7.27 (m, 11H), 7.24-7.21 (m, 3H), 7.14-7.13 (m, 2H), 6.03 (d, *J* = 16.5 Hz, 1H), 5.38-5.34 (m, 1H), 5.23-5.20 (m, 1H), 5.15-5.11 (m, 1H), 4.90-4.75 (m, 2H), 3.74 (s, 3H), 3.72 (s, 3H), 3.37 (s, 3H), 3.23-3.19 (m, 1H), 3.00-2.94 (m, 1H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 197.2, 169.3, 169.0, 166.1, 142.8, 138.6, 135.5, 134.5, 129.1, 128.9, 128.6, 128.10,128.07, 128.01, 127.9, 127.3, 123.5, 58.9, 55.8, 54.0, 53.5, 53.4, 52.9, 51.9, 42.3 **HRMS (ESI)** m/z: $[M+H]^+$ calcd for $C_{32}H_{34}NO_6S_2$ 592.1822; found 592.1847. **FTIR (cm^{-1})** 2950, 1733, 1651, 1436, 1263, 1218.

Trimethyl (*E*)-5-((diallylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4r)

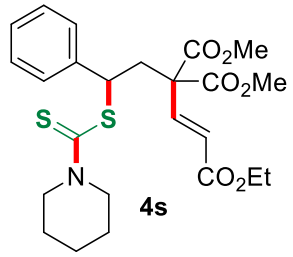


4r

Following the general procedure, a mixture of diallyl amine **2g** (0.039 g, 49 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and methyl propiolate **3a** (0.034 g, 36 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded Trimethyl (*E*)-5-((diallylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate **4r** as yellow oil (0.050 g, 51 % yield with E/Z ratio 6:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.36; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.32-7.28 (m, 5H),7.27-7.25 (m, 1H), 6.01 (d, *J* = 16.3 Hz, 1H), 5.87-5.76 (m, 2H), 5.26-5.12 (m, 5H), 4.67-4.64 (m, 1H), 4.59-4.55 (m, 1H), 4.26 (bs, 2H), 3.76 (s, 3H), 3.74 (s, 3H), 3.39 (s, 3H), 3.16-3.11 (m, 1H), 2.98-2.92 (m, 1H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 195.6, 169.2, 169.0, 166.1, 142.8, 138.8, 131.1, 130.5, 129.0, 128.6, 128.0, 123.4, 118.8, 118.6, 58.9, 56.3, 53.6, 53.3, 52.9, 52.8, 51.8, 42.3. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{24}H_{29}NNaO_6S_2$ 514.1329; found 514.1334. **FTIR (cm^{-1})** 2922, 1730, 1646, 1434, 1400, 1224.

1-Ethyl 3,3-dimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4s)



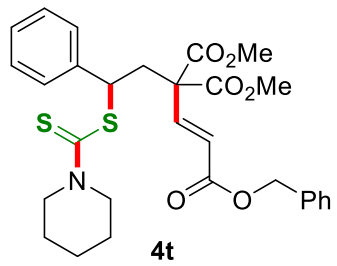
4s

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-phenylcyclopropane-1,1-dicarboxylate **1a** (0.046 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and ethyl propiolate **3b** (0.039 g, 40 µL, 0.4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 81/19) of the crude reaction mixture afforded 1-ethyl 3,3-dimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4s** as yellow oil (0.060 g, 61% yield with E/Z ratio 5:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.32; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.32-7.20 (m, 6H), 5.97 (d, *J* = 16.8 Hz, 1H), 5.20- 5.17 (m, 1H), 4.20-4.15 (m, 4H), 3.93-3.79 (m, 2H), 3.75 (s, 3H), 3.37 (s, 3H), 3.14-3.10 (m, 1H), 2.97-2.91 (m, 1H), 1.67 (s, 6H), 1.31-1.26 (m, 3H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.2, 169.3, 169.1, 165.7, 142.5, 139.1, 129.0, 128.6, 128.0, 123.8, 60.6, 59.0, 53.2, 52.8, 52.5, 51.5, 42.6, 29.7, 25.8, 25.7, 24.4, 14.3. **HRMS (ESI)** m/z: $[M+Na]^+$ calcd for $C_{24}H_{31}NNaO_6S_2$ 516.1485 ; found 516.1489. **FTIR (cm^{-1})** 2942, 1734, 1650, 1434, 1232, 1123.

1-Benzyl 3,3-dimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4t)

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1a** (0.047 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and

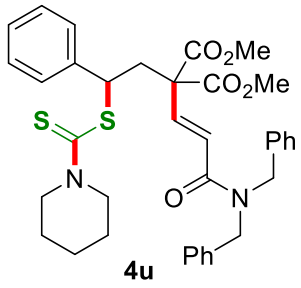


4t

the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and benzyl propiolate **3c** (0.064 g, 62 µL, 4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded 1-benzyl 3,3-dimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4t** as yellow oil (0.072 g, 65% yield with E/Z ratio 4:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.35; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.37-7.31 (m, 6H), 7.28-7.26 (m, 2H), 7.21-7.19 (m, 2H), 7.15-7.12 (m, 1H), 5.99 (d, *J* = 16.2 Hz, 1H), 5.18-5.13 (m, 3H), 4.22-4.06 (m, 2H), 3.75 (bs, 2H), 3.71 (s, 3H), 3.35 (s, 3H), 3.12-3.07 (m, 1H), 2.94-2.88 (m, 1H), 1.63 (bs, 6H) . **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.0, 169.2, 169.0, 165.4, 143.1, 138.9, 135.9, 128.9, 128.6, 128.5, 128.4, 128.3, 128.0, 123.3, 66.4, 58.9, 53.3, 52.8, 52.4, 51.3, 42.6, 26.1, 25.5, 24.3. **HRMS (ESI)** m/z: $[M+H]^+$ calcd for $C_{29}H_{34}NO_6S_2$ 556.1822; found 556.1830. **FTIR (cm^{-1})** 2945, 1732, 1649, 1428, 1223, 1171.

Dimethyl (*E*)-2-(3-(dibenzylamino)-3-oxoprop-1-en-1-yl)-2-(2-phenyl-2-((piperidine-1-carbonothioyl)thio)ethyl)malonate (4u)



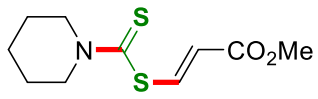
4u

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1a** (0.047 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C and the mixture was stirred for 16 h. After that, Cs_2CO_3 (0.163 g, 0.5 mmol) and *N*,*N*-dibenzyl propiolamide **3d** (0.099 g, 0.4 mmol) and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 82/18) of the crude reaction mixture afforded Dimethyl (*E*)-2-(3-(dibenzylamino)-3-oxoprop-1-en-1-yl)-2-(2-phenyl-2-((piperidine-1-carbonothioyl)thio) ethyl)malonate **4u** as yellow oil (0.094 g, 73% yield with E/Z ratio >19:1).

***R*f** (Pet. ether /EtOAc = 80/20): 0.23; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.42-7.32 (m, 5H), 7.29-7.22 (m, 8H), 7.20-7.16 (m, 3H), 6.60 (d, *J* = 15.8 Hz, 1H), 5.19-5.15 (m, 1H), 4.87-4.84 (m, 1H), 4.68-4.64 (m, 1H), 4.49-4.42 (m, 2H), 4.24-4.11 (m, 2H), 3.78 (bs, 2H), 3.56 (s, 3H), 3.23 (s, 3H), 3.16-3.11 (m, 1H), 2.94-2.88 (m, 1H), 1.65 (bs, 6H) . **^{13}C NMR (100 MHz, $CDCl_3$)** δ 193.2, 169.6, 169.3, 166.2, 140.4, 138.8, 137.3, 136.9, 129.1, 128.9, 128.7, 128.5, 128.5, 128.0, 127.6, 127.5, 126.8, 123.4, 59.0, 53.1, 52.6, 52.4, 51.3, 50.3, 48.9, 41.8, 26.1, 25.5, 24.3.

HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{36}H_{41}N_2O_5S_2$ 645.2451; found 645.2482. **FTIR (cm^{-1})** 2945, 1735, 1658, 1621, 1427, 1224.

Methyl (*E*)-3-((piperidine-1-carbonothioyl) thio)acrylate (5a)



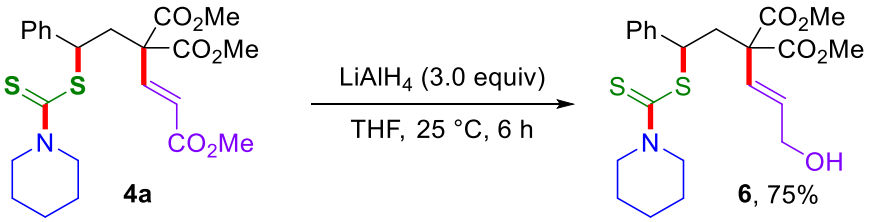
5a

Following the general procedure, a mixture of piperidine **2a** (0.034 g, 39 µL, 0.4 mmol), CS_2 (0.030 g, 24 µL, 0.4 mmol), and dimethyl 2-(phenyl)cyclopropane-1,1-dicarboxylate **1a** (0.047 g, 0.2 mmol) were treated with $Yb(OTf)_3$ (0.025 g, 0.04 mmol) in THF (1.5 mL) at 25 °C .After that, Cs_2CO_3 (0.163 g, 0.5 mmol) methyl propiolate **3a** (0.064 g, 62 µL, 4 mmol) was added and then stirring for 12 h followed by purification via silica gel flash column chromatography (Pet. ether /EtOAc = 84/16) of the crude reaction mixture afforded Methyl (*E*)-3-((piperidine-1-carbonothioyl) thio)acrylate **5a** as yellow oil (0.045 g, 46% yield).

***R*f** (Pet. ether /EtOAc = 80/20): 0.37; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 8.73 (d, J = 10.5 Hz, 1H), 6.12 (d, J = 10.4 Hz, 1H), 4.33 (s, 2H), 4.01 (s, 2H), 3.75 (s, 3H), 1.72 (m, 6H). **^{13}C NMR (100 MHz, $CDCl_3$)** δ 191.6, 167.0, 146.1, 114.4, 54.4, 51.7, 29.7, 26.4, 25.5, 24.3.

6. Product Functionalization

Selective reduction of the allylic ester to alcohol



Compound **6** was prepared using the literature procedure.[2] To a 25 mL two neck round bottom flask equipped with stir bar, $LiAlH_4$ (0.023 g, 0.6 mmol) was dissolved in dry THF (1.0 mL). The reaction mixture was cooled to 0 °C with an ice bath. Then, the solution of trimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate **4a** (0.096 g, 0.2 mmol) in dry THF (1.0 mL) was added slowly and reaction mixture was allowed to stir for 12h at room temperature. After this time, the reaction was cooled to 0 °C and quenched with 10% KOH solution (2.0 mL). The resulting suspension was filtered through celite, washed with ethyl acetate. The combined filtrate was dried, concentrated and purified by flash column chromatography (Pet. ether /EtOAc = 70/30) of the crude reaction mixture afforded dimethyl (*E*)-2-(3-hydroxyprop-

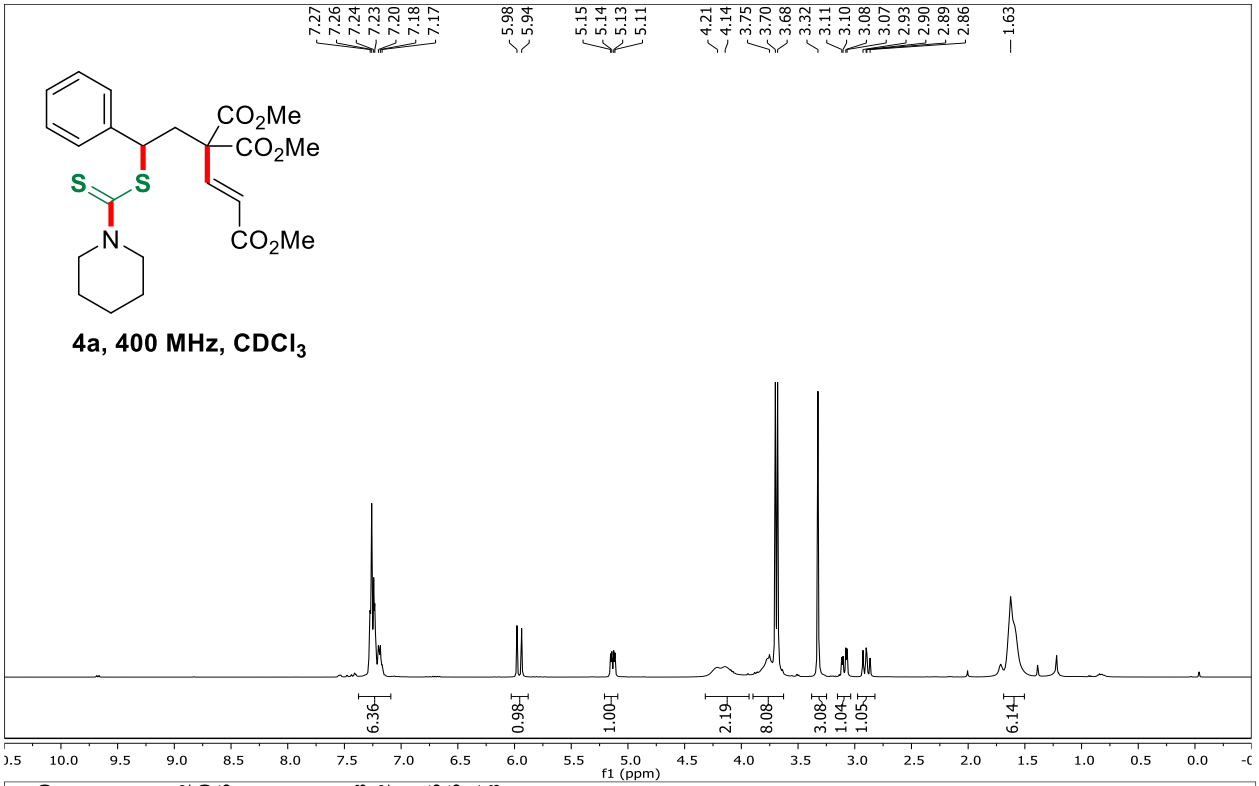
[2] A. O. Chagarovskiy, V. S. Vasin, V. V. Kuznetsov, O. A. Ivanova, V. B. Rybakov, A. N. Shumsky, N. N. Makhova and I. V. Trushkov, *Angew. Chem., Int. Ed.*, 2018, **57**, 10338.

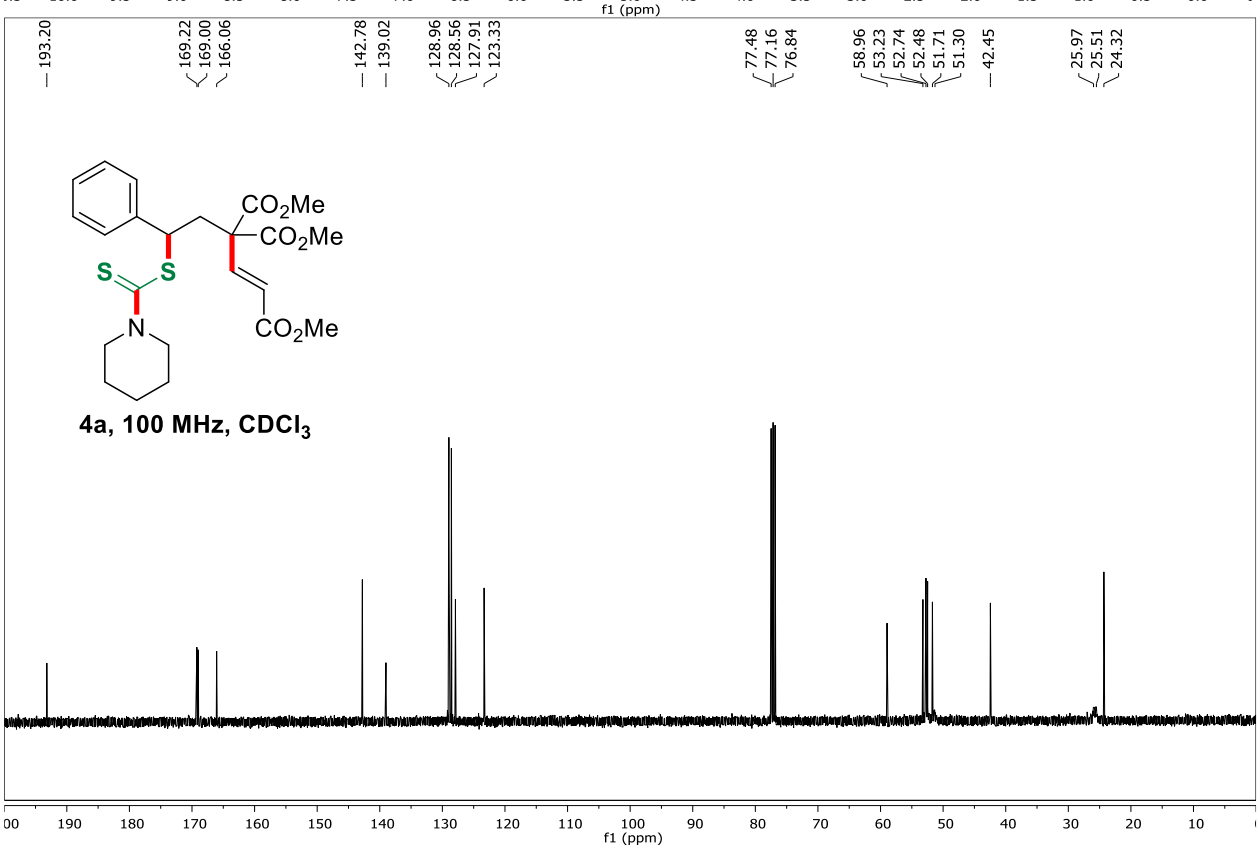
1-en-1-yl)-2-(2-phenyl-2-((piperidine-1-carbonothioyl)thio)ethyl)malonate **6** as a white solid (0.068 g, 75% yield).

***R*f** (Pet. ether /EtOAc = 76/24): 0.19; **^{1}H NMR (400 MHz, $CDCl_3$)** δ 7.36-7.34 (m, 3H), 7.29-7.25 (m, 3H), 7.23-7.21 (m, 1H), 6.91 (t, J = 7.3 Hz, 1H), 5.40-5.26 (m, 1H), 4.31-4.14 (m, 2H), 3.89-3.82 (m, 2H), 3.71 (s, 3H), 3.60 (s, 3H), 3.47-3.41 (m, 1H), 3.32-3.16 (m, 2H), 3.09-3.03 (m, 1H), 1.67-1.64 (m, 6H) . **^{13}C NMR (100 MHz, $CDCl_3$)** δ 194.1, 170.9, 167.6, 140.4, 135.9, 132.0, 128.6, 128.4, 127.6, 55.4, 53.0, 52.3, 52.0, 51.5, 34.4, 34.0, 26.1, 25.5, 24.4. **HRMS (ESI)** m/z: $[M+H]^+$ calcd for $C_{22}H_{30}NO_5S_2$ 452.1560; found 452.1827. **FTIR (cm^{-1})** 2925, 1738, 1714, 1428, 1226, 1165.

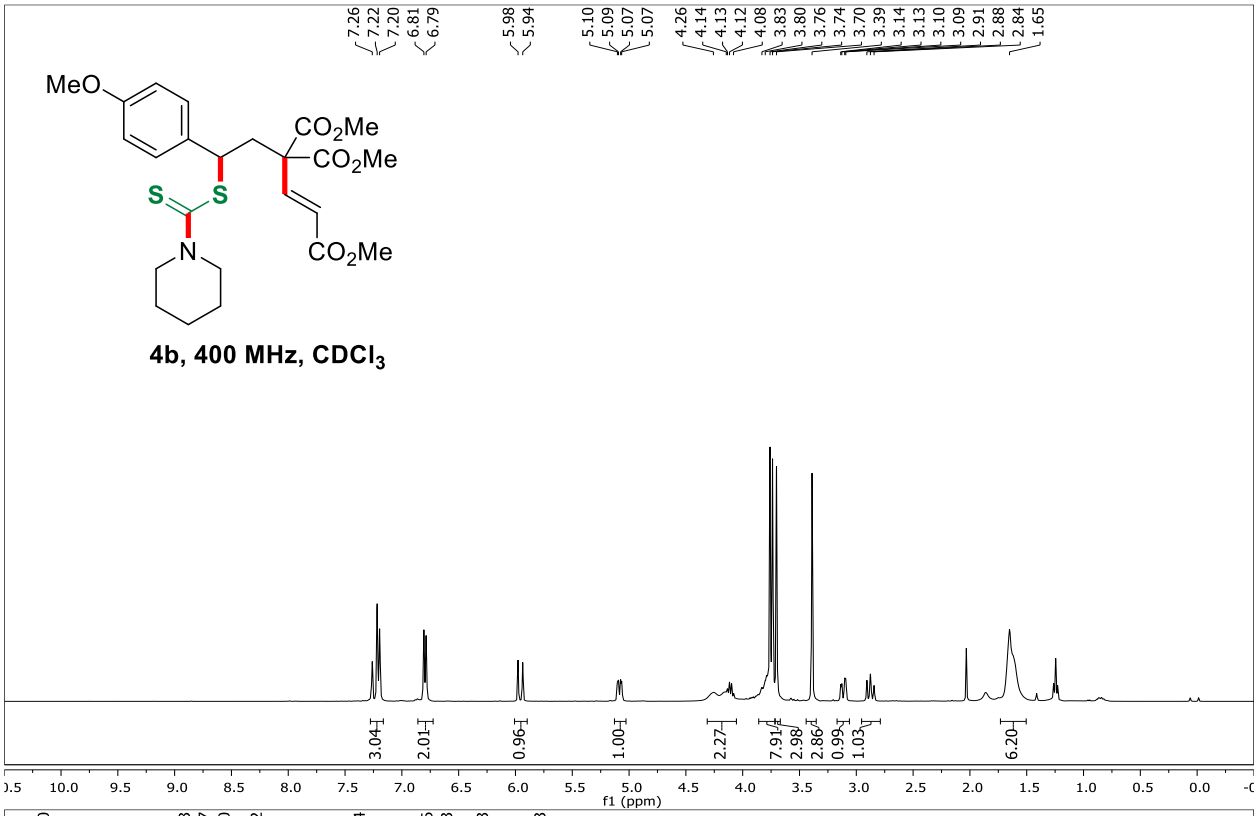
7. ^{1}H and ^{13}C NMR Spectra of all Products

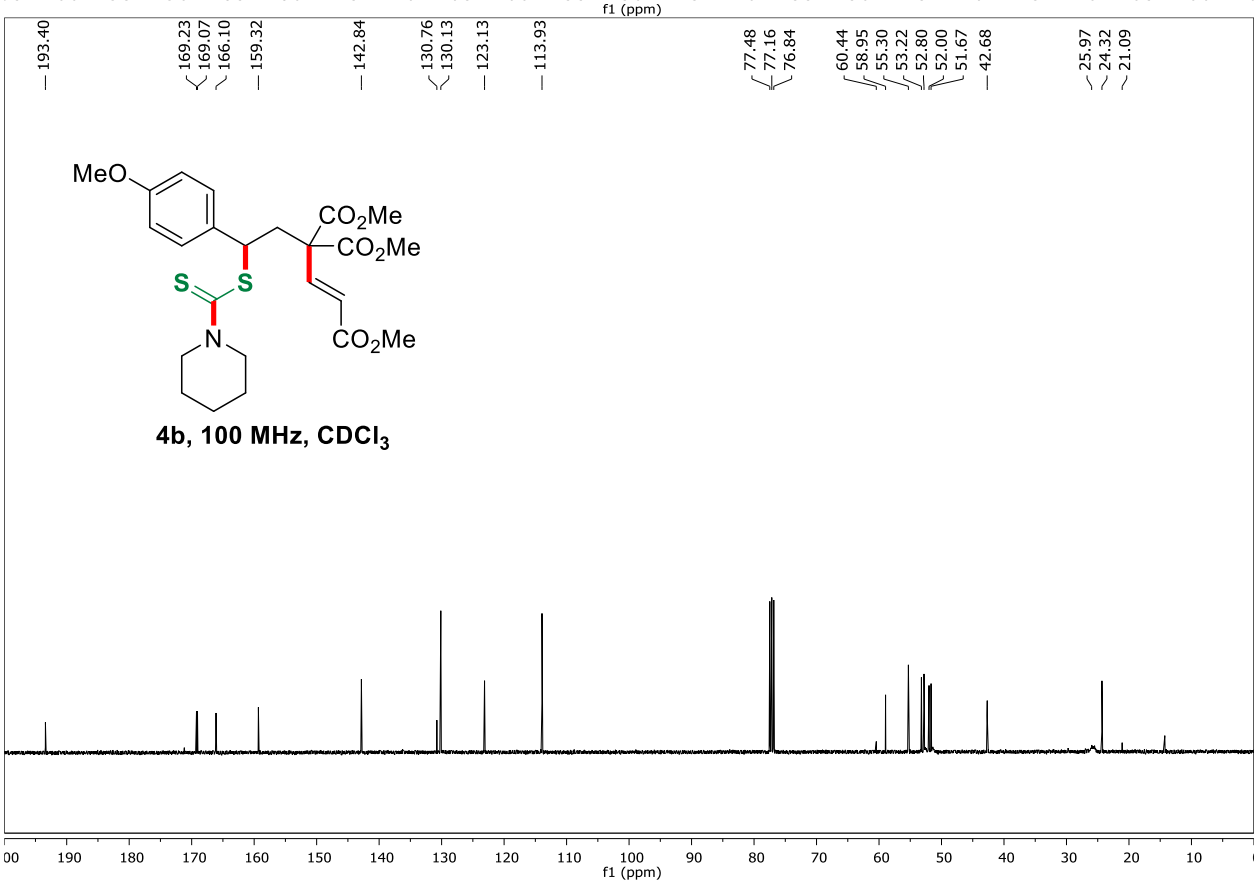
Trimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4a)



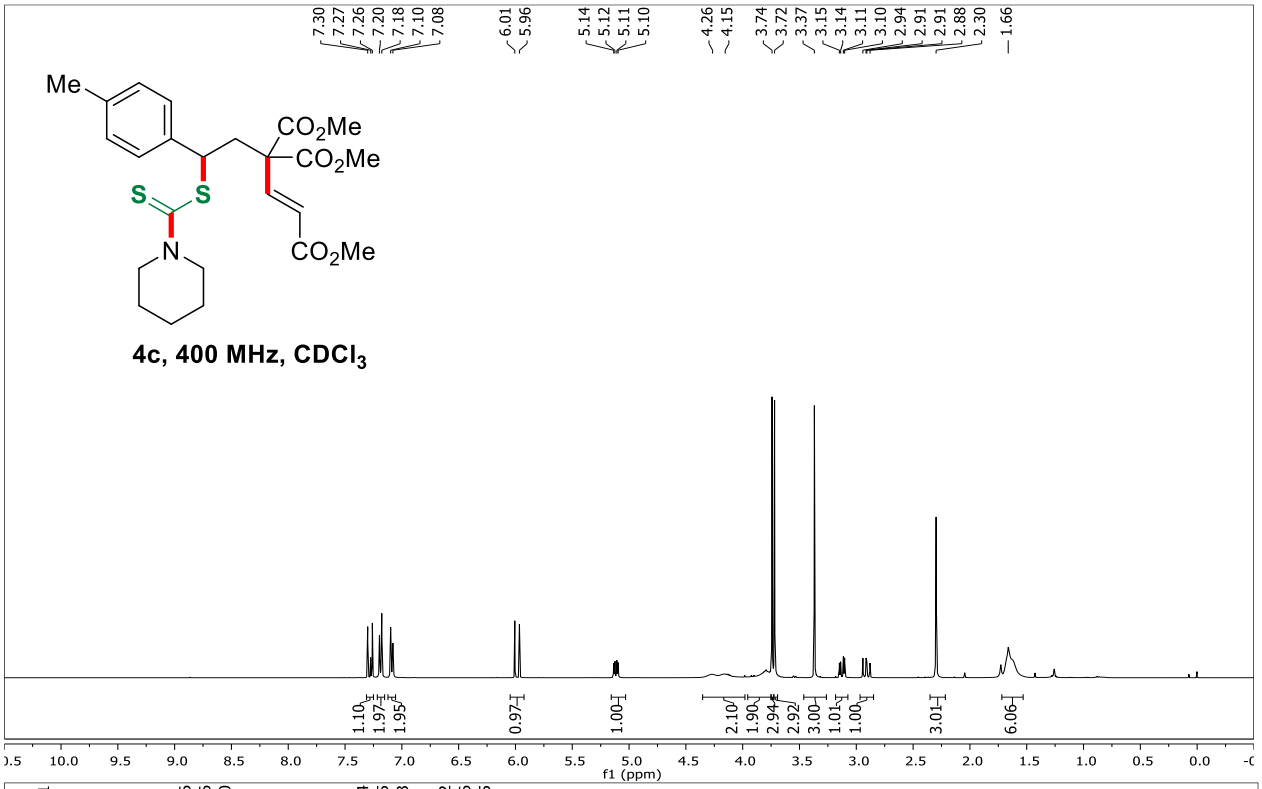


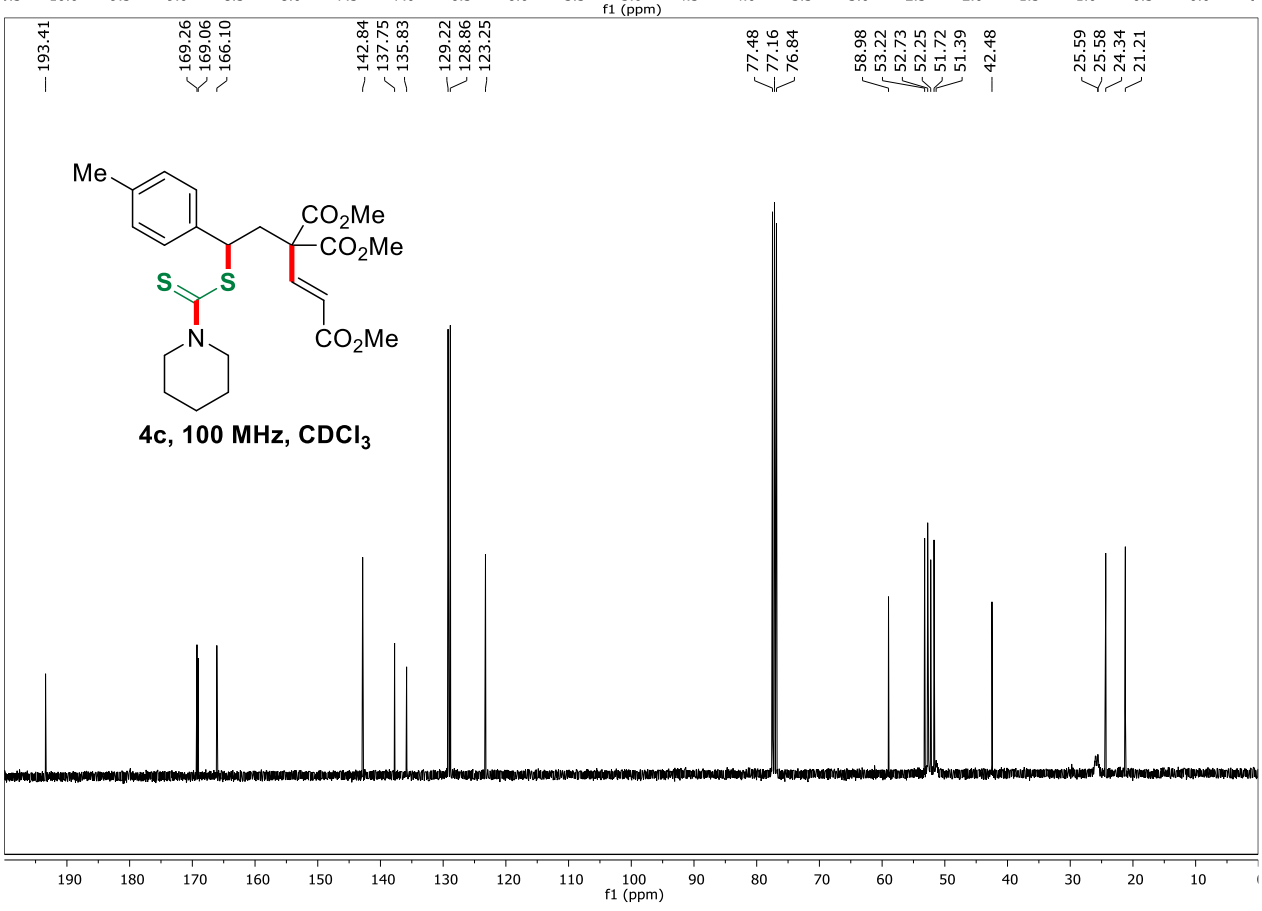
Trimethyl (*E*)-5-(4-methoxyphenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4b)



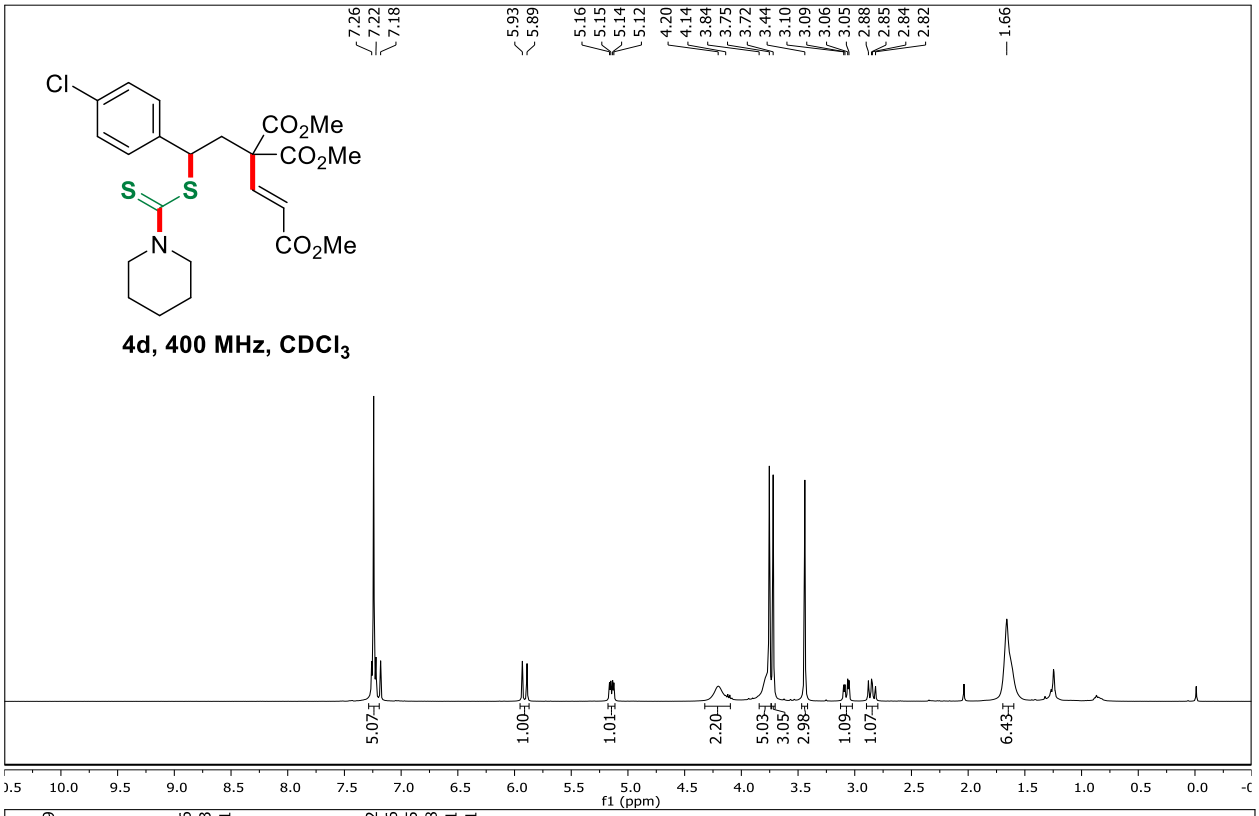


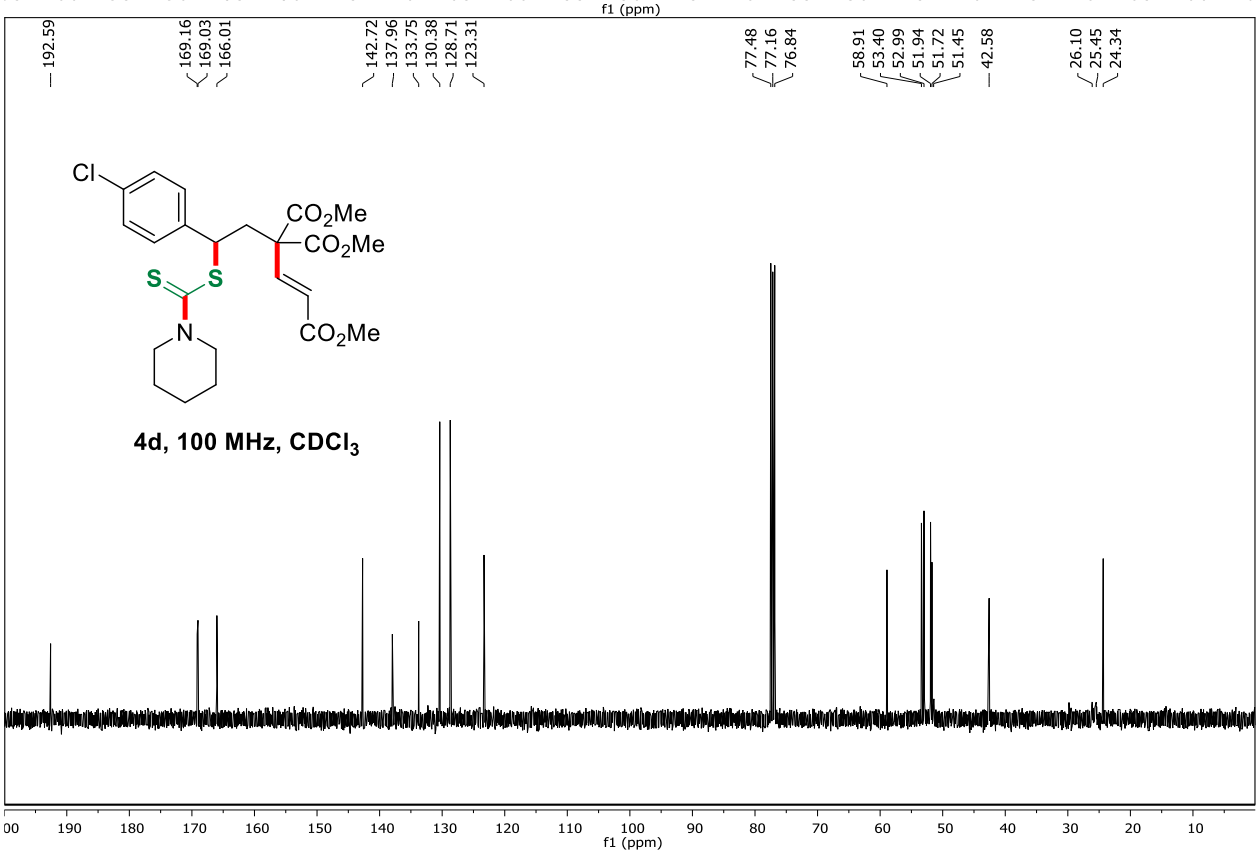
Trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(*p*-tolyl)pent-1-ene-1,3,3-tricarboxylate (4c)



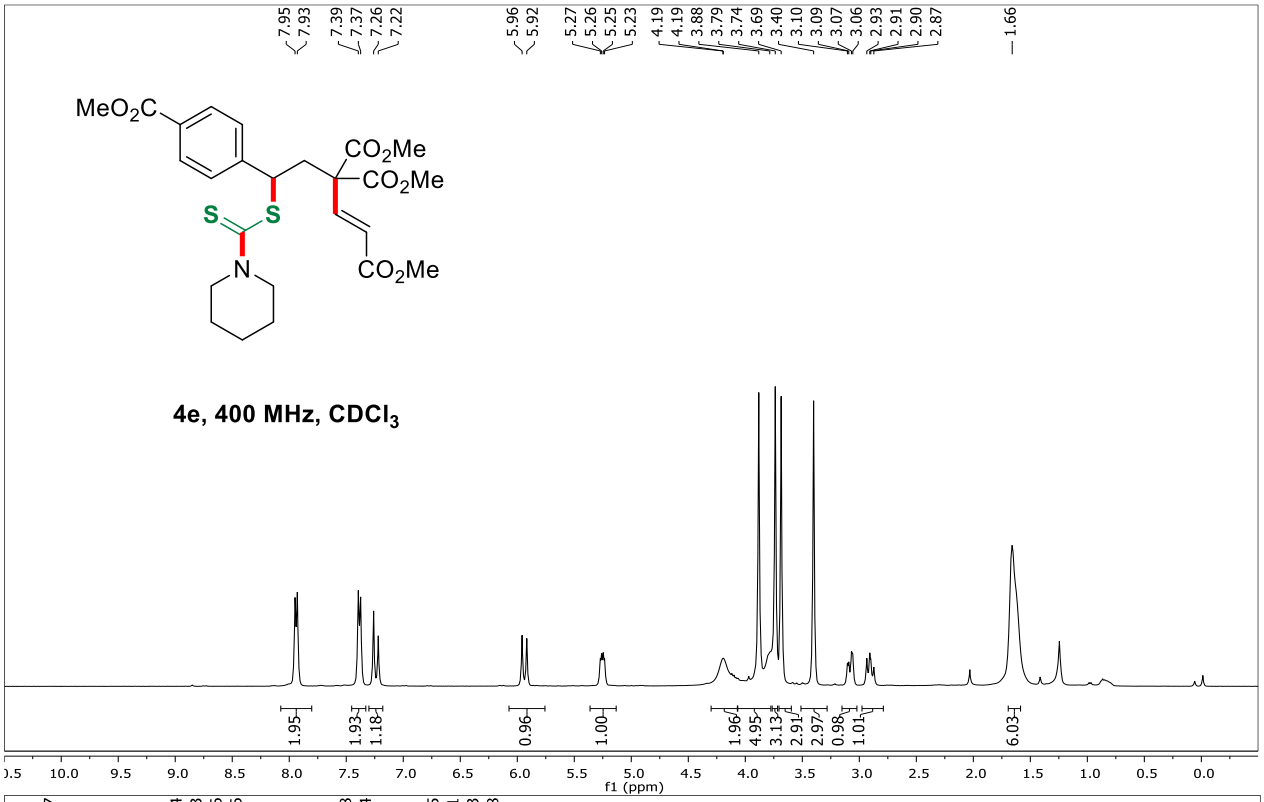


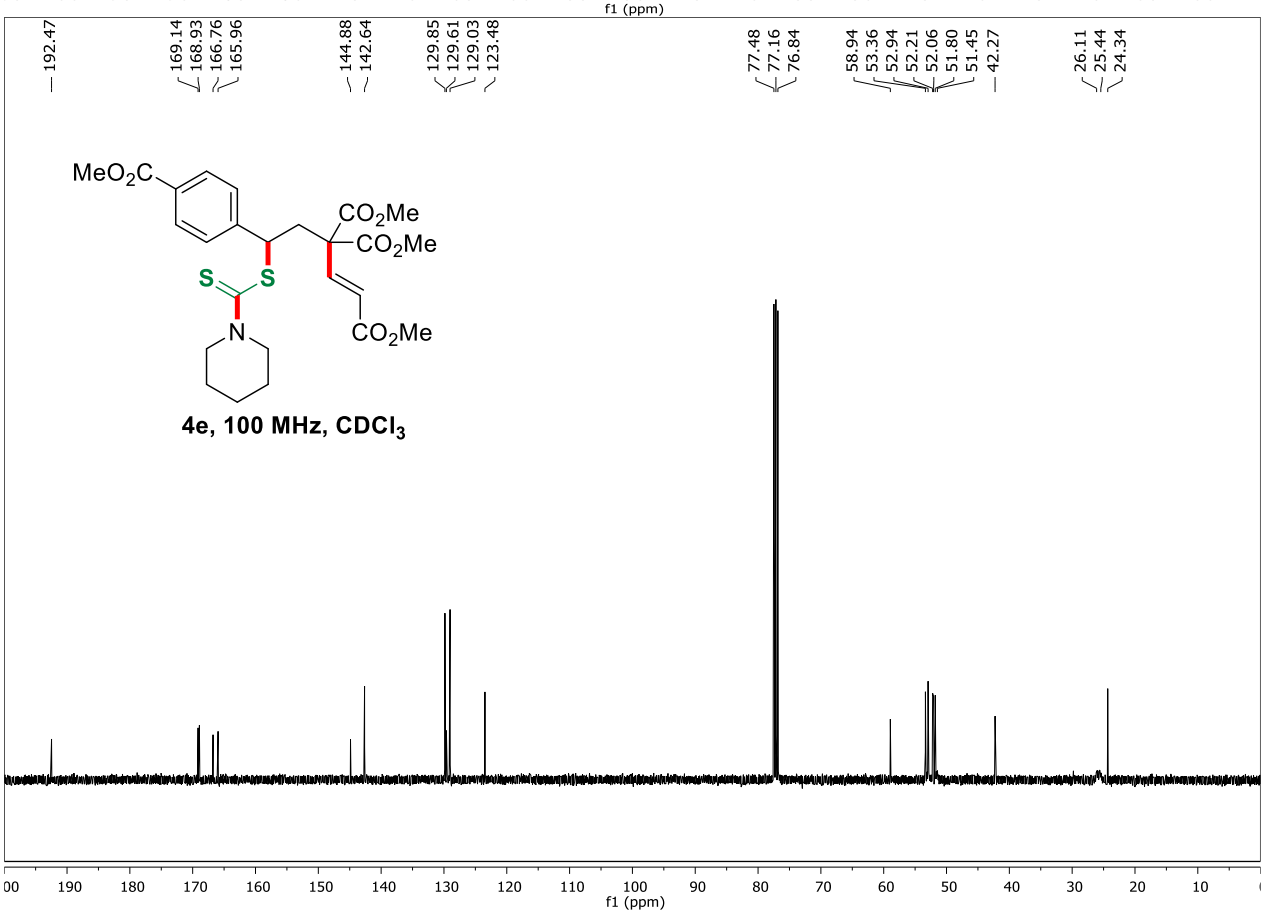
Trimethyl (*E*)-5-(4-chlorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4d)



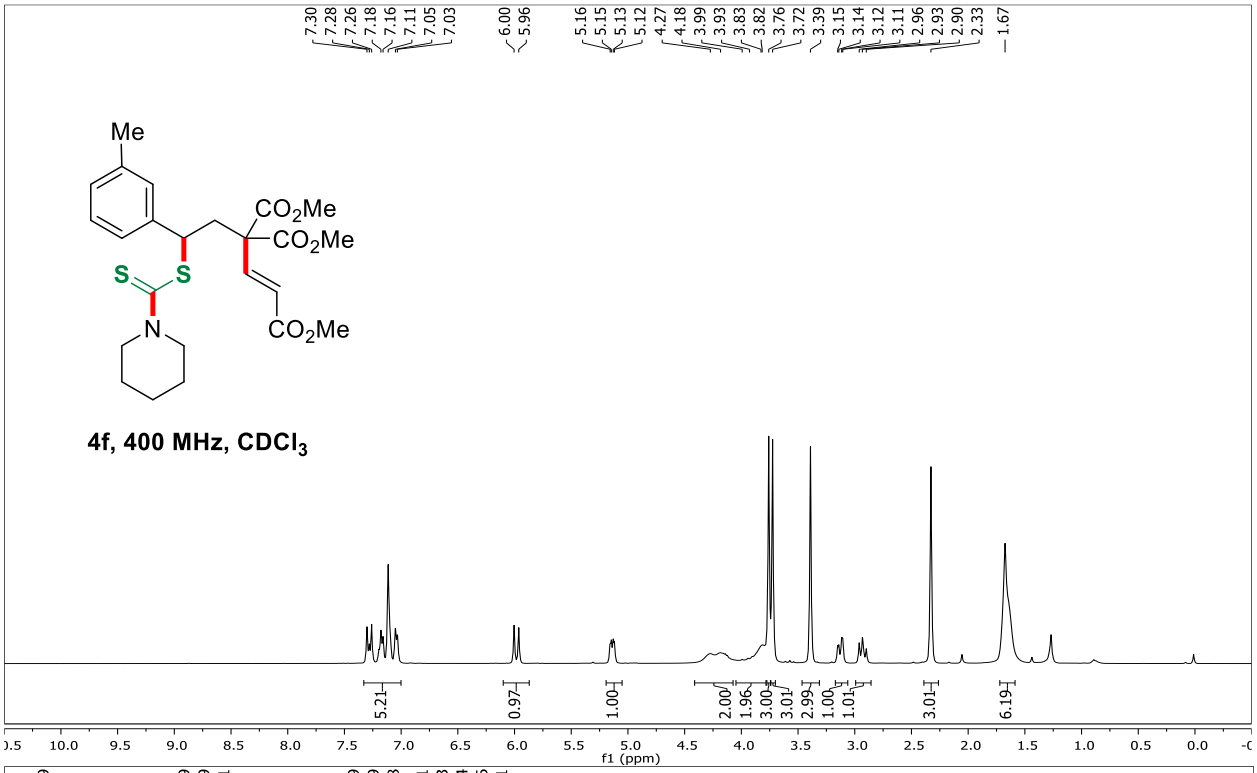


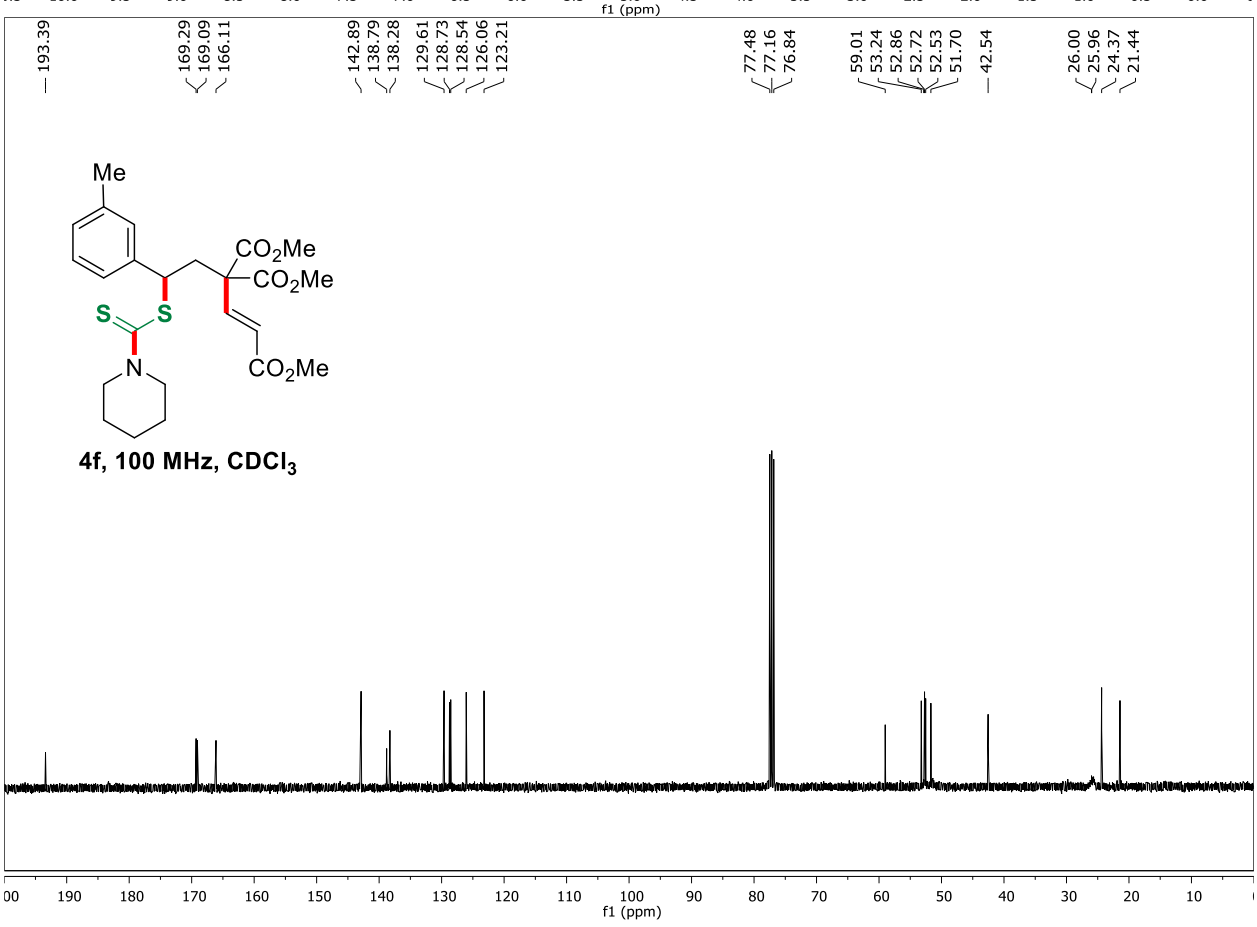
Trimethyl (*E*)-5-(4-(methoxycarbonyl)phenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4e)



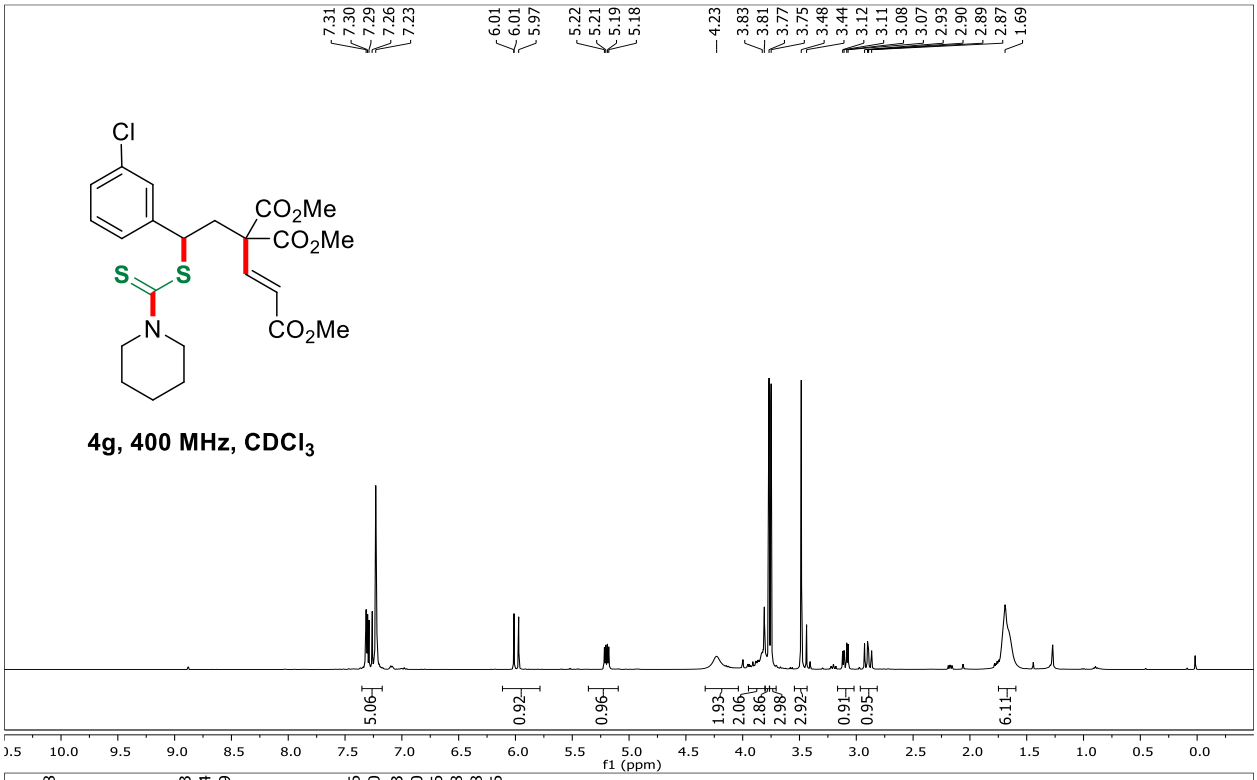


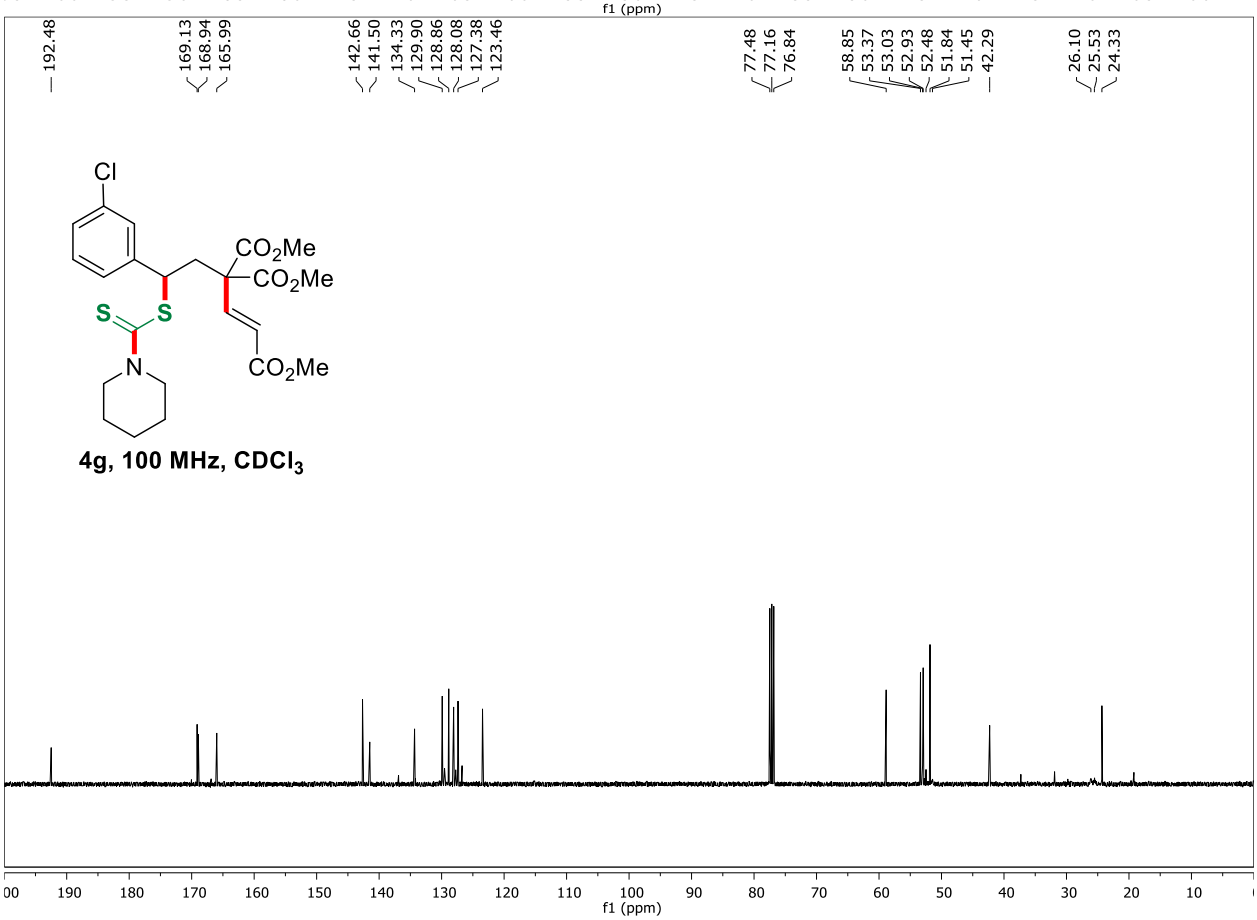
Trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(*m*-tolyl)pent-1-ene-1,3,3-tricarboxylate (4f)



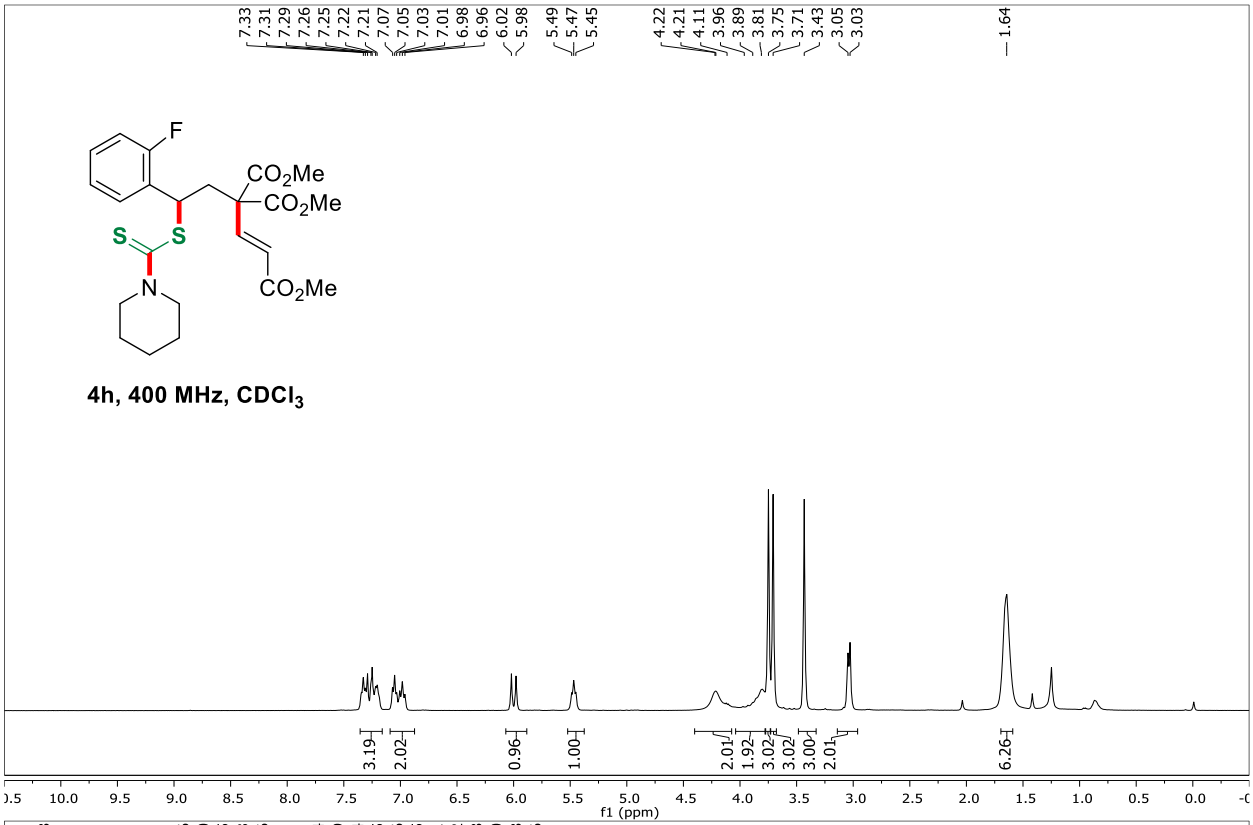


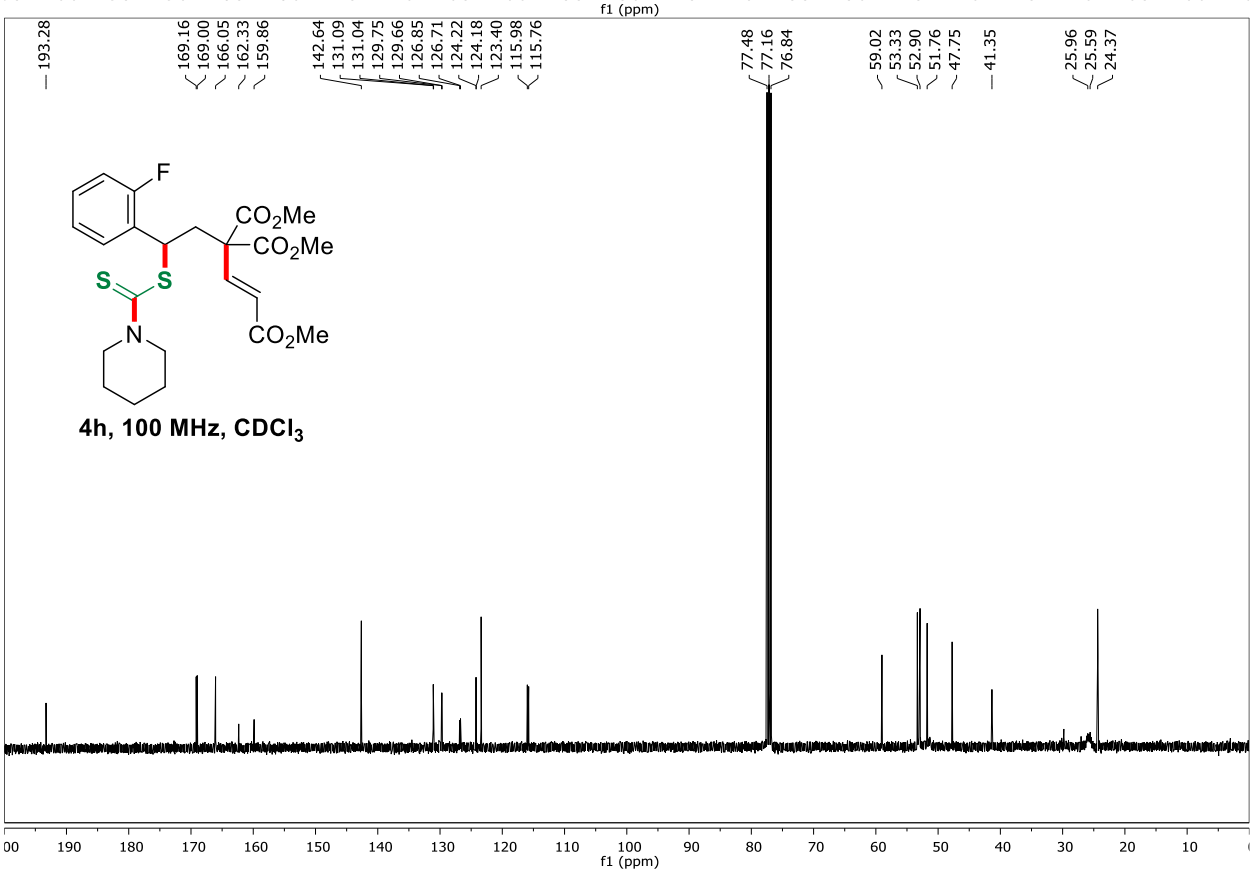
Trimethyl (*E*)-5-(3-chlorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4g)



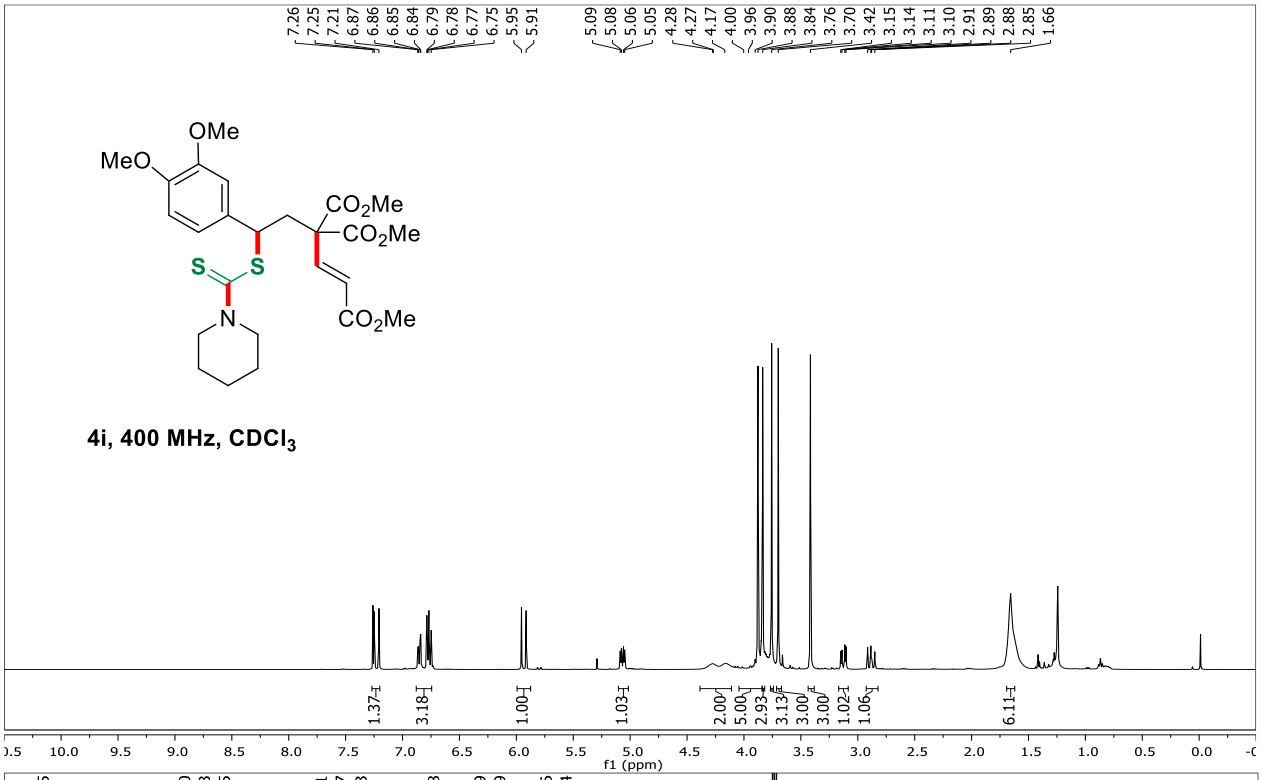


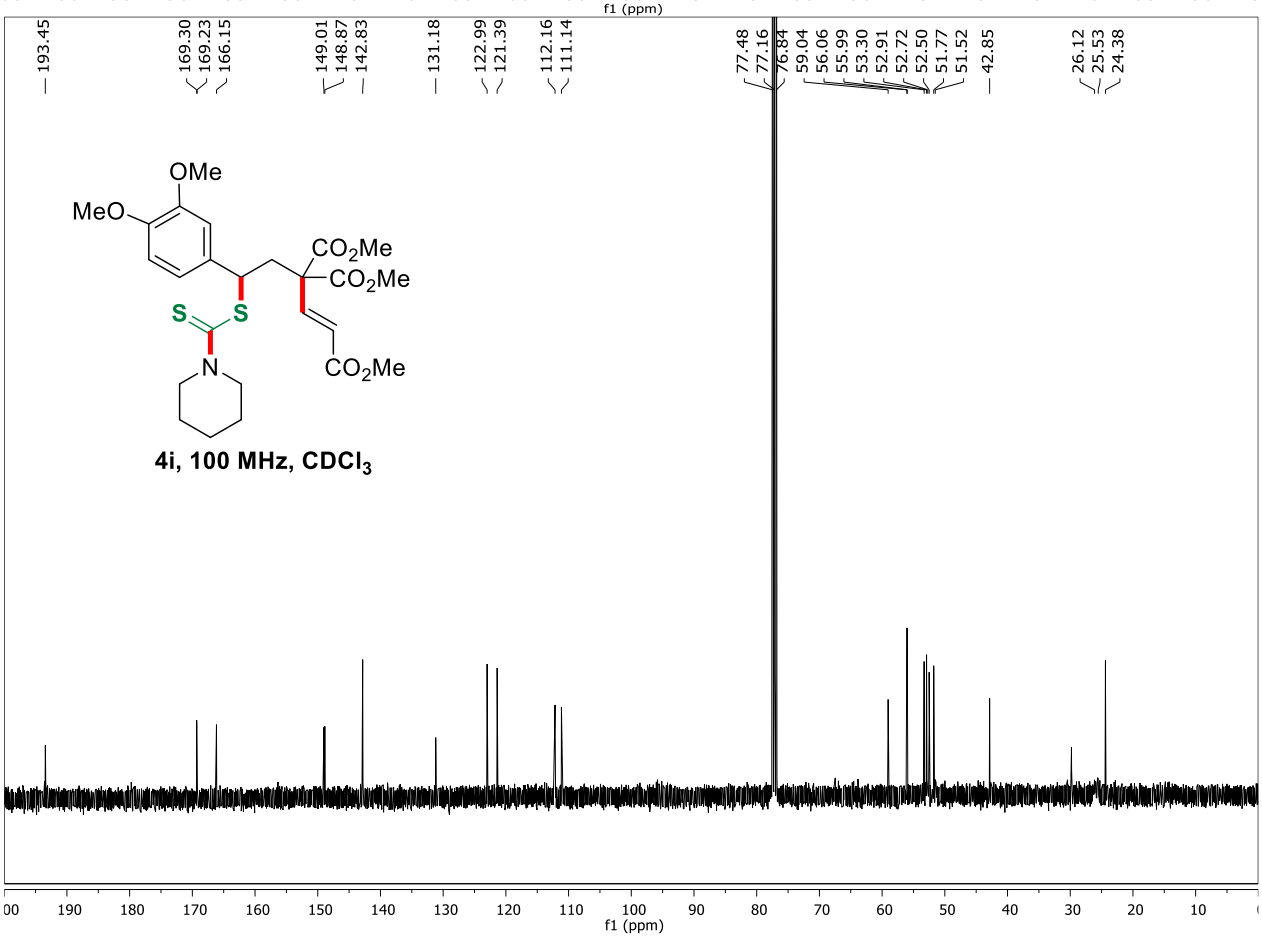
Trimethyl (*E*)-5-(2-fluorophenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4h)



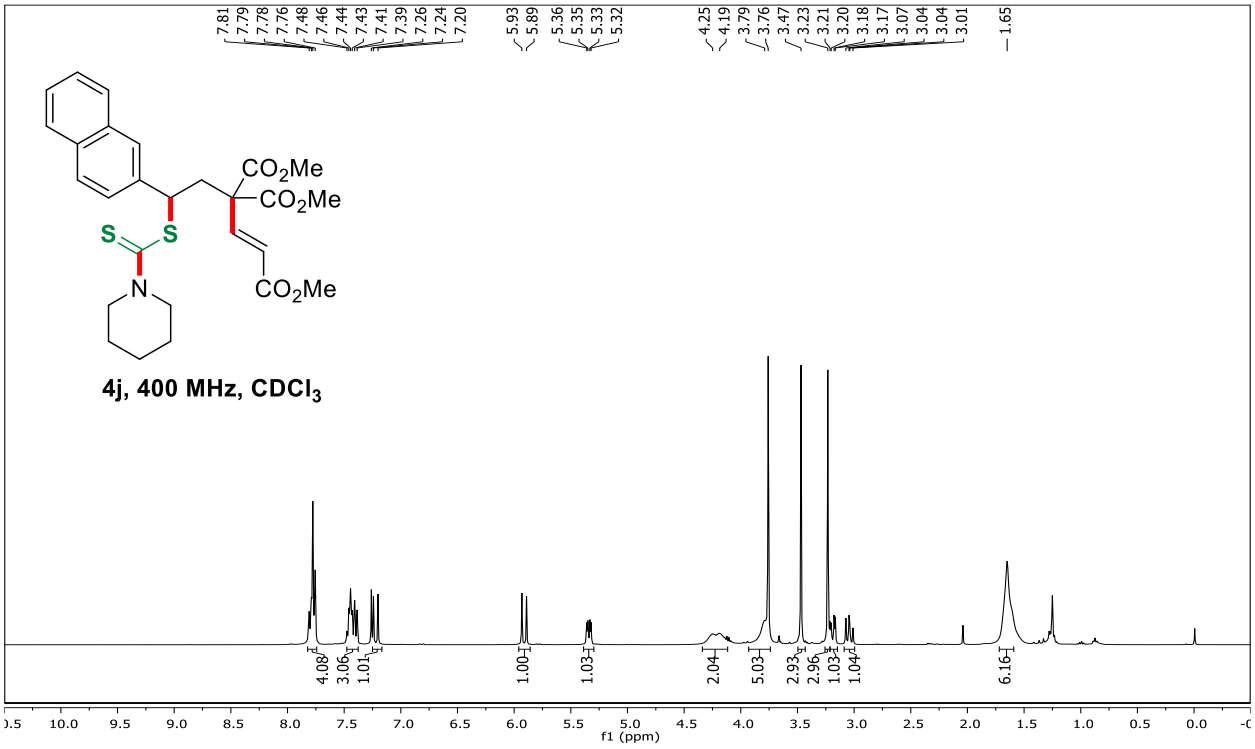


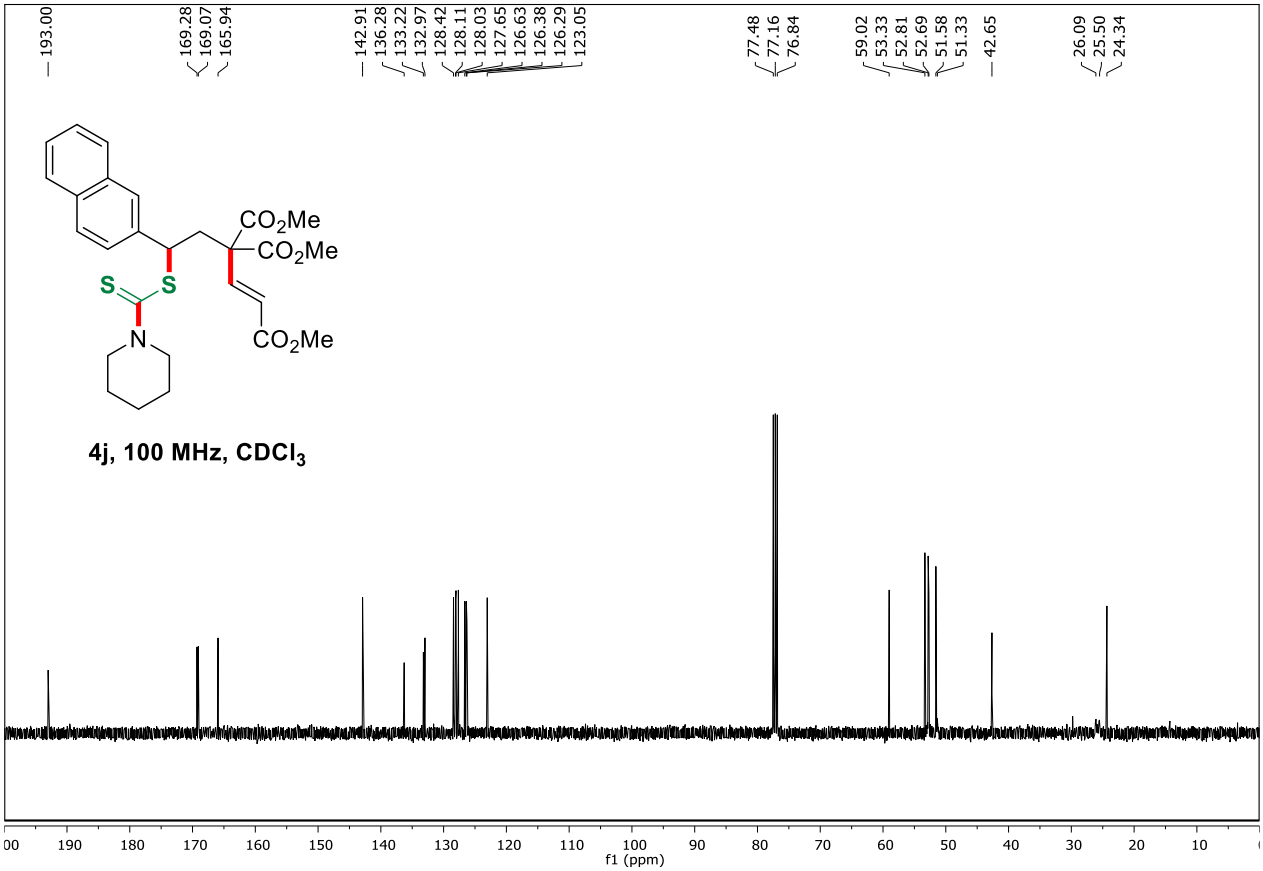
Trimethyl (*E*)-5-(3,4-dimethoxyphenyl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4i)



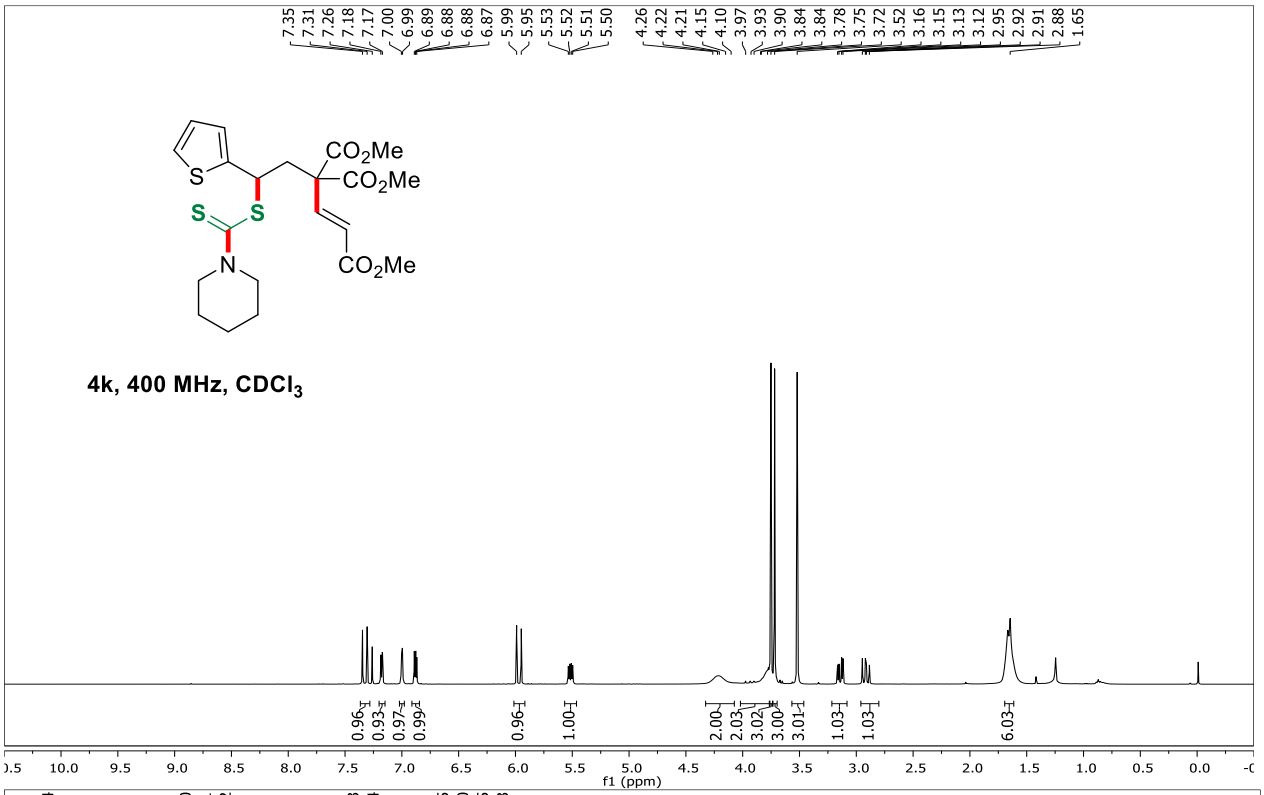


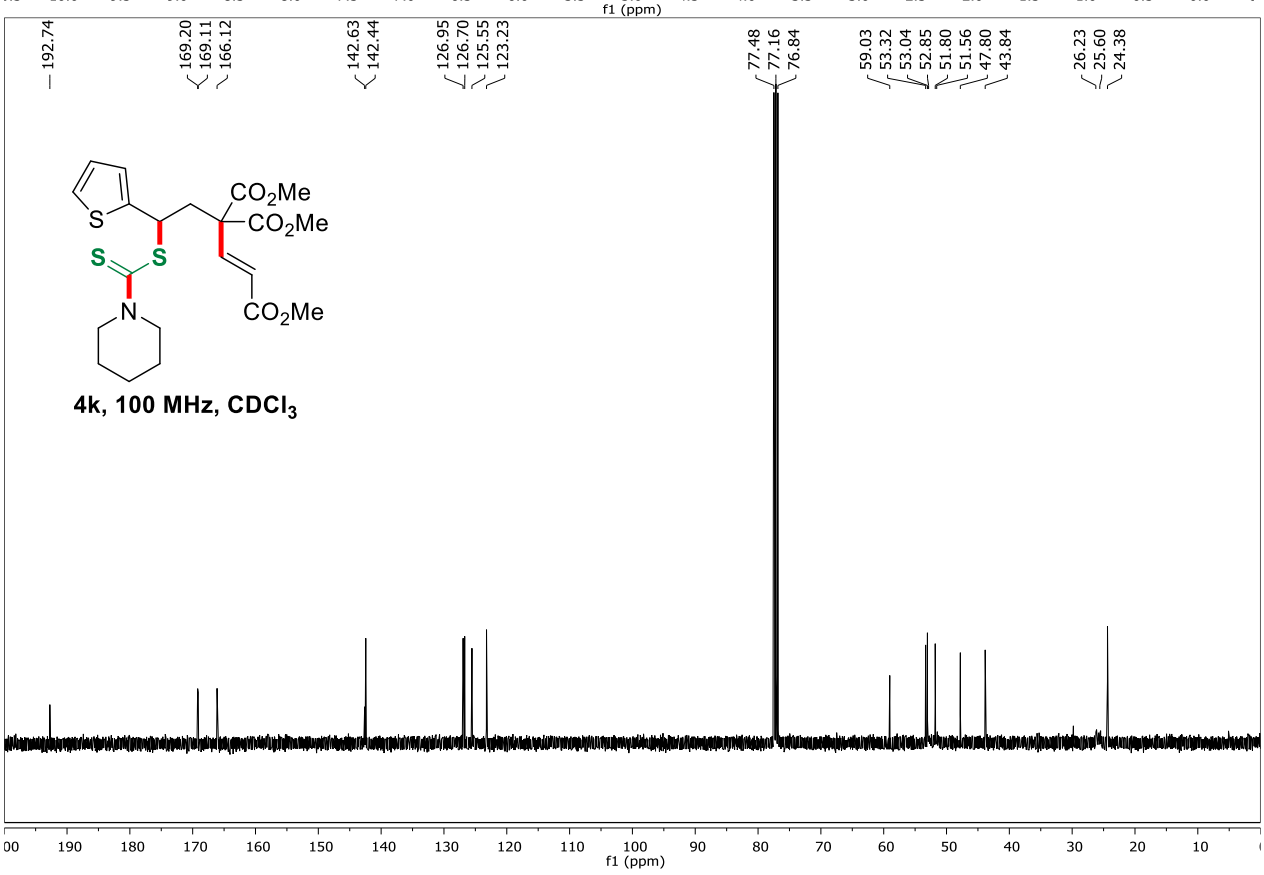
Trimethyl (*E*)-5-(naphthalen-2-yl)-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4j)



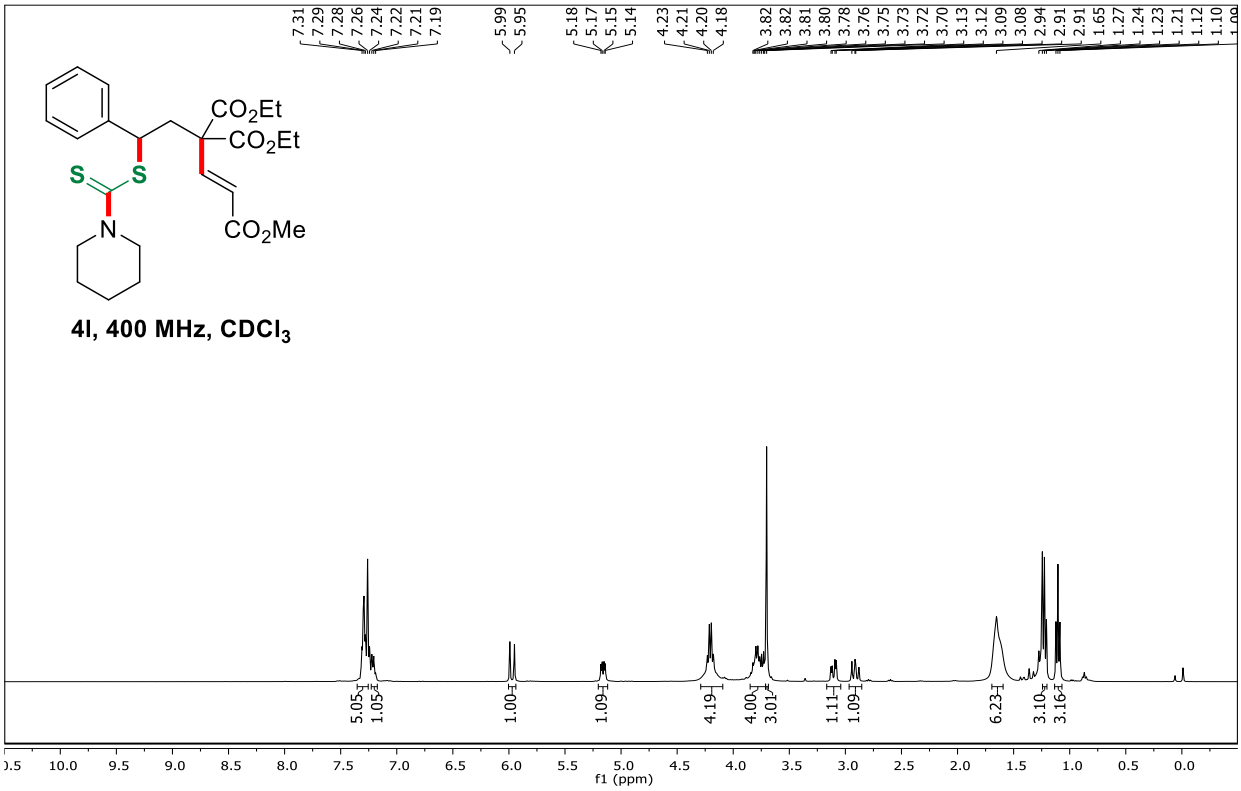


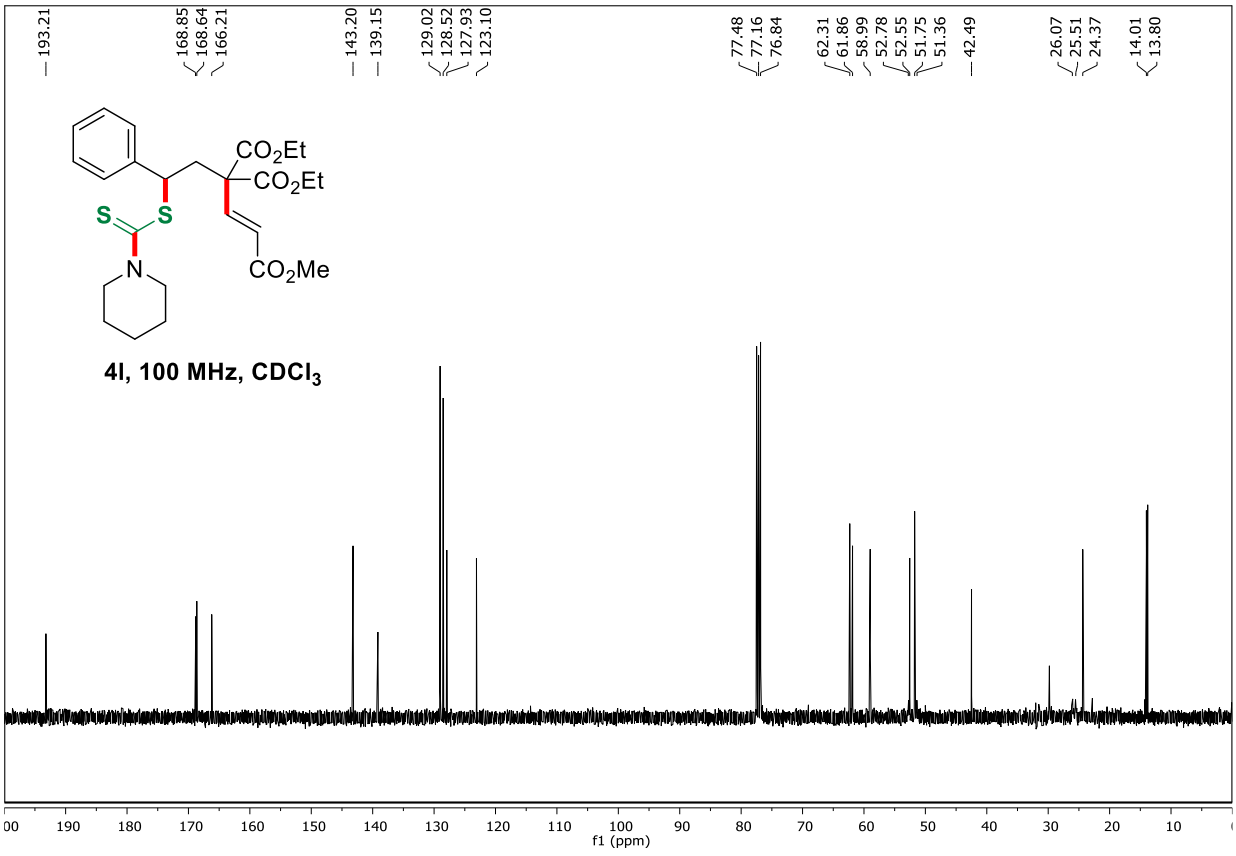
Trimethyl (*E*)-5-((piperidine-1-carbonothioyl)thio)-5-(thiophen-2-yl)pent-1-ene-1,3,3-tricarboxylate (4k)



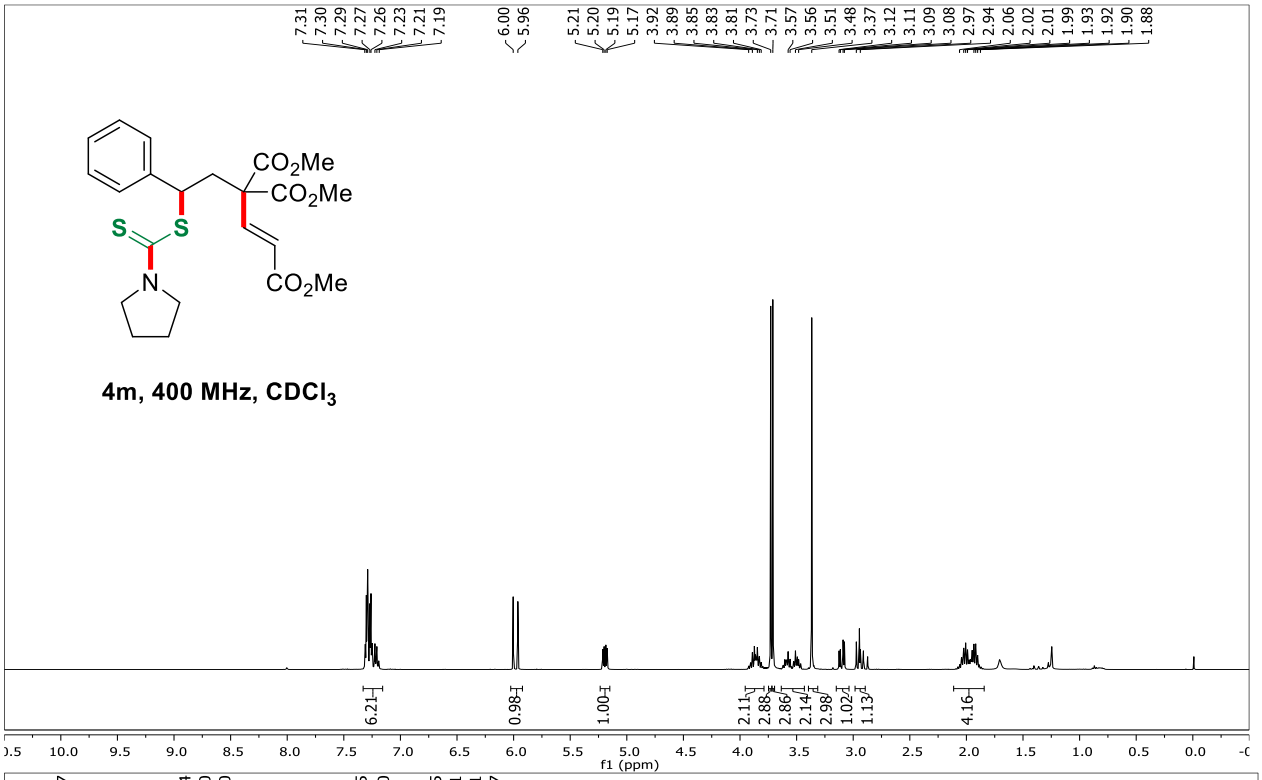


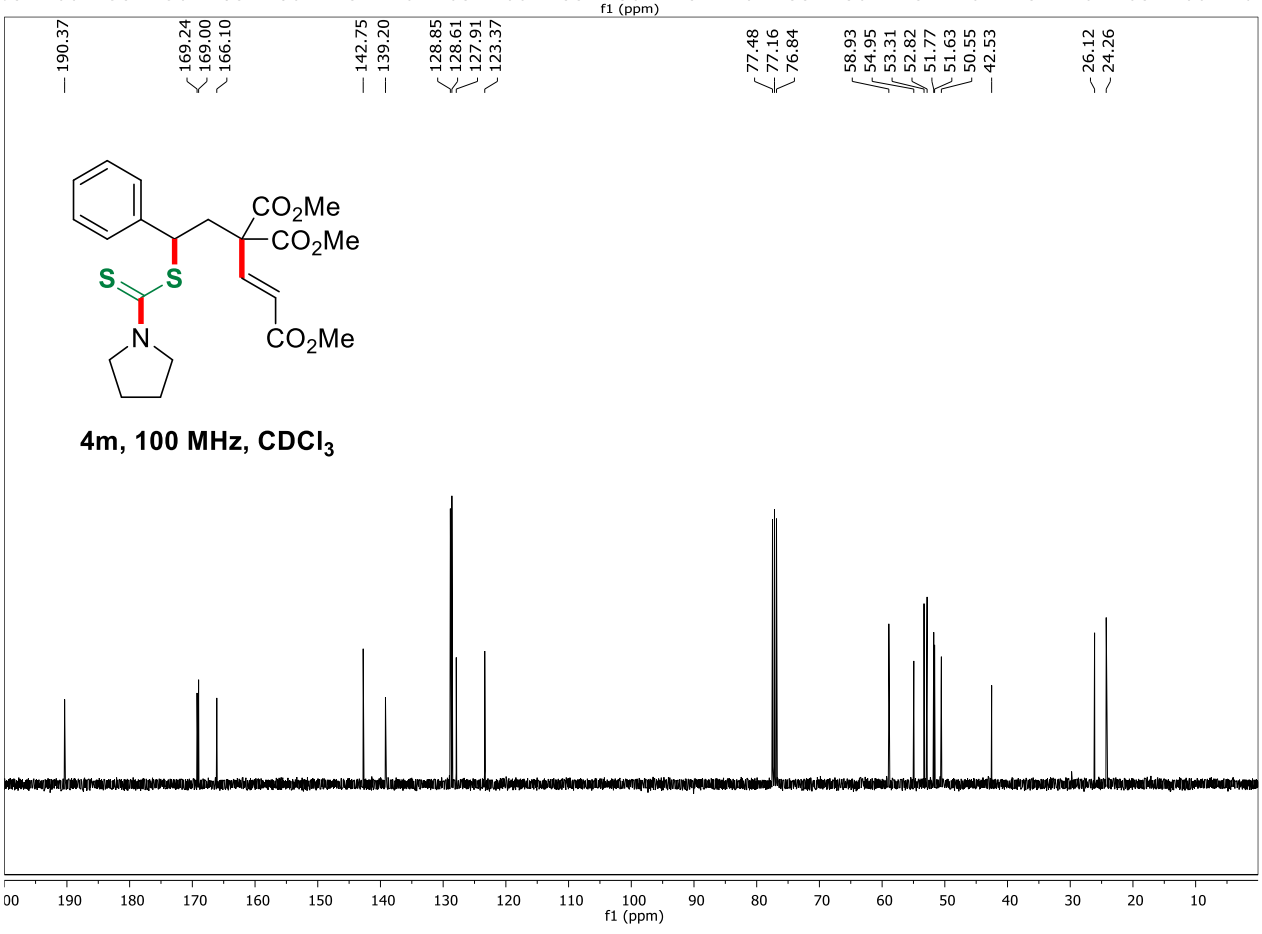
3,3-Diethyl 1-methyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4l)



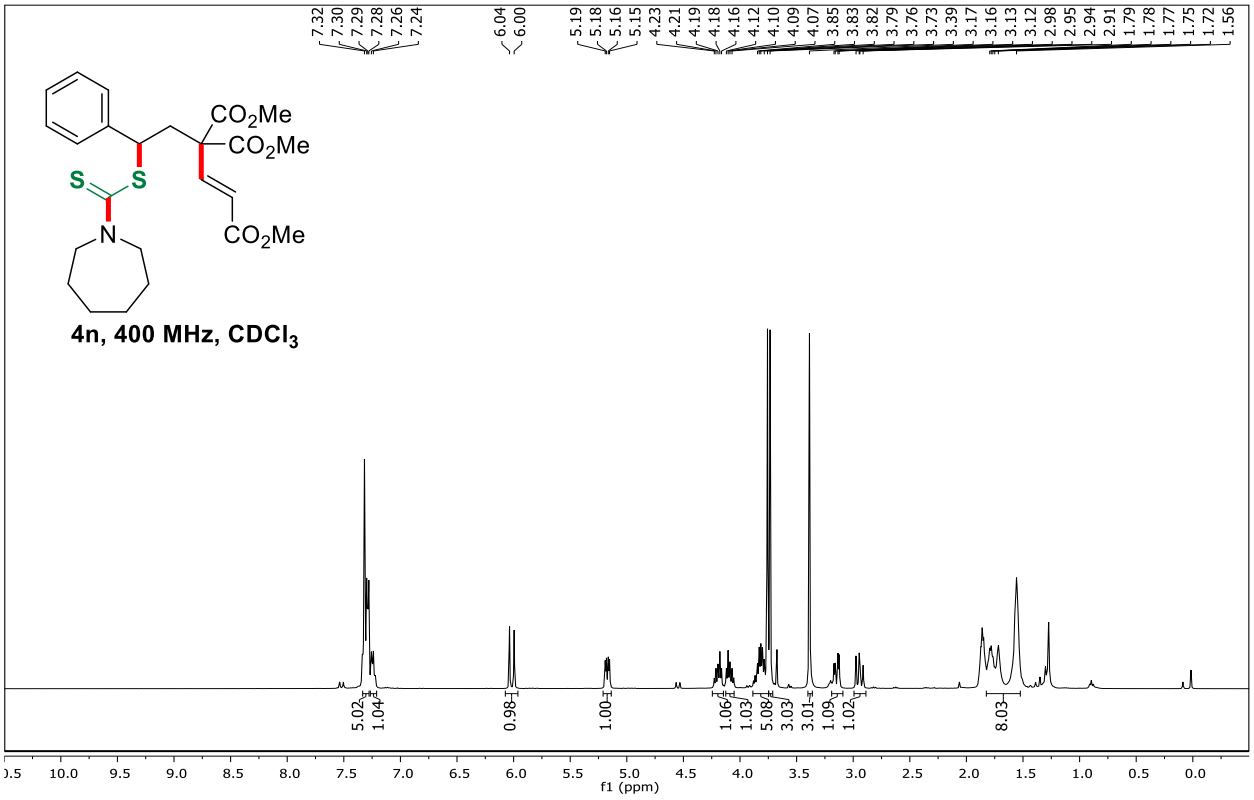


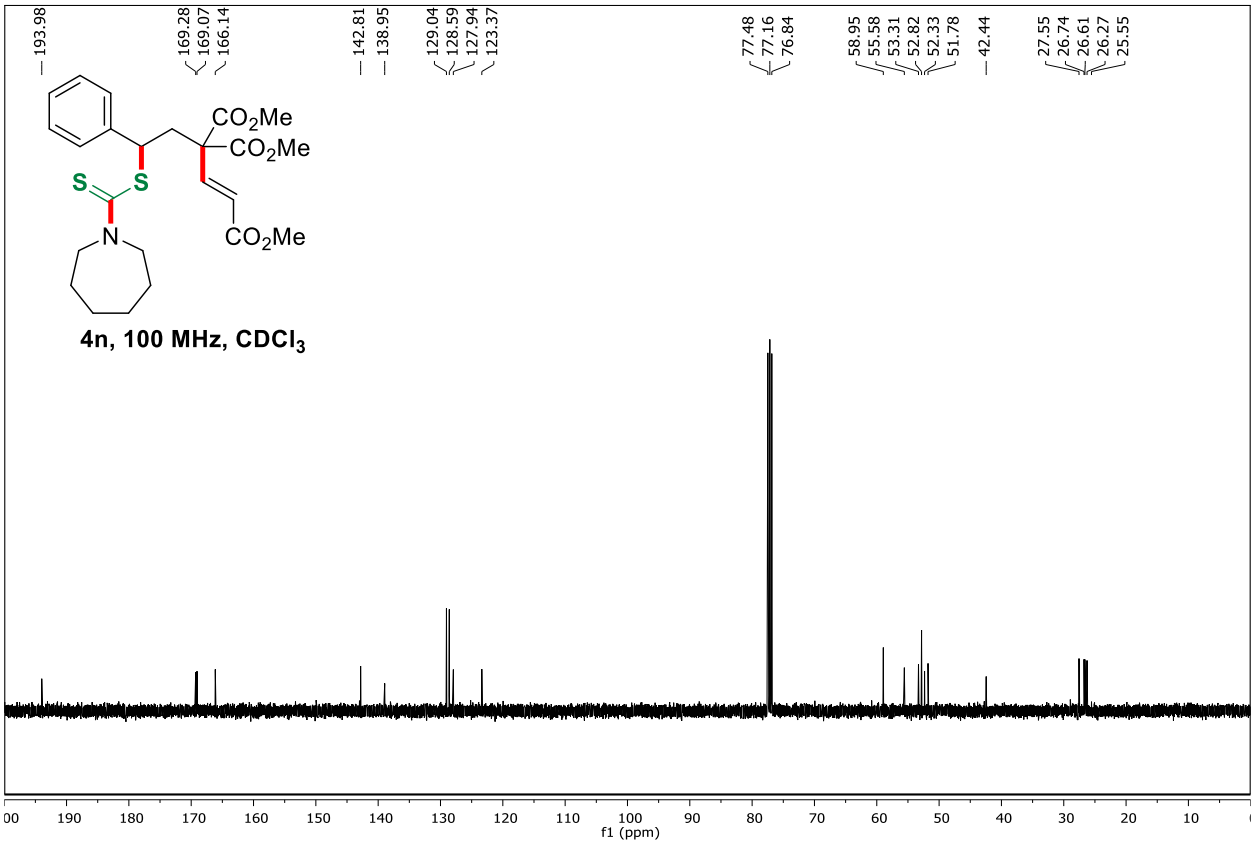
Trimethyl (*E*)-5-phenyl-5-((pyrrolidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4m)



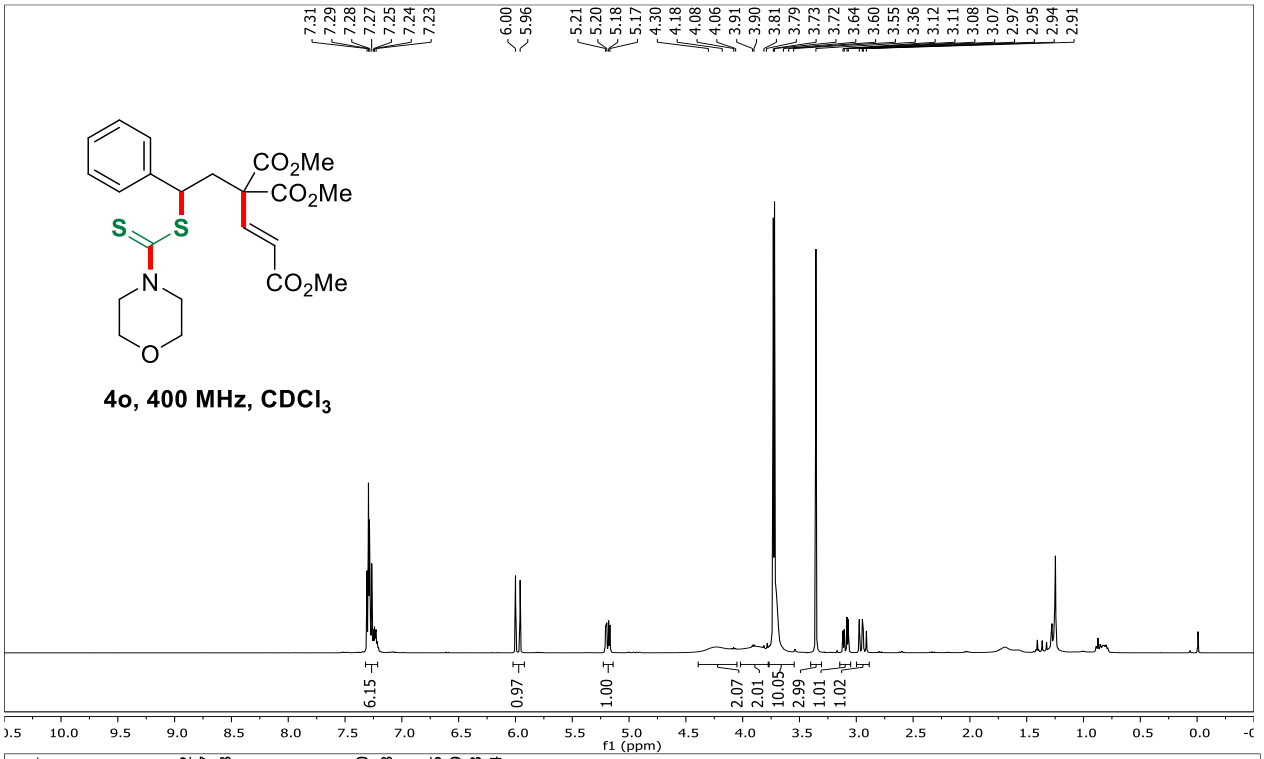


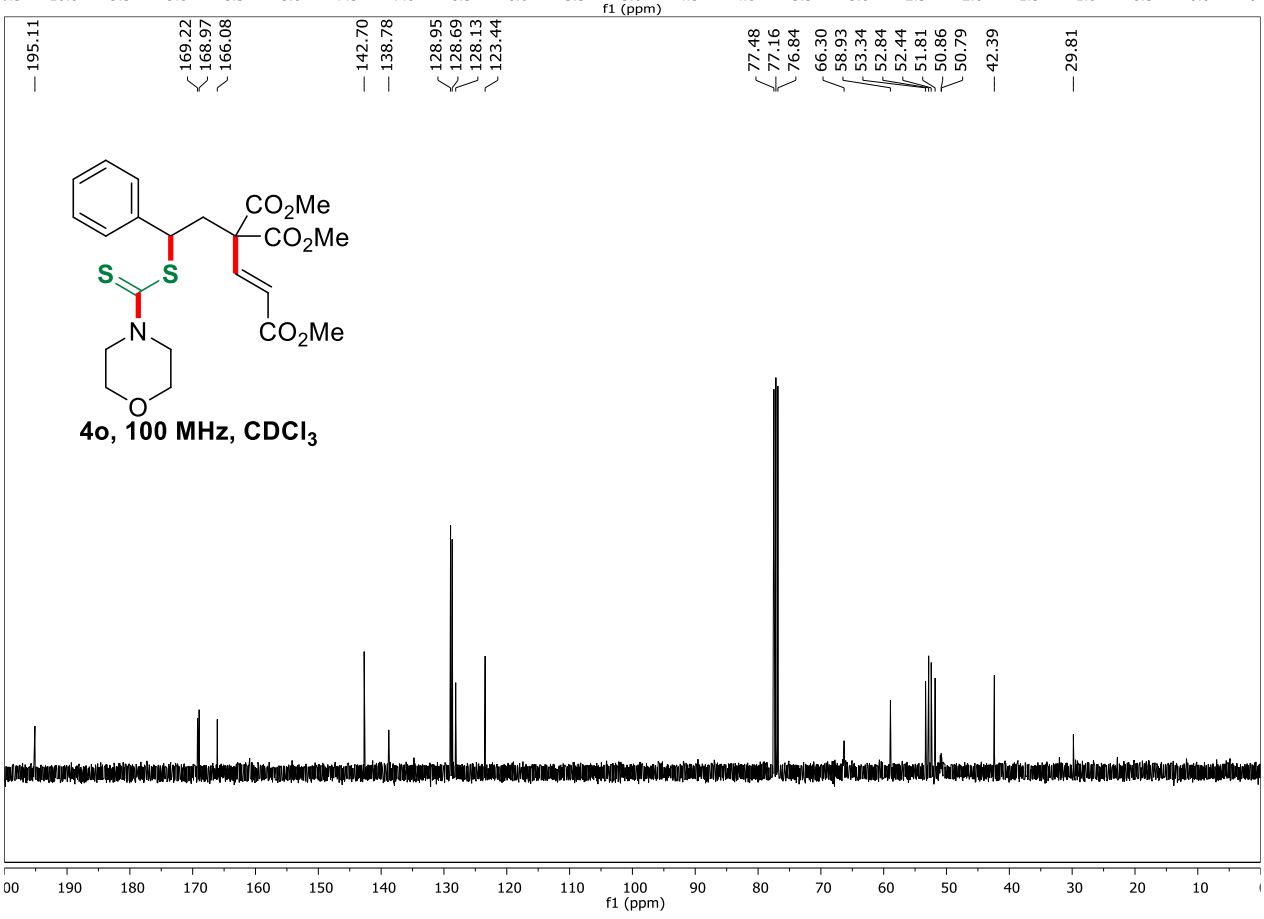
Trimethyl (*E*)-5-((azepane-1-carbonothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4n)



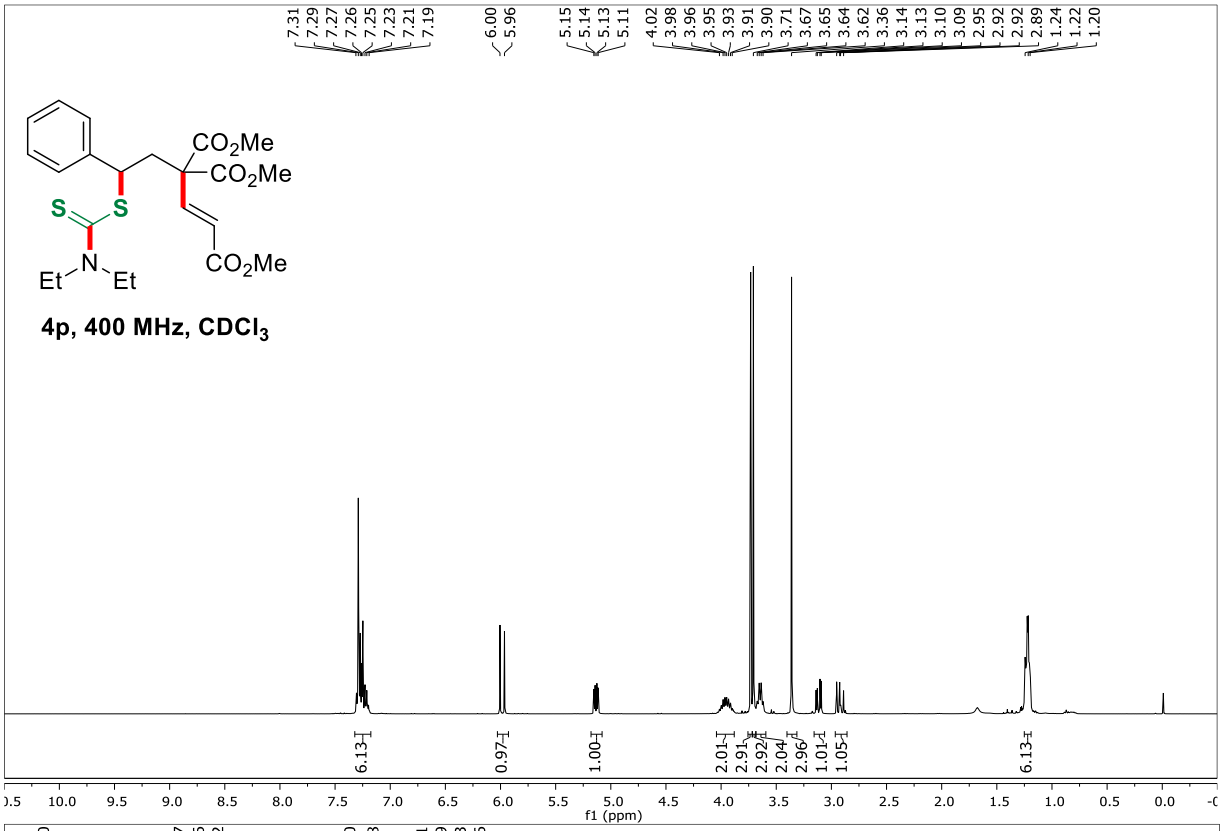


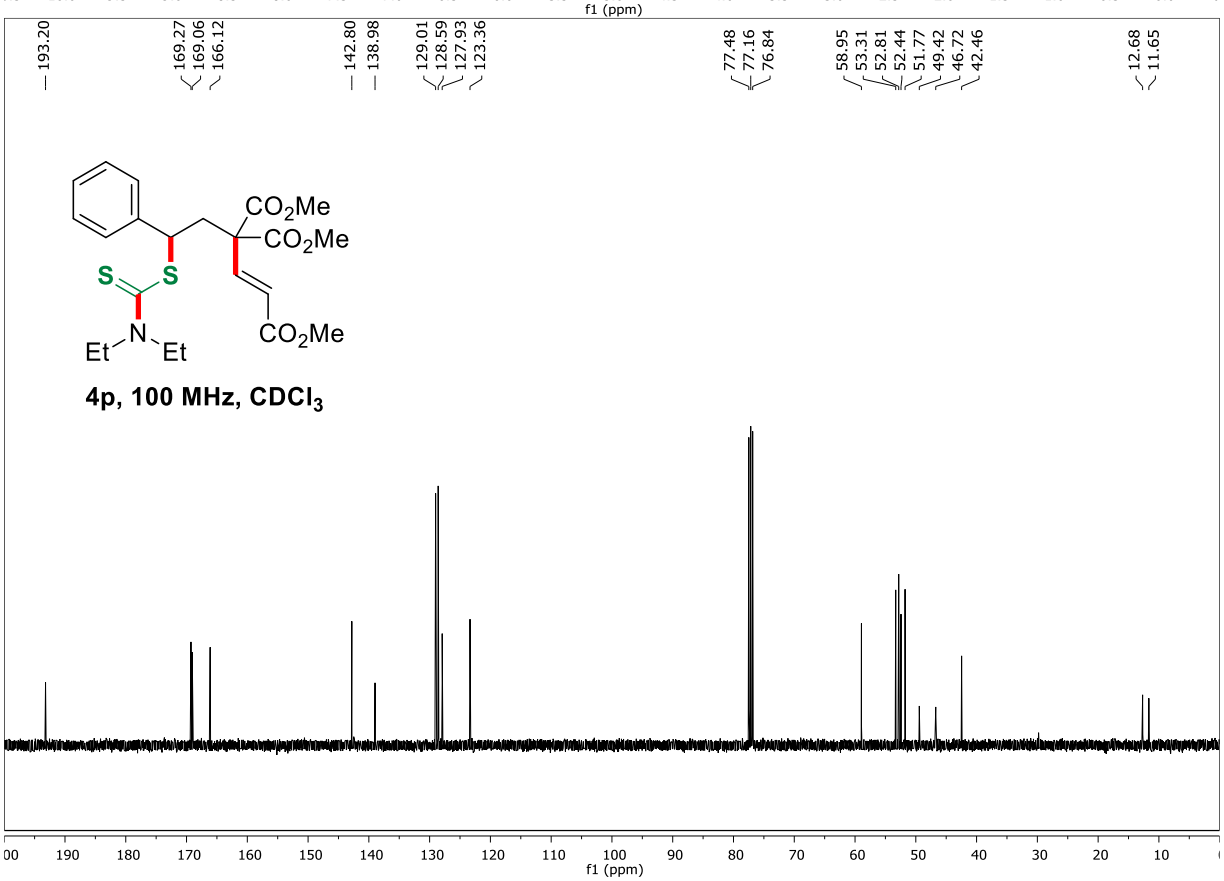
Trimethyl (*E*)-5-((morpholine-4-carbonothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4o)



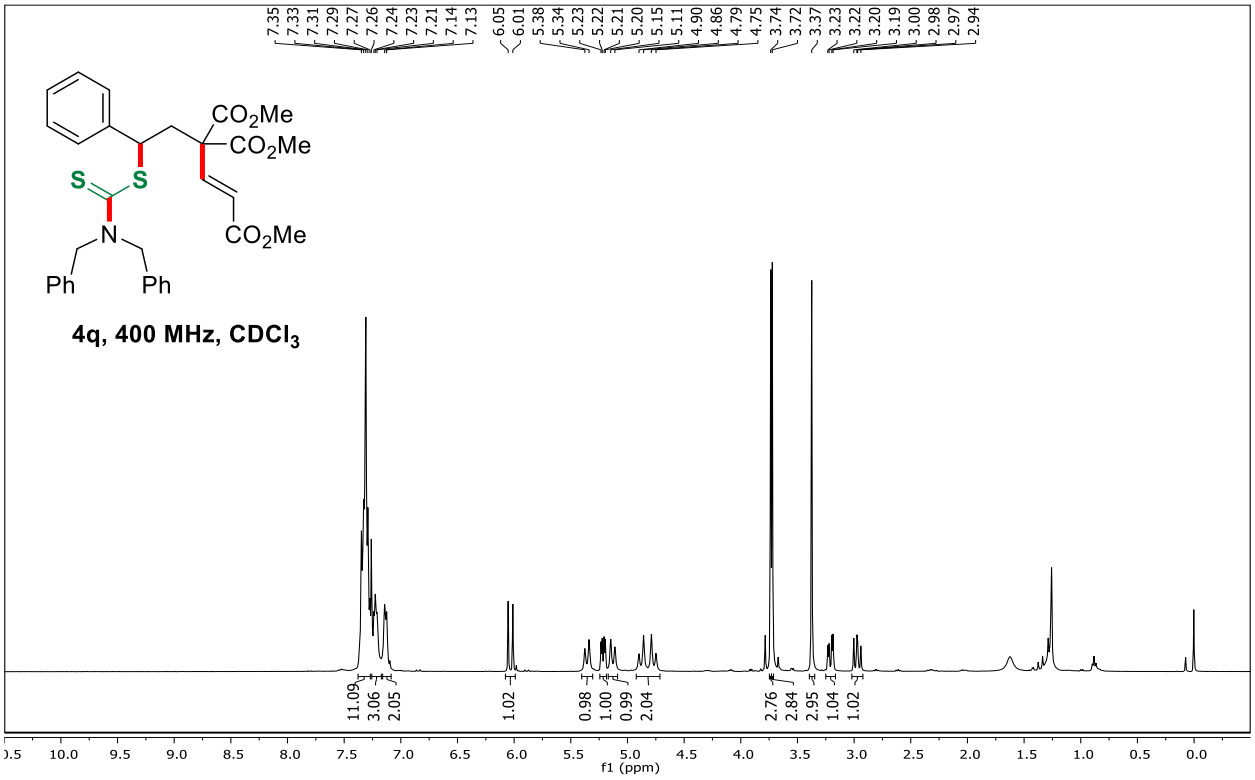


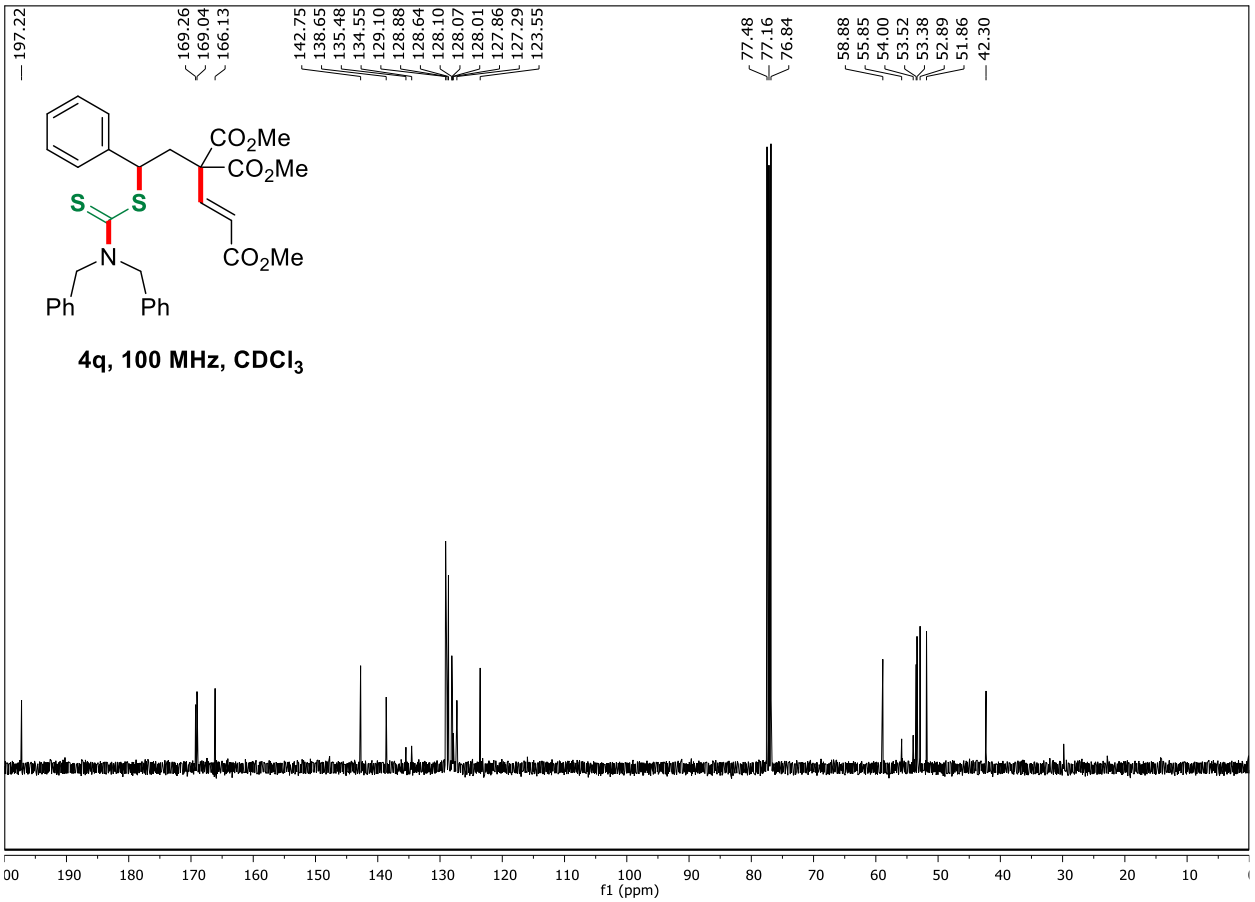
Trimethyl (*E*)-5-((diethylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4p)



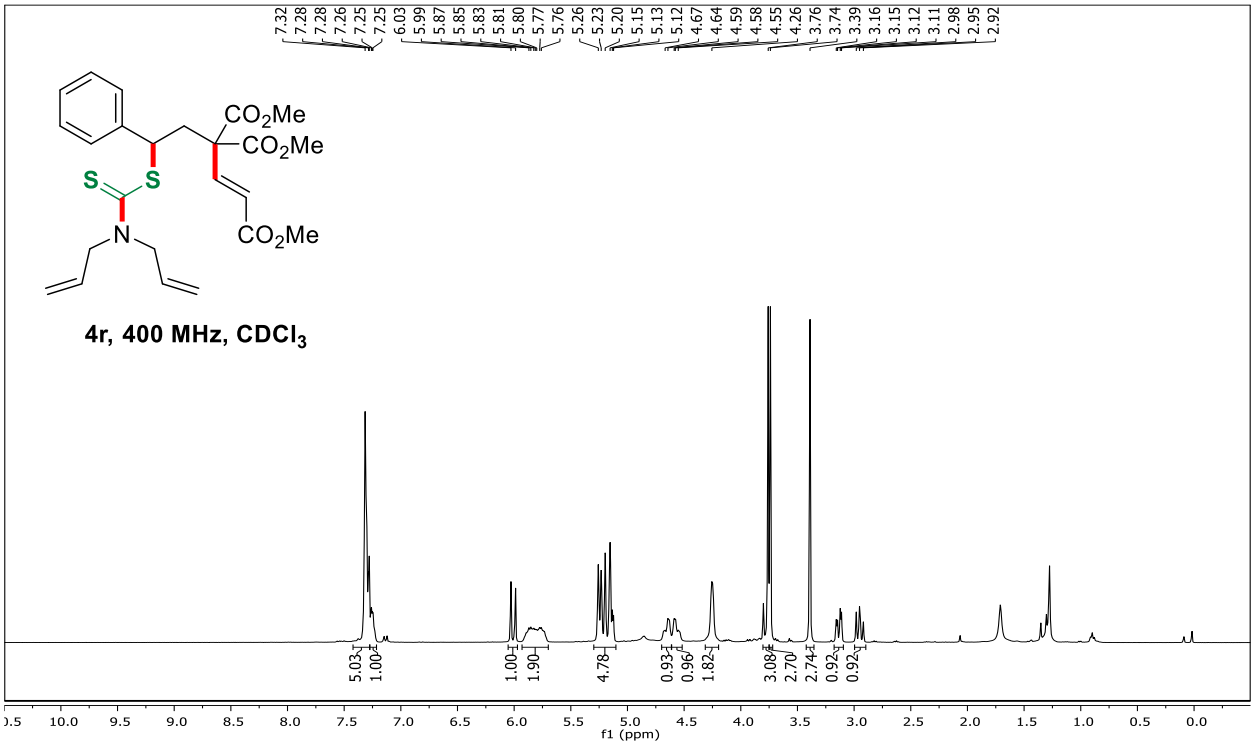


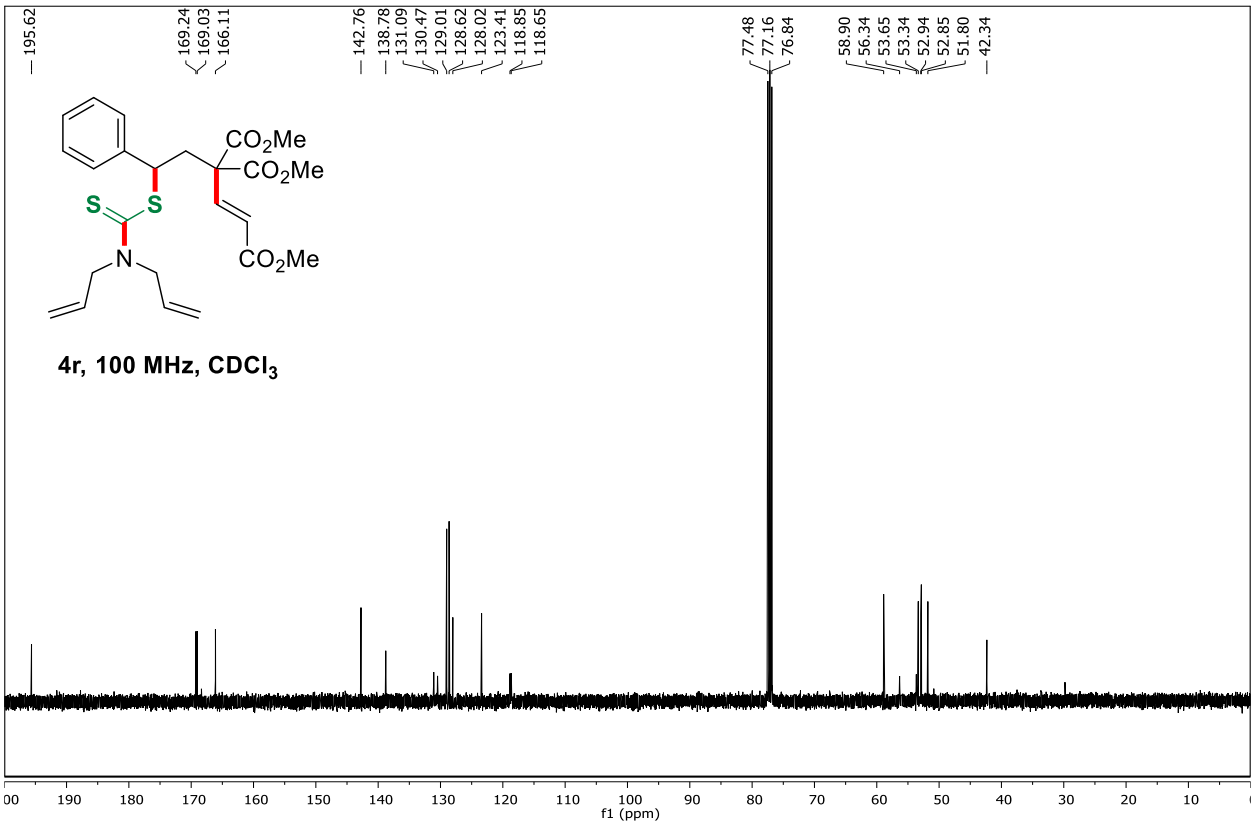
Trimethyl (*E*)-5-((dibenzylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4q)



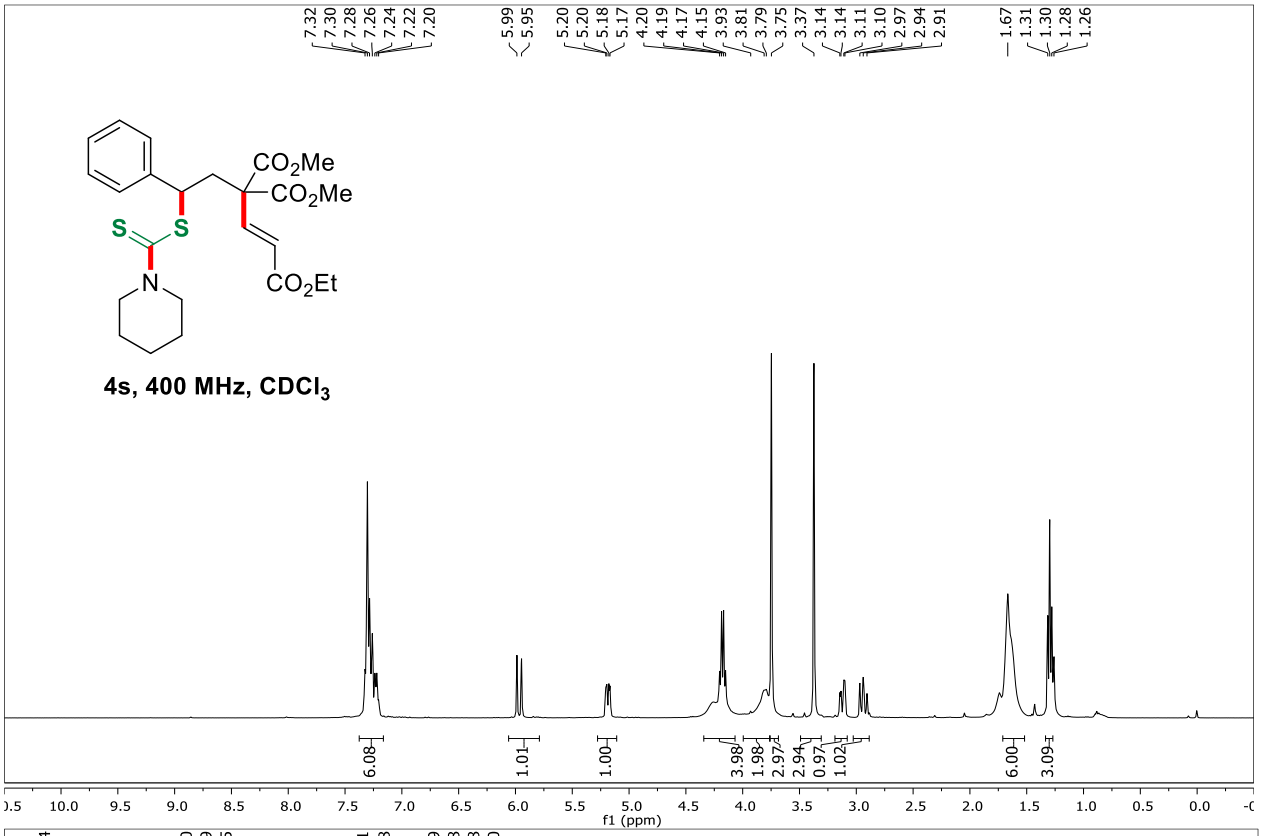


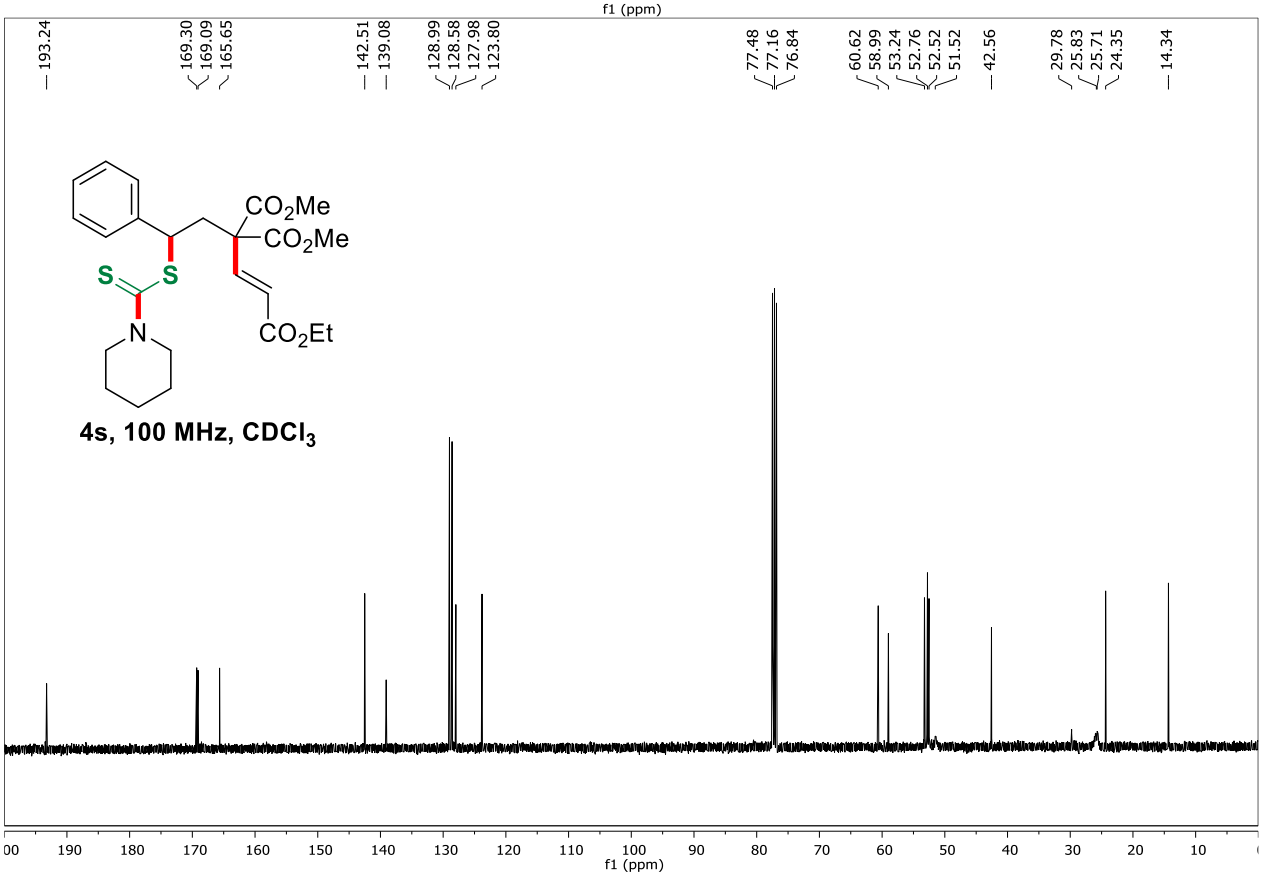
Trimethyl (*E*)-5-((diallylcarbamothioyl)thio)-5-phenylpent-1-ene-1,3,3-tricarboxylate (4r)



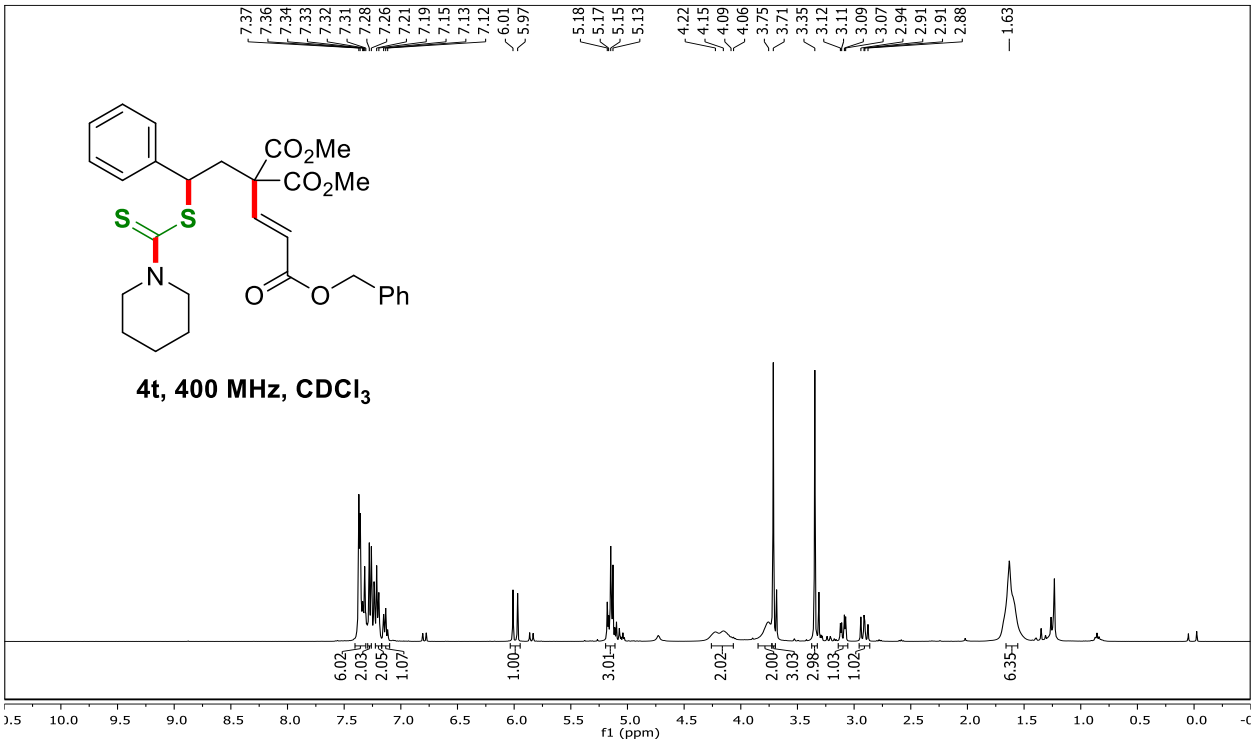


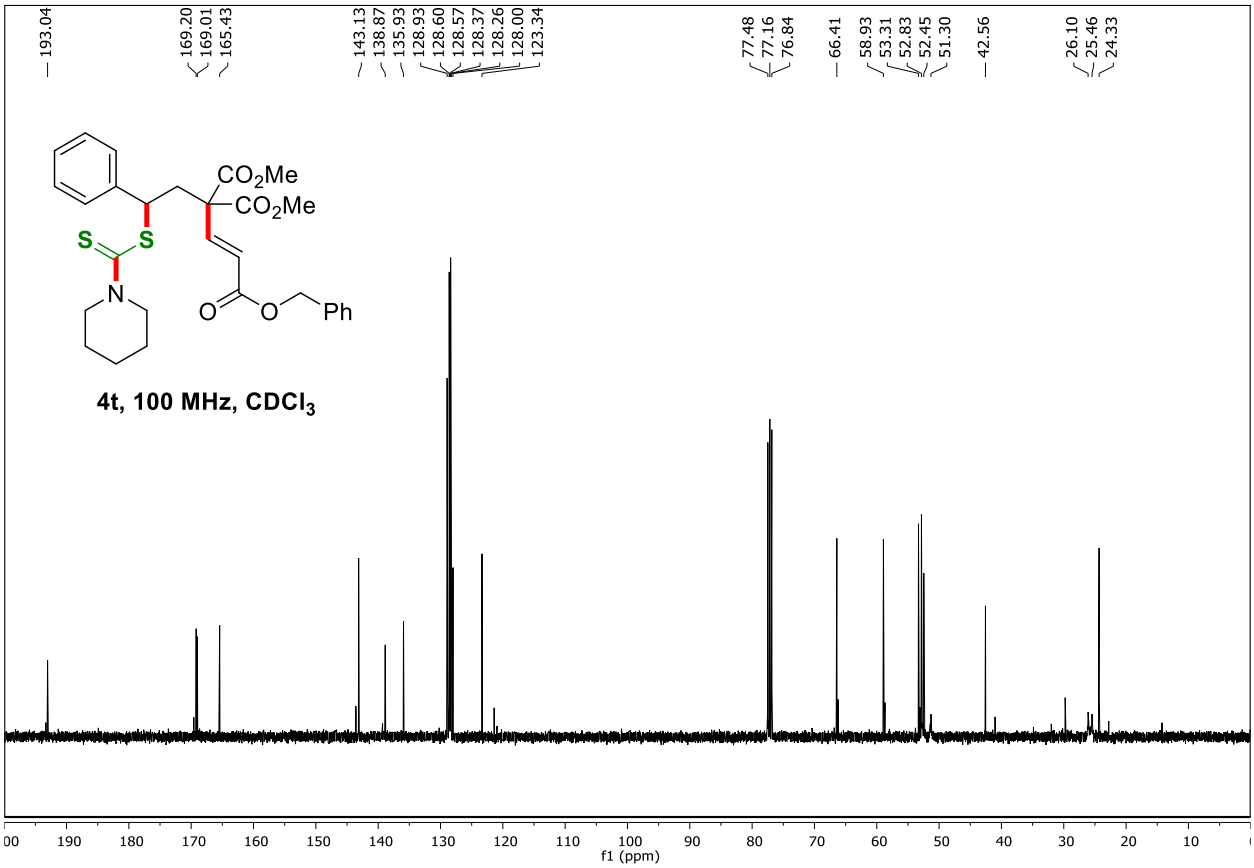
1-Ethyl 3,3-dimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4s)



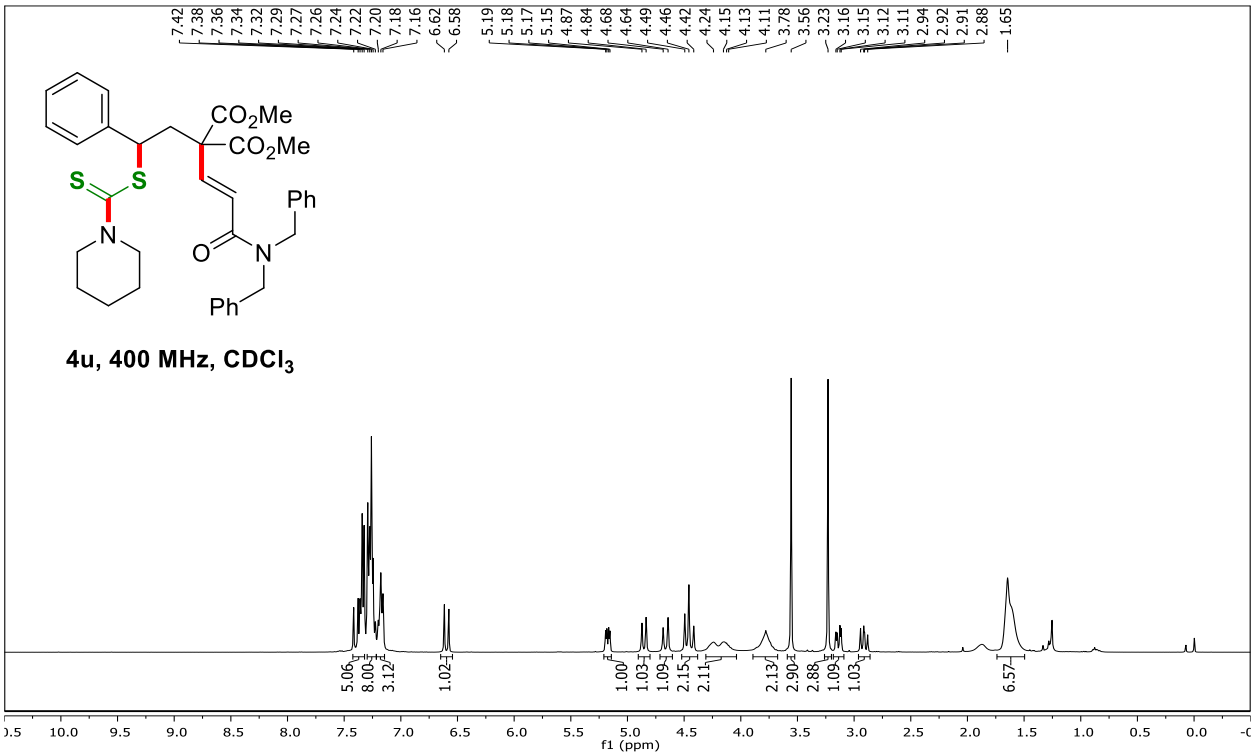


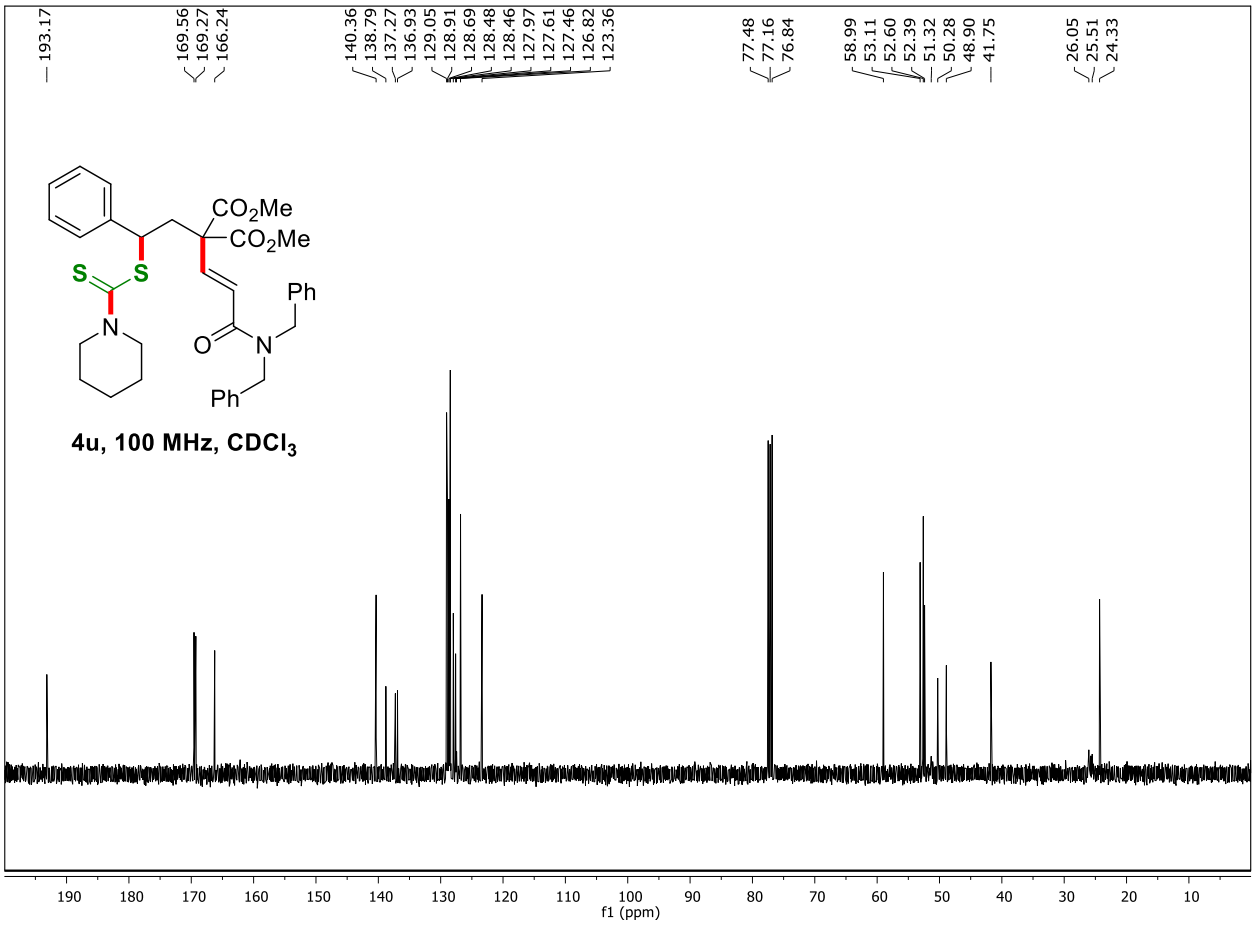
1-Benzyl 3,3-dimethyl (*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4t)



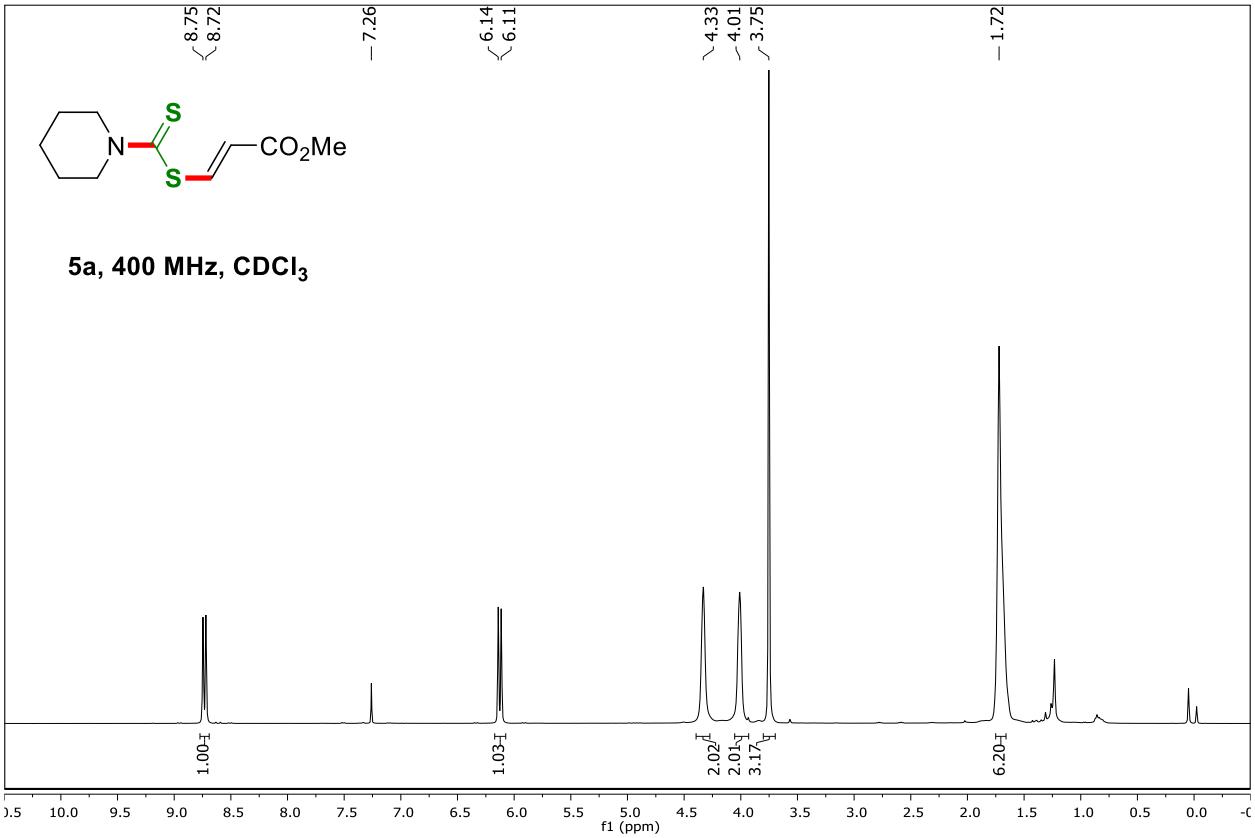


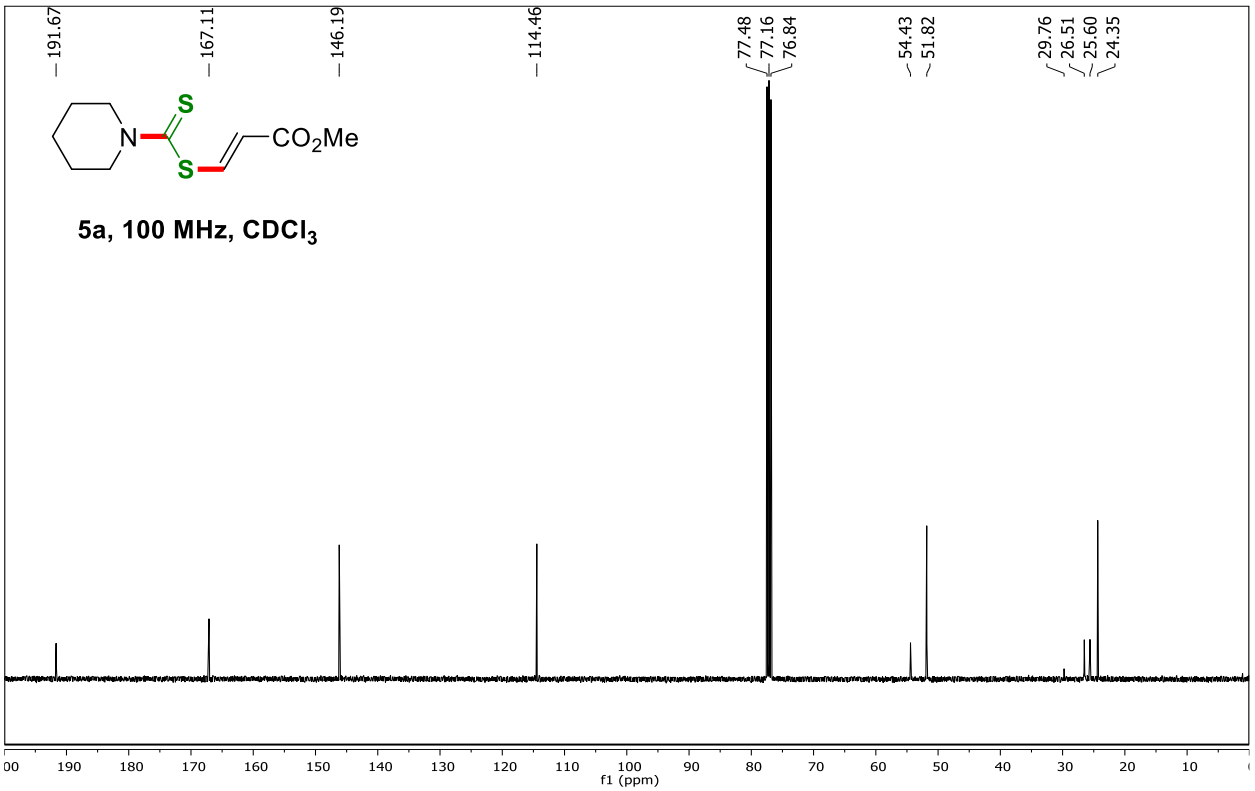
Dimethyl (*E*)-2-(3-(dibenzylamino)-3-oxoprop-1-en-1-yl)-2-(2-phenyl-2-((piperidine-1-carbonothioyl)thio)ethyl)malonate (4u)



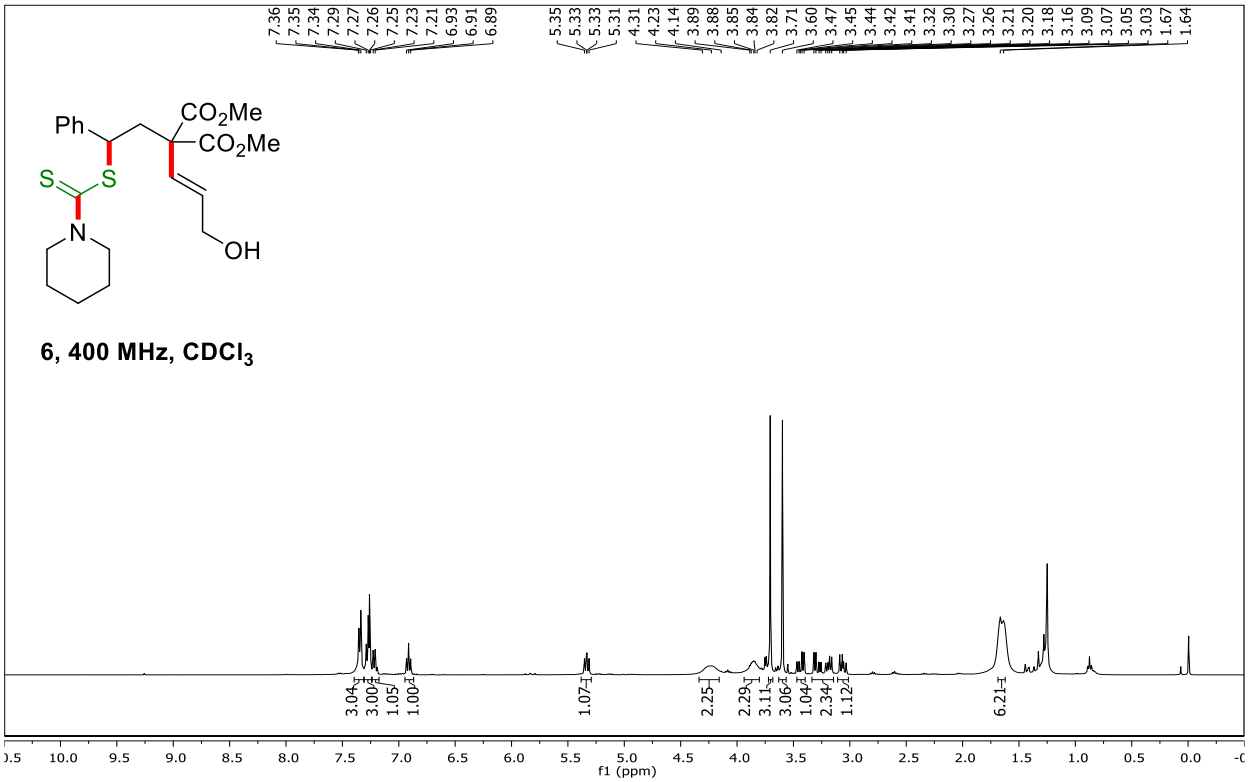


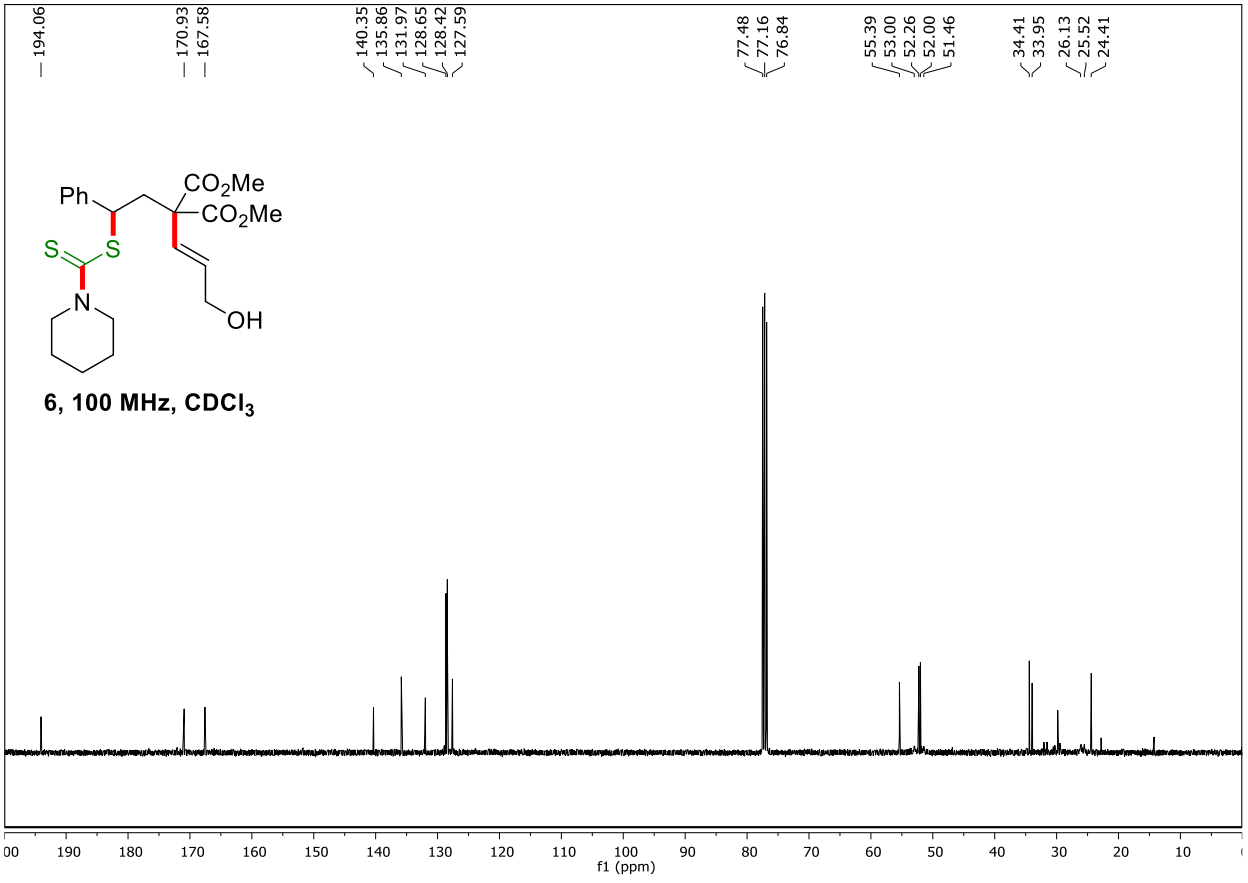
Methyl (*E*)-3-((piperidine-1-carbonothioyl) thio)acrylate (5a)





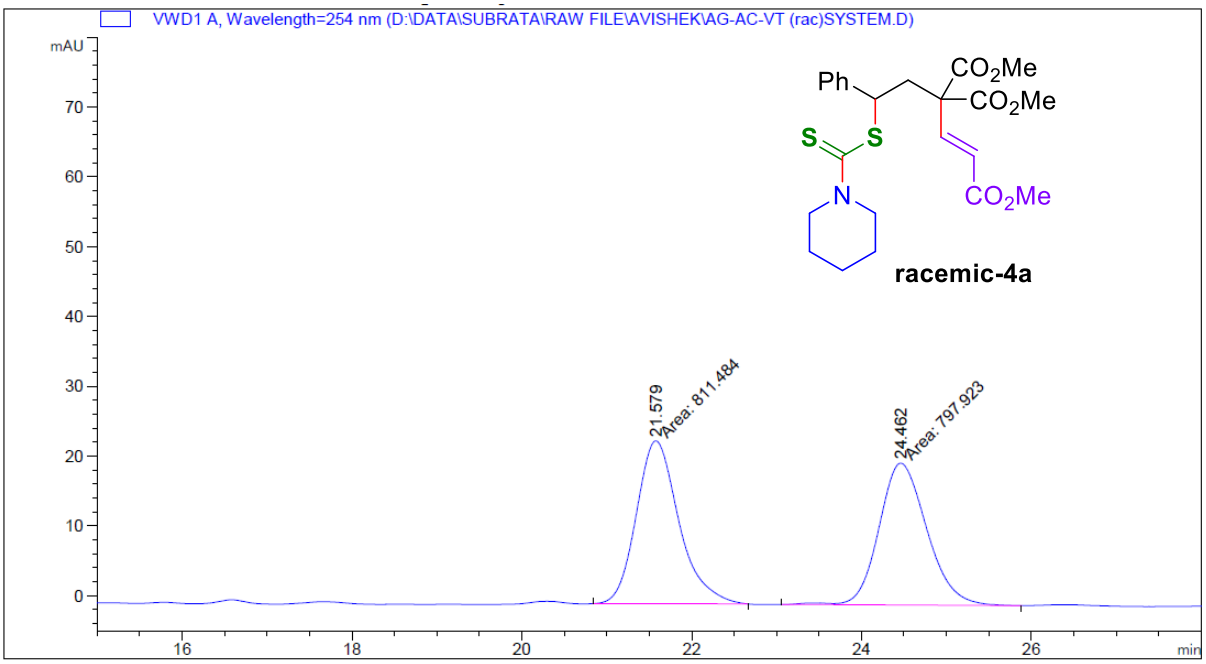
Dimethyl (*E*)-2-(3-hydroxyprop-1-en-1-yl)-2-(2-phenyl-2-((piperidine-1-carbonothioyl) thio)ethyl)malonate (6)



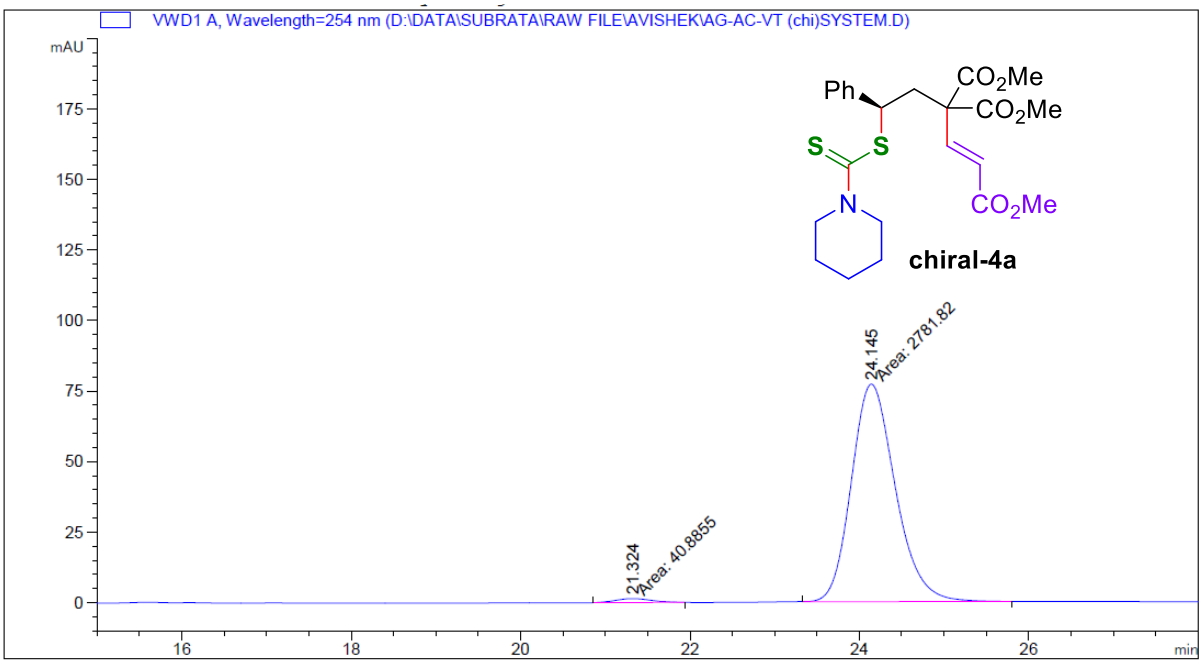


8. HPLC Data

Trimethyl (R,*E*)-5-phenyl-5-((piperidine-1-carbonothioyl)thio)pent-1-ene-1,3,3-tricarboxylate (4a)



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	21.579	MM	0.5802	811.48401	23.31169	50.4213
2	24.462	MM	0.6544	797.92279	20.32333	49.5787



Peak #	RetTime [min]	Type	Width [min]	Area [mAU*s]	Height [mAU]	Area %
1	21.324	MM	0.4962	40.88550	1.37340	1.4484
2	24.145	MM	0.6017	2781.82471	77.05938	98.5516

Sample Info : CHIRALPAK IA, 2% IPA-HEXANE, 1.0 mL/min, 254 nm