Copper-catalyzed C-H/N-H annulation of enaminones and alkynyl esters for the construction of densely substituted Pyrroles

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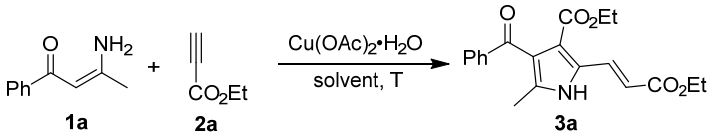
General experimental information

All experiments were carried out under air atmosphere. All enaminones **1** were synthesized following literature process,[1] and other chemicals and solvents used in the experiments were obtained from commercial sources and used directly without further treatment. ^{1}H and ^{13}C NMR spectra were recorded in 400 MHz apparatus and the frequencies for ^{1}H NMR and ^{13}C NMR test are 400 MHz and 100 MHz, respectively. The chemical shifts were reported in ppm with TMS as internal standard. Melting points were tested in X-4A instrument without correcting temperature and the HRMS were obtained under ESI model with TOF analyzer.

Table S1 Optimization of the reaction conditions[a]



1a 2a 3a

Entry	Catalyst (equiv)	Additive (equiv)	T (°C)	Solvent	Yield [b](%)
1	$Cu(OAc)_2$	-	80	MeCN	36
2	CuBr	-	80	MeCN	no
3	$Cu(OTf)_2$	-	80	MeCN	trace
4	$Cu(NO_3)_2$	-	80	MeCN	no
5	-	-	80	MeCN	no
6	$Cu(OTf)_2·H_2O$	-	80	MeCN	no
7	$Cu(OAc)_2·H_2O$	NaOAc (1.0)	80	MeCN	32
8	$Cu(OAc)_2·H_2O$	NaOH (1.0)	80	MeCN	trace
9	$Cu(OAc)_2·H_2O$	HOAc (1.0)	80	MeCN	34
10	$Cu(OAc)_2·H_2O$	-	80	DMSO	no
11	$Cu(OAc)_2·H_2O$	-	80	DMF	no
12	$Cu(OAc)_2·H_2O$	-	80	DCE	25
13	$Cu(OAc)_2·H_2O$	-	80	toluene	no
14[c]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	42
15[d]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	47
16[e]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	40
17[d,f]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	trace
18[d,g]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	43
19[d,h]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	42
20[d,i]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	51
21[d,j]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	62
22[d,k]	$Cu(OAc)_2·H_2O$	-	80	MeCN/DCE	60
23[d,j]	$Cu(OAc)_2·H_2O$	-	60	MeCN/DCE	53
24[d,j,l]	$Cu(OAc)_2·H_2O$	-	100	MeCN/DCE	68
25[d,j,l]	$Cu(OAc)_2·H_2O$	-	120	MeCN/DCE	41
26[d,j,m]	$Cu(OAc)_2·H_2O$	-	100	MeCN/DCE	trace
27[d,j,n]	$Cu(OAc)_2·H_2O$	-	100	MeCN/DCE	64

[a]Reaction conditions: **1a** (0.2 mmol), **2a** (0.5 mmol), and copper catalyst (0.5 equiv) in 2.0 mL solvent, stirred under air for 12 h. [b]Isolated yield. [c]With 1.5 mL and 0.5 mL DCE. [d]With 1.0 mL and 1.0 mL DCE. [e]With 0.5 mL and 1.5 mL DCE. [f]With 0.25 equiv $Cu(OAc)_2•H_2O$. [g]With 0.75 equiv $Cu(OAc)_2•H_2O$. [h]With **2a** (0.4 mmol). [i]With **2a** (0.6 mmol). [j]With **2a** (0.8 mmol). [k]With **2a** (0.9 mmol). [l]Reaction in sealed tube. [m]Reaction under nitrogen atmosphere. [n]Reaction under oxygen (1 atm).

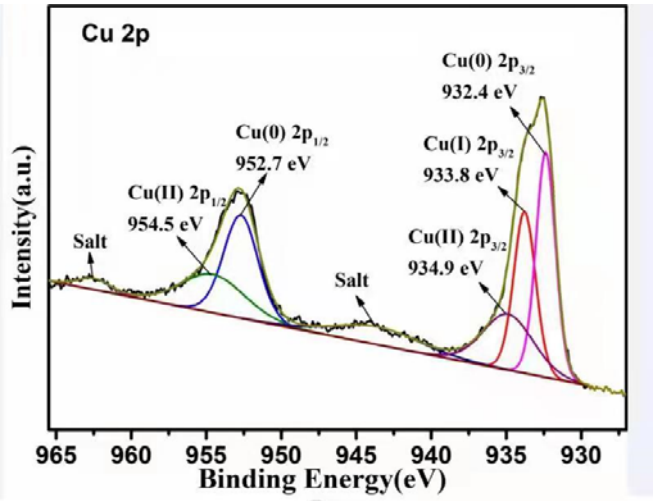


Figure S1 XPS analysis on the reaction residue after washing with EtOAc

General procedure for the synthesis of 3

To a 10 mL sealed tube were added enaminone **1** (0.2 mmol), alkyl propiolate **2** (0.8 mmol), $Cu(OAc)_2 \cdot H_2O$ (0.1 mmol), MeCN (1.0 mL) and DCE (1.0 mL). Then, the mixture was stirred at 100 °C in an oil bath for 12 h. Upon completion, the vessel was allowed to cool down to room temperature. After adding 5 mL saturated brine, the resulting mixture was extracted with ethyl acetate (3 × 8 mL). The organic phases were combined and washed with small amount of water for three times. After drying with anhydrous Na_2SO_4, the solid was filtered and the solvent in the acquired solution was removed under reduced pressure. The resulting residue was subjected to flash silica gel column chromatography to provide pure products with the elution of mixed petroleum ether/ethyl acetate (v /v = 10:1-3:1).

Procedure for the 1 mmol scale synthesis of 3a

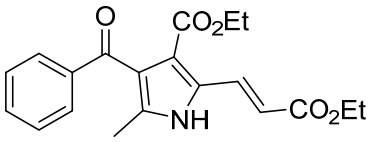
To a 100 mL sealed tube were added enaminone **1a** (1 mmol, 161.1 mg), ethyl propiolate **2a** (4 mmol, 392.5 mg), $Cu(OAc)_2 \cdot H_2O$ (0.5 mmol, 99.8 mg), MeCN (5.0 mL) and DCE (5.0 mL). Then, the mixture was stirred at 100 °C in an oil bath for 12 h. Upon completion, the vessel was allowed to cool down to room temperature. After adding 15 mL saturated brine, the resulting mixture was extracted with ethyl acetate (3 × 15 mL). The organic phases were combined and washed with small amount of water for three times. After drying with anhydrous Na_2SO_4, the solid was filtered and

the solvent in the acquired solution was removed under reduced pressure. The resulting residue was subjected to flash silica gel column chromatography to provide pure products **3a** (110.1 mg, 31%) with the elution of mixed petroleum ether/ethyl acetate (v /v = 5:1).

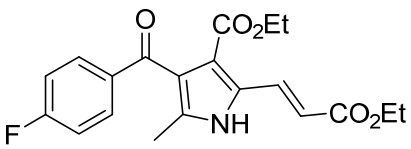
General procedure for the synthesis of 5

To a 25 mL round-bottom flask were added enaminone **1** (0.2 mmol), dialkyl acetylenedicarboxylate **4** (0.3 mmol), $Cu(OAc)_2 \cdot H_2O$ (0.04 mmol), and EtOH (2.0 mL). The mixture was then stirred at room temperature for 6 h. Upon completion, the mixture was directly employed to reduced pressure to remove the solvent, and the resulting residue was purified by flash column chromatography to give pure product by using mixed petroleum ether/ethyl acetate (v /v = 8:1-3:1).

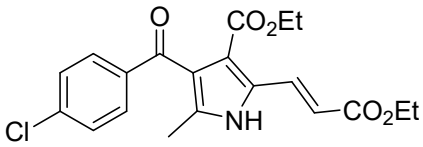
Characterization data of all products



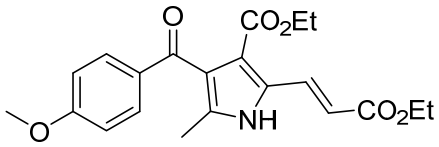
Ethyl (*E*)-4-benzoyl-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3a). Eluent: V_{PET}/V_{EA} = 5:1; white solid (48.3 mg, 68% yield); mp 133-135°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.18 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.81 (d, *J* = 7.8 Hz, 2 H), 7.52 (t, *J* = 7.2 Hz, 1 H), 7.42 (t, *J* = 7.0 Hz, 2 H), 6.40 (d, *J* = 16.4 Hz, 1 H), 4.29 (q, *J* = 6.2, 2 H), 3.80 (q, *J* = 7.0, 2 H), 2.39 (s, 3 H), 1.34 (t, *J* = 7.6 Hz, 3 H), 0.81 (t, *J* = 7.6 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4, 167.6, 163.9, 139.6, 136.3, 132.5, 132.5, 129.7, 129.0, 128.3, 122.5, 118.2, 116.2, 60.9, 60.4, 14.2, 13.4, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{20}H_{22}NO_5$ 356.1492; Found 356.1501.



Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-4-(4-fluorobenzoyl)-5-methyl-1*H*-pyrrole-3-carboxylate (3b). Eluent: V_{PET}/V_{EA} = 5:1; white solid (42.5 mg, 57% yield); mp 151-153-°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.67 (s, 1 H), 8.19 (d, *J* = 16.4 Hz, 1 H), 7.91-7.79 (m, 2 H), 7.10 (t, *J* = 8.4 Hz, 2 H), 6.47 (d, *J* = 16.4 Hz, 1 H), 4.29 (q, *J* = 7.0 Hz, 2 H), 3.88 (q, *J* = 7.0 Hz, 2 H), 2.36 (s, 3 H), 1.34 (t, *J* = 7.0 Hz, 3 H), 0.88 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.8, 165.7 (d, J_{C-F} = 386 Hz), 165.4 (d, J_{C-F} = 253 Hz), 136.1, 136.0, 132.5, 131.6, 131.5, 129.9, 122.3, 117.9, 116.3, 115.5 (d, J_{C-F} = 22 Hz), 61.1, 60.5, 14.2, 13.5, 11.9; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{20}H_{21}FNO_5$ 374.1398; Found 374.1405.

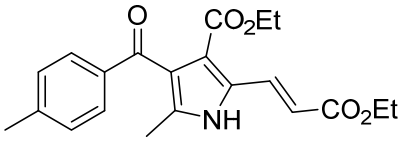


Ethyl (*E*)-4-(4-chlorobenzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3c). Eluent: V_{PET}/V_{EA} = 5:1; white solid (45.1 mg, 58% yield); mp 147-149°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.62 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.75 (d, *J* = 8.2 Hz, 2 H), 7.39 (d, *J* = 8.2 Hz, 2 H), 6.46 (d, *J* = 16.2 Hz, 1 H), 4.29 (q, *J* = 7.0 Hz, 2 H), 3.87 (q, *J* = 7.0 Hz, 2 H), 2.37 (s, 3 H), 1.35 (t, *J* = 7.0 Hz, 3 H), 0.89 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.0, 167.6, 163.7, 138.9, 137.9, 136.4, 132.5, 130.4, 129.9, 128.6, 122.2, 117.9, 116.3, 61.1, 60.5, 14.2, 13.5, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{20}H_{21}ClNO_5$ 390.1103; Found 390.1108.

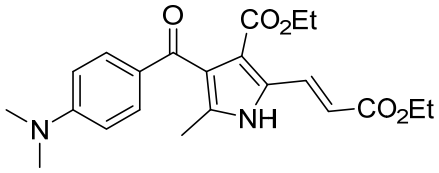


Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-4-(4-methoxybenzoyl)-5-methyl-1*H*-pyrrole-3-carboxylate (3d). Eluent: V_{PET}/V_{EA} = 3:1; white solid (47.8 mg, 62% yield); mp 154-156°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.59 (s, 1 H), 8.19 (d, *J* = 16.4 Hz, 1 H), 7.80 (d, *J* = 8.8 Hz, 2 H), 6.90 (d, *J* = 8.8 Hz, 2 H), 6.44 (d, *J* = 16.4 Hz, 1 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.95-3.82 (m, 5 H), 2.31 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.87 (t, *J* = 7.2 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.3, 167.6, 163.9,

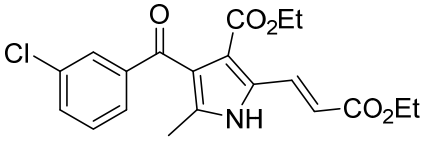
163.3, 135.3, 132.5, 132.4, 131.4, 129.7, 122.9, 117.9, 116.0, 113.6, 60.9, 60.4, 55.5, 14.3, 13.5, 11.8; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{24}NO_6$ 386.1598; Found 386.1605.



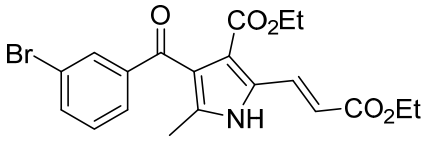
Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-4-(4-methylbenzoyl)-1*H*-pyrrole-3-carboxylate (3e). Eluent: V_{PET}/V_{EA} = 5:1; white solid (48.0 mg, 65% yield); mp 138-140℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.71 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.71 (d, *J* = 8.0 Hz, 2 H), 7.21 (d, *J* = 7.8 Hz, 2 H), 6.45 (d, *J* = 16.4 Hz, 1 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.84 (q, *J* = 7.0 Hz, 2 H), 2.40 (s, 3 H), 2.33 (s, 3 H), 1.33 (t, *J* = 7.2 Hz, 3 H), 0.84 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.3, 167.6, 164.0, 143.4, 136.9, 135.8, 132.5, 129.7, 129.3, 129.0, 122.8, 118.0, 116.1, 60.9, 60.4, 21.6, 14.3, 13.4, 11.9; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{24}NO_5$ 370.1649; Found 370.1654.



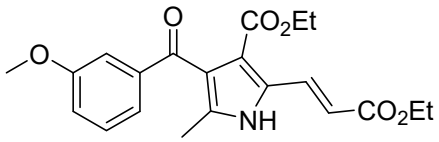
Ethyl (*E*)-4-(4-(dimethylamino)benzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3f). Eluent: V_{PET}/V_{EA} = 3:1; white solid (47.8 mg, 60% yield); mp 243-245℃; ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.17 (s, 1 H), 8.00 (d, *J* = 16.2 Hz, 1 H), 7.54 (d, *J* = 9.0 Hz, 2 H), 6.68 (d, *J* = 9.0 Hz, 2 H), 6.53 (d, *J* = 16.2 Hz, 1 H), 4.18 (q, *J* = 7.0 Hz, 2 H), 3.83 (q, *J* = 7.0 Hz, 2 H), 2.99 (s, 6 H), 2.17 (s, 3 H), 1.25 (t, *J* = 7.0 Hz, 3 H), 0.80 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 190.4, 166.8, 163.9, 153.5, 134.4, 132.3, 131.2, 129.2, 127.0, 123.6, 117.4, 116.0, 111.0, 60.4, 60.1, 40.1, 14.6, 13.8, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{22}H_{27}N_2O_5$ 399.1914; Found 399.1940.



Ethyl (*E*)-4-(3-chlorobenzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3g). Eluent: V_{PET}/V_{EA} = 5:1; white solid (41.2 mg, 53% yield); mp 90-92℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.67 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.79 (s, 1 H), 7.66 (d, *J* = 7.6 Hz, 1 H), 7.49 (d, *J* = 8.0 Hz, 1 H), 7.35 (t, *J* = 7.8 Hz, 1 H), 6.47 (d, *J* = 16.2 Hz, 1 H), 4.29 (q, *J* = 7.2 Hz, 2 H), 3.87 (q, *J* = 7.1 Hz, 2 H), 2.38 (s, 3 H), 1.34 (t, *J* = 7.0 Hz, 3 H), 0.89 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.8, 167.6, 163.7, 141.3, 136.7, 134.7, 132.5, 132.3, 129.9, 129.7, 128.9, 127.1, 122.0, 118.0, 116.4, 61.1, 60.6, 14.2, 13.5, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{20}H_{21}ClNO_5$ 390.1103; Found 390.1111.

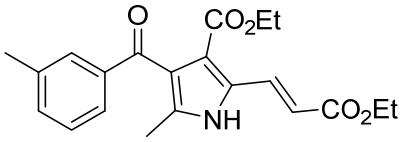


Ethyl (*E*)-4-(3-bromobenzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3h). Eluent: V_{PET}/V_{EA} = 5:1; white solid (44.2 mg, 51% yield); mp 107-109℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.67 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.95 (s, 1 H), 7.71 (d, *J* = 7.6 Hz, 1 H), 7.65 (d, *J* = 7.8 Hz, 1 H), 7.30 (d, *J* = 7.8 Hz, 1 H), 6.47 (d, *J* = 16.2 Hz, 1 H), 4.29 (q, *J* = 7.0 Hz, 2 H), 3.87 (q, *J* = 7.0 Hz, 2 H), 2.39 (s, 3 H), 1.35 (t, *J* = 7.0 Hz, 3 H), 0.89 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.6, 167.6, 163.7, 141.5, 136.8, 135.2, 132.5, 131.8, 129.9, 129.9, 127.5, 122.7, 121.9, 118.0, 116.4, 61.1, 60.6, 14.2, 13.5, 12.1; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{20}H_{21}BrNO_5$ 434.0598; Found 434.0602.

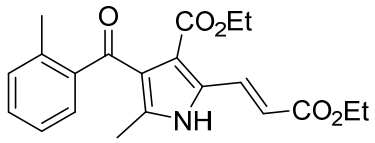


Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-4-(3-methoxybenzoyl)-5-methyl-1*H*-pyrrole-3-carboxylate (3i). Eluent: V_{PET}/V_{EA} = 3:1; white solid (44.7 mg, 58% yield); mp 121-123℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.70 (s, 1 H), 8.16 (d, *J* = 16.2 Hz, 1 H), 7.39 (s, 1 H), 7.37-7.28 (m, 2 H), 7.11-7.03 (m, 1 H), 6.46 (d, *J* = 16.2 Hz, 1 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.88-3.79 (m, 5 H), 2.37 (s, 3 H), 1.33 (t, *J* = 7.1 Hz, 3 H), 0.87 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.1, 167.6, 163.9,

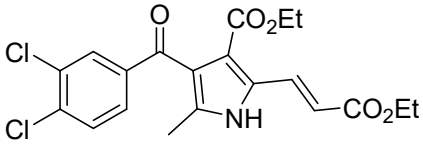
159.7, 140.9, 136.4, 132.5, 129.6, 129.4, 122.5, 122.0, 119.2, 118.3, 116.1, 112.9, 61.0, 60.5, 55.4, 14.2, 13.5, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{24}NO_6$ 386.1598; Found 386.1605.



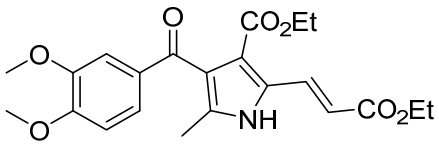
Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-4-(3-methylbenzoyl)-1*H*-pyrrole-3-carboxylate (3j). Eluent: V_{PET}/V_{EA} = 5:1; white solid (43.6 mg, 59% yield); mp 92-94℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.58 (s, 1 H), 8.16 (d, *J* = 16.2 Hz, 1 H), 7.63 (s, 1 H), 7.58 (d, *J* = 7.4 Hz, 1 H), 7.37-7.28 (m, 2 H), 6.44 (d, *J* = 16.4 Hz, 1 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.82 (q, *J* = 7.0 Hz, 2 H), 2.37 (s, 3 H), 2.36 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.83 (t, *J* = 7.0 Hz, 3 H; ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.5, 167.6, 163.9, 139.6, 138.1, 136.3, 133.3, 132.5, 129.6, 129.4, 128.3, 126.4, 122.7, 118.3, 116.0, 61.0, 60.4, 21.3, 14.3, 13.4, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{24}NO_5$ 370.1649; Found 370.1658.



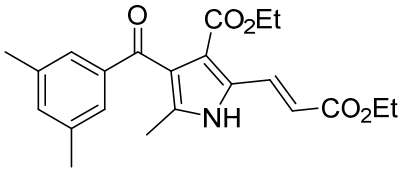
Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-4-(2-methylbenzoyl)-1*H*-pyrrole-3-carboxylate (3k). Eluent: V_{PET}/V_{EA} = 5:1; white solid (44.3 mg, 60% yield); mp 93-95℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.71 (s, 1 H), 8.03 (d, *J* = 16.2 Hz, 1 H), 7.32 (t, *J* = 7.2 Hz, 2 H), 7.26 (d, *J* = 7.6 Hz, 1 H), 7.13 (t, *J* = 7.4 Hz, 1 H), 6.42 (d, *J* = 16.2 Hz, 1 H), 4.26 (q, *J* = 7.0 Hz, 2 H), 3.77 (q, *J* = 7.0 Hz, 2 H), 2.56 (s, 3 H), 2.37 (s, 3 H), 1.32 (t, *J* = 7.0 Hz, 3 H), 0.95 (t, *J* = 7.2 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.8, 167.6, 164.1, 139.8, 138.2, 132.4, 131.5, 130.9, 129.7, 129.3, 125.4, 123.5, 119.1, 116.0, 61.0, 60.6, 20.8, 14.2, 13.6, 12.4; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{24}NO_5$ 370.1649; Found 370.1656.



Ethyl (*E*)-4-(3,4-dichlorobenzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl -1*H*-pyrrole-3-carboxylate (3l). Eluent: V_{PET}/V_{EA} = 5:1; white solid (43.2 mg, 51% yield); mp 170-172°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.73 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.92-7.87 (m, 1 H), 7.65-7.60 (m, 1 H), 7.50 (d, *J* = 8.2 Hz, 1 H), 6.47 (d, *J* = 16.4 Hz, 1 H), 4.29 (q, *J* = 7.0 Hz, 2 H), 3.93 (q, *J* = 7.0 Hz, 2 H), 2.37 (s, 3 H), 1.35 (t, *J* = 7.0 Hz, 3 H), 0.95 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.7, 167.6, 163.5, 139.3, 136.9, 136.7, 133.0, 132.5, 130.8, 130.4, 130.0, 128.0, 121.8, 117.7, 116.5, 61.1, 60.7, 14.2, 13.6, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{20}H_{20}Cl_2NO_5$ 424.0713; Found 424.0718.

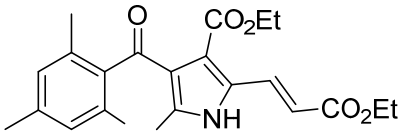


Ethyl (*E*)-4-(3,4-dimethoxybenzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl -1*H*-pyrrole-3-carboxylate (3m). Eluent: V_{PET}/V_{EA} = 3:1; white solid (49.8 mg, 60% yield); mp 132-134°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.71 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.52 (s, 1 H), 7.39-7.31 (m, 1 H), 6.83 (d, *J* = 8.4 Hz, 1 H), 6.46 (d, *J* = 16.2 Hz, 1 H), 4.27 (q, *J* = 7.2 Hz, 2 H), 3.95-3.86 (m, 8 H), 2.33 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.90 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.2, 167.6, 164.0, 153.0, 148.9, 135.4, 132.5, 129.6, 124.5, 122.7, 118.1, 116.0, 110.8, 109.9, 60.9, 60.4, 56.1, 56.0, 14.2, 13.6, 11.9; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{22}H_{26}NO_7$ 416.1704; Found 416.1712.

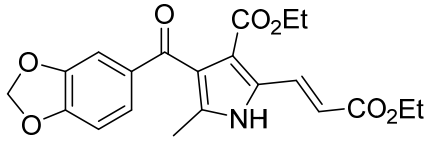


Ethyl (*E*)-4-(3,5-dimethylbenzoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl -1*H*-pyrrole-3-carboxylate (3n). Eluent: V_{PET}/V_{EA} = 5:1; white solid (47.5 mg, 62% yield); mp 107-109°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.72 (s, 1 H), 8.16 (d, *J* = 16.2 Hz, 1 H), 7.41 (s, 2 H), 7.15 (s, 1 H), 6.46 (d, *J* = 16.2 Hz, 1 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.83 (q, *J* = 7.0 Hz, 2 H), 2.37-2.29 (m, 9 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.85 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.7, 167.6, 164.0, 139.6, 138.0, 136.2,

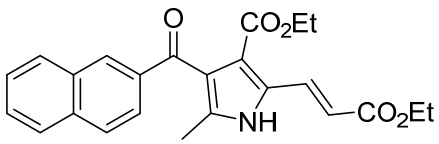
134.2, 132.5, 129.5, 126.9, 122.8, 118.4, 116.0, 60.9, 60.4, 21.1, 14.2, 13.4, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{22}H_{26}NO_5$ 384.1805; Found 384.1814.



Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-4-(2,4,6-trimethylbenzoyl) -1*H*-pyrrole-3-carboxylate (3o). Eluent: V_{PET}/V_{EA} = 10:1; colourless liquid (50.0 mg, 63% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.64 (s, 1 H), 7.69 (d, *J* = 16.0 Hz, 1 H), 6.81 (s, 2 H), 6.32 (d, *J* = 16.2 Hz, 1 H), 4.21 (q, *J* = 7.0 Hz, 2 H), 4.01 (q, *J* = 7.0 Hz, 2 H), 2.27 (s, 3 H), 2.14 (s, 6 H), 2.11 (s, 3 H), 1.29 (t, *J* = 7.0 Hz, 3 H), 1.21 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.9, 167.4, 165.0, 139.7, 138.7, 138.3, 134.6, 131.8, 128.6, 128.1, 123.5, 120.9, 115.5, 61.1, 60.8, 21.1, 19.6, 14.2, 13.9, 12.8; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{23}H_{28}NO_5$ 398.1962; Found 398.1969.

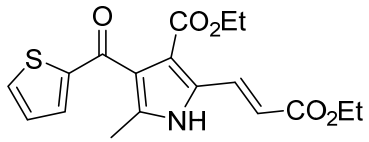


Ethyl (*E*)-4-(benzo[d][1,3]dioxole-5-carbonyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5 -methyl-1*H*-pyrrole-3-carboxylate (3p). Eluent: V_{PET}/V_{EA} = 3:1; white solid (49.5mg, 62% yield); mp 147-149℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.66 (s, 1 H), 8.18 (d, *J* = 16.2 Hz, 1 H), 7.40-7.31 (m, 2 H), 6.78 (d, *J* = 8.0 Hz, 1 H), 6.43 (d, *J* = 16.2 Hz, 1 H), 6.03 (s, 2 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.96 (q, *J* = 7.0 Hz, 2 H), 2.29 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.96 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 191.9, 167.6, 163.8, 151.5, 148.1, 135.1, 134.2, 132.5, 129.7, 126.0, 122.9, 117.8, 116.1, 108.6, 107.7, 101.8, 60.9, 60.4, 14.2, 13.7, 11.8; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{21}H_{22}NO_7$ 400.1391; Found 400.1399.

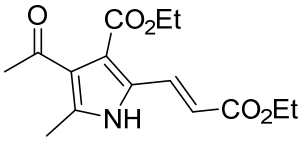


Ethyl (*E*)-4-(2-naphthoyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H* -pyrrole-3-carboxylate (3q). Eluent: V_{PET}/V_{EA} = 5:1; white solid (42.1 mg, 52% yield); mp 166-168℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.70 (s, 1 H), 8.27-8.16 (m, 2

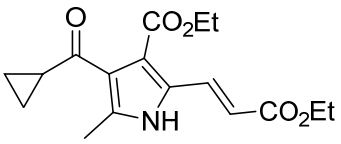
H), 7.99 (d, *J* = 8.4 Hz, 1 H), 7.92-7.83 (m, 3 H), 7.57 (t, *J* = 7.4 Hz, 1 H), 7.51 (t, *J* = 7.4 Hz, 1 H), 6.51 (d, *J* = 16.2 Hz, 1 H), 4.28 (q, *J* = 7.2 Hz, 2 H), 3.73 (q, *J* = 7.2 Hz, 2 H), 2.40 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.71 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.3, 167.6, 163.9, 136.9, 136.1, 135.3, 132.6, 132.5, 132.0, 130.9, 129.8, 129.5, 128.3, 127.7, 126.7, 124.7, 122.8, 118.3, 116.2, 61.0, 60.4, 14.3, 13.4, 12.1; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{24}H_{24}NO_5$ 406.1649; Found 406.1657.



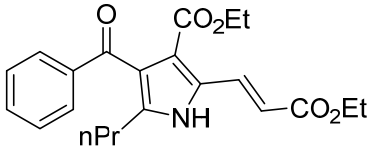
Ethyl (*E*)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-4-(thiophene-2-carbonyl) -1*H*-pyrrole-3-carboxylate (3r). Eluent: V_{PET}/V_{EA} = 5:1; white solid (46.2 mg, 64% yield); mp 139-141°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.82 (s, 1 H), 8.19 (d, *J* = 16.4 Hz, 1 H), 7.64 (d, *J* = 4.2 Hz, 1 H), 7.46 (d, *J* = 2.8 Hz, 1 H), 7.15-7.00 (m, 1 H), 6.47 (d, *J* = 16.4 Hz, 1 H), 4.27 (q, *J* = 7.0 Hz, 2 H), 3.97 (q, *J* = 7.0 Hz, 2 H), 2.36 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 0.93 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 185.5, 167.6, 163.9, 146.3, 135.5, 133.6, 132.4, 130.0, 128.0, 122.6, 117.6, 116.3, 60.9, 60.5, 14.2, 13.5, 11.8; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{18}H_{20}SNO_5$ 362.1057; Found 362.1064.



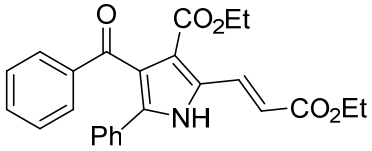
Ethyl (*E*)-4-acetyl-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl-1H-pyrrole-3 -carboxylate (3s). Eluent: V_{PET}/V_{EA} = 5:1; white solid (28.1 mg, 48% yield); mp 124-126°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.61 (s, 1 H), 7.99 (d, *J* = 16.2 Hz, 1 H), 6.37 (d, *J* = 16.2 Hz, 1 H), 4.37 (q, *J* = 7.2 Hz, 2 H), 4.26 (q, *J* = 7.2 Hz, 2 H), 2.44 (s, 3 H), 2.42 (s, 3 H), 1.39 (t, *J* = 7.0 Hz, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 197.9, 167.4, 164.6, 137.2, 132.4, 129.0, 124.3, 118.0, 116.0, 61.1, 60.9, 30.9, 14.2, 14.1, 12.9; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{15}H_{20}NO_5$ 294.1336; Found 294.1343.



Ethyl (*E*)-4-(cyclopropanecarbonyl)-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-methyl -1*H*-pyrrole-3-carboxylate (3t). Eluent: V_{PET}/V_{EA} = 3:1; colourless liquid (29.4 mg, 46% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.45 (s, 1 H), 8.07 (d, *J* = 16.2 Hz, 1 H), 6.35 (d, *J* = 16.2 Hz, 1 H), 4.32 (q, *J* = 7.0 Hz, 2 H), 4.25 (q, *J* = 7.0 Hz, 2 H), 2.34 (s, 3 H), 2.23-2.18 (m, 1 H), 1.39-1.29 (m, 6 H), 1.22-1.16 (m, 2 H), 0.99-0.91 (m, 2 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 200.7, 167.5, 164.4, 135.4, 132.5, 129.4, 125.2, 117.4, 115.9, 60.9, 22.5, 14.2, 14.1, 12.4, 12.1; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{17}H_{22}NO_5$ 320.1492; Found 320.1498.

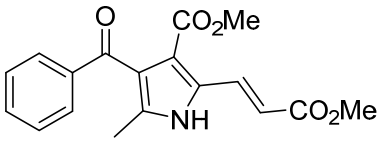


Ethyl (*E*)-4-benzoyl-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-propyl-1H-pyrrole-3 -carboxylate (3u). Eluent: V_{PET}/V_{EA} = 10:1; white solid (39.9 mg, 52% yield); mp 119-121°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.47 (s, 1 H), 8.21 (d, *J* = 16.2 Hz, 1 H), 7.85-7.77 (m, 2 H), 7.54-7.49 (m, 1 H), 7.44-7.38 (m, 2 H), 6.53 (d, *J* = 16.4 Hz, 1 H), 4.26 (q, *J* = 7.0 Hz, 2 H), 3.80 (q, *J* = 7.0 Hz, 2 H), 2.70 (t, *J* = 7.6 Hz, 2 H), 1.72-1.61 (m, 2 H), 1.32 (t, *J* = 7.0 Hz, 3 H), 0.87 (t, *J* = 7.4 Hz, 3 H), 0.80 (t, *J* = 7.2 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.4 167.6, 163.9, 140.4, 139.7, 132.6, 129.8, 129.0, 128.3, 127.7, 122.5, 117.9, 116.2, 60.9, 60.3, 28.3, 23.2, 14.3, 13.7, 13.4; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{22}H_{26}NO_5$ 384.1805; Found $C_{22}H_{26}NO_5$ 384.1810.

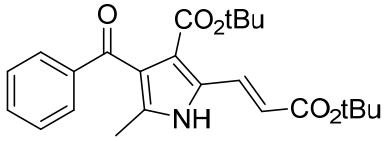


Ethyl (*E*)-4-benzoyl-2-(3-ethoxy-3-oxoprop-1-en-1-yl)-5-phenyl-1H-pyrrole-3 -carboxylate (3v). Eluent: V_{PET}/V_{EA} = 10:1; white solid (45.1 mg, 54% yield); mp 191-193°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.59 (s, 1 H), 8.27 (d, *J* = 16.4 Hz, 1 H), 7.87 (d, *J* = 7.6 Hz, 2 H), 7.51 (t, *J* = 7.2 Hz, 1 H), 7.46-7.36 (m, 4 H), 7.24-7.16 (m, 3 H), 6.70 (d, *J* = 16.4 Hz, 1 H), 4.12 (q, *J* = 7.0 Hz, 2 H), 3.95 (q, *J* = 7.0 Hz, 2 H),

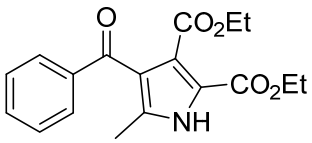
1.23 (t, *J* = 7.0 Hz, 3 H), 0.87 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 194.2, 167.5, 163.4, 138.6 135.2, 133.0, 132.3, 131.4, 130.0, 129.4, 128.6, 128.5, 128.4, 127.6, 123.2, 118.1, 117.3, 61.0, 60.5, 14.2, 13.4; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{25}H_{24}NO_5$ 418.1649; Found 418.1657.



Methyl (*E*)-4-benzoyl-2-(3-methoxy-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3w). Eluent: V_{PET}/V_{EA} = 5:1; white solid (39.9 mg, 61% yield); mp 203-205°C; ^{1}H NMR (400 MHz, DMSO-d_6) δ 12.39 (s, 1 H), 7.92 (d, *J* = 16.2 Hz, 1 H), 7.64 (d, *J* = 7.2 Hz, 2 H), 7.59 (t, *J* = 7.2 Hz, 1 H), 7.48 (t, *J* = 7.4 Hz, 2 H), 6.58 (d, *J* = 16.2 Hz, 1 H), 3.74 (s, 3 H), 3.18 (s, 3 H), 2.28 (s, 3 H); ^{13}C NMR (100 MHz, DMSO-d_6) δ 192.3, 167.1, 164.1, 140.0, 137.0, 132.7, 132.0, 129.4, 128.9, 128.6, 122.2, 117.8, 116.5, 52.0, 51.2, 12.2; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{18}H_{18}NO_5$ 328.1179; Found 328.1188.

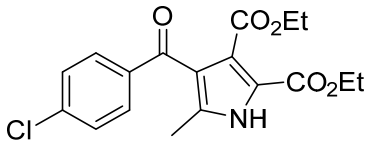


***tert*-Butyl (*E*)-4-benzoyl-2-(3-(tert-butoxy)-3-oxoprop-1-en-1-yl)-5-methyl-1*H*-pyrrole-3-carboxylate (3x)**. Eluent: V_{PET}/V_{EA} = 8:1; white solid (53.5 mg, 65% yield); mp 142-144°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.57 (s, 1 H), 8.09 (d, *J* = 16.2 Hz, 1 H), 7.85 (d, *J* = 7.0 Hz, 2 H), 7.53 (t, *J* = 7.2 Hz, 1 H), 7.42 (t, *J* = 7.6 Hz, 2 H), 6.39 (d, *J* = 16.4 Hz, 1 H), 2.37 (s, 3 H), 1.54 (s, 9 H), 1.13 (s, 9 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.3, 167.1, 163.1, 139.5, 135.5, 132.5, 132.0, 129.5, 129.4, 128.3, 122.4, 119.6, 117.7, 81.2, 81.1, 28.2, 27.6, 12.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{24}H_{30}NO_5$ 412.2118; Found 412.2123.

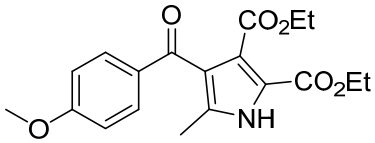


Diethyl 4-benzoyl-5-methyl-1H-pyrrole-2,3-dicarboxylate (5a). Eluent: V_{PET}/V_{EA} = 5:1; colourless liquid (49.4 mg, 75% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.23 (s, 1

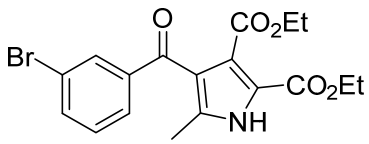
H), 7.73 (d, *J* = 7.6 Hz, 2 H), 7.52 (t, *J* = 7.4 Hz, 1 H), 7.42 (t, *J* = 7.6 Hz, 2 H), 4.33 (q, *J* = 7.0 Hz, 2 H), 3.80 (q, *J* = 7.2 Hz, 2 H), 2.40 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3 H), 1.04 (t, *J* = 7.2 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.0, 164.4, 160.5, 139.4, 137.4, 132.3, 128.8, 128.3, 123.1, 121.9, 119.5, 61.4, 61.2, 14.1, 13.6, 12.8; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{18}H_{20}NO_5$ 330.1336; Found 330.1334.



Diethyl 4-(4-chlorobenzoyl)-5-methyl-1H-pyrrole-2,3-dicarboxylate (5b). Eulent: V_{PET}/V_{EA} = 5:1; white solid (53.0 mg, 73% yield); mp 96-98°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.21 (s, 1 H), 7.68 (d, *J* = 8.4 Hz, 2 H), 7.40 (d, *J* = 8.4 Hz, 2 H), 4.34 (q, *J* = 7.0 Hz, 2 H), 3.86 (q, *J* = 7.0 Hz, 2 H), 2.41 (s, 3 H), 1.34 (t, *J* = 7.0 Hz, 3 H), 1.07 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.7, 164.4, 160.6, 138.7, 137.7, 137.6, 130.3, 128.6, 123.0, 121.5, 119.6, 61.6, 61.4, 14.1, 13.7, 12.9; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{18}H_{19}ClNO_5$ 364.0946; Found 364.0953.

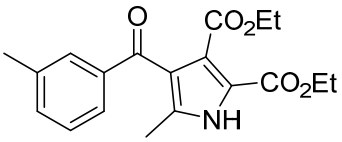


Diethyl 4-(4-methoxybenzoyl)-5-methyl-1H-pyrrole-2,3-dicarboxylate (5c). Eulent: V_{PET}/V_{EA} = 3:1; colourless liquid (56.0 mg, 78% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.91 (s, 1 H), 7.75 (d, *J* = 8.8 Hz, 2 H), 6.91 (d, *J* = 8.8 Hz, 2 H), 4.34 (q, *J* = 7.0 Hz, 2 H), 3.92-3.87 (m, 2 H), 3.86 (s, 3 H), 2.38 (s, 3 H), 1.34 (t, *J* = 7.0 Hz, 3 H), 1.05 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.7, 164.5, 163.1, 160.5, 136.4, 132.1, 131.3, 122.8, 122.3, 119.4, 113.5, 61.4, 61.2, 55.5, 14.1, 13.7, 12.7; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{19}H_{22}NO_6$ 360.1442; Found 360.1449.

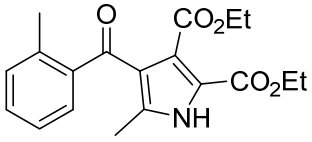


Diethyl 4-(3-bromobenzoyl)-5-methyl-1H-pyrrole-2,3-dicarboxylate (5d). Eulent: V_{PET}/V_{EA} = 5:1; colourless liquid (60.2 mg, 74% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.31 (s, 1 H), 7.86 (s, 1 H), 7.69-7.61 (m, 2 H), 7.31 (t, *J* = 7.8 Hz, 1 H), 4.34 (q, *J*

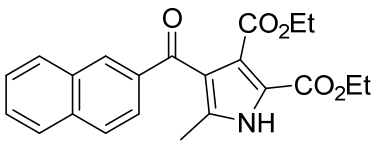
= 7.0 Hz, 2 H), 3.87 (q, *J* = 7.2 Hz, 2 H), 2.43 (s, 3 H), 1.34 (t, *J* = 7.0 Hz, 3 H), 1.11 (t, *J* = 7.2 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.4, 164.5, 160.6, 141.2, 138.2, 135.0, 131.7, 130.0, 127.4, 122.5, 121.1, 119.6, 77.3, 61.6, 61.5, 14.1, 13.7, 13.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{18}H_{19}BrlNO_5$ 408.0441; Found 408.0446.



Diethyl 5-methyl-4-(3-methylbenzoyl)-1H-pyrrole-2,3-dicarboxylate (5e). Eluent: V_{PET}/V_{EA} = 5:1; colourless liquid (54.9 mg, 80% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.75 (s, 1 H), 7.59-7.49 (m, 2 H), 7.36-7.28 (m, 2 H), 4.33 (q, *J* = 7.0 Hz, 2 H), 3.80 (q, *J* = 7.2 Hz, 2 H), 2.41 (s, 3 H), 2.38 (s, 3 H), 1.34 (t, *J* = 7.0 Hz, 3 H), 1.03 (t, *J* = 7.2 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.2, 164.5, 160.4, 139.3, 138.1, 137.2, 133.0, 129.4, 128.2, 126.1, 123.1, 122.0, 119.4, 61.4, 61.2, 21.3, 14.1, 13.6, 13.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{19}H_{22}NO_5$ 344.1492; Found 344.1500.

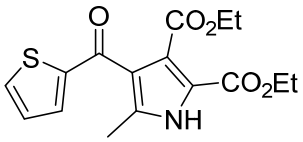


Diethyl 5-methyl-4-(2-methylbenzoyl)-1H-pyrrole-2,3-dicarboxylate (5f). Eluent: V_{PET}/V_{EA} = 5:1; colourless liquid (48.0 mg, 70% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.28-7.20 (m, 2 H), 7.17-7.08 (m, 2 H), 4.22 (q, *J* = 7.0 Hz, 2 H), 3.76 (q, *J* = 7.2 Hz, 2 H), 2.31 (s, 3 H), 2.26 (s, 3 H), 1.23 (t, *J* = 7.0 Hz, 3 H), 1.10 (t, *J* = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.4, 164.0, 159.5, 138.9, 138.0, 135.4, 129.7, 129.2, 127.0, 124.2, 123.0, 121.0, 117.8, 60.4, 18.7, 13.0, 12.8, 12.2; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{19}H_{22}NO_5$ 344.1492; Found 344.1505.

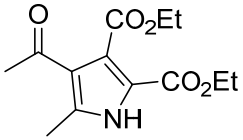


Diethyl 4-(2-naphthoyl)-5-methyl-1H-pyrrole-2,3-dicarboxylate (5g). Eluent: V_{PET}/V_{EA} = 5:1; white solid (56.9 mg, 75% yield); mp 130-132°C; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.95 (s, 1 H), 8.19 (s, 1 H), 7.94-7.85 (m, 4 H), 7.60-7.50 (m, 2 H), 4.34 (q, *J* = 7.0 Hz, 2 H), 3.64 (q, *J* = 7.2 Hz, 2 H), 2.45 (s, 3 H), 1.33 (t, *J* = 7.0 Hz, 3

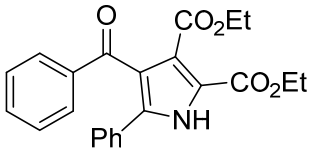
H), 0.90 (t, J = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.0, 164.6, 160.5, 137.4, 136.6, 135.2, 132.2, 130.6, 129.4, 128.4, 128.2, 127.8, 126.8, 124.7, 123.3, 122.1, 119.4, 61.5, 61.2, 14.1, 13.5, 13.0; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{22}H_{22}NO_5$ 380.1492; Found 380.1499.



Diethyl 5-methyl-4-(thiophene-2-carbonyl)-1H-pyrrole-2,3-dicarboxylate (5h). Eluent: V_{PET}/V_{EA} = 5:1; white solid (52.9 mg, 79% yield); mp 122-124℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.30 (s, 1 H), 7.65 (dd, J = 4.8, 1.2 Hz, 1 H), 7.49 (dd, J = 3.6, 1.2 Hz, 1 H), 7.07 (dd, J = 4.8, 3.8 Hz, 1 H), 4.35 (q, J = 7.0 Hz, 2 H), 3.96 (q, J = 7.2 Hz, 2 H), 2.44 (s, 3 H), 1.35 (t, J = 7.0 Hz, 3 H), 1.05 (t, J = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 183.8, 164.3, 160.5, 145.4, 136.2, 133.6, 133.5, 127.7, 122.2, 122.2, 119.8, 61.5, 61.3, 14.1, 13.7, 12.4; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{16}H_{18}SNO_5$ 336.0900; Found 336.0910.

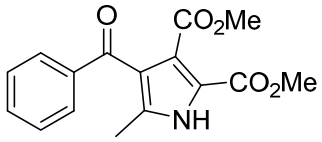


Diethyl 4-acetyl-5-methyl-1H-pyrrole-2,3-dicarboxylate (5i). Eluent: V_{PET}/V_{EA} = 5:1; white solid (32.6 mg, 61% yield); mp 45-47℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.79 (s, 1 H), 4.41 (q, J = 7.0 Hz, 2 H), 4.32 (q, J = 7.0 Hz, 2 H), 2.57 (s, 3 H), 2.39 (s, 3 H), 1.41 (t, J = 7.2 Hz, 3 H), 1.34 (t, J = 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 193.2, 166.5, 160.1, 138.1, 123.7, 121.3, 118.3, 61.9, 61.4, 29.3, 14.5, 14.2, 14.1; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{13}H_{18}NO_5$ 268.1179; Found 268.1185.

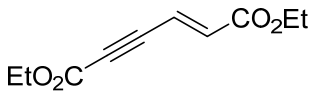


Diethyl 4-benzoyl-5-phenyl-1H-pyrrole-2,3-dicarboxylate (5j). Eluent: V_{PET}/V_{EA} = 8:1; colourless liquid (57.9 mg, 74% yield); ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.42 (s, 1 H), 7.76-7.65 (m, 2 H), 7.43-7.35 (m, 3 H), 7.28-7.26 (m, 2 H), 7.25-7.22 (m, 3 H), 4.20 (q, J = 7.0 Hz, 2 H), 4.03 (q, J = 7.0 Hz, 2 H), 1.28 (t, J = 7.0 Hz, 3 H), 1.12 (t, J

= 7.0 Hz, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 190.7 , 163.2, 159.4, 137.0, 136.6, 131.6, 128.8, 128.4, 127.9, 127.5, 127.4, 127.0, 122.6, 121.1, 120.0, 60.6, 60.3, 13.0, 12.7; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{23}H_{22}NO_5$ 392.1492; Found 392.1502.



Dimethyl 4-benzoyl-5-methyl-1H-pyrrole-2,3-dicarboxylate (5k). Eluent: V_{PET}/V_{EA} = 3:1; white solid (43.4 mg, 72% yield); mp 114-116℃; ^{1}H NMR (400 MHz, $CDCl_3$) δ 10.06 (s, 1 H), 7.71 (d, *J* = 7.0 Hz, 2 H), 7.53 (t, *J* = 7.4 Hz, 1 H), 7.43 (t, *J* = 7.4 Hz, 2 H), 3.87 (s, 3 H), 3.34 (s, 3 H), 2.41 (s, 3 H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 192.0, 164.7, 160.7, 139.4, 137.3, 132.3, 128.7, 128.3, 122.8, 122.2, 119.4, 52.3, 51.9, 12.8; HRMS (ESI) *m/z*: $[M + H]^+$ Calcd for $C_{16}H_{16}NO_5$ 302.1023; Found 302.1028.



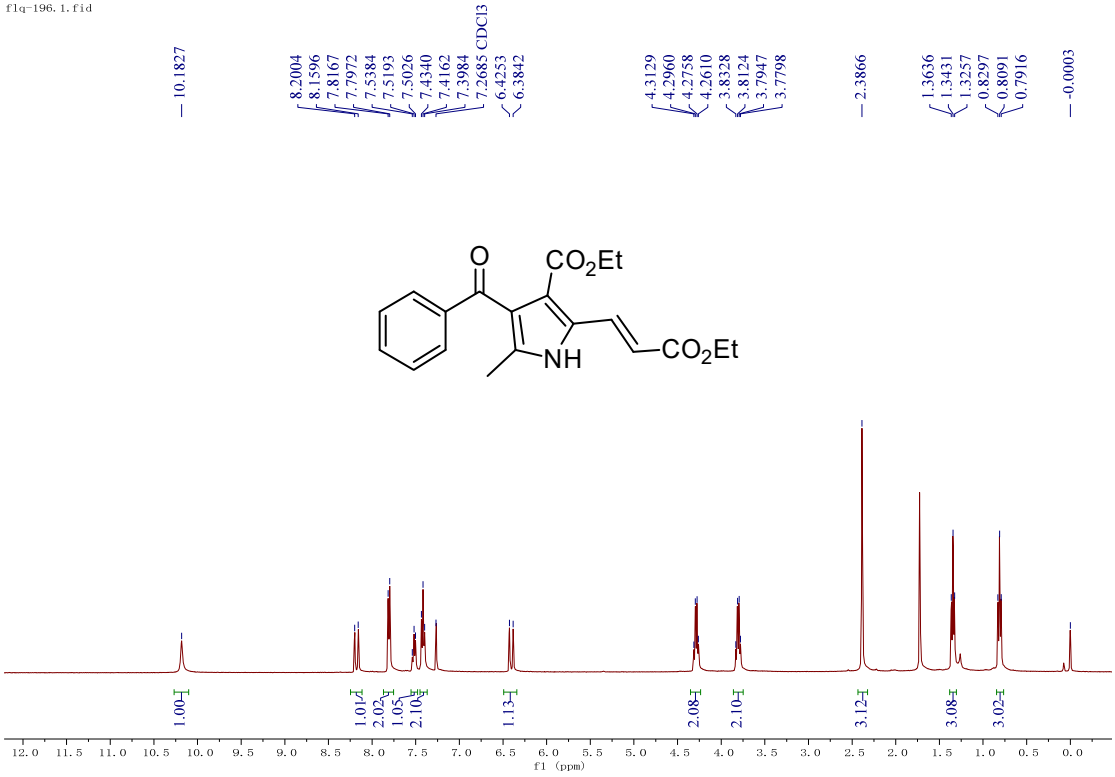
Diethyl (*E*)-hex-2-en-4-ynedioate (**6**).[2] Colorless liquid; ^{1}H NMR (400 MHz, $CDCl_3$) δ 6.78 (d, *J* = 16.0 Hz, 1H), 6.46 (d, *J* = 16.0 Hz, 1H), 4.35-4.18 (m, 4H), 1.36-1.29 (m, 6H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.7, 153.1, 135.4, 121.5, 87.0, 81.5, 62.4, 61.3, 14.1, 14.0.

References

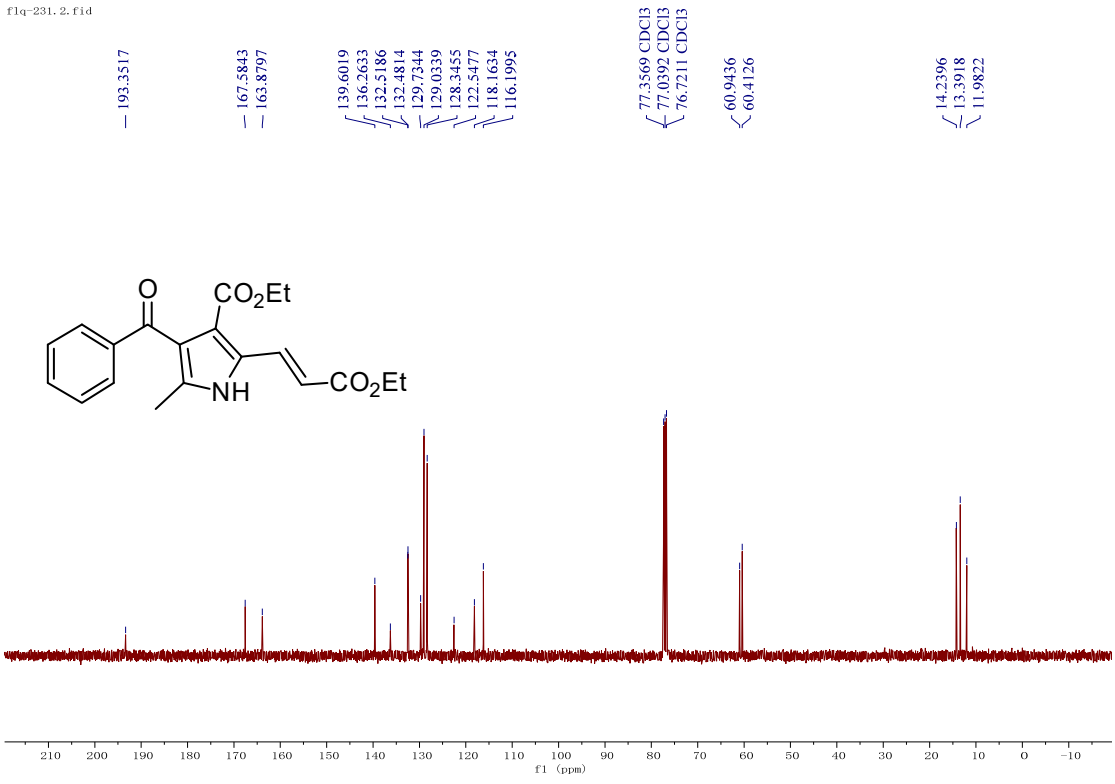
1. (a) X. Sun, Y. Lyu, D. Zhang-Negrerie, Y. Du and K. Zhao, *Org. Lett.,* 2013, **15**, 6222. (b) B. Prek, U. Groselj, M. Kasunic, S. Zupancic, J. Svete and B. Stanovnik, *Aust. J. Chem.,* 2015, **68**, 184.

2. S. Chen, Y. Li, J. Zhao and X. Li, *Inorg. Chem.,* 2009, **48**, 1198.

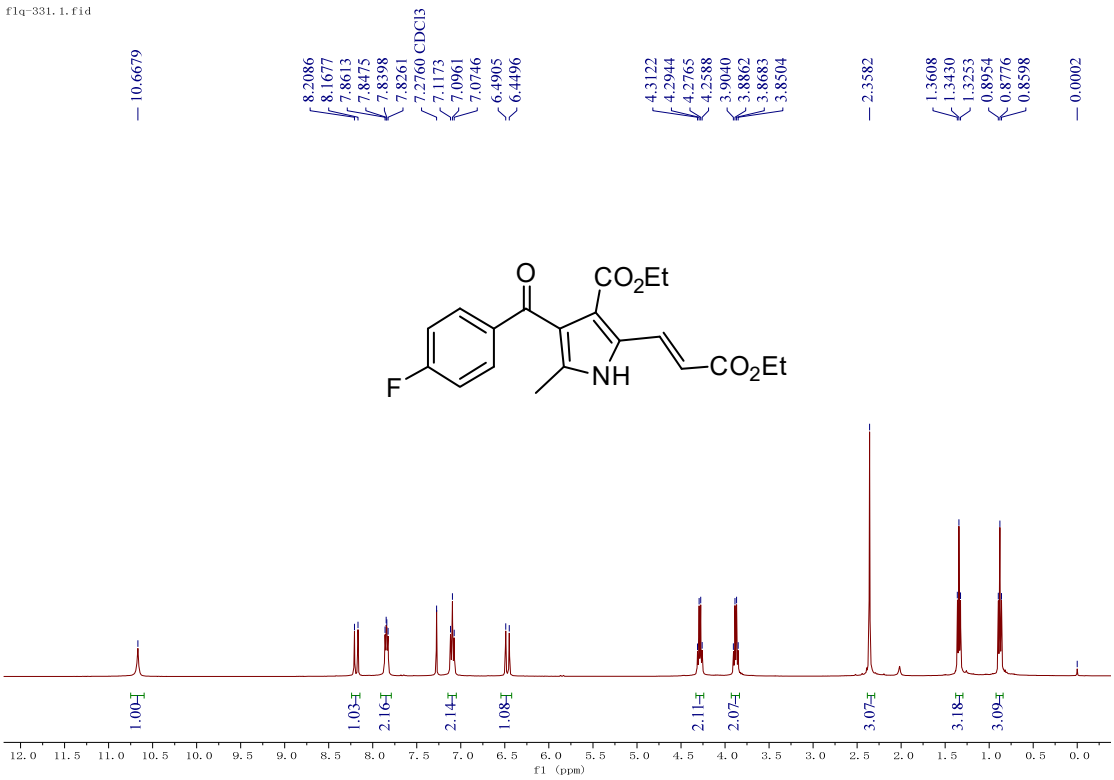
The ^{1}H and ^{13}C NMR spectra of all products



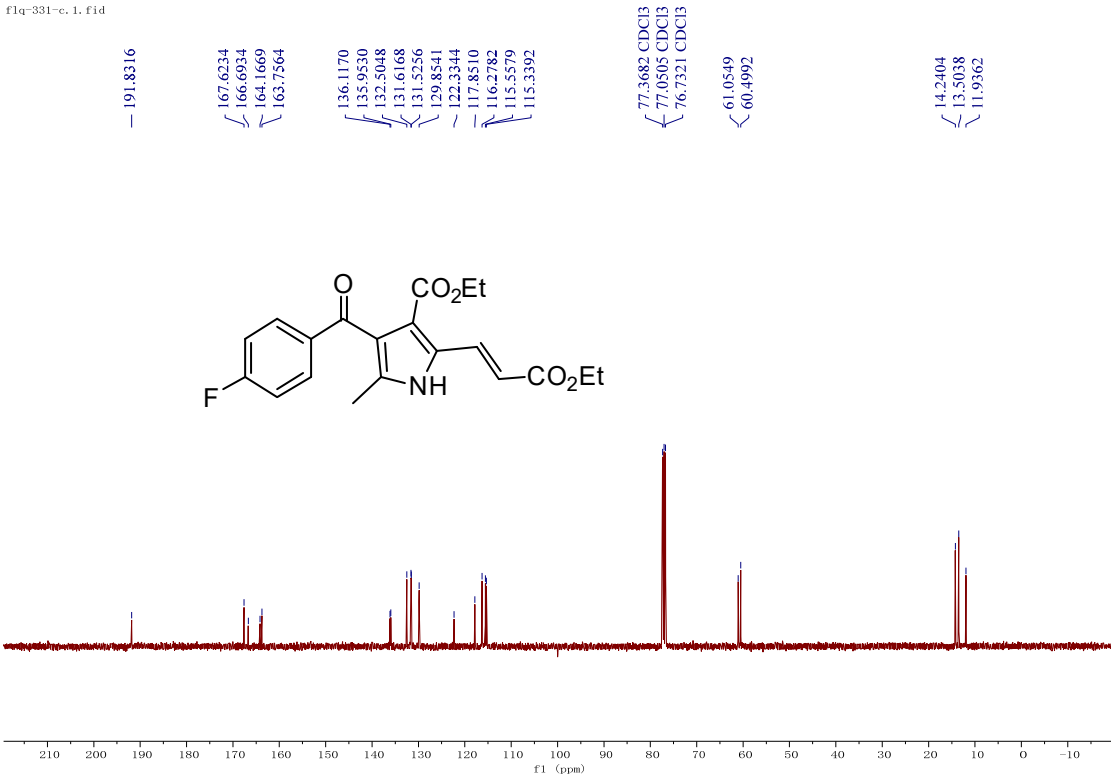
^{1}H NMR spectrum of **3a** (400 MHz, $CDCl_3$)



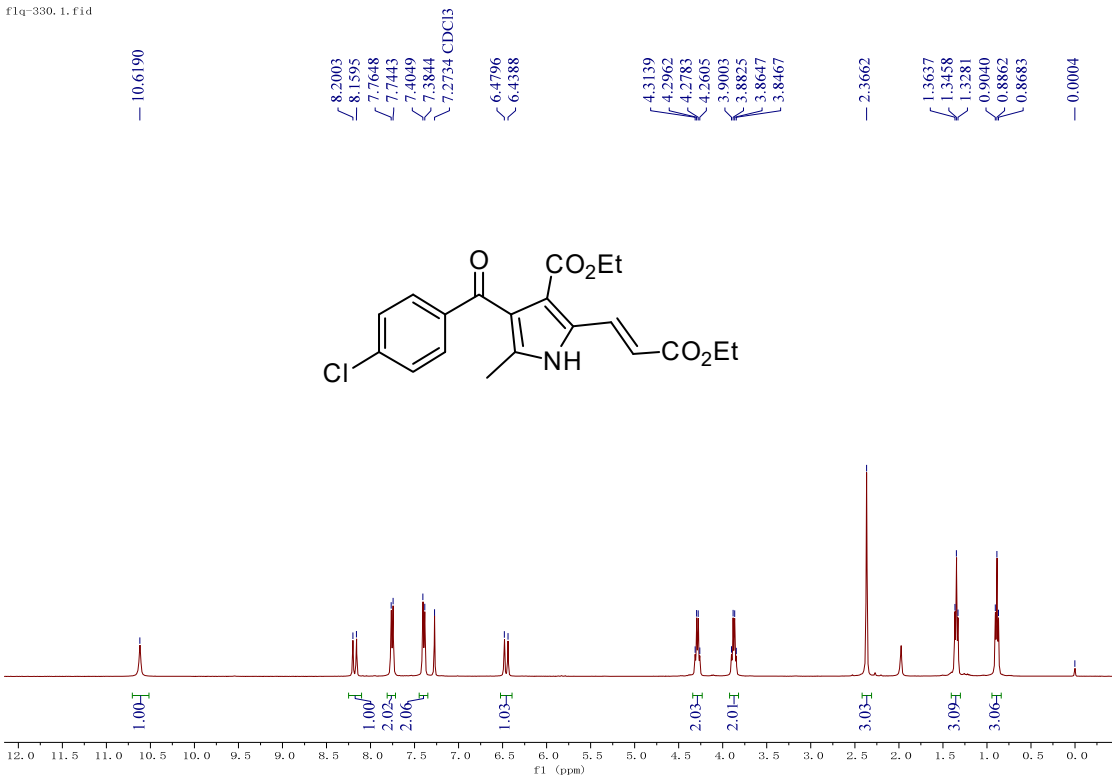
^{13}C NMR spectrum of **3a** (100 MHz, $CDCl_3$)



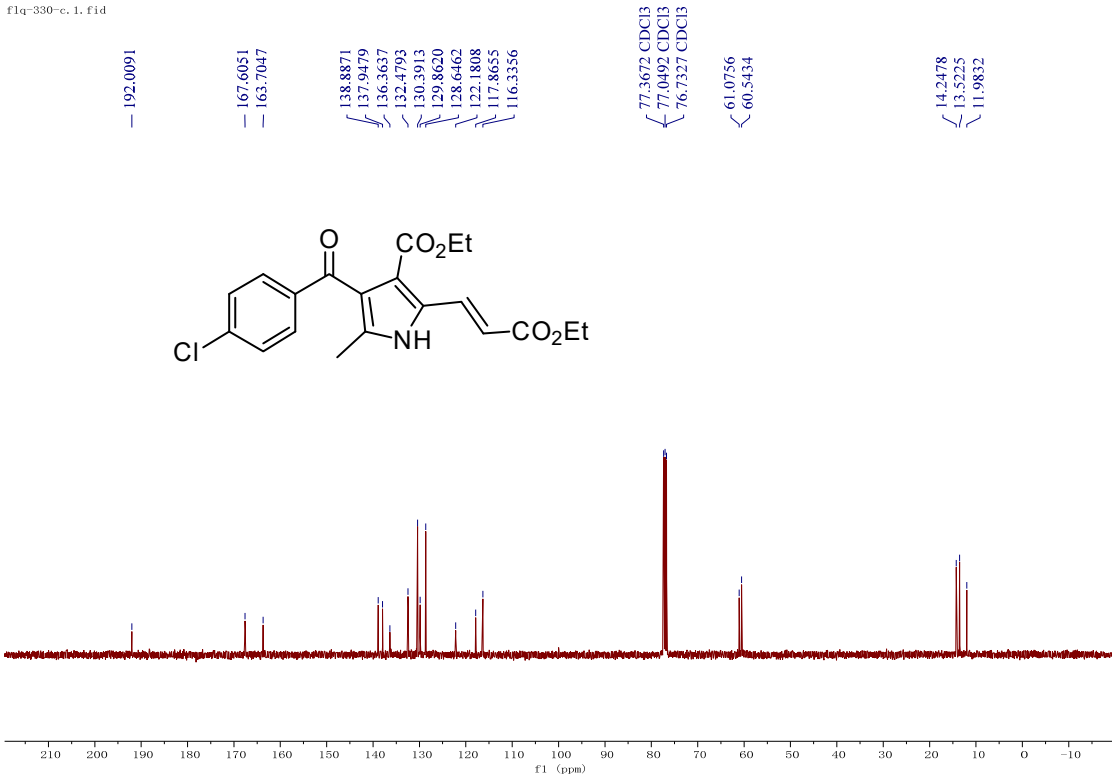
^{1}H NMR spectrum of **3b** (400 MHz, $CDCl_3$)



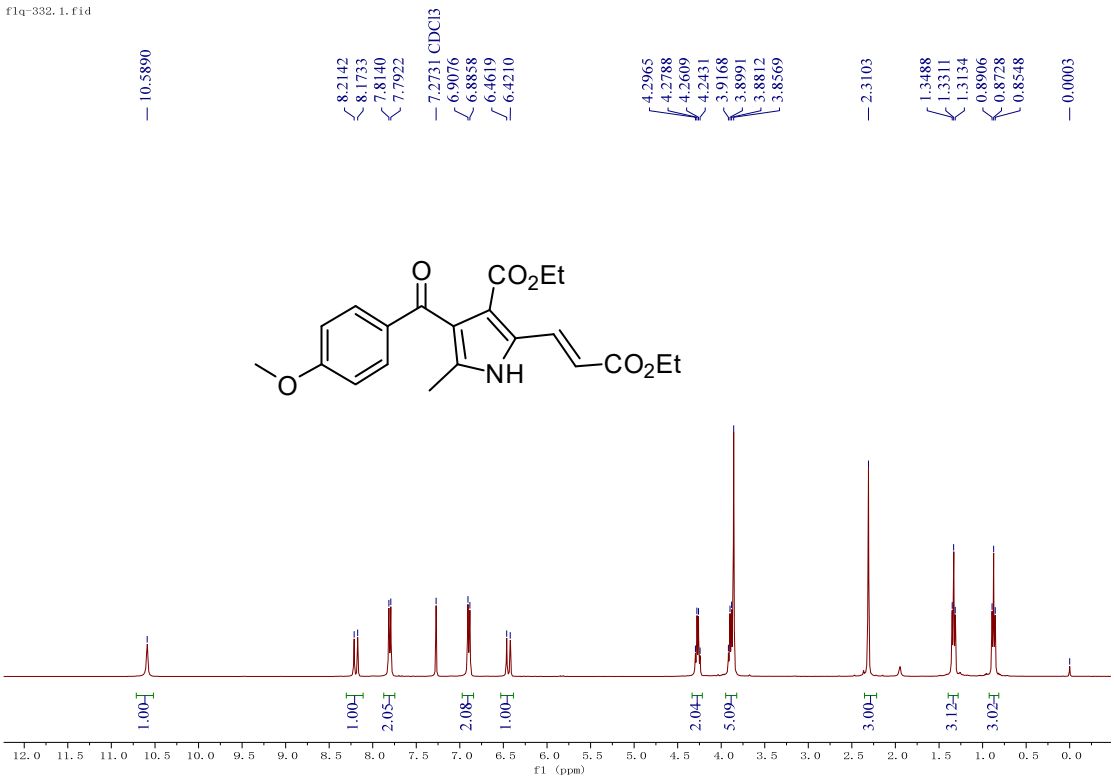
^{13}C NMR spectrum of **3b** (100 MHz, $CDCl_3$)



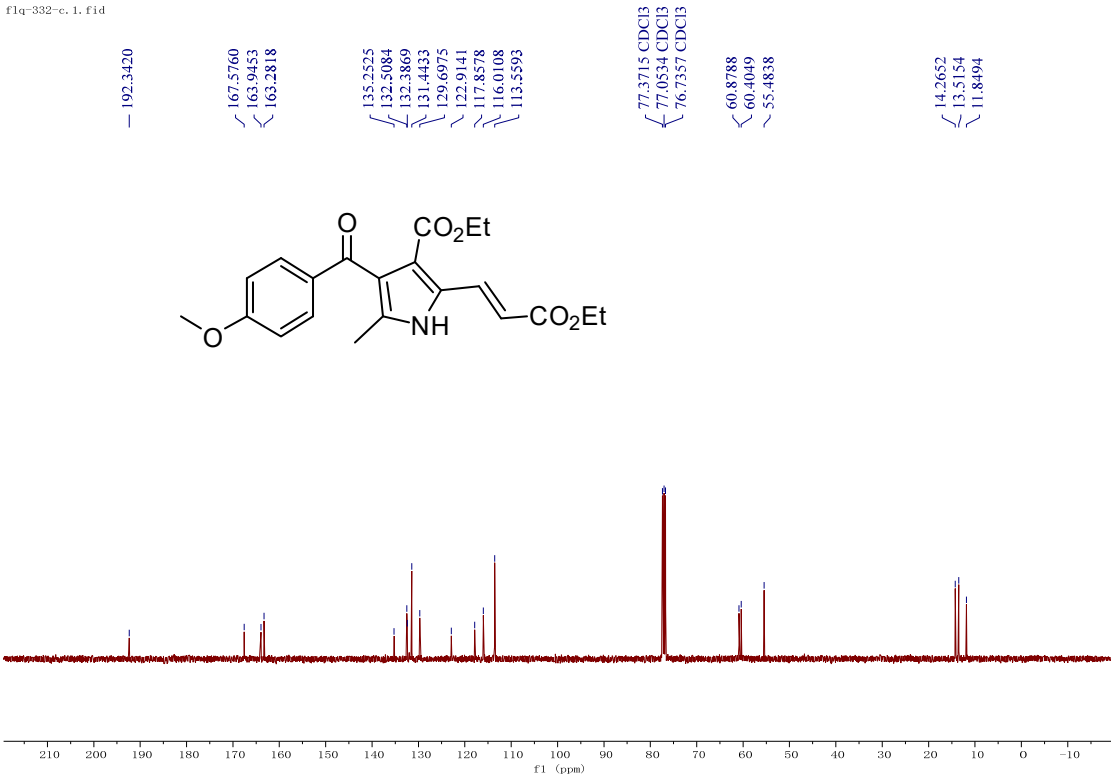
^{1}H NMR spectrum of **3c** (400 MHz, $CDCl_3$)



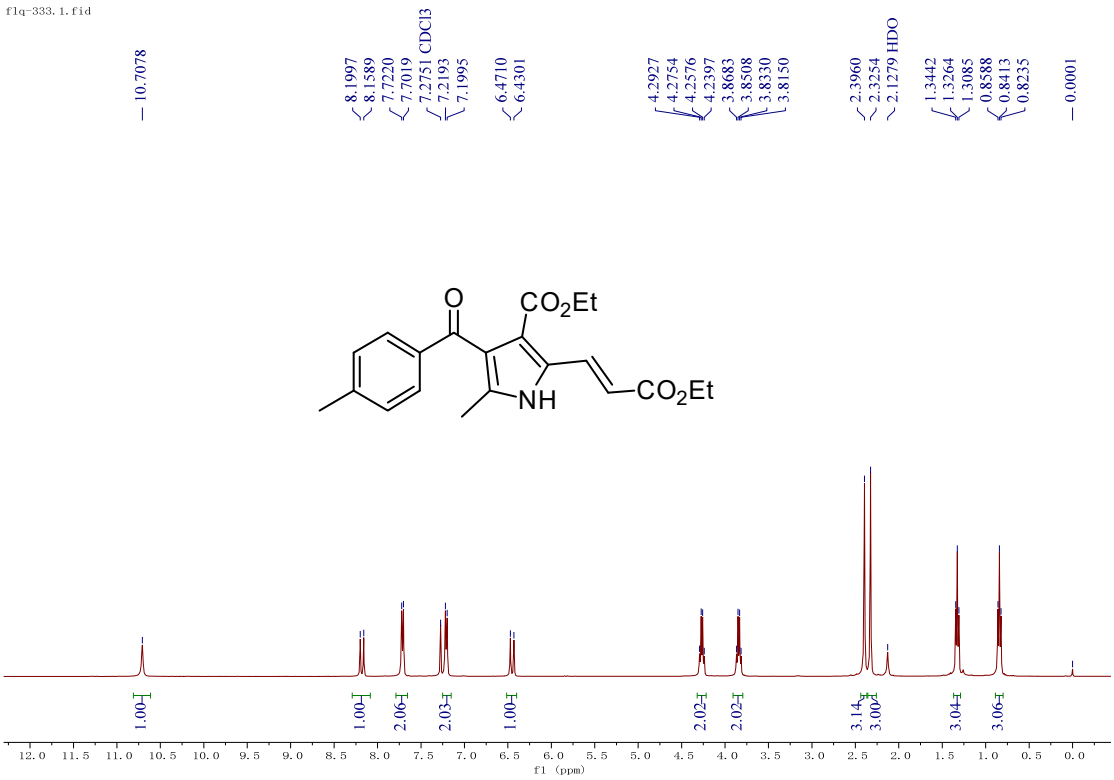
^{13}C NMR spectrum of **3c** (100 MHz, $CDCl_3$)



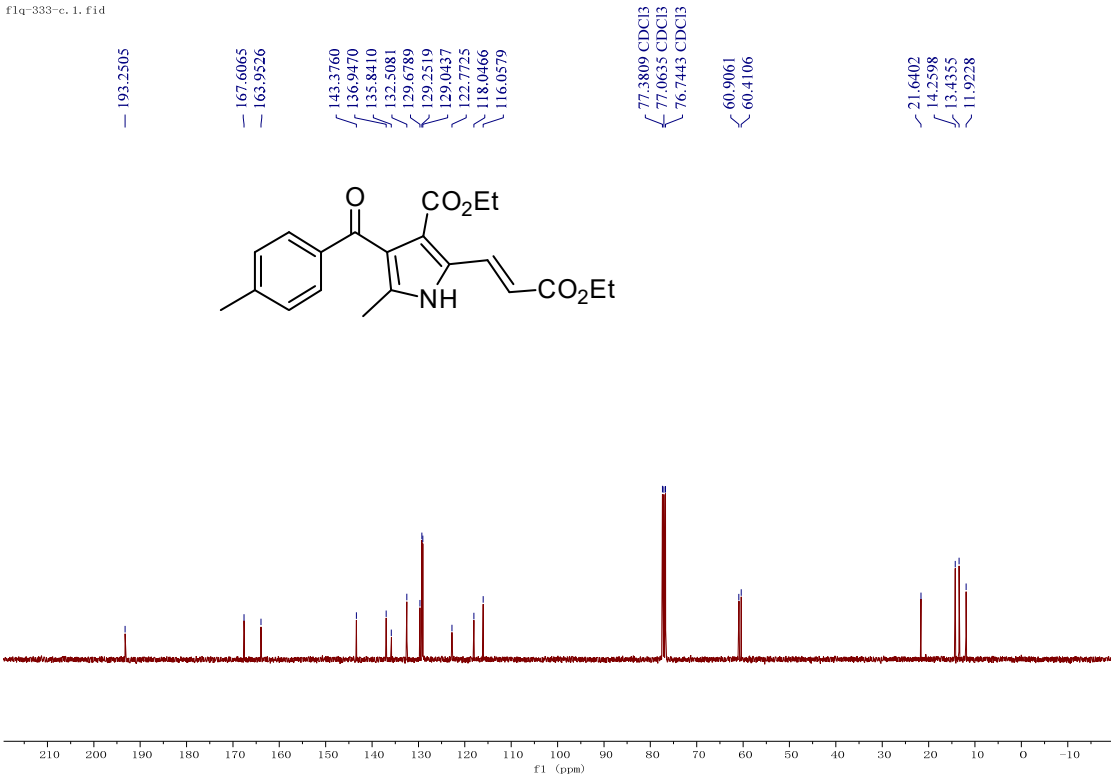
^{1}H NMR spectrum of **3d** (400 MHz, $CDCl_3$)



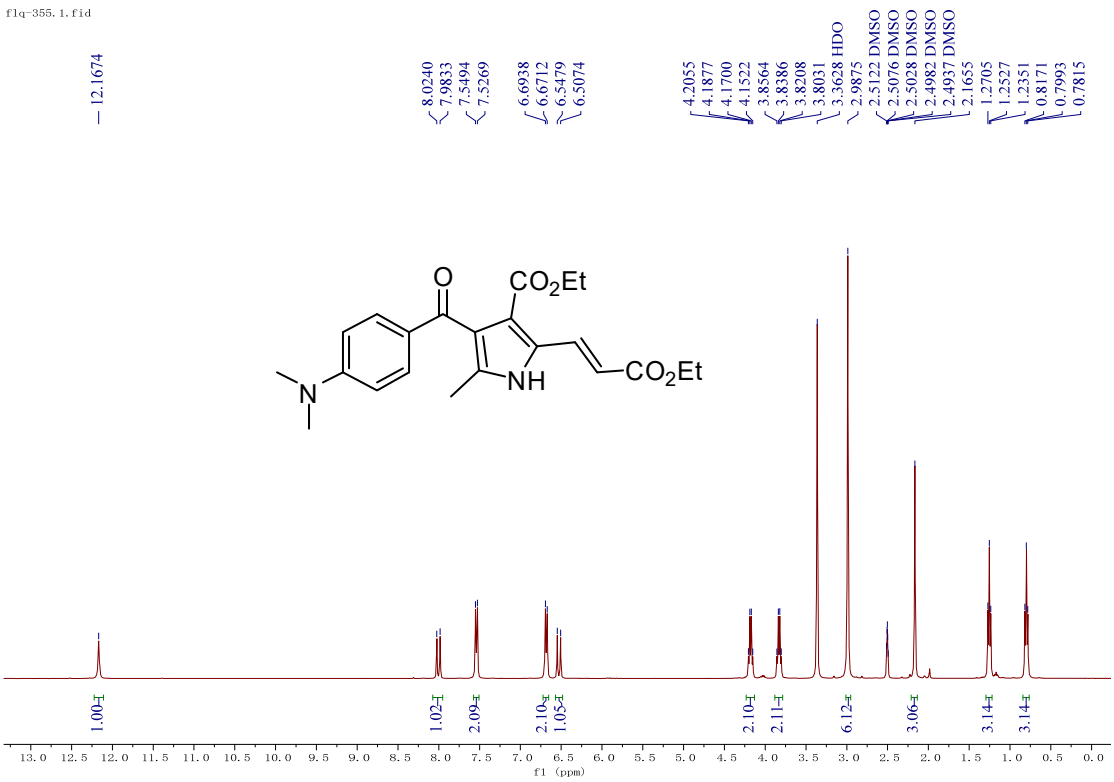
^{13}C NMR spectrum of **3d** (100 MHz, $CDCl_3$)



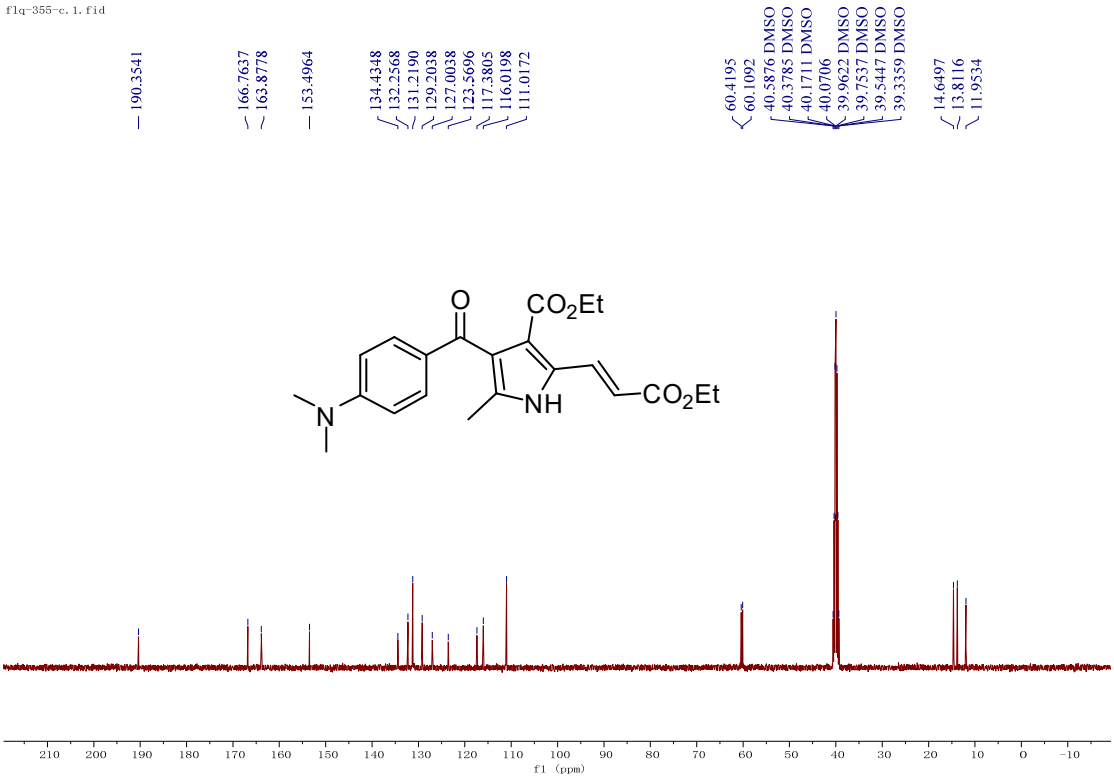
^{1}H NMR spectrum of **3e** (400 MHz, $CDCl_3$)



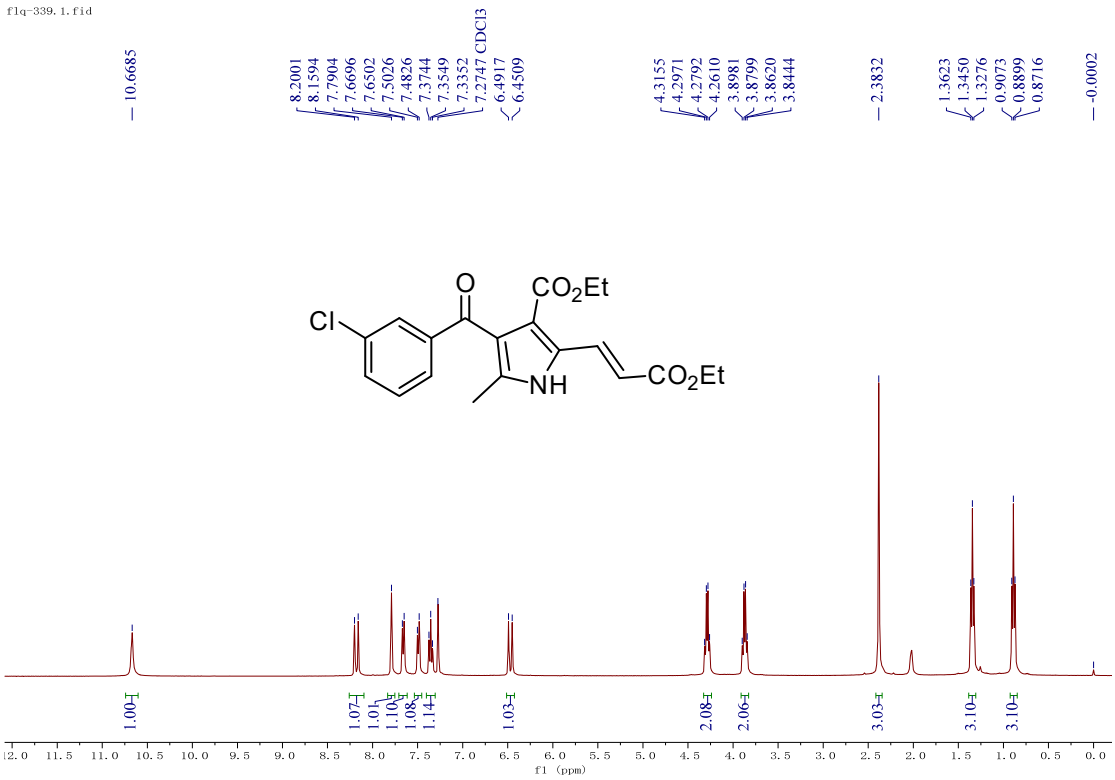
^{13}C NMR spectrum of **3e** (100 MHz, $CDCl_3$)



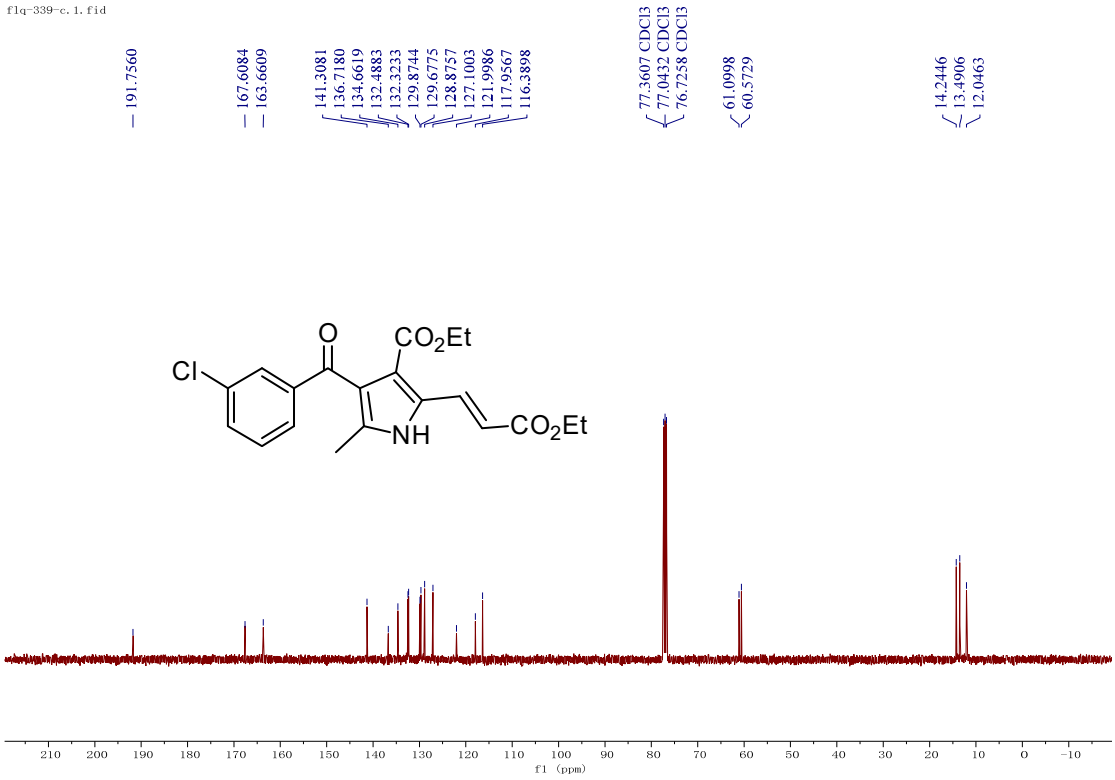
^{1}H NMR spectrum of **3f** (400 MHz, DMSO-d_6)



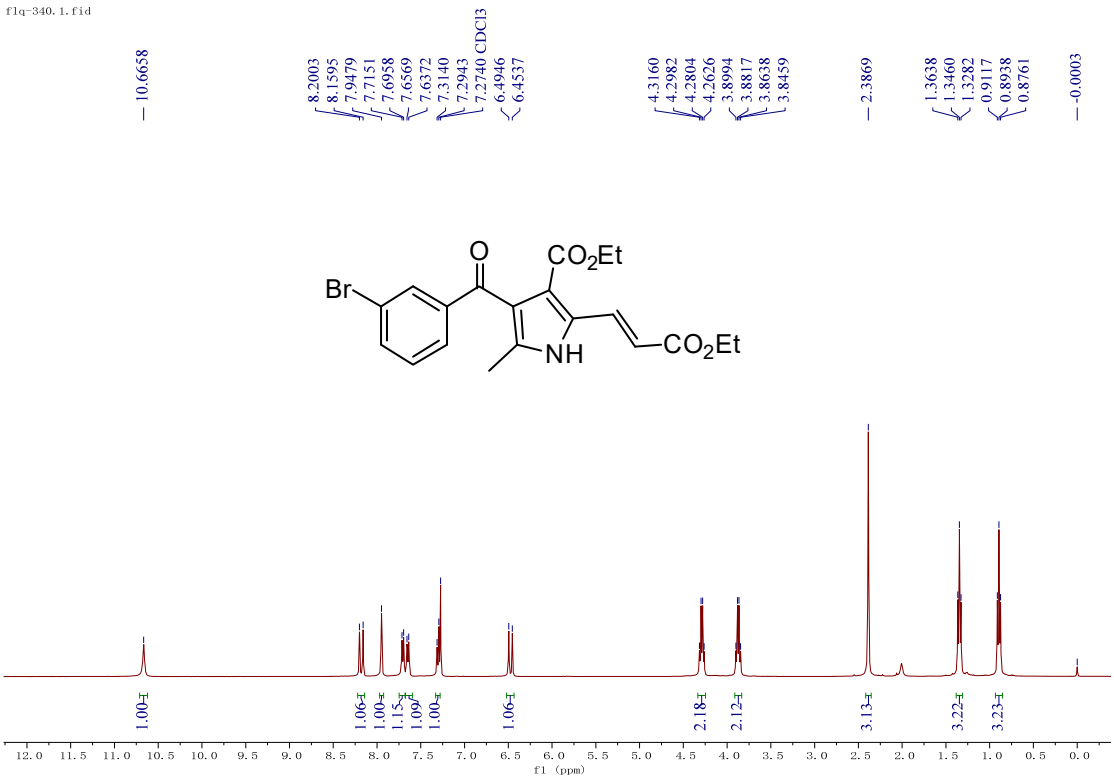
^{13}C NMR spectrum of **3f** (100 MHz, DMSO-d_6)



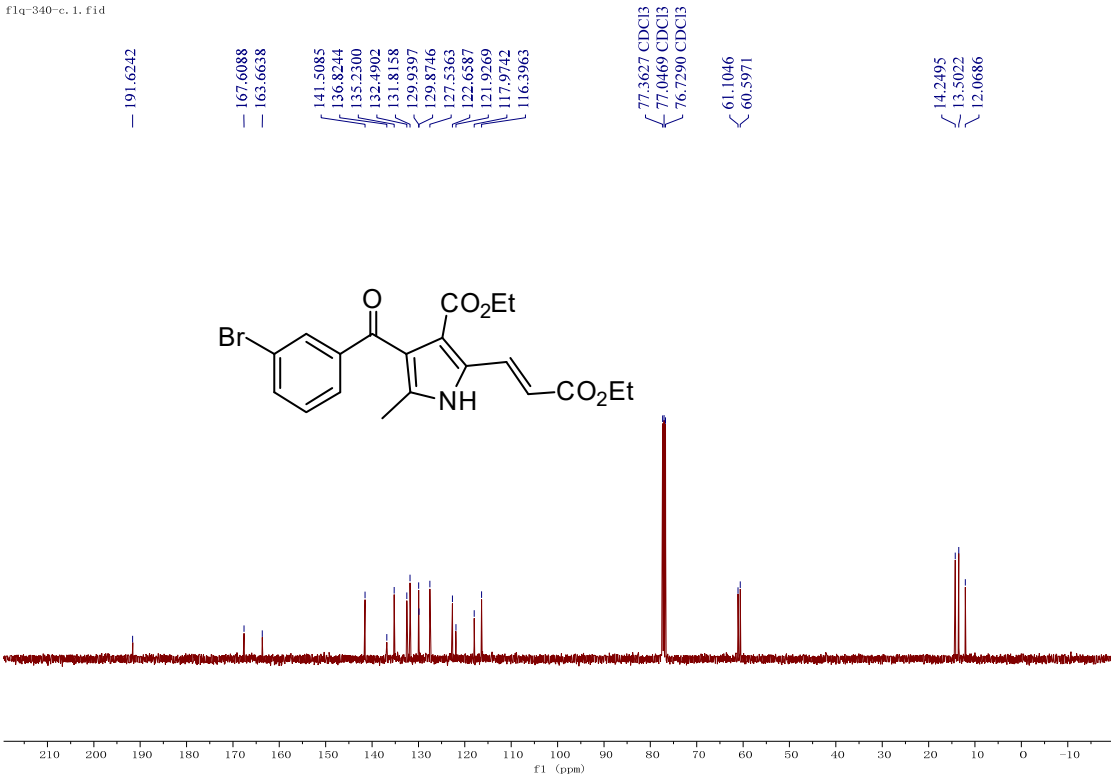
^{1}H NMR spectrum of **3g** (400 MHz, $CDCl_3$)



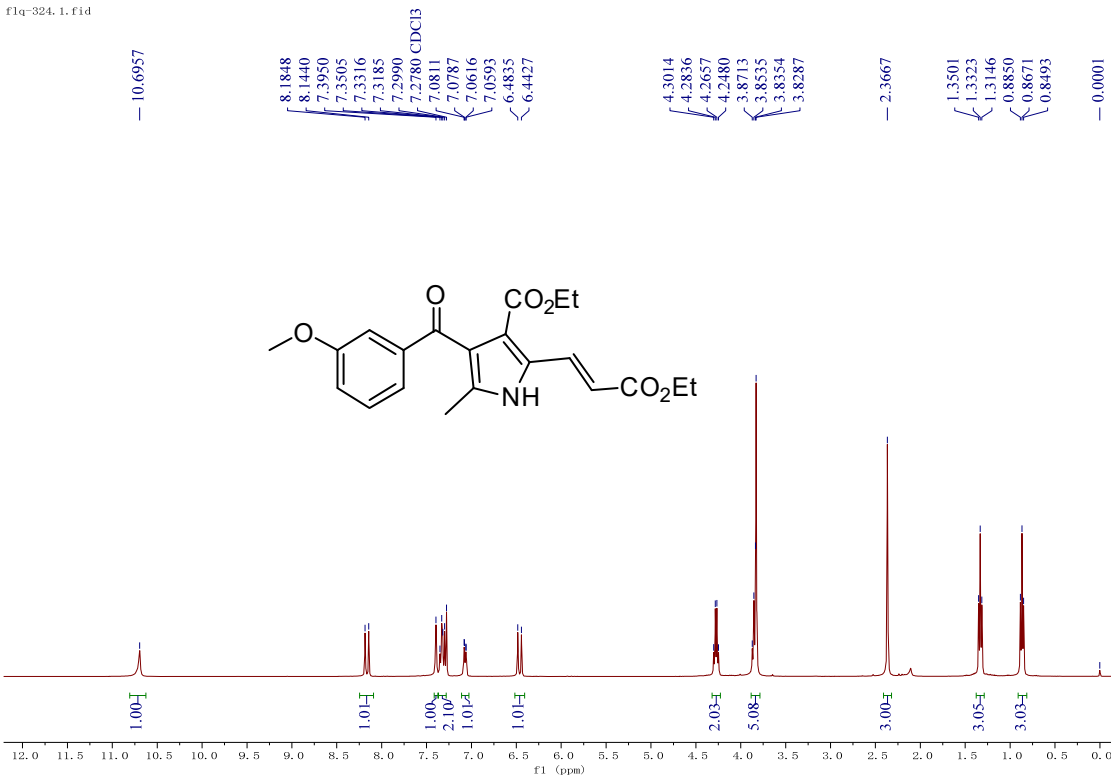
^{13}C NMR spectrum of **3g** (100 MHz, $CDCl_3$)



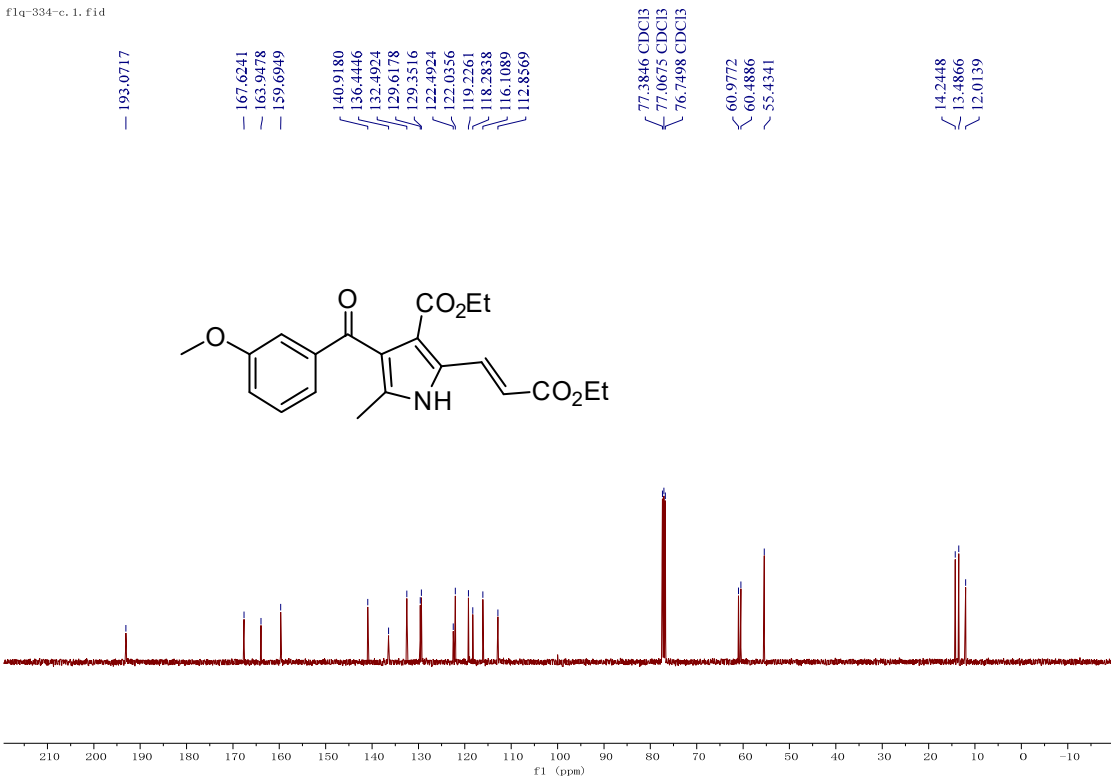
^{1}H NMR spectrum of **3h** (400 MHz, $CDCl_3$)



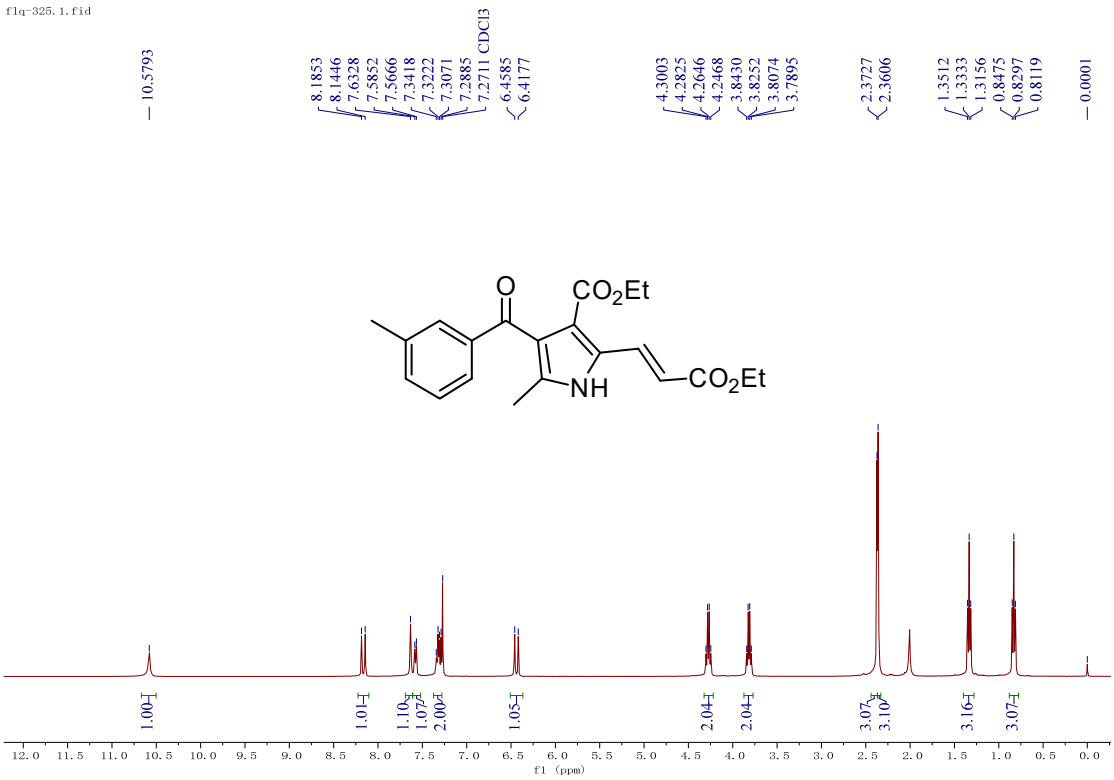
^{13}C NMR spectrum of **3h** (100 MHz, $CDCl_3$)



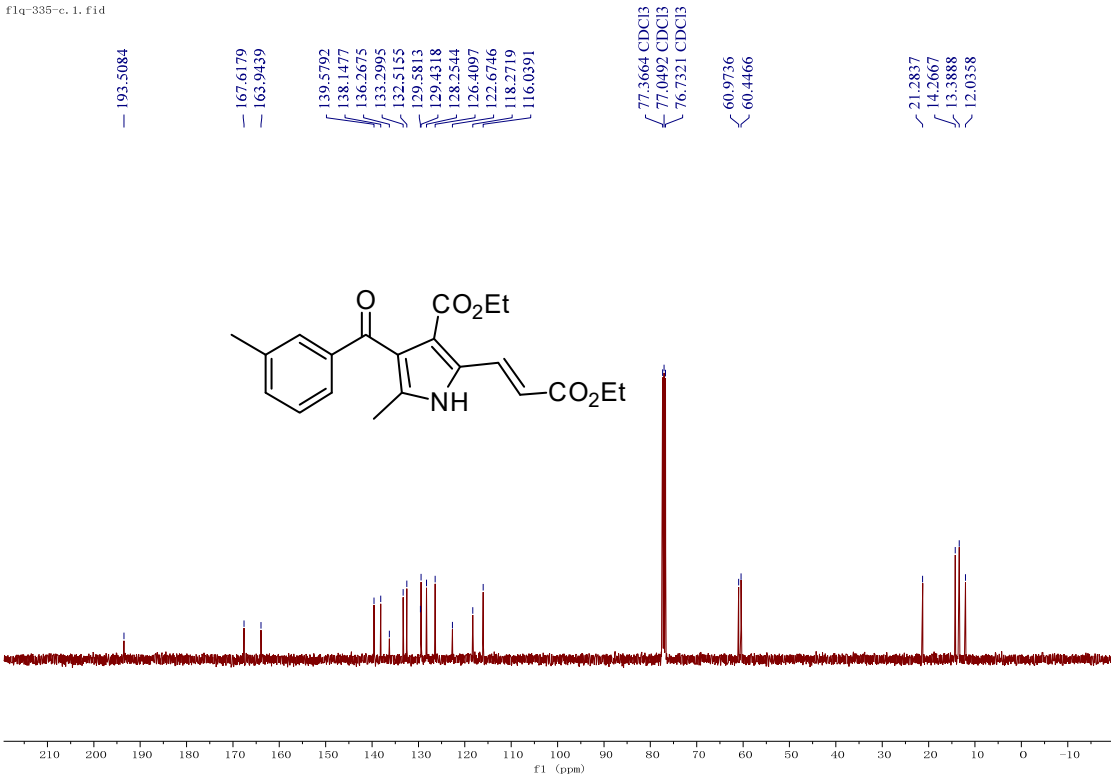
^{1}H NMR spectrum of **3i** (400 MHz, $CDCl_3$)



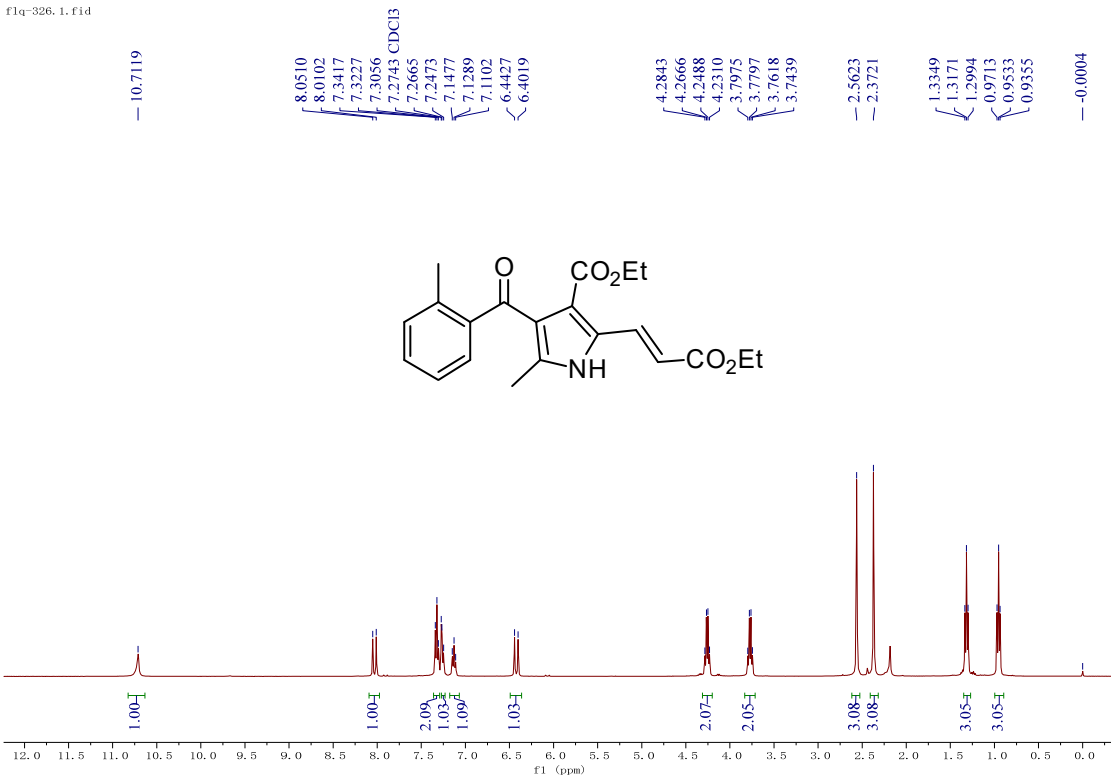
^{13}C NMR spectrum of **3i** (100 MHz, $CDCl_3$)



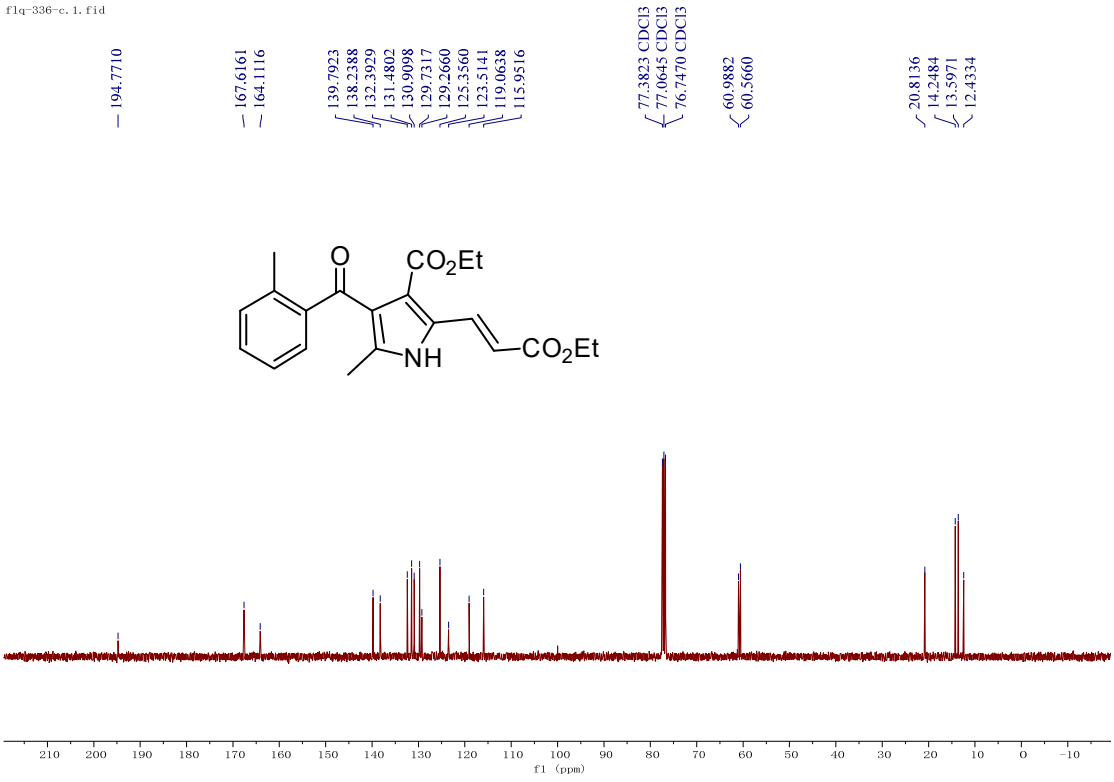
^{1}H NMR spectrum of **3j** (400 MHz, $CDCl_3$)



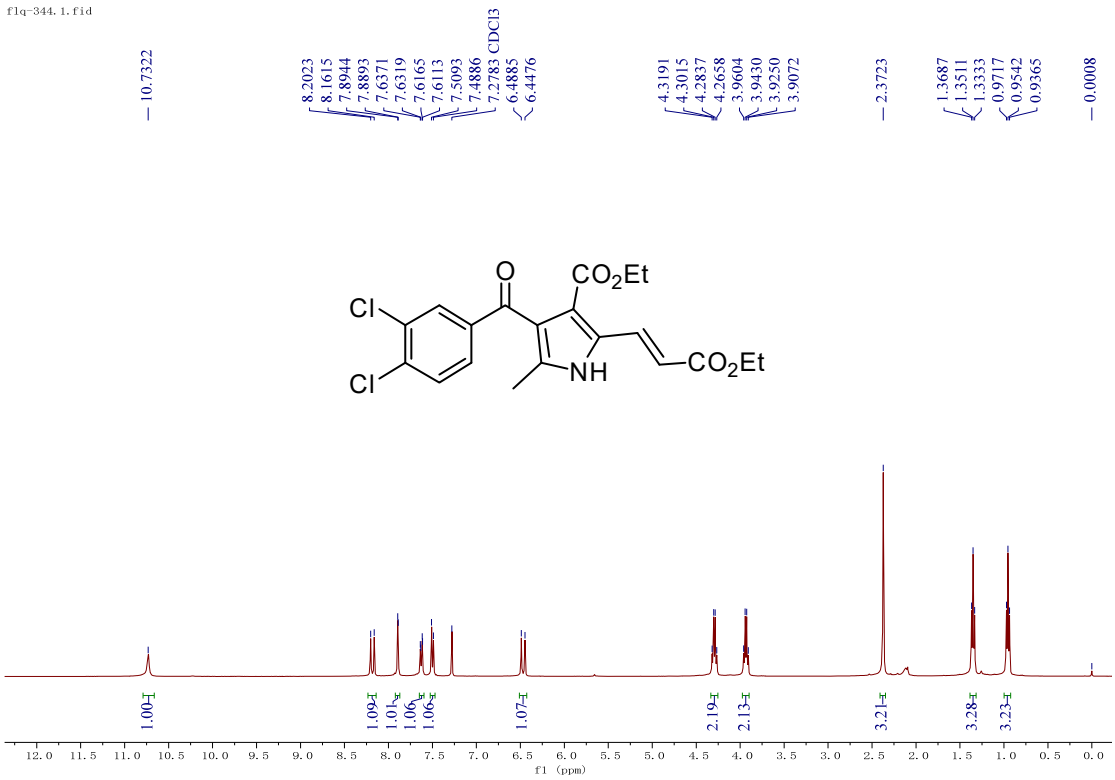
^{13}C NMR spectrum of **3j** (100 MHz, $CDCl_3$)



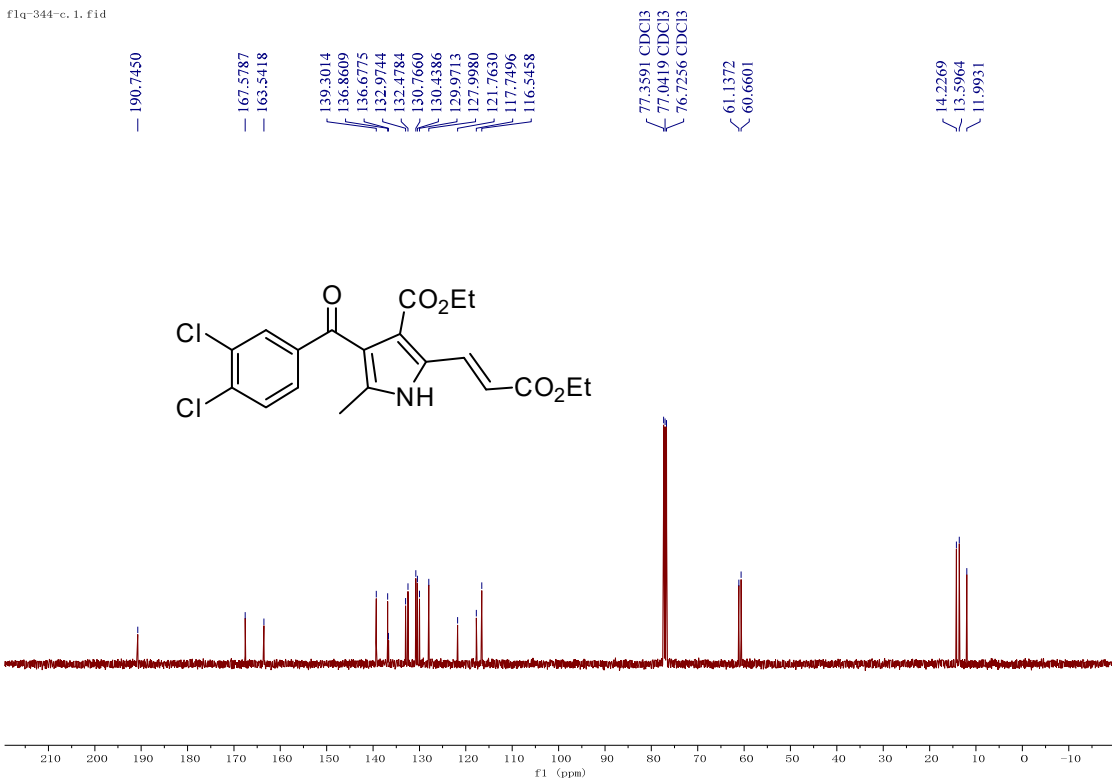
^{1}H NMR spectrum of **3k** (400 MHz, $CDCl_3$)



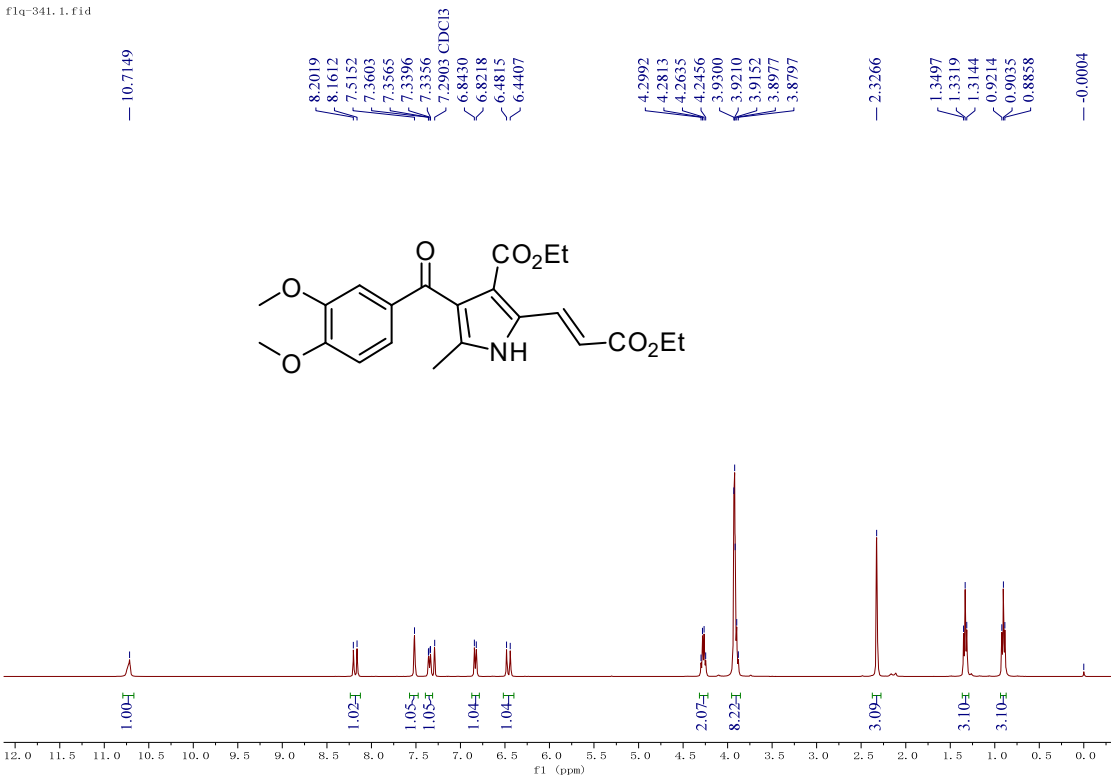
^{13}C NMR spectrum of **3k** (100 MHz, $CDCl_3$)



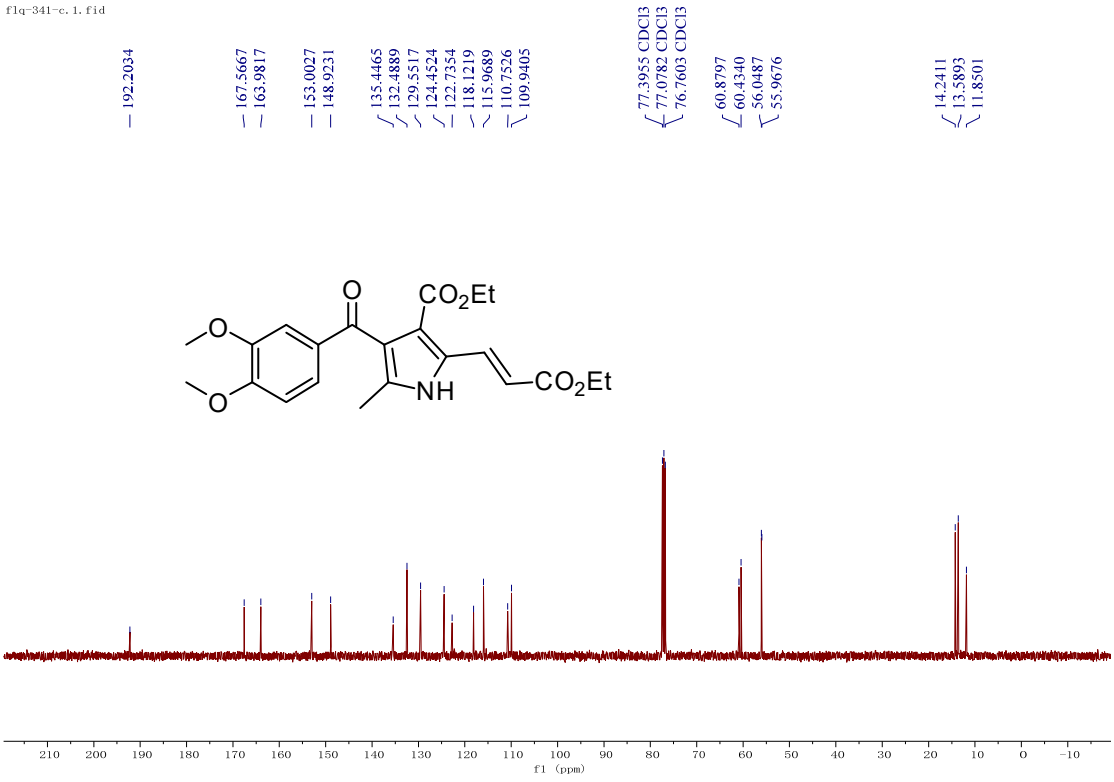
^{1}H NMR spectrum of **3l** (400 MHz, $CDCl_3$)



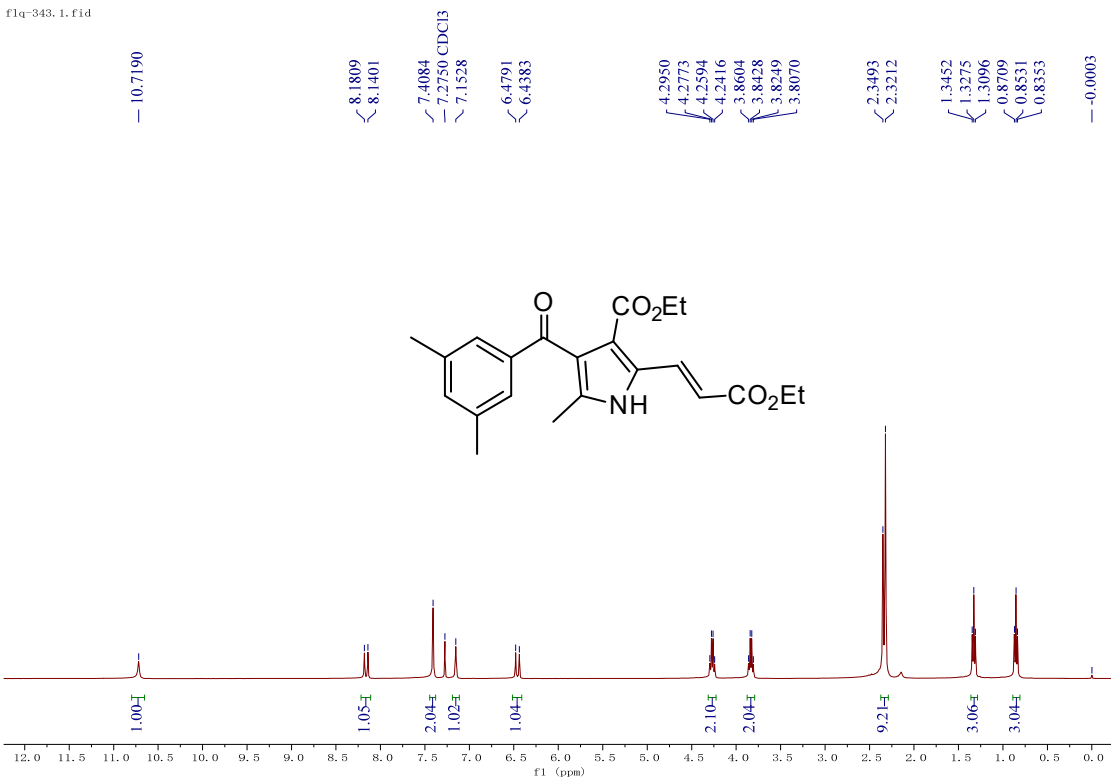
^{13}C NMR spectrum of **3l** (100 MHz, $CDCl_3$)



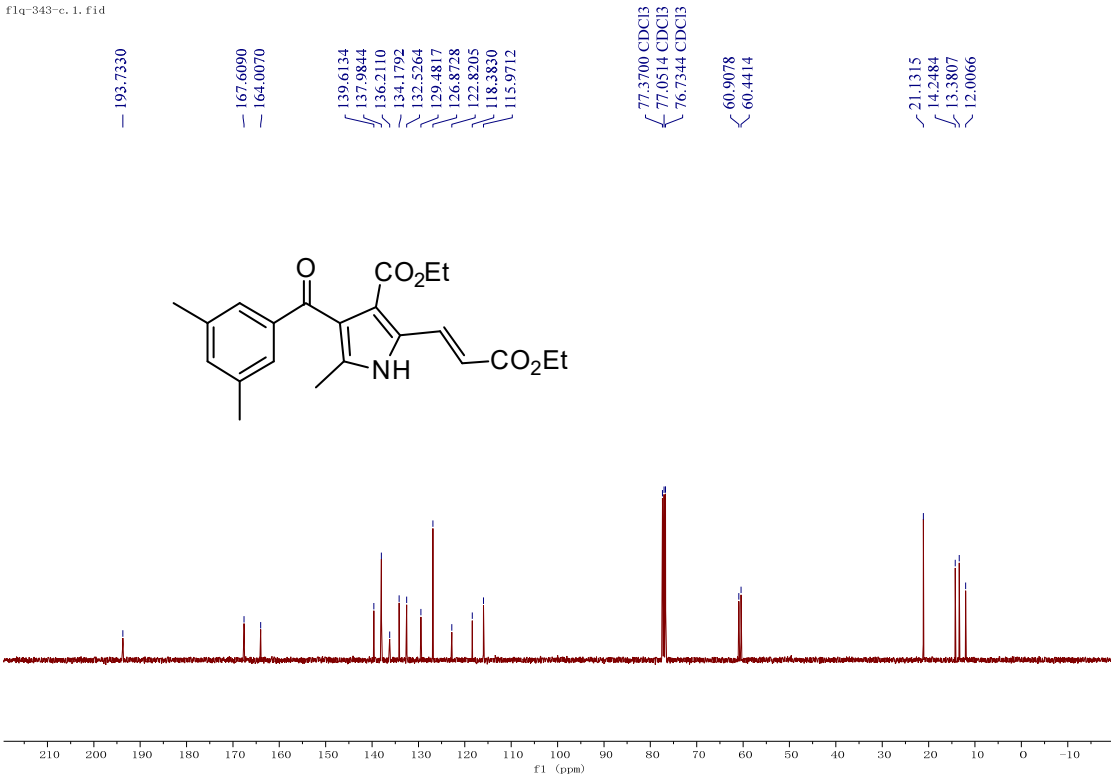
^{1}H NMR spectrum of **3m** (400 MHz, $CDCl_3$)



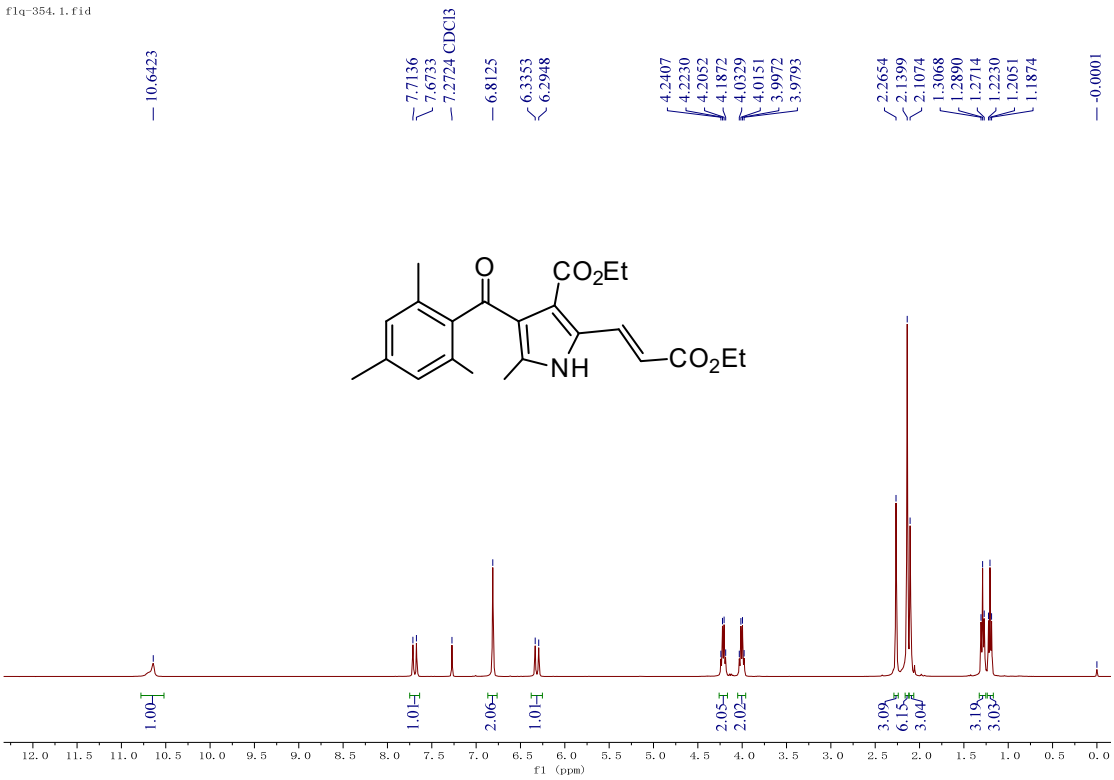
^{13}C NMR spectrum of **3m** (100 MHz, $CDCl_3$)



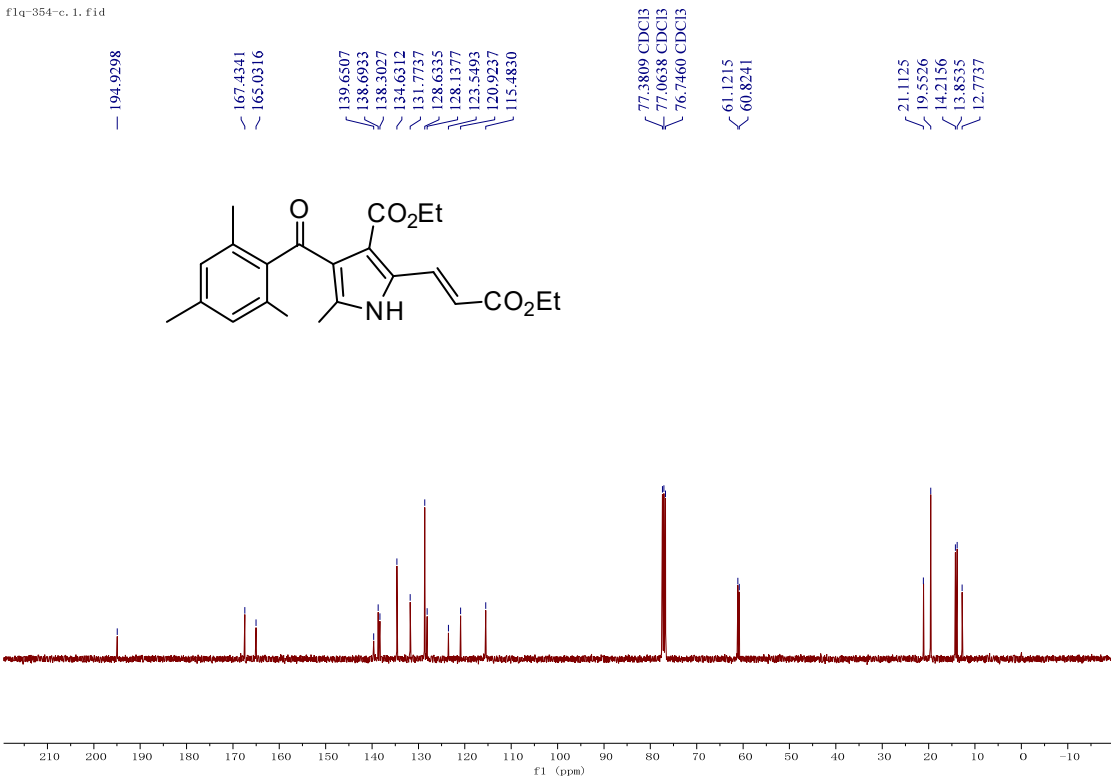
^{1}H NMR spectrum of **3n** (400 MHz, $CDCl_3$)



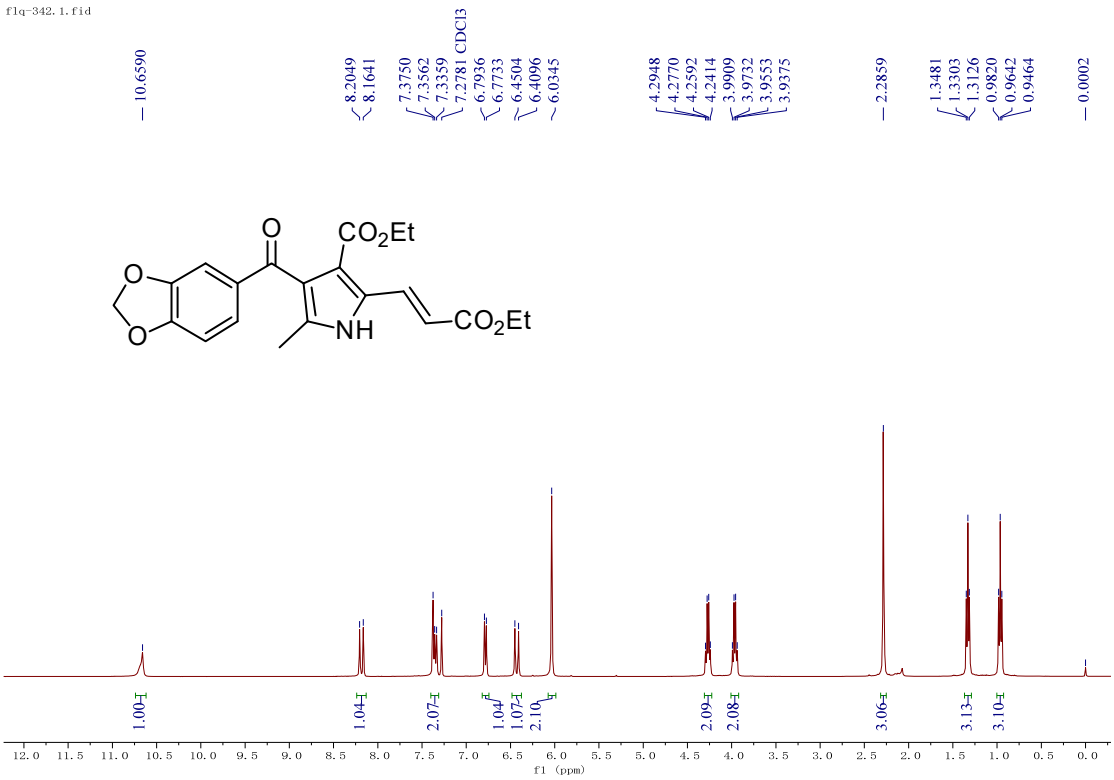
^{13}C NMR spectrum of **3n** (100 MHz, $CDCl_3$)



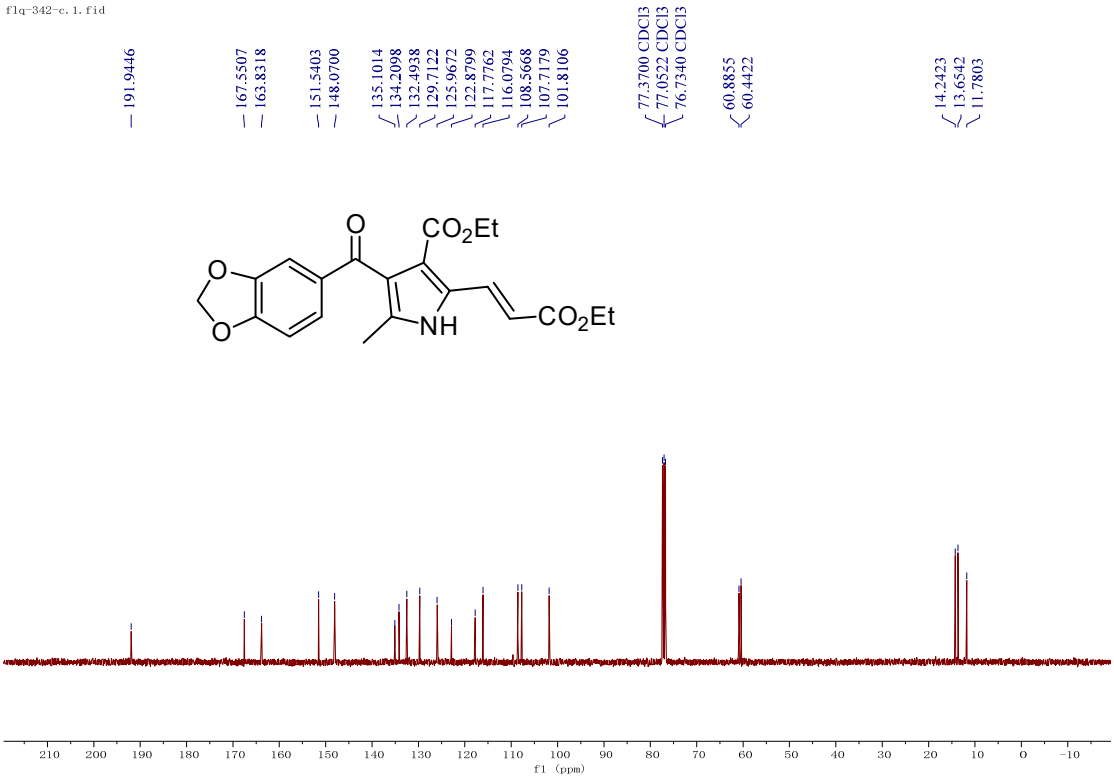
^{1}H NMR spectrum of **3o** (400 MHz, $CDCl_3$)



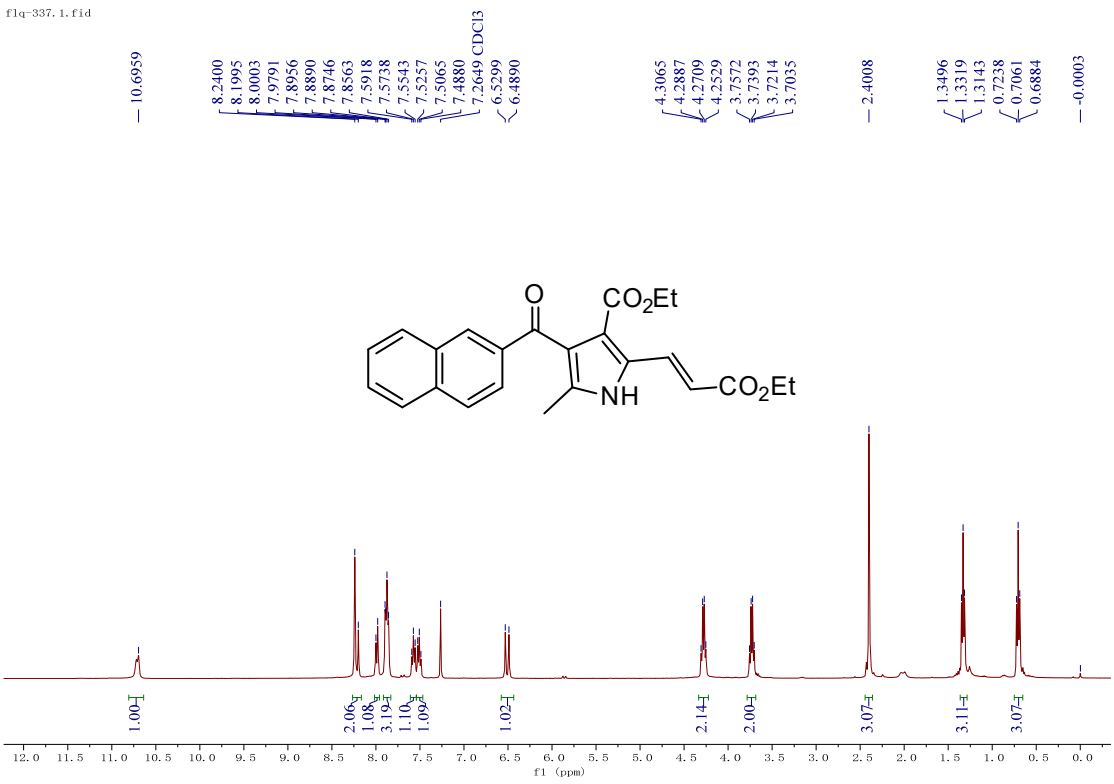
^{13}C NMR spectrum of **3o** (100 MHz, $CDCl_3$)



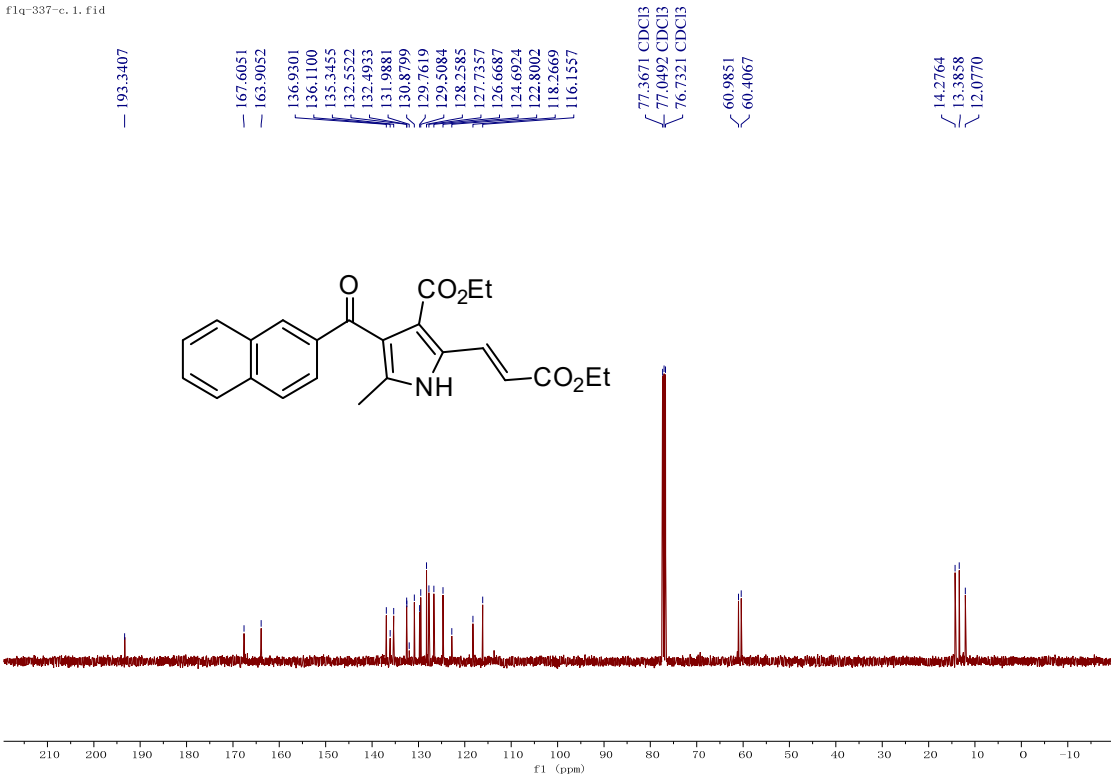
^{1}H NMR spectrum of **3p** (400 MHz, $CDCl_3$)



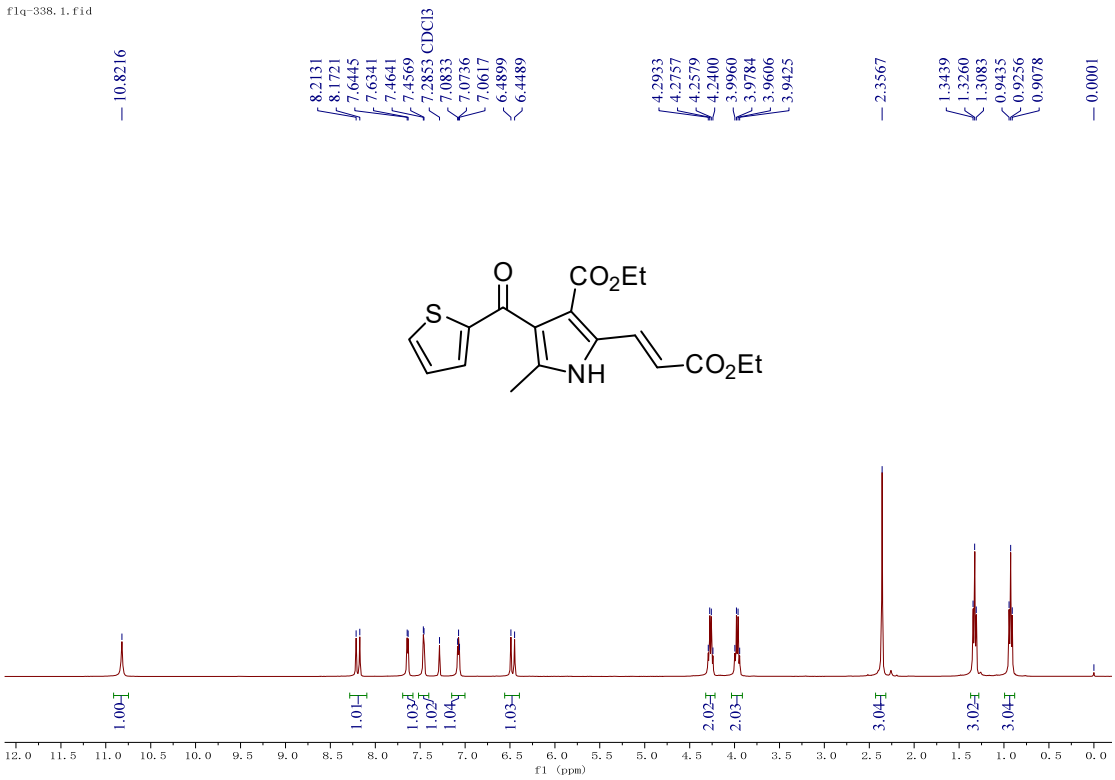
^{13}C NMR spectrum of **3p** (100 MHz, $CDCl_3$)



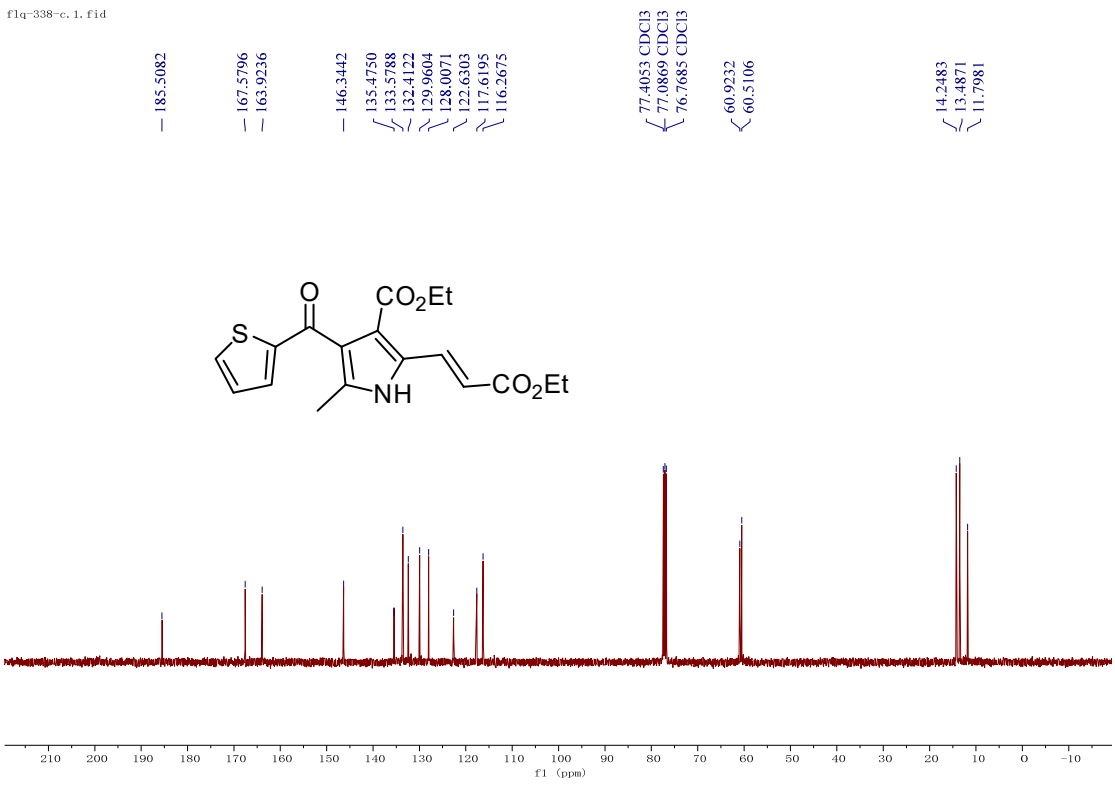
^{1}H NMR spectrum of **3q** (400 MHz, $CDCl_3$)



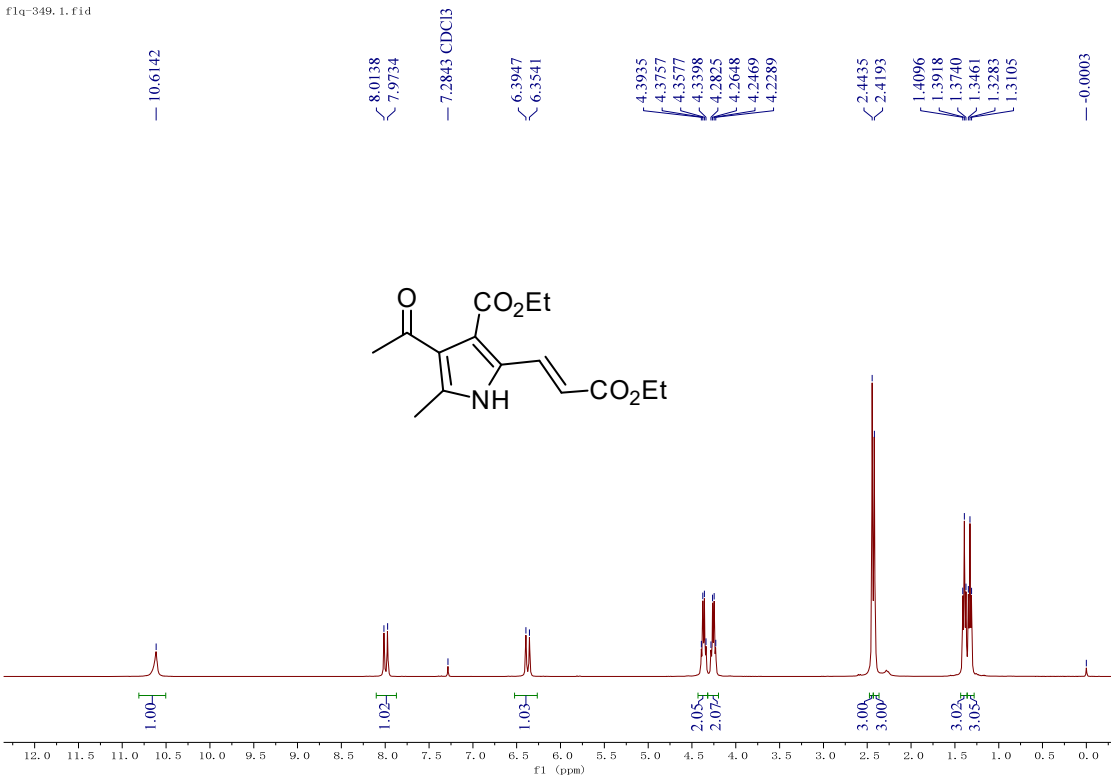
^{13}C NMR spectrum of **3q** (100 MHz, $CDCl_3$)



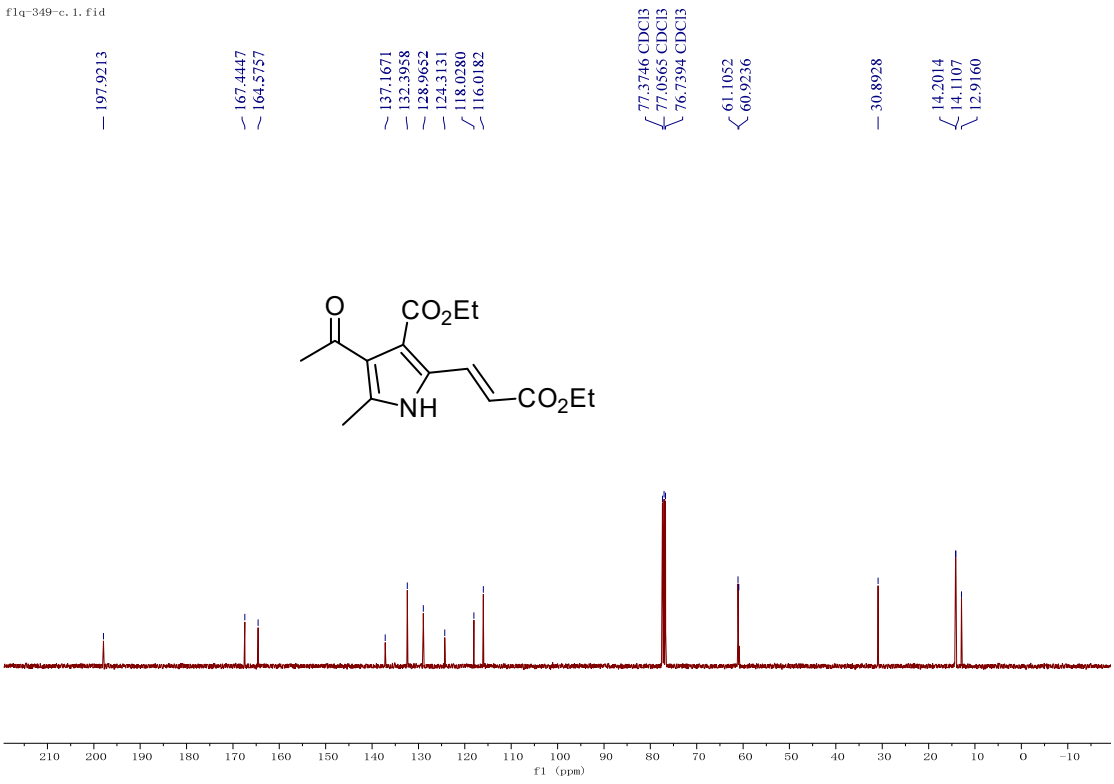
^{1}H NMR spectrum of **3r** (400 MHz, $CDCl_3$)



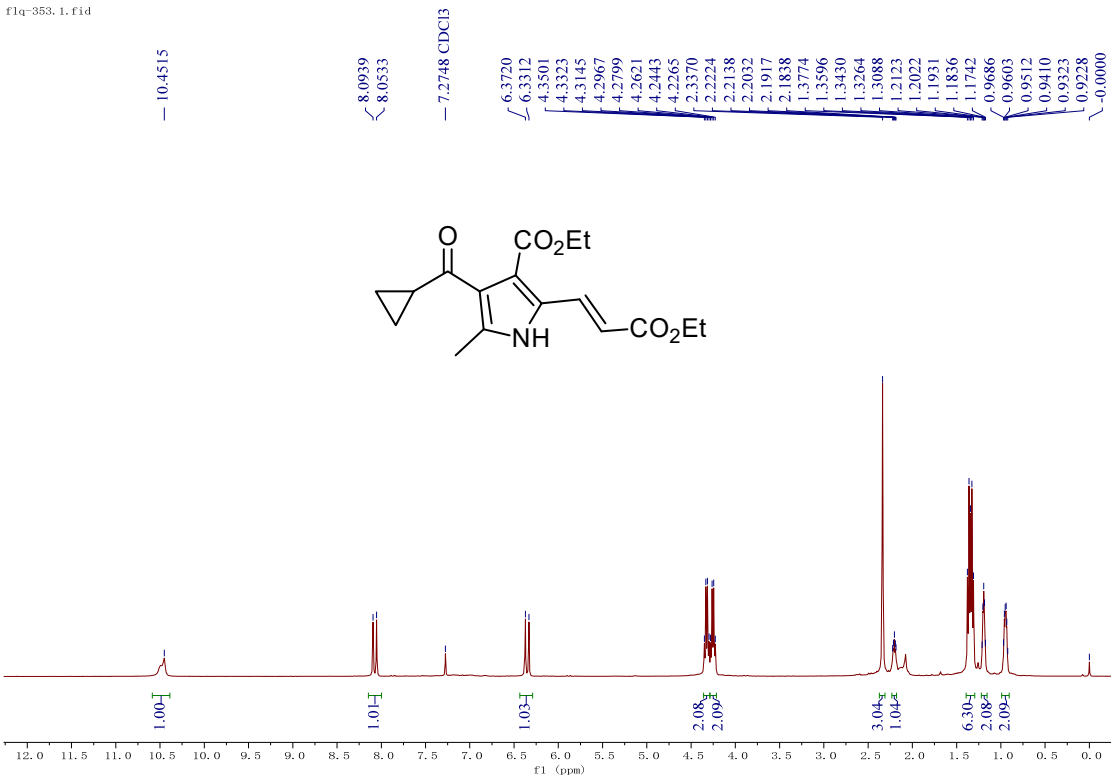
^{13}C NMR spectrum of **3r** (100 MHz, $CDCl_3$)



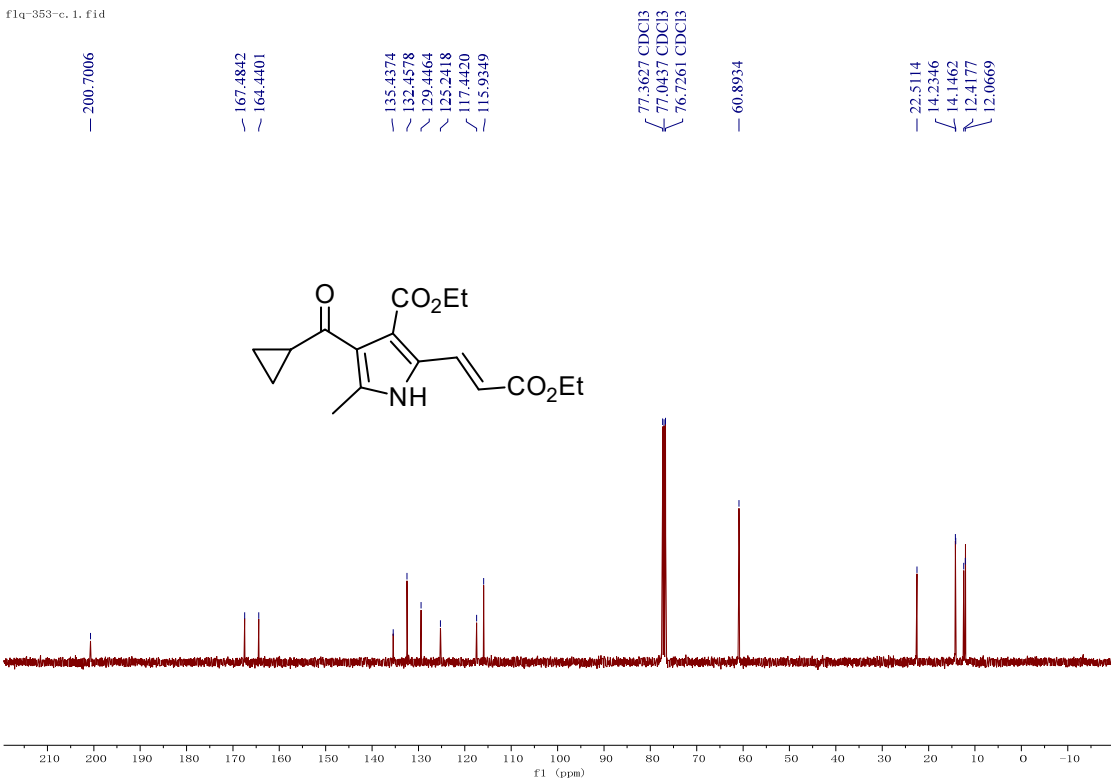
^{1}H NMR spectrum of **3s** (400 MHz, $CDCl_3$)



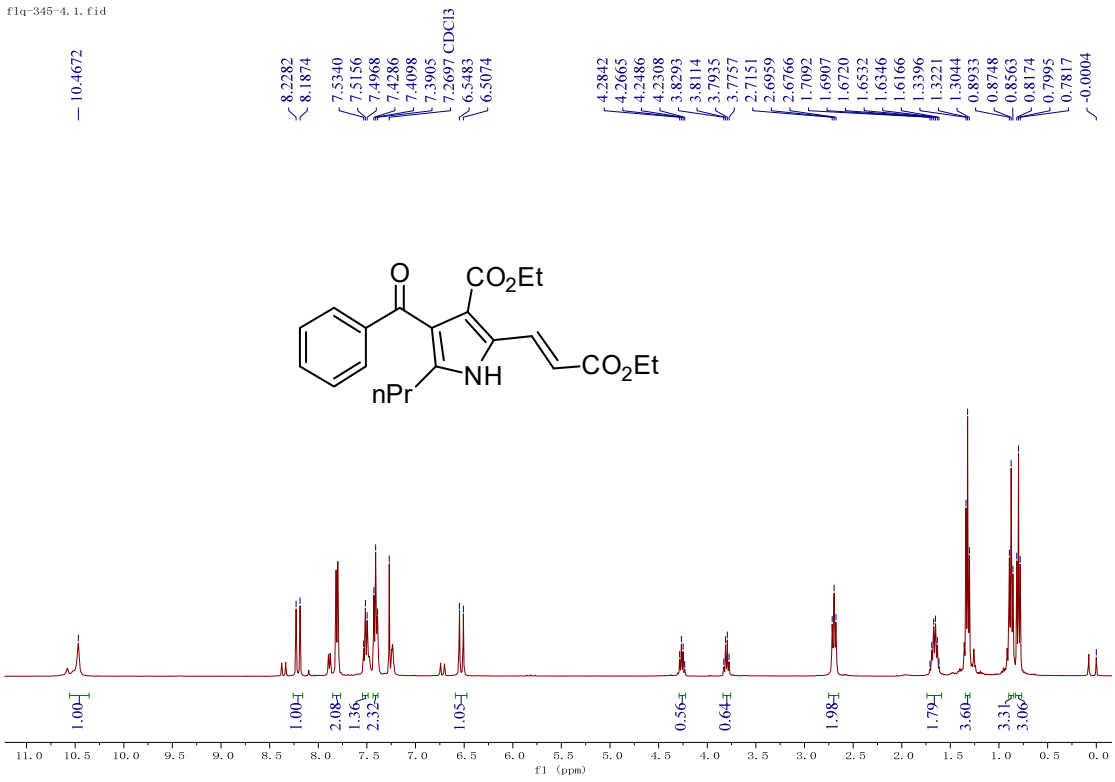
^{13}C NMR spectrum of **3s** (100 MHz, $CDCl_3$)



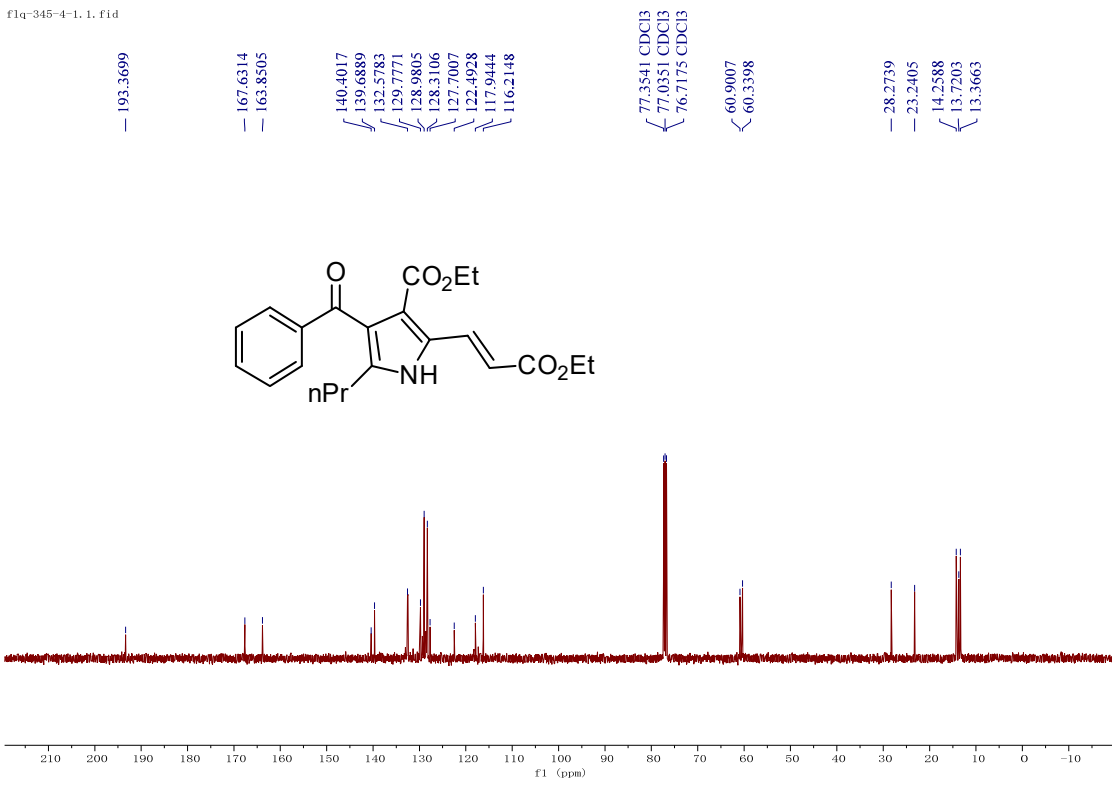
^{1}H NMR spectrum of **3t** (400 MHz, $CDCl_3$)



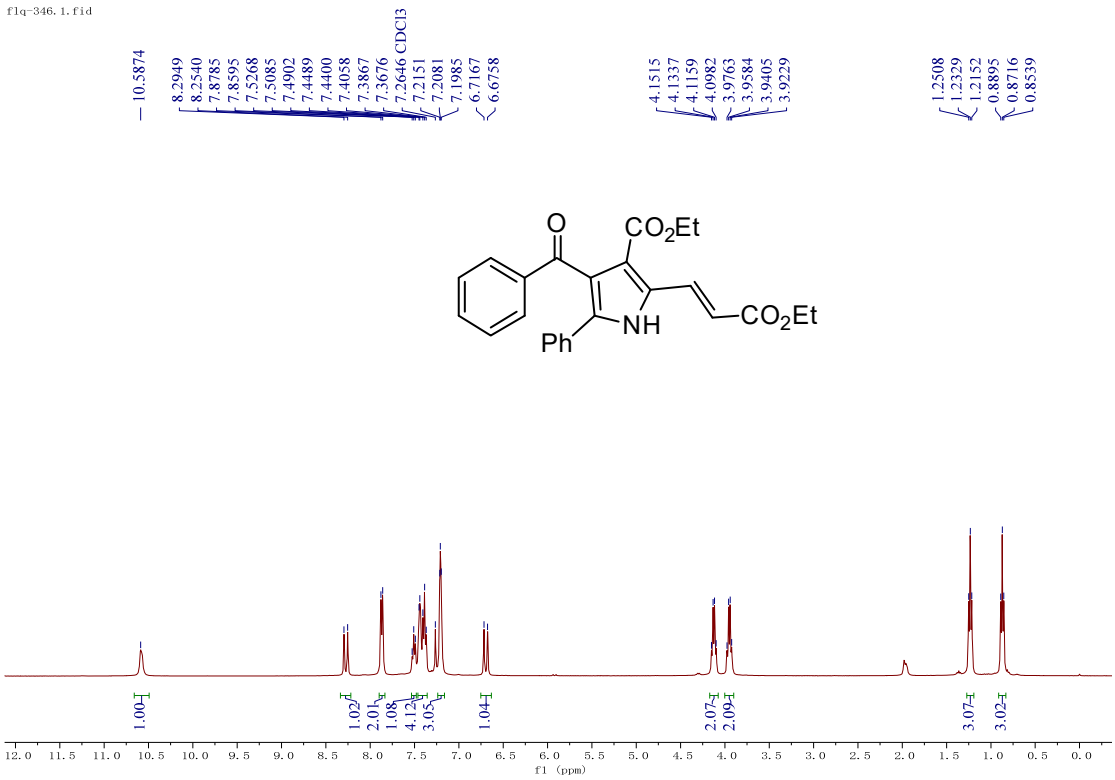
^{13}C NMR spectrum of **3t** (100 MHz, $CDCl_3$)



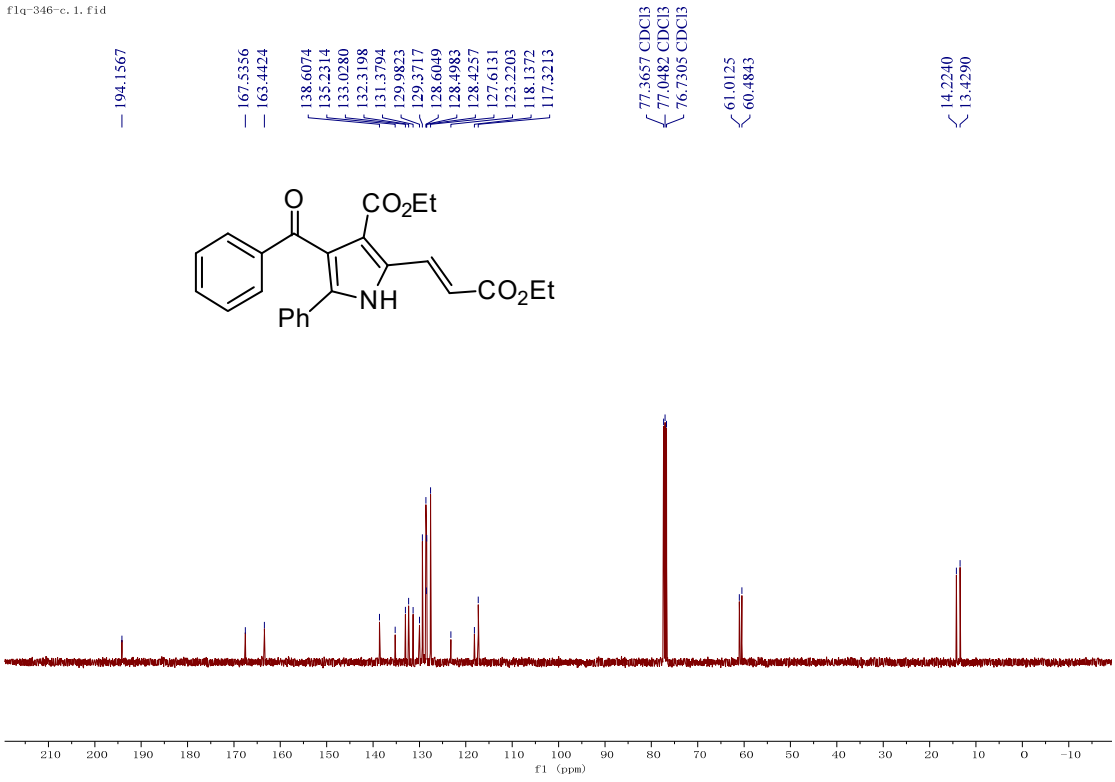
^{1}H NMR spectrum of **3u** (400 MHz, $CDCl_3$)



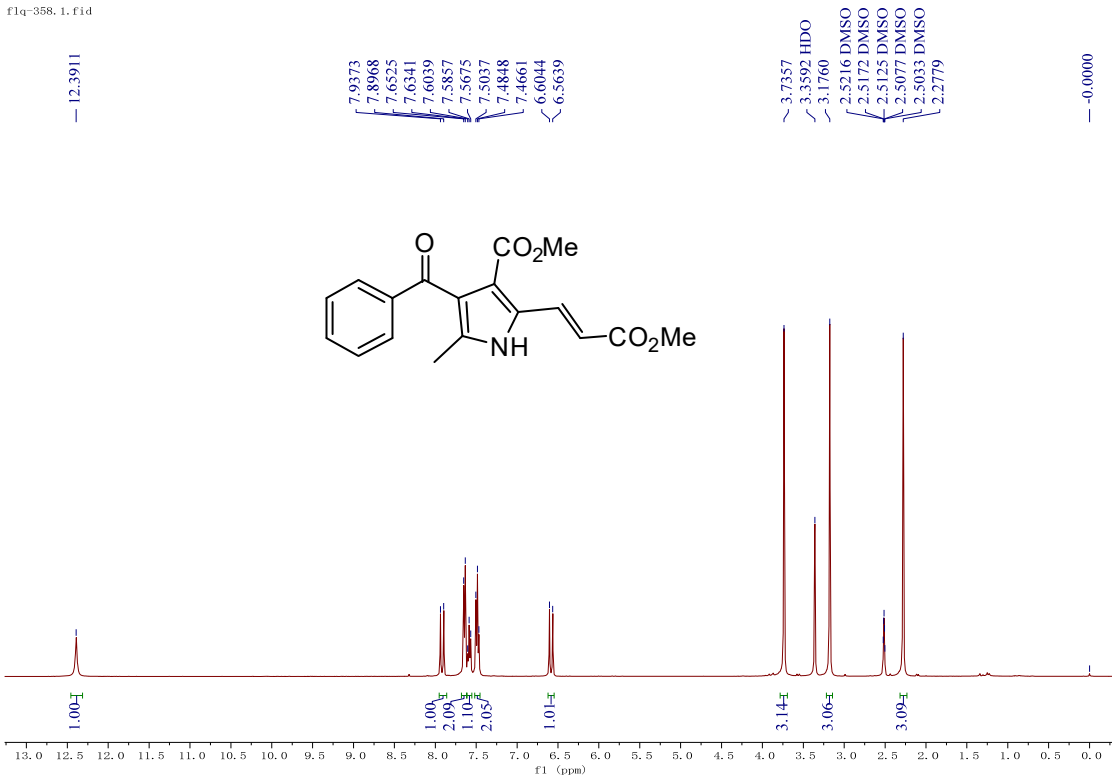
^{13}C NMR spectrum of **3u** (100 MHz, $CDCl_3$)



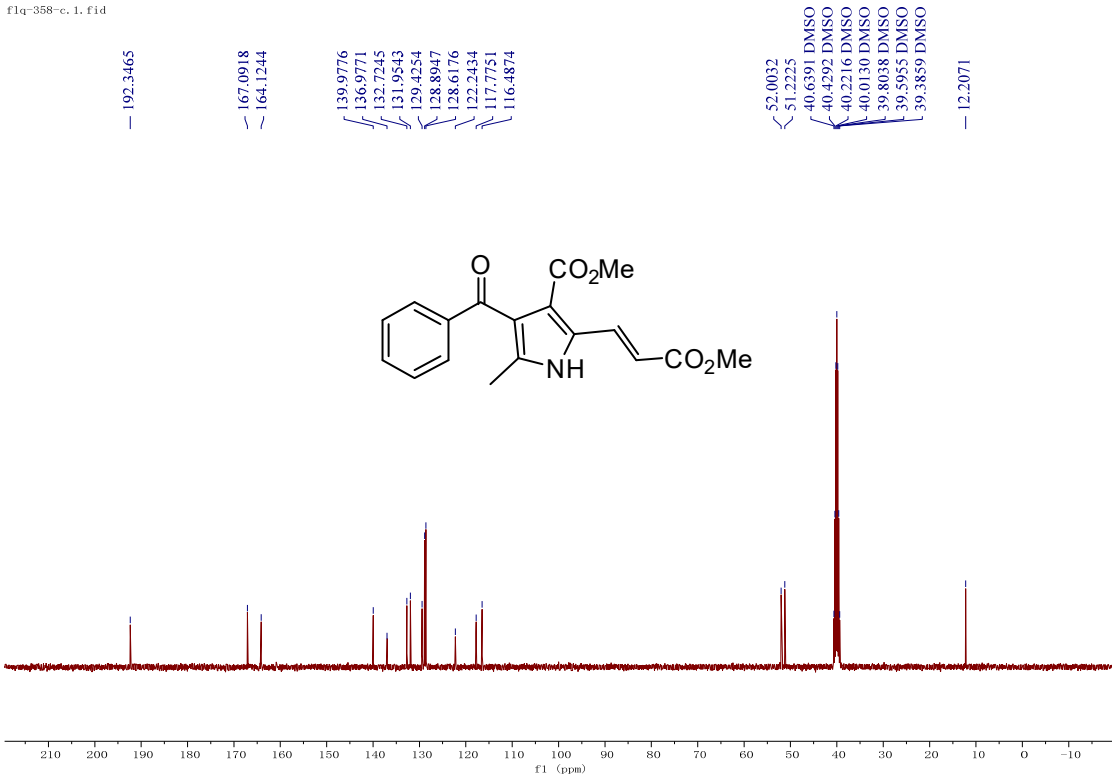
^{1}H NMR spectrum of **3v** (400 MHz, $CDCl_3$)



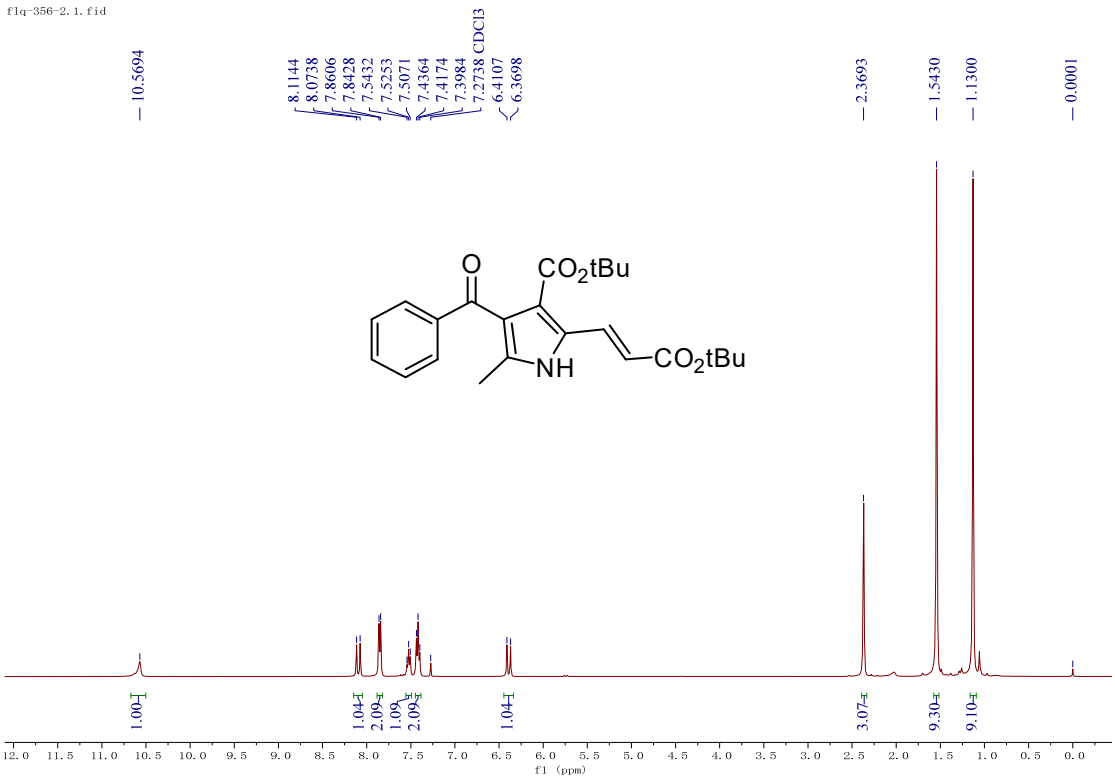
^{13}C NMR spectrum of **3v** (100 MHz, $CDCl_3$)



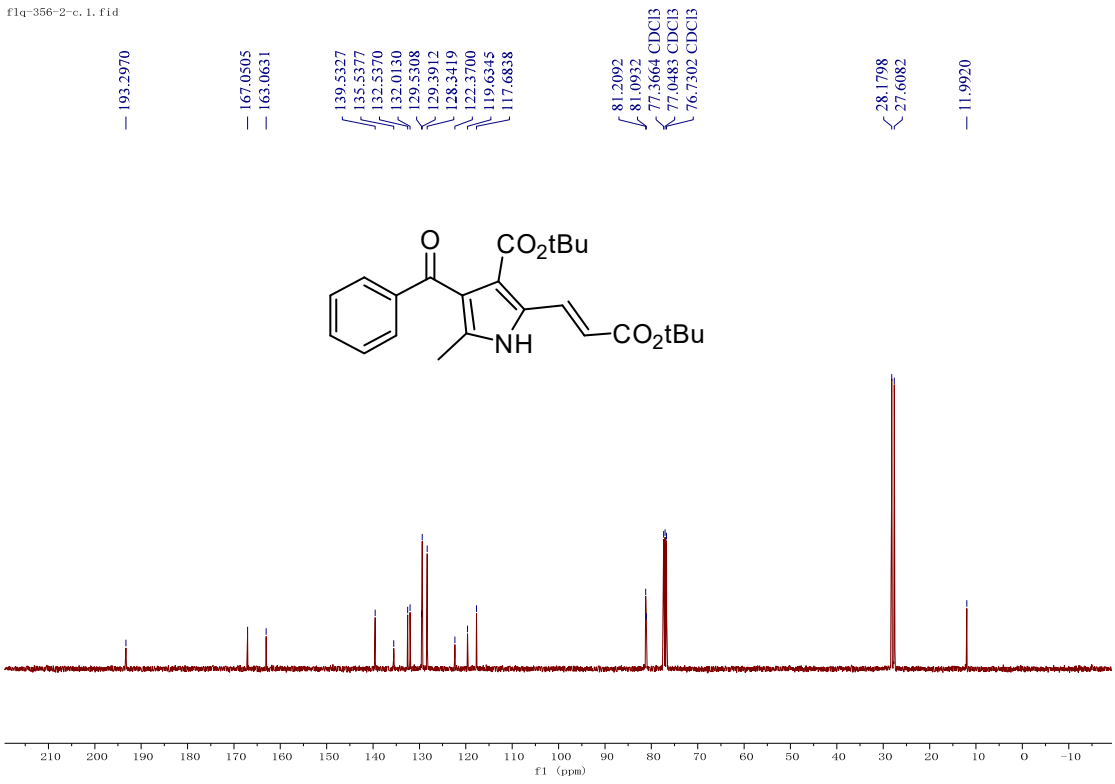
^{1}H NMR spectrum of **3w** (400 MHz, DMSO-d_6)



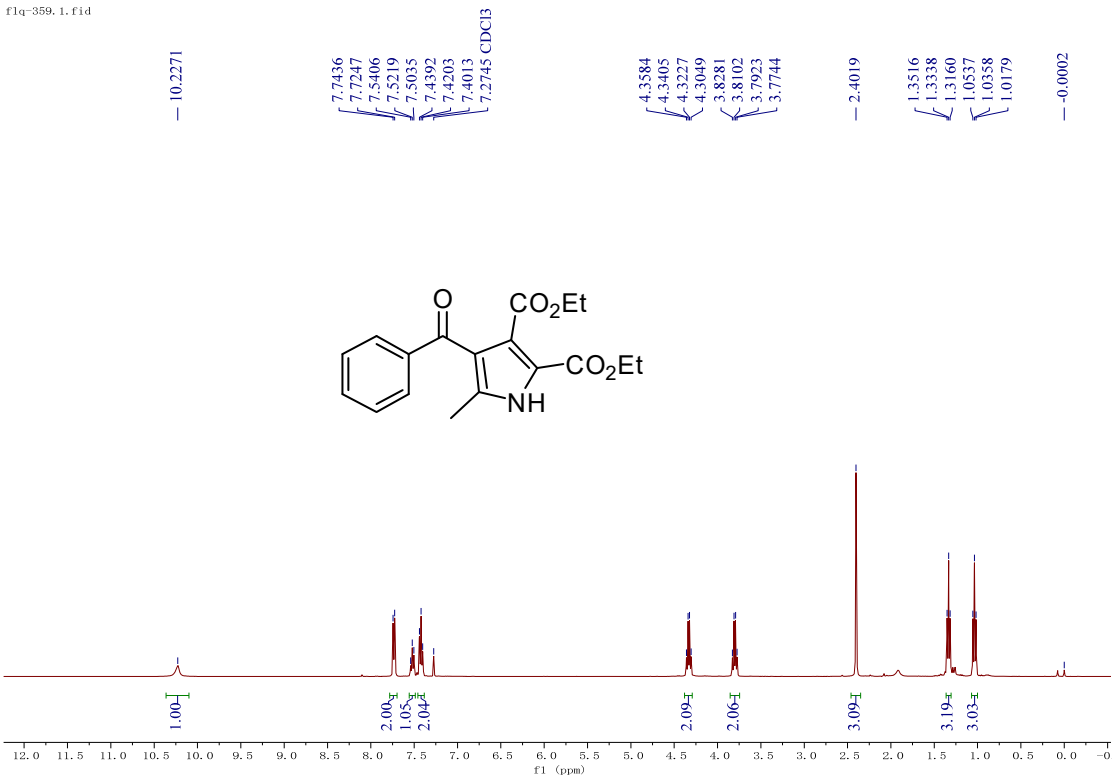
^{13}C NMR spectrum of **3w** (100 MHz, DMSO-d_6)



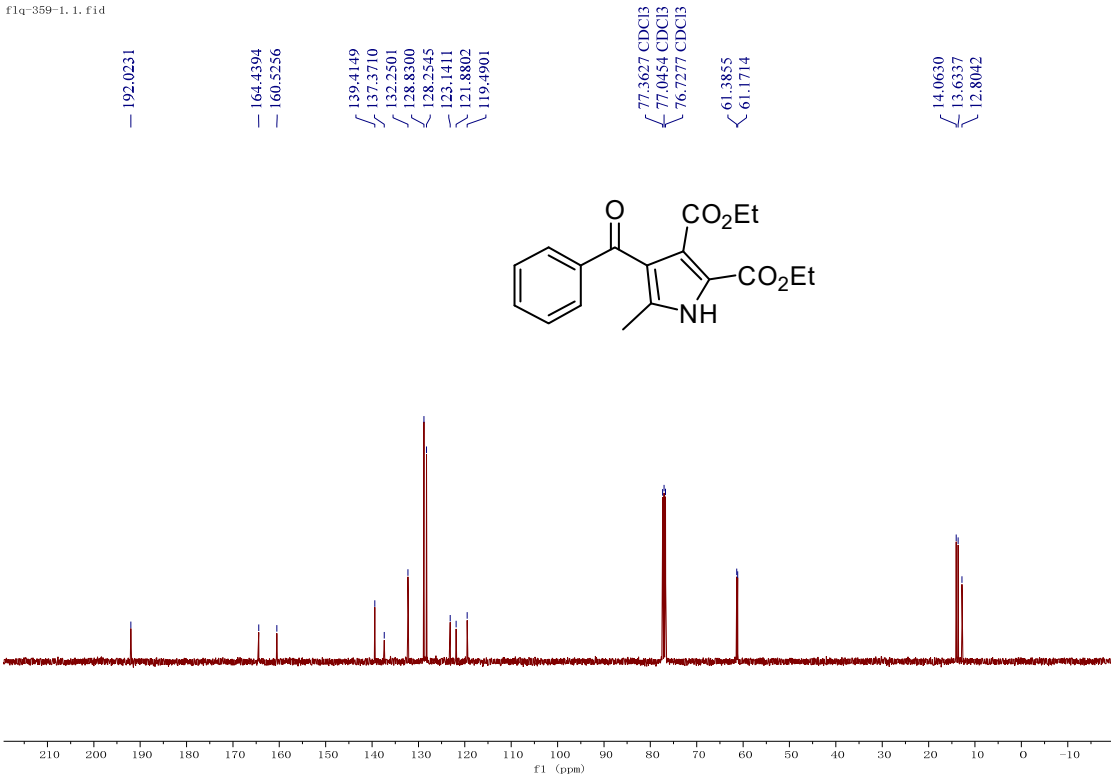
^{1}H NMR spectrum of **3x** (400 MHz, $CDCl_3$)



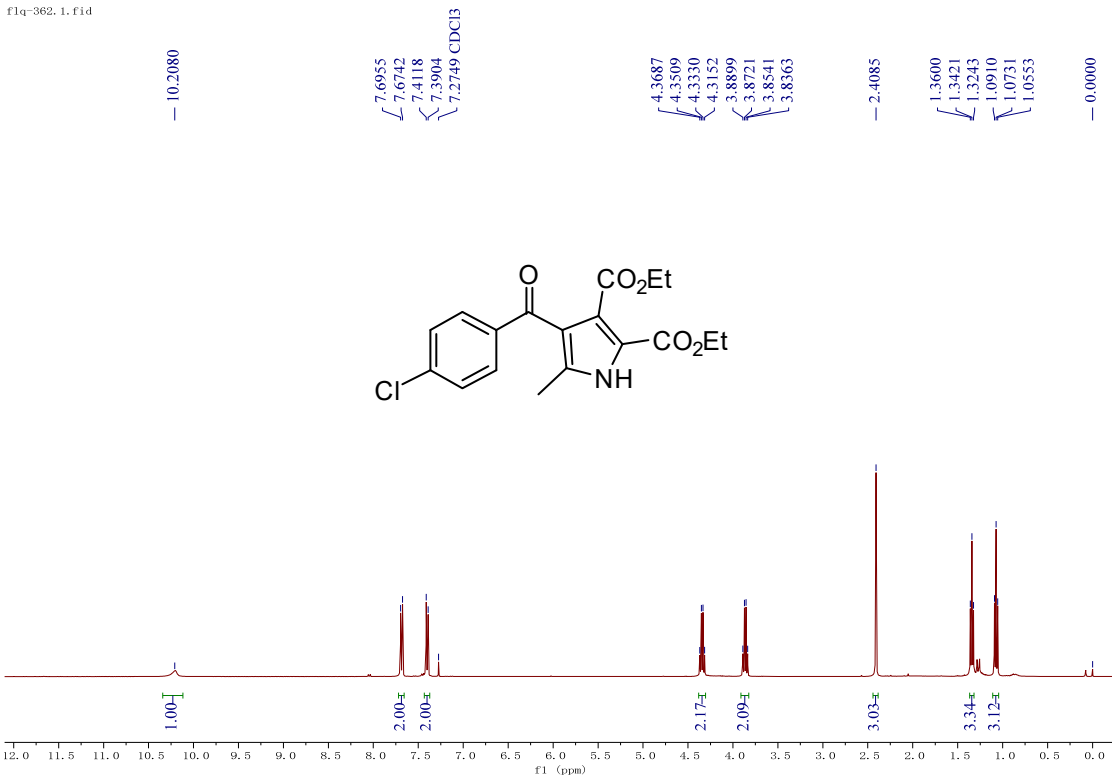
^{13}C NMR spectrum of **3x** (100 MHz, $CDCl_3$)



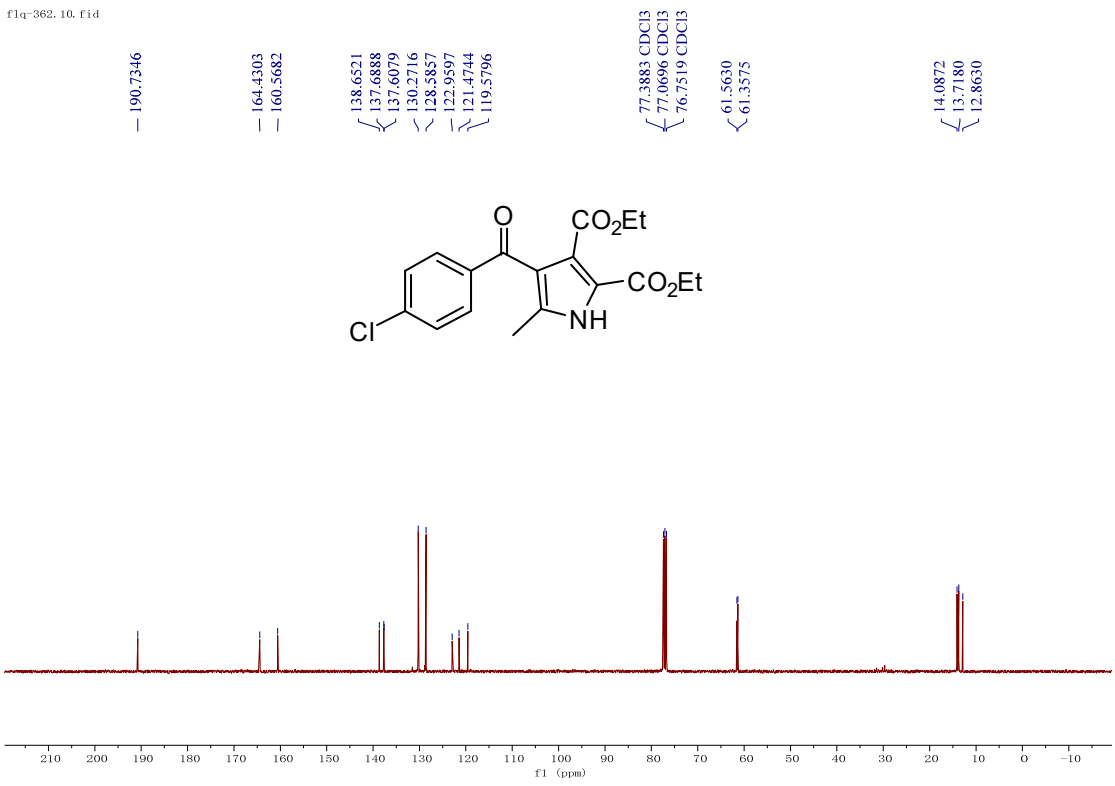
^{1}H NMR spectrum of **5a** (400 MHz, $CDCl_3$)



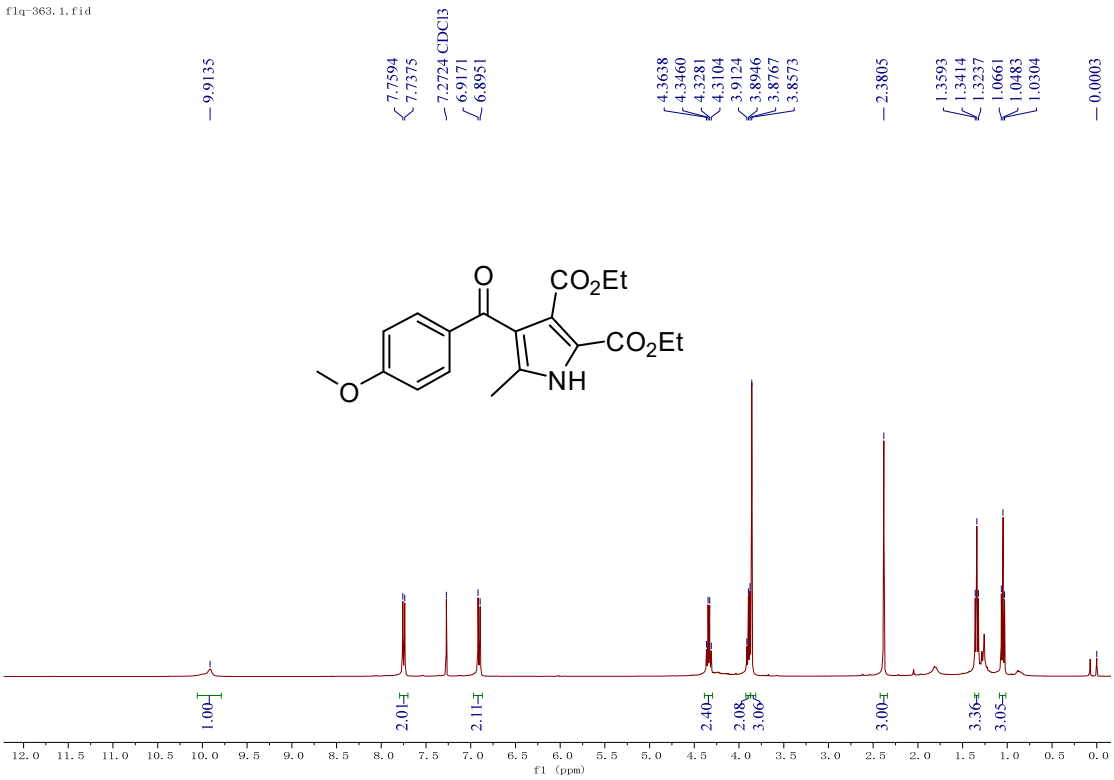
^{13}C NMR spectrum of **5a** (100 MHz, $CDCl_3$)



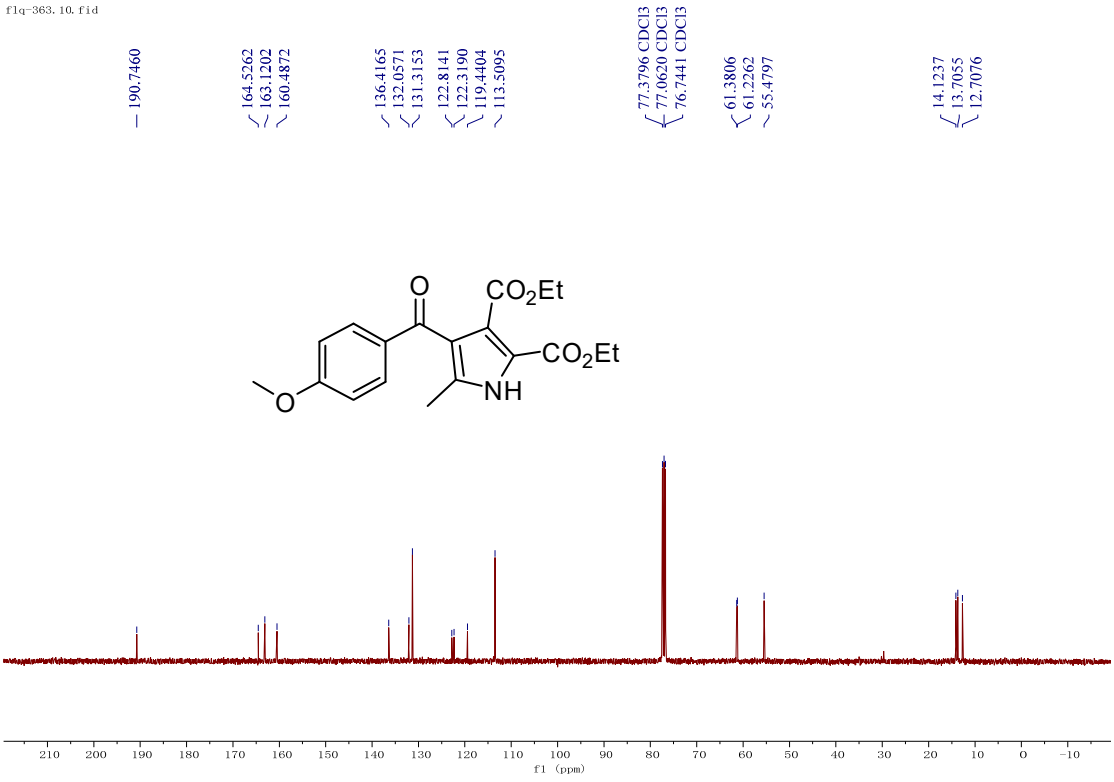
^{1}H NMR spectrum of **5b** (400 MHz, $CDCl_3$)



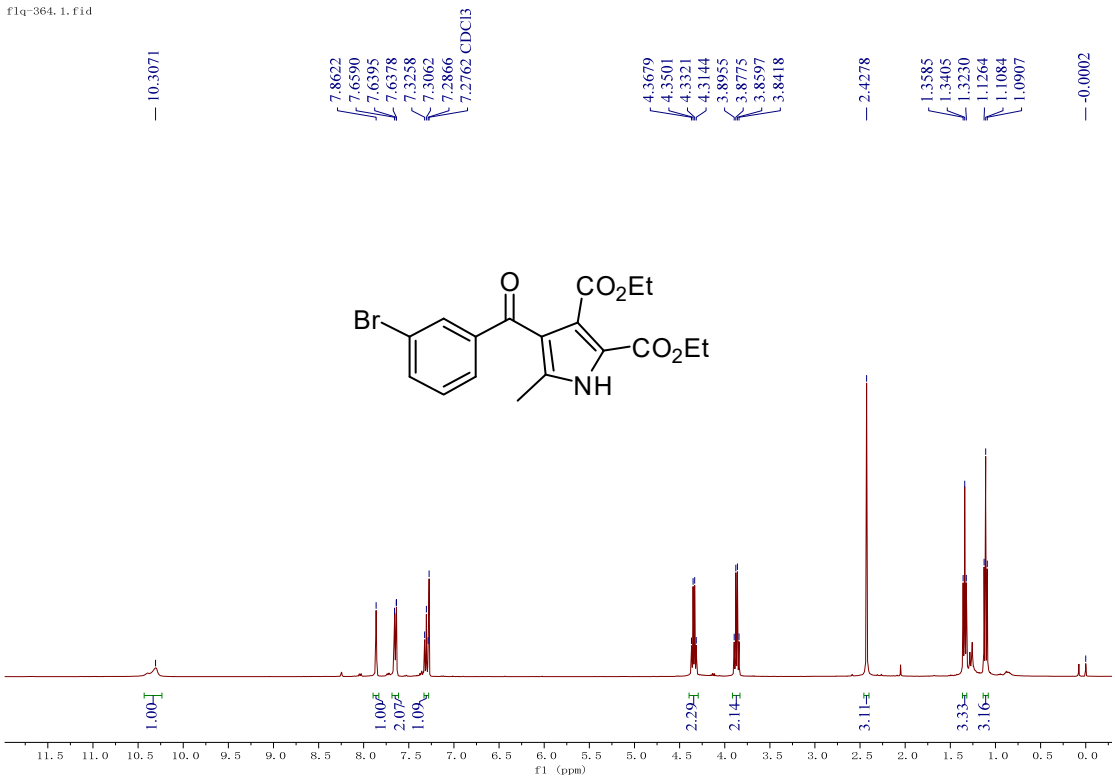
^{13}C NMR spectrum of **5b** (100 MHz, $CDCl_3$)



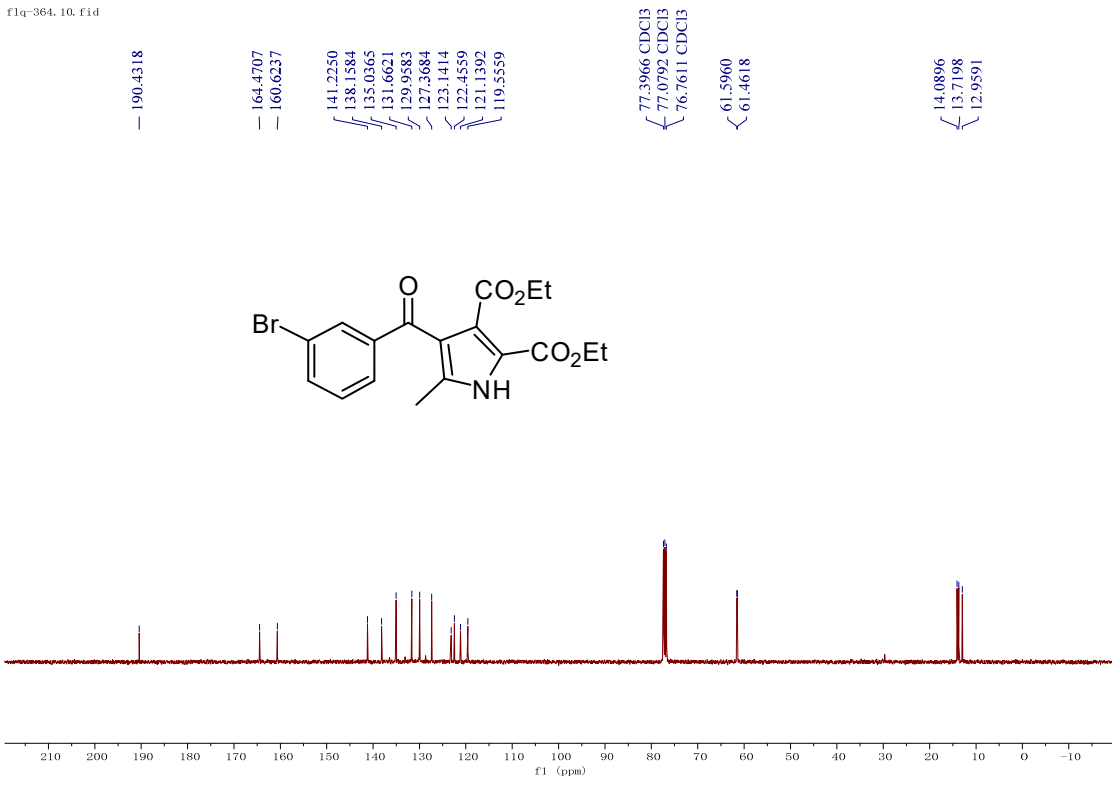
^{1}H NMR spectrum of **5c** (400 MHz, $CDCl_3$)



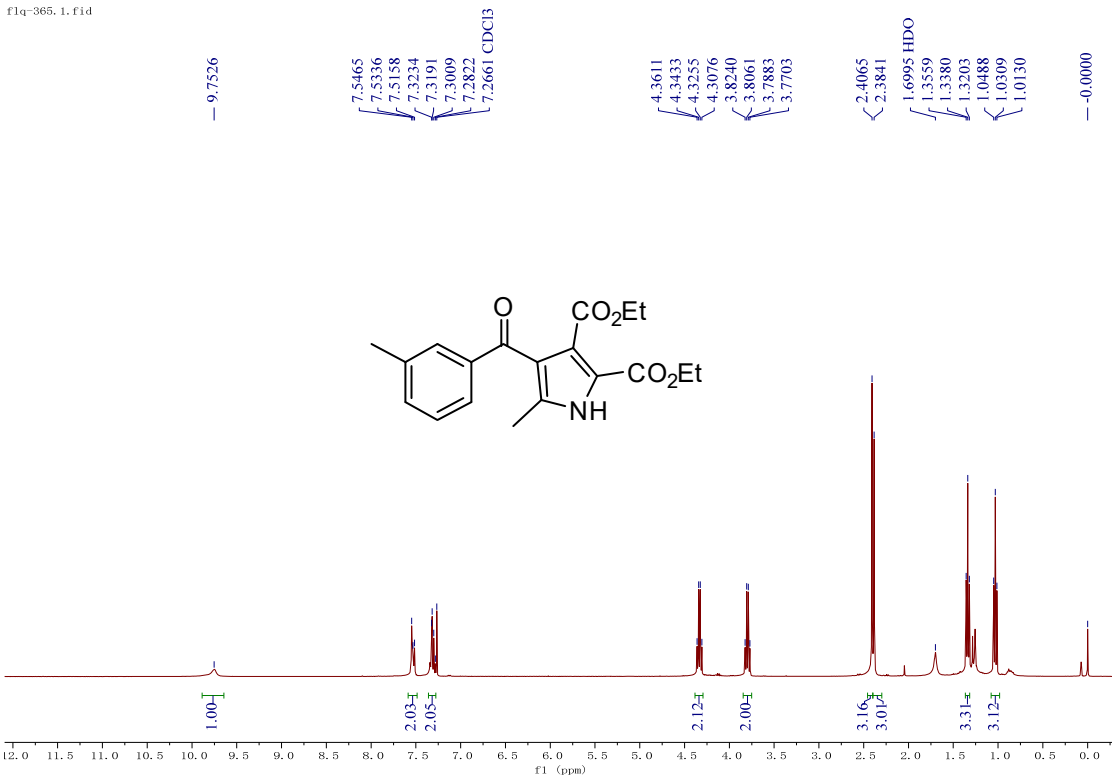
^{13}C NMR spectrum of **5c** (100 MHz, $CDCl_3$)



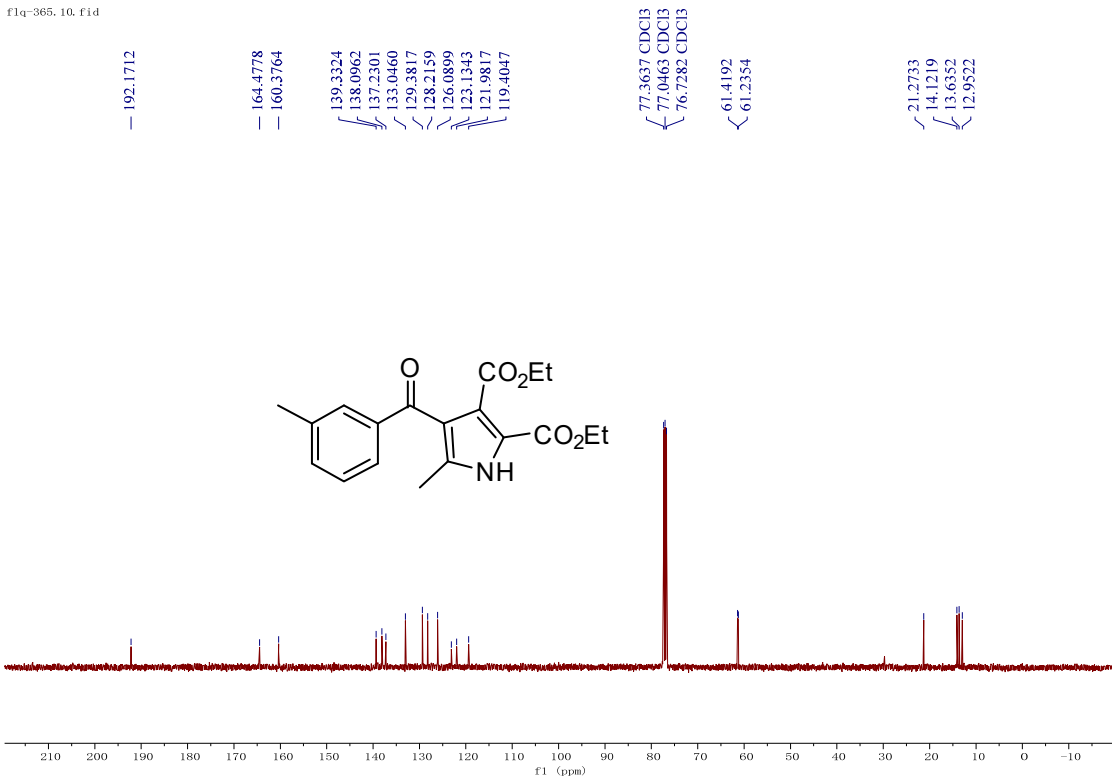
^{1}H NMR spectrum of **5d** (400 MHz, $CDCl_3$)



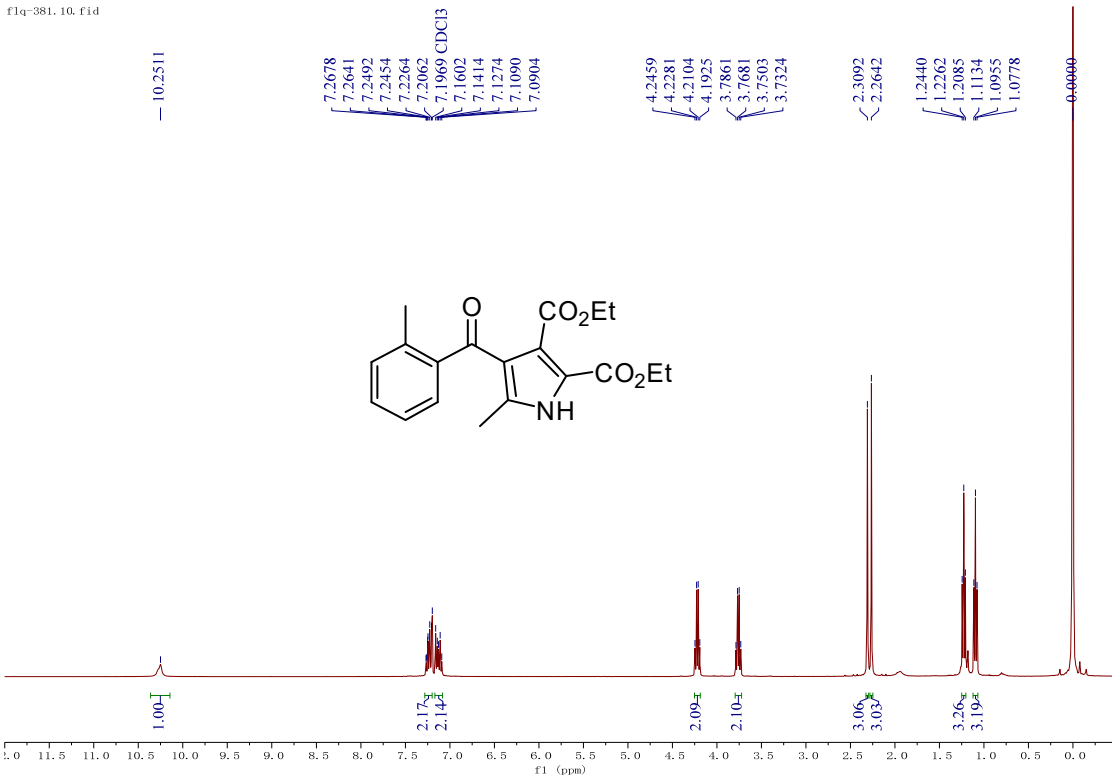
^{13}C NMR spectrum of **5d** (100 MHz, $CDCl_3$)



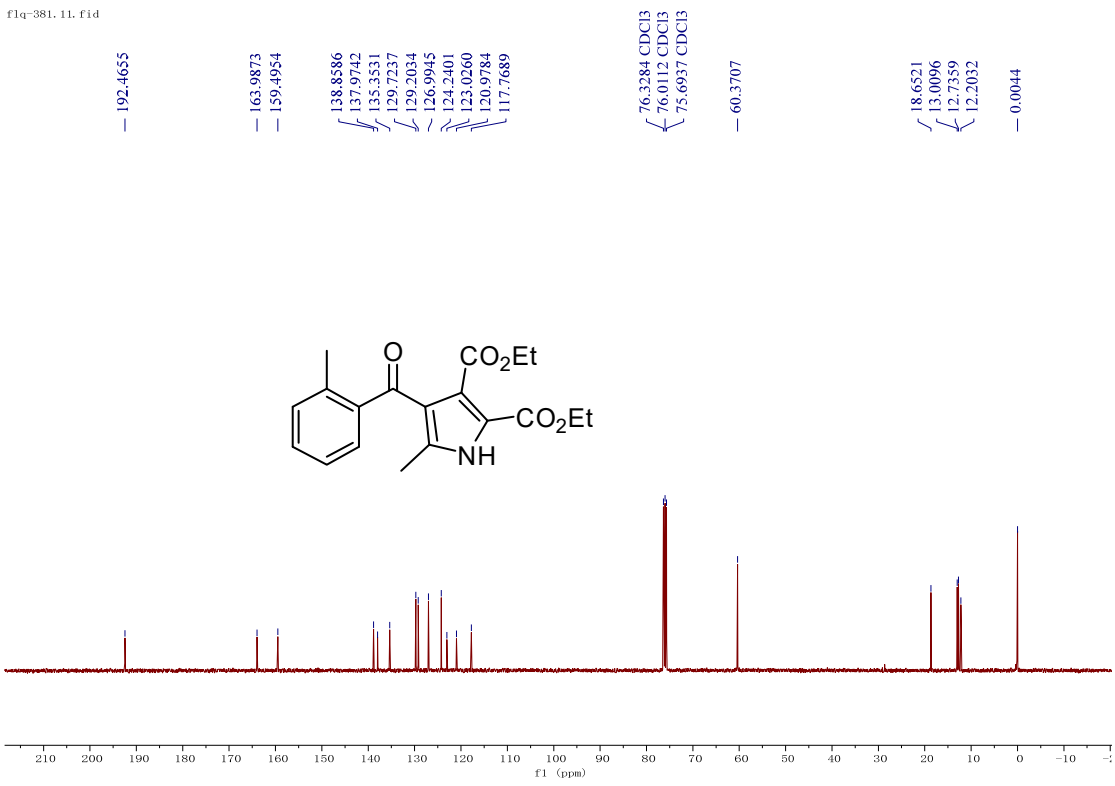
^{1}H NMR spectrum of **5e** (400 MHz, $CDCl_3$)



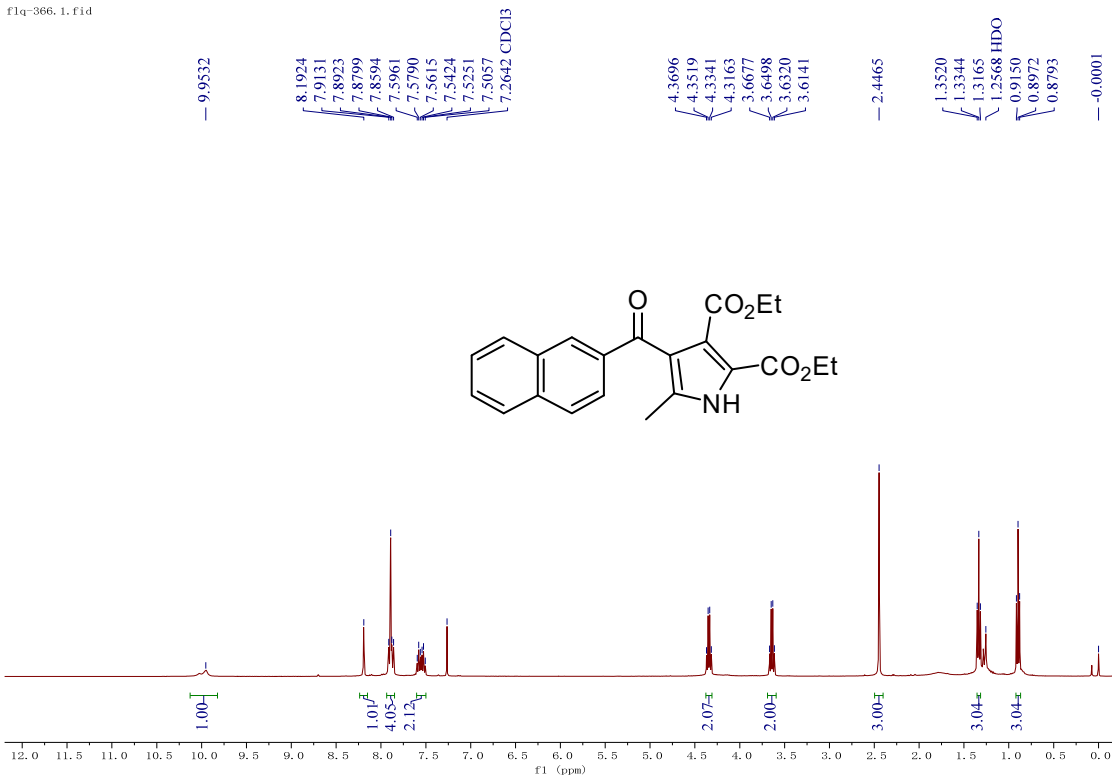
^{13}C NMR spectrum of **5e** (100 MHz, $CDCl_3$)



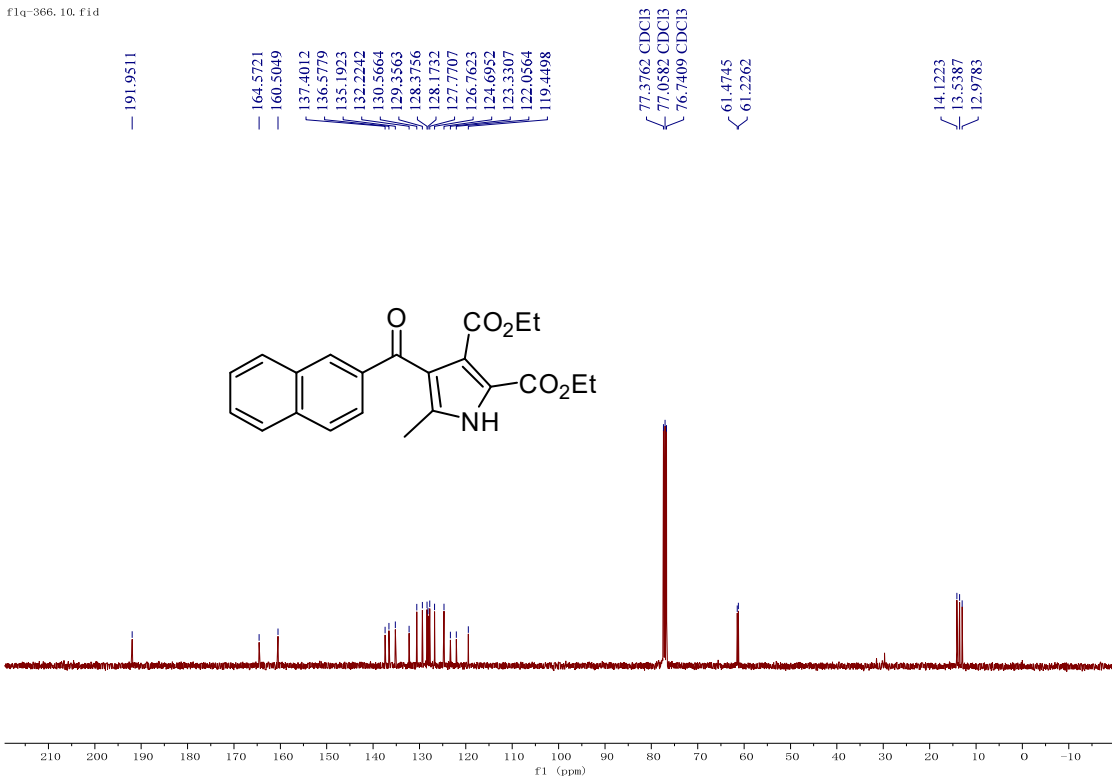
^{1}H NMR spectrum of **5f** (400 MHz, $CDCl_3$)



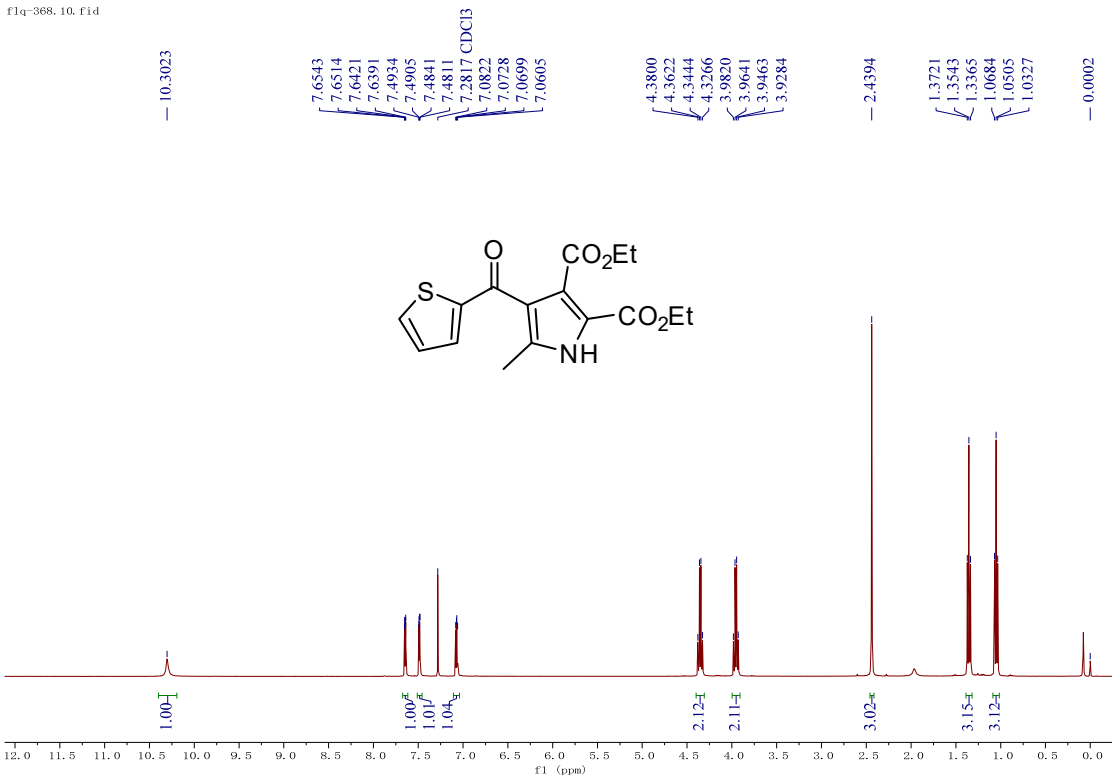
^{13}C NMR spectrum of **5f** (100 MHz, $CDCl_3$)



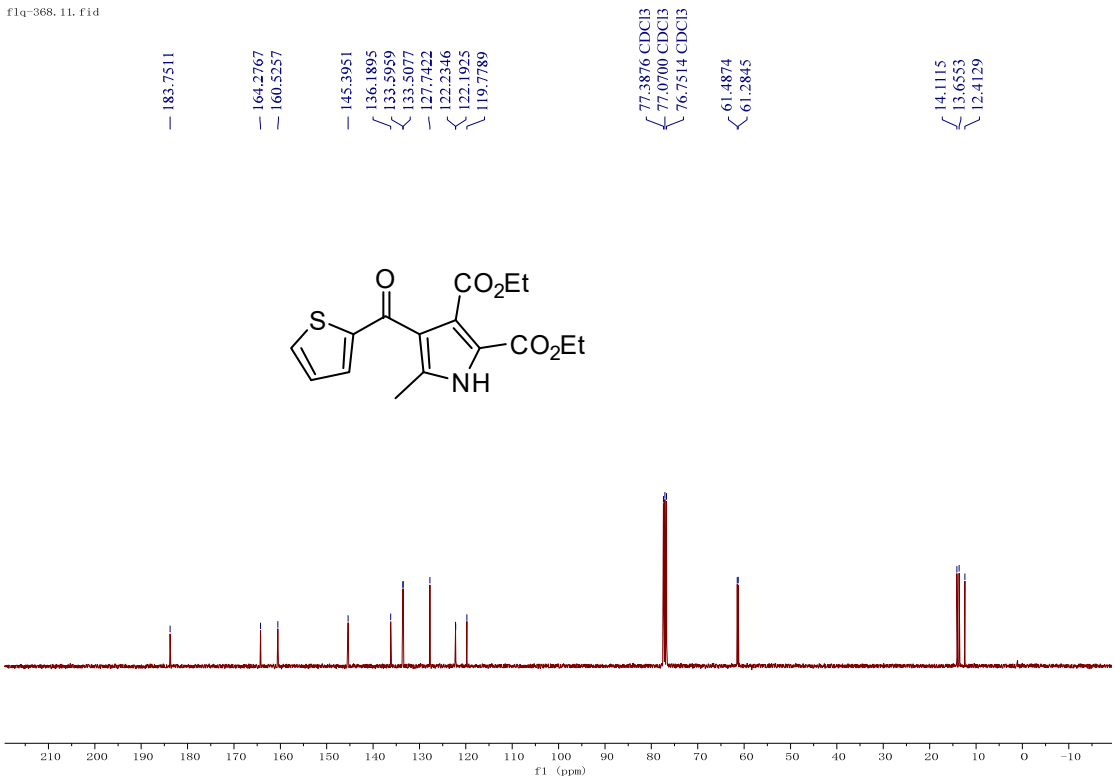
^{1}H NMR spectrum of **5g** (400 MHz, $CDCl_3$)



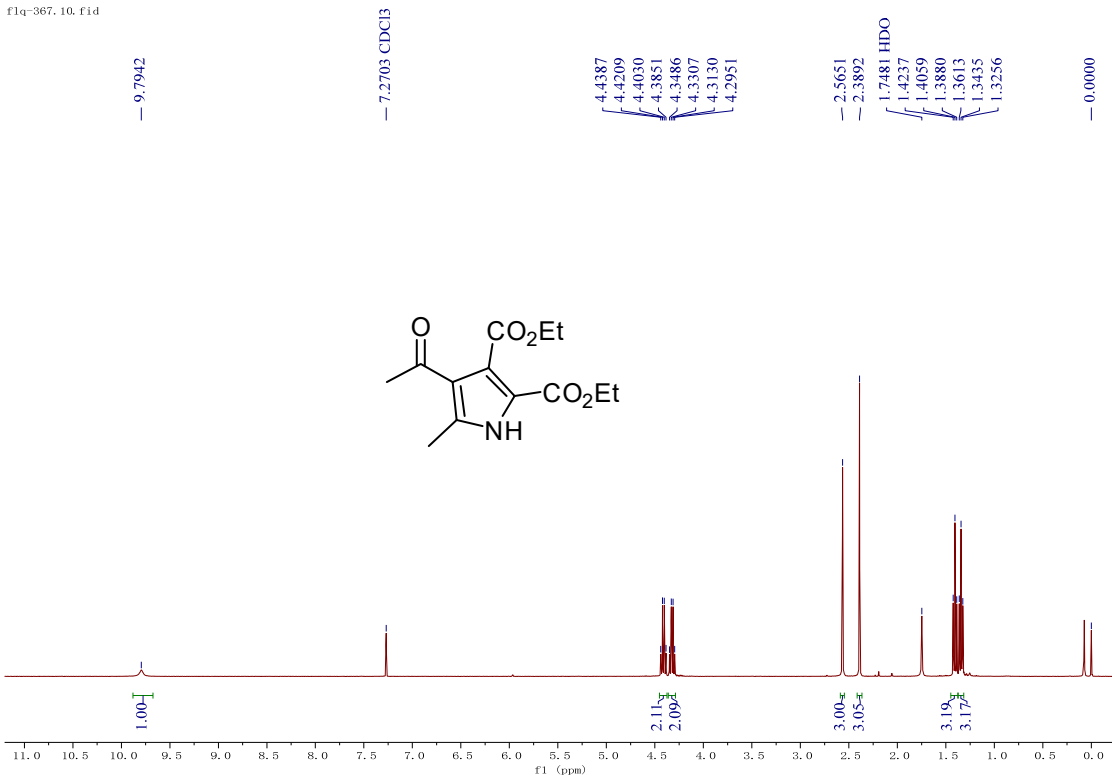
^{13}C NMR spectrum of **5g** (100 MHz, $CDCl_3$)



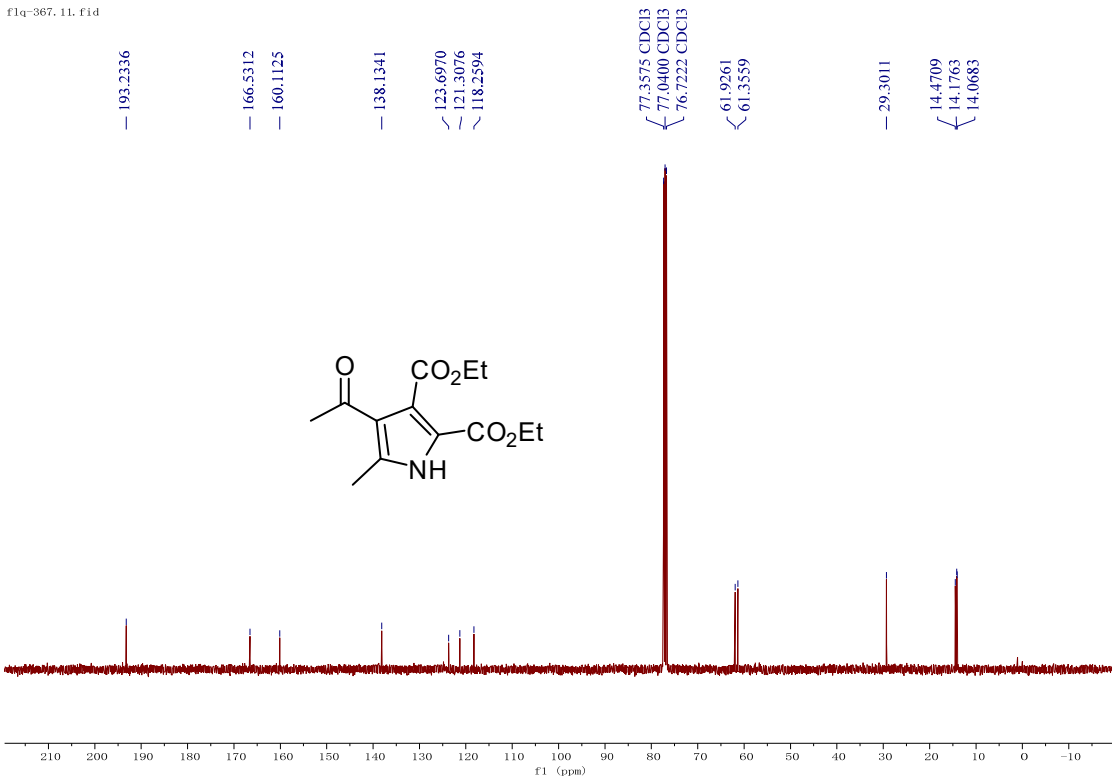
^{1}H NMR spectrum of **5h** (400 MHz, $CDCl_3$)



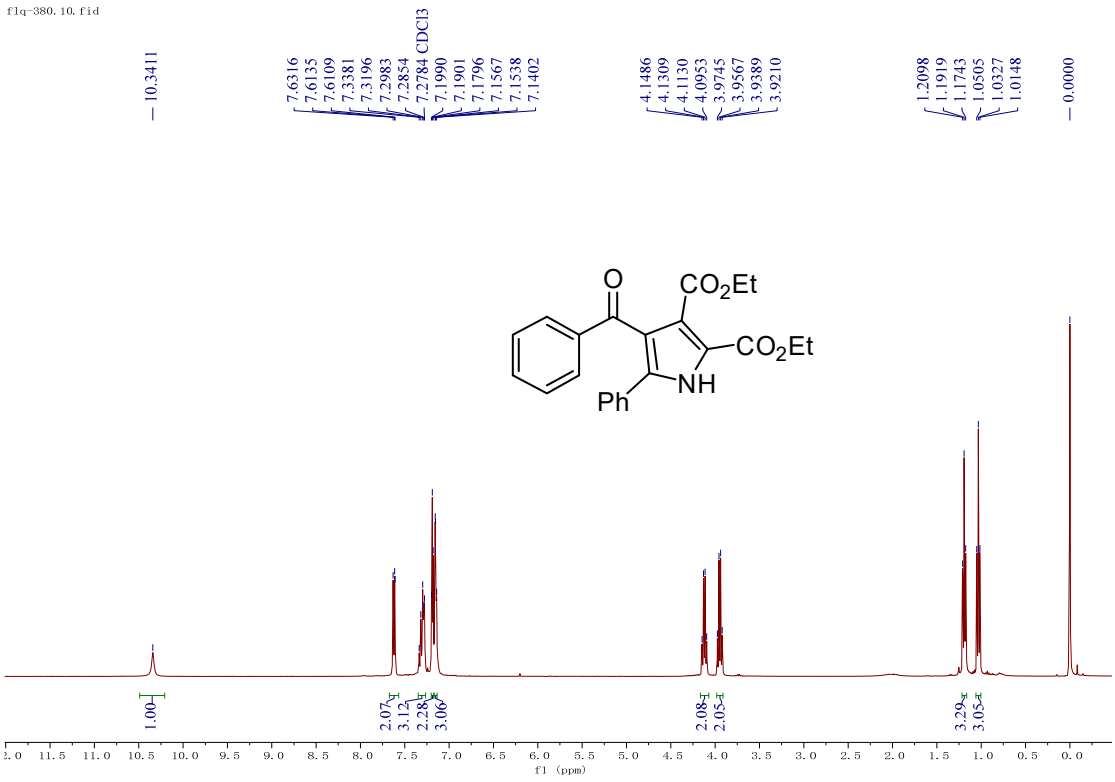
^{13}C NMR spectrum of **5h** (100 MHz, $CDCl_3$)



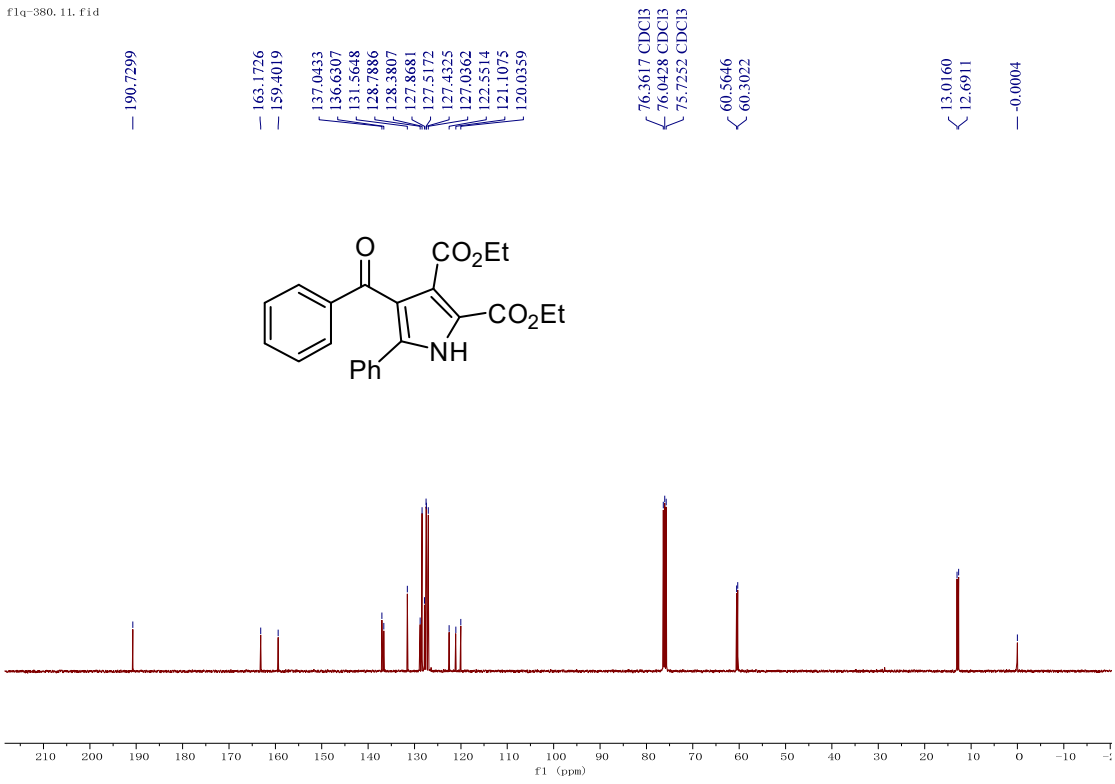
^{1}H NMR spectrum of **5i** (400 MHz, $CDCl_3$)



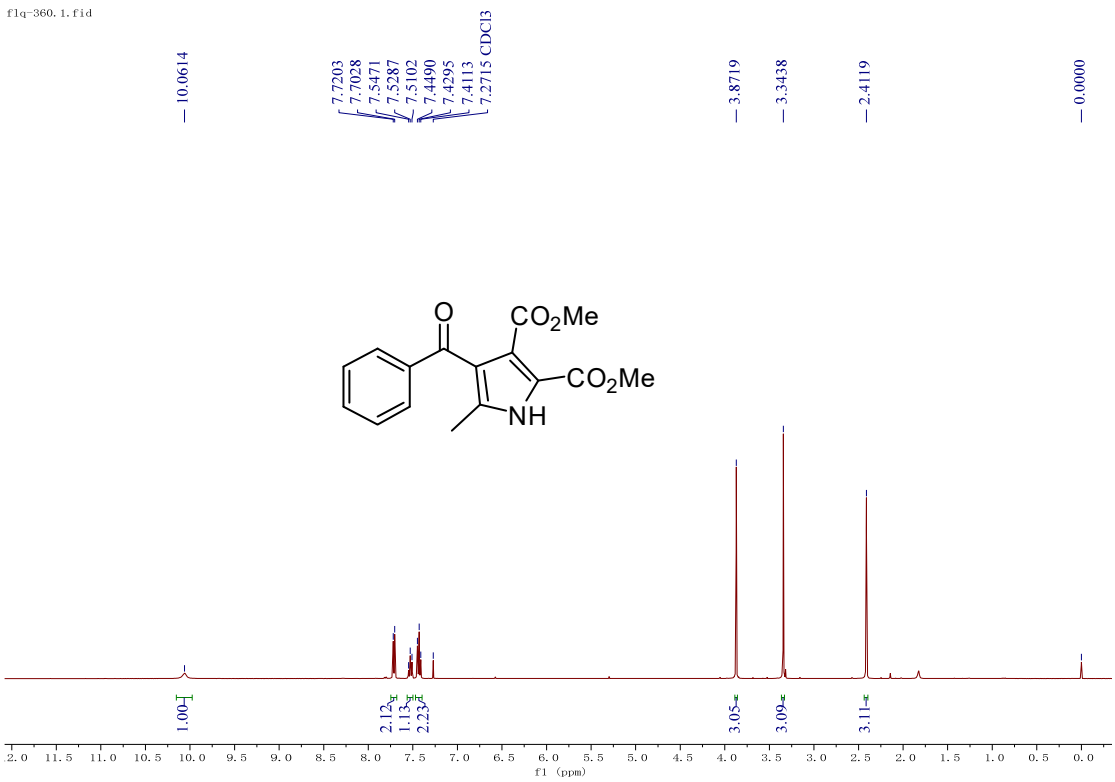
^{13}C NMR spectrum of **5i** (100 MHz, $CDCl_3$)



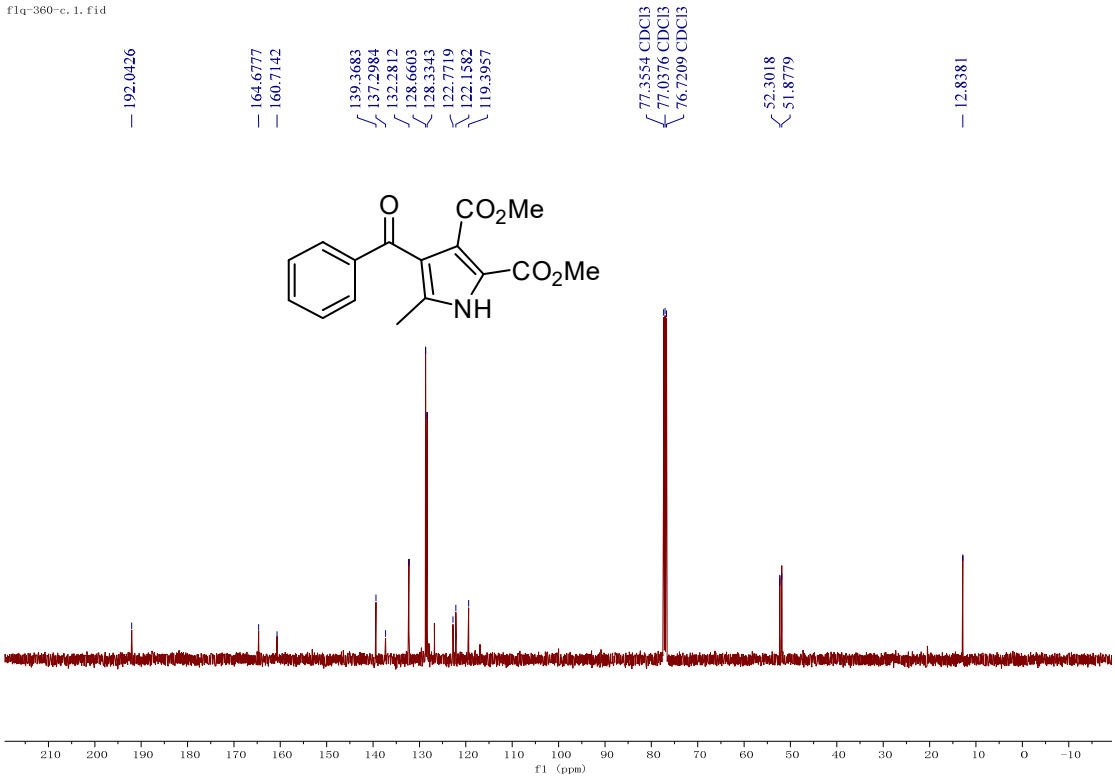
^{1}H NMR spectrum of **5j** (400 MHz, $CDCl_3$)



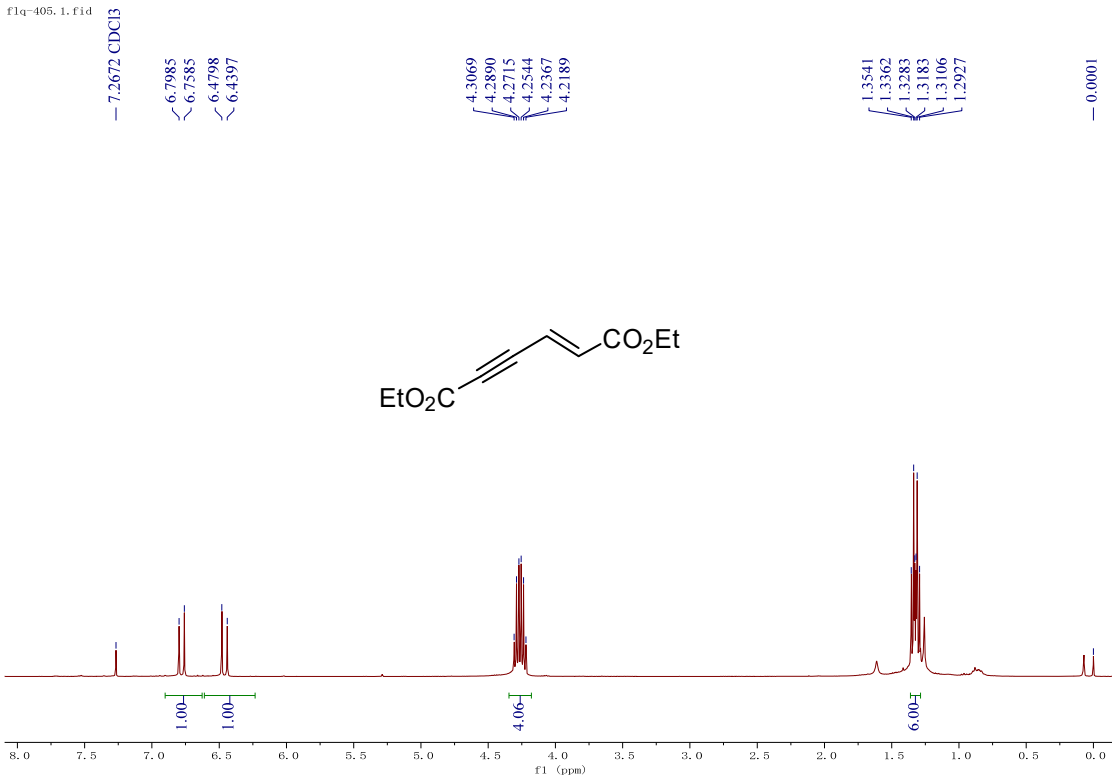
^{13}C NMR spectrum of **5j** (100 MHz, $CDCl_3$)



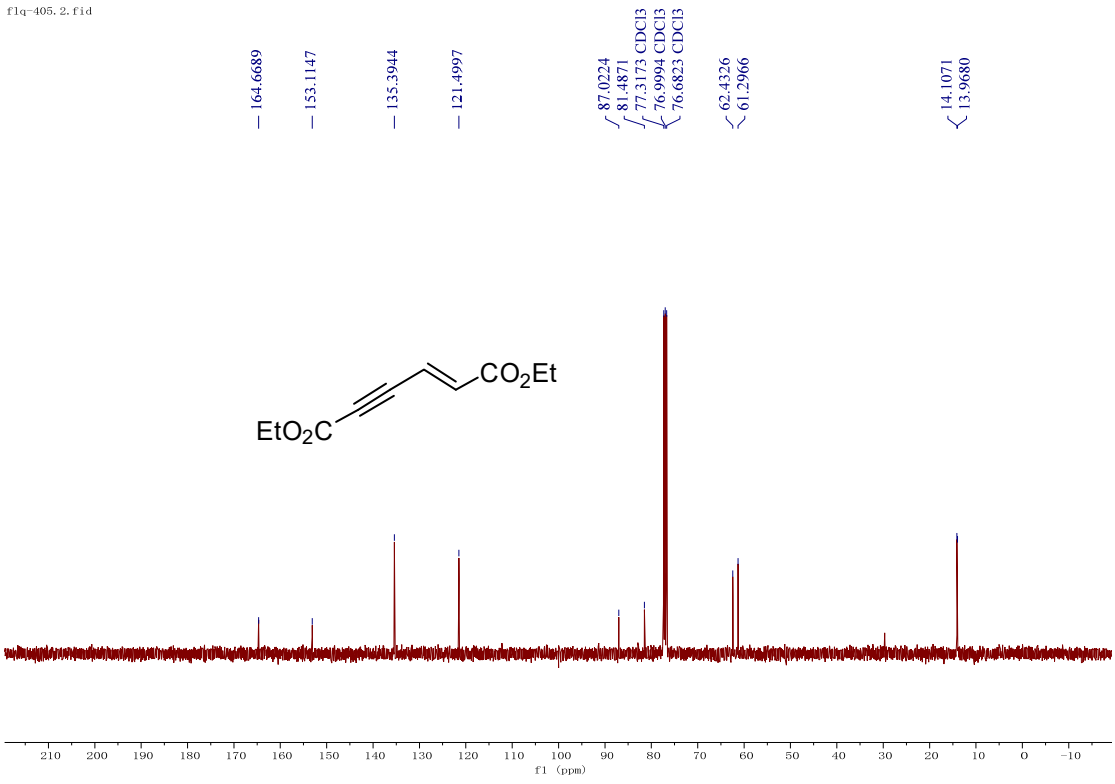
^{1}H NMR spectrum of **5k** (400 MHz, $CDCl_3$)



^{13}C NMR spectrum of **5k** (100 MHz, $CDCl_3$)



^{1}H NMR spectra of **6** (400 MHz, $CDCl_3$)



^{13}C NMR spectra of **6** (100 MHz, $CDCl_3$)