Metal-free Access to 3-Allyl-2-alkoxychromanones via Phosphine-Catalyzed Alkoxy Allylation of Chromones with MBH Carbonates and Alcohols

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Supporting Information

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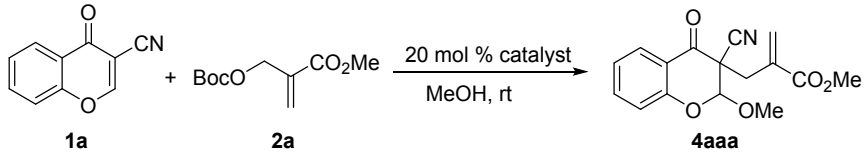
1. General Information

All air- and moisture-sensitive manipulations were carried out with standard Schlenk techniques under nitrogen or in a glove box under argon. Common chemicals were purchased from commercial suppliers and used without further purification. NMR Spectra were recorded on a Bruker DPX-400 spectrometer at 400 MHz or 500 MHz for ^{1}H NMR, 376 MHz for ^{19}F NMR and 100 MHz or 125 MHz for ^{13}C NMR in $CDCl_3$ with tetramethylsilane (TMS) as internal standard, and ^{19}F NMR chemical shifts were determined relative to $CFCl_3$ as inter standard. Chemical shifts (δ) are reported in ppm, and coupling constants (*J*) are in Hertz (Hz). The following abbreviations were used to explain the multiplicities: s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet, br = broad. Flash column chromatograph was carried out using 200-300 mesh silica gel at medium pressure or ODS-A-HG C18 reversed silica gel. Infrared spectra (IR) were measured using IRPrestige-21 spectrophotometer. High resolution mass spectra (HRMS) were recorded on a LC-TOF spectrometer. ESI-HRMS data were acquired using a Thermo LTQ Orbitrap XL Instrument equipped with an ESI source.

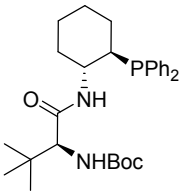
2. Initial Investigation

(a)

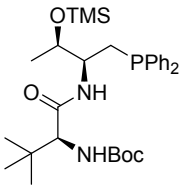


1a **2a** **4aaa**

catalyst:



P8
0% ee



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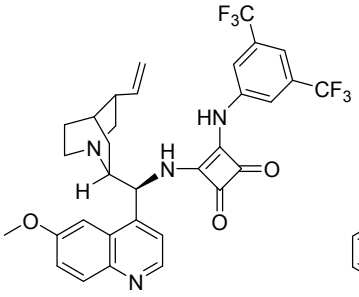
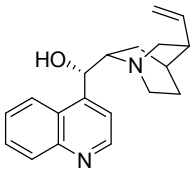


N1
9% ee



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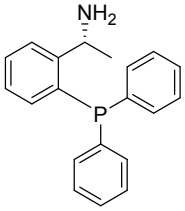
5% ee



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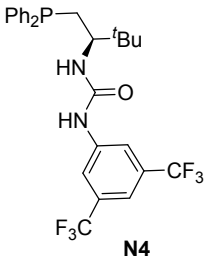

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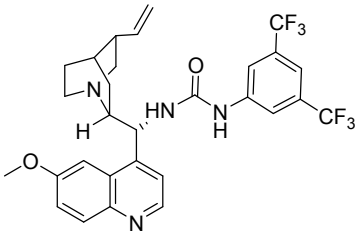
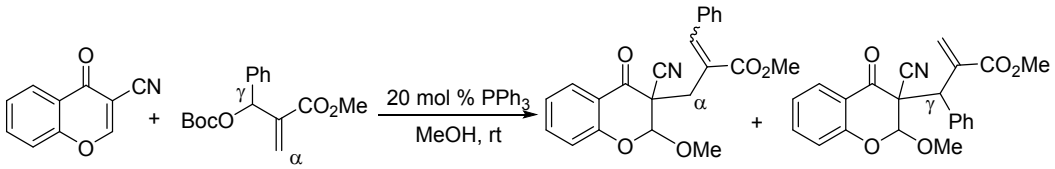


N5
5% ee

(b)

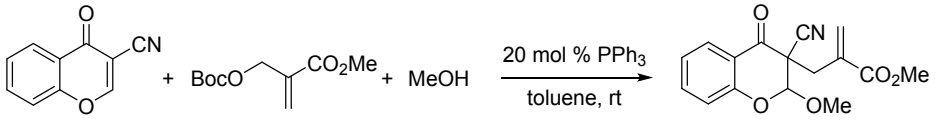


1a **11** **12** **13**

α-regioselective product
dr = 1:4 (NMR)

γ-regioselective product
12:**13** = 13 :1 (NMR)

(c)



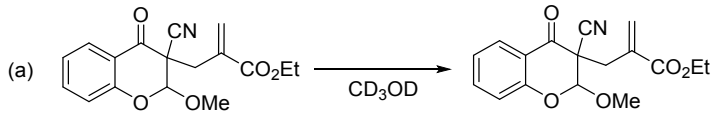
1.0 equive
1a

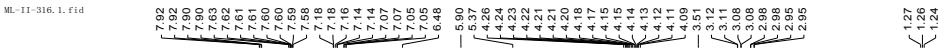
2.0 equive
2a

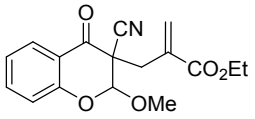
20 equive
3a

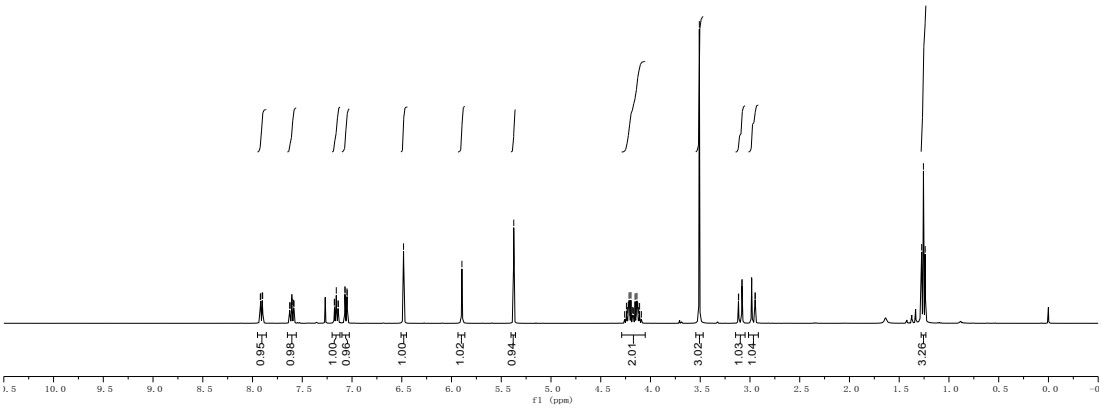
4aaa
28% yield

3. The NMR Data and ^{1}H Spectra of Deuterium-labeling Experiments

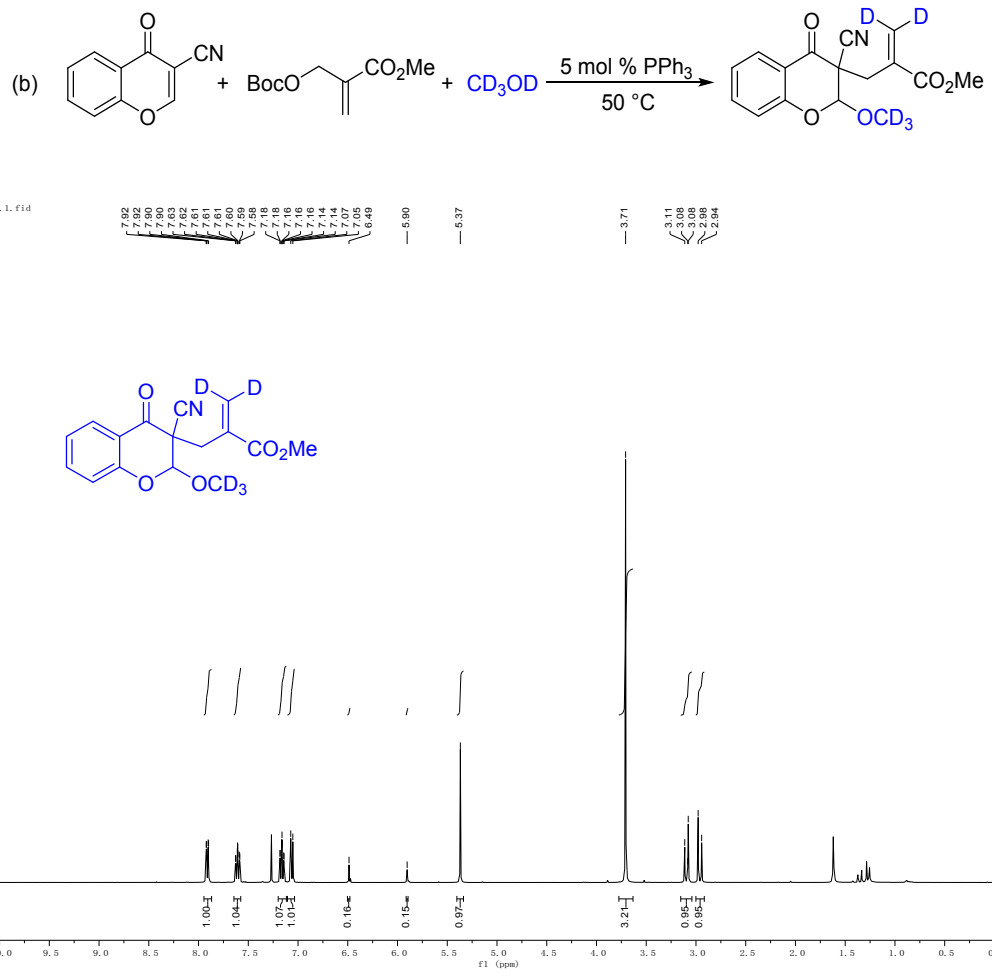






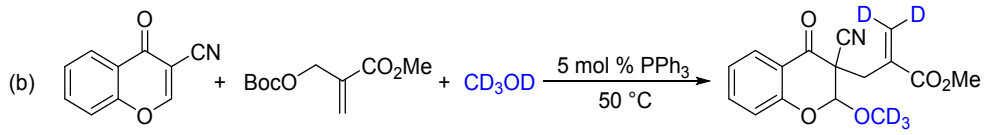


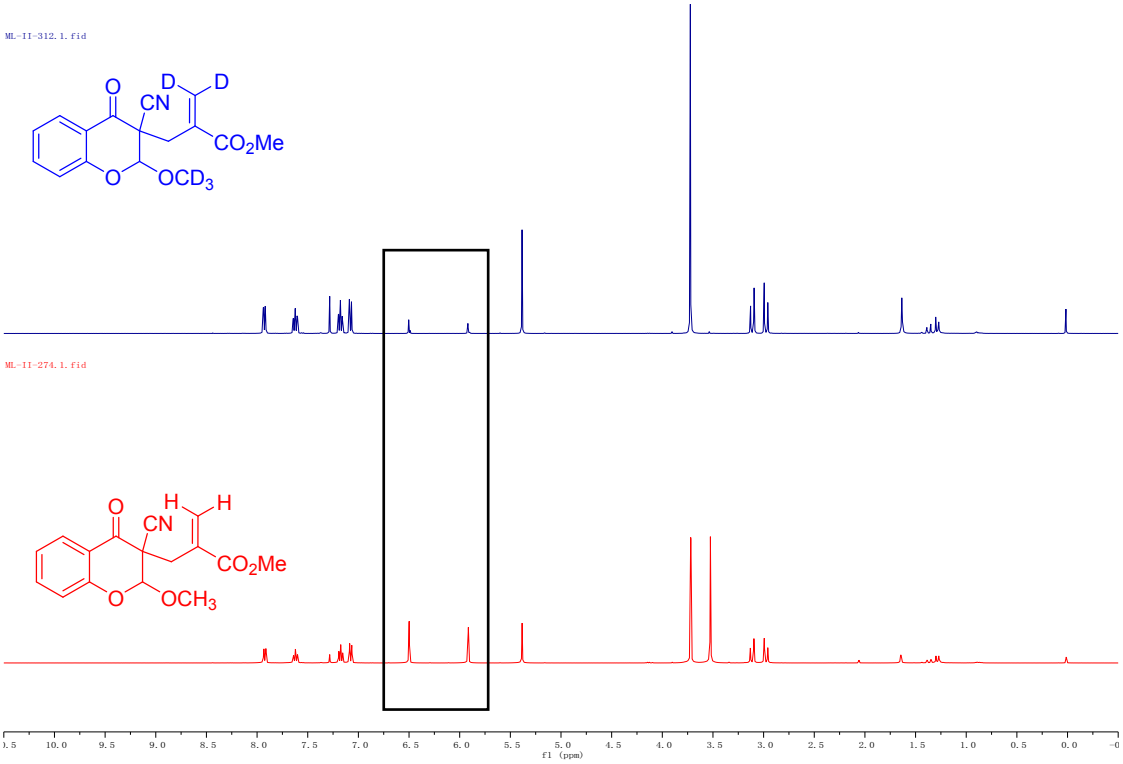
^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.91 (dd, *J* = 7.9, 1.7 Hz, 1H), 7.60 (ddd, *J* = 8.4, 7.3, 1.7 Hz, 1H), 7.18–7.14 (m, 1H), 7.07–7.05 (m, 1H), 6.48 (s, 1H), 5.90 (s, 1H), 5.37 (s, 1H), 4.26–4.09 (m, 2H), 3.51 (s, 3H), 3.10 (dd, *J* = 13.9, 0.9 Hz, 1H), 2.97 (dd, *J* = 14.0, 0.8 Hz, 1H), 1.26 (t, *J* = 7.1 Hz, 3H).

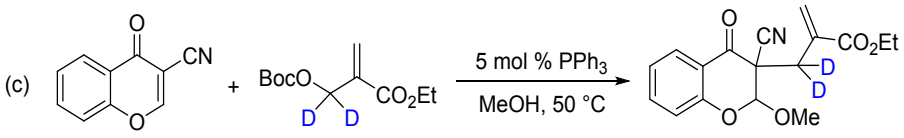


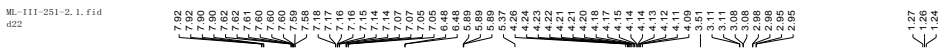
^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.91 (dd, *J* = 7.8, 1.8 Hz, 1H), 7.61 (ddd, *J* = 8.3, 7.3, 1.8 Hz, 1H), 7.16 (ddd, *J* = 8.0, 7.3, 1.1 Hz, 1H), 7.06 (d, *J* = 8.3 Hz, 1H), 5.37 (s, 1H), 3.71 (s, 3H), 3.10 (d, *J* = 14.0 Hz, 1H), 2.96 (d, *J* = 14.1 Hz, 1H).

Stack spectra






(c)
O
CN
O
+
BocO
D
D
CO2Et
5 mol % PPh3
MeOH, 50 °C
O
CN
CO2Et
D
D
O
OMe


ML-III-251-2.1.fid
d22
7.92
7.92
7.90
7.90
7.62
7.62
7.61
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7.60
7.60
7.59
7.58
7.18
7.17
7.16
7.16
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7.14
7.14
7.07
7.07
7.05
7.05
6.48
6.48
5.89
5.89
5.89
5.37
4.26
4.24
4.23
4.22
4.21
4.21
4.20
4.18
4.17
4.15
4.14
4.14
4.13
4.12
4.11
4.09
3.51
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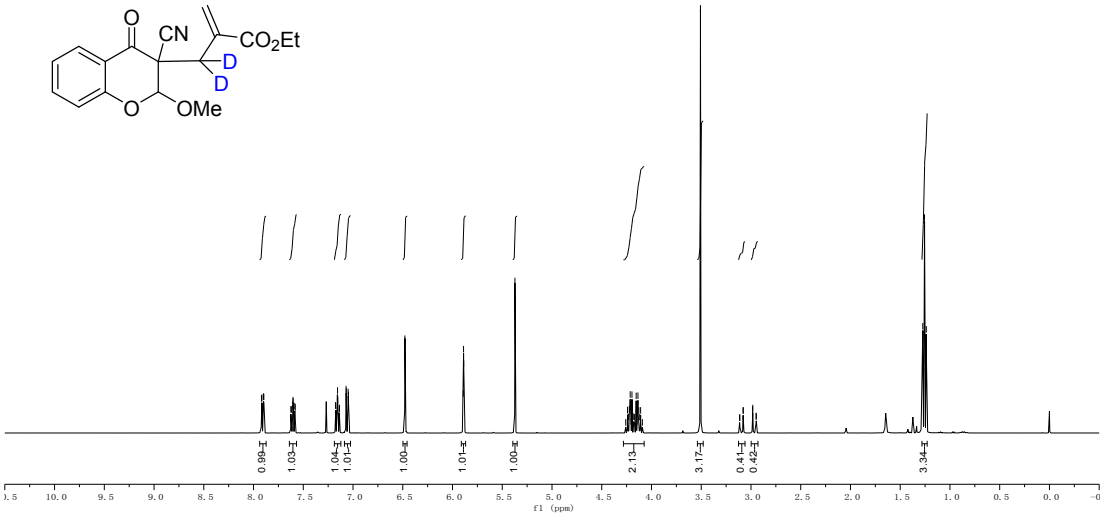
1.27
1.26
1.24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CN
CO2Et
D
D
O
OMe
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1.03
1.04
1.01
1.00
1.01
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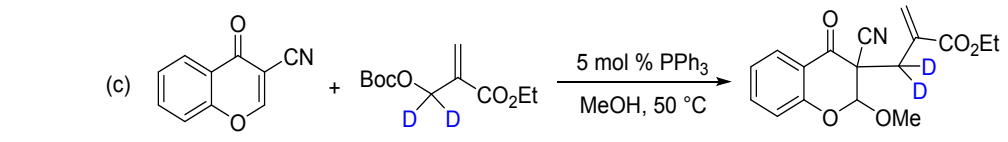
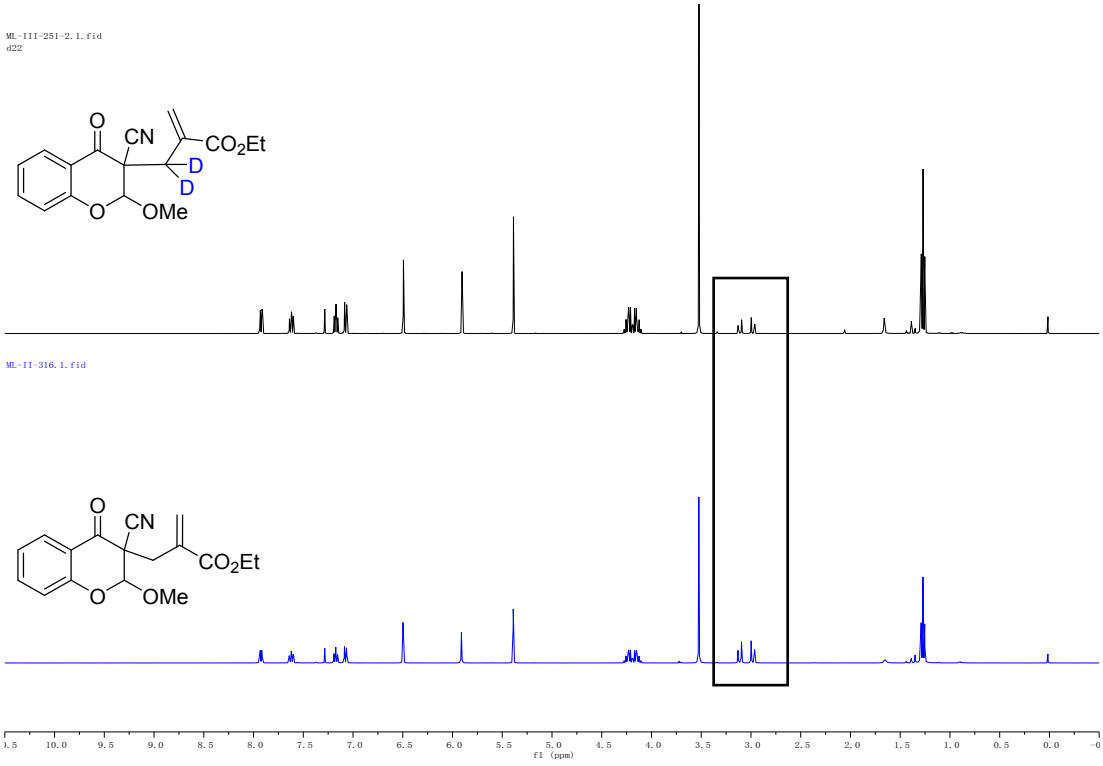
0.41
0.42
3.34
f1 (ppm)

Stack spectra

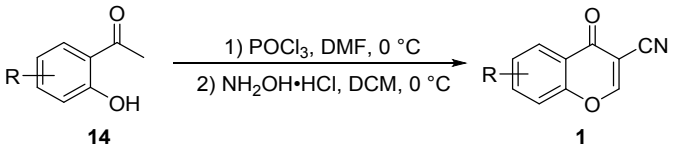




4. Procedure for Synthesis of Substrates

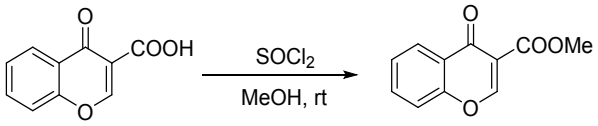
4.1 Synthesis of 3-Subsituted Chromones

Chromone substrates were prepared by following the reported literature procedures. The analytical data are in agreement with those reported in the literature.



14 **1**

All 3-cyanochromones were synthesized according to the literature. General procedure: a mixture of dimethylformamide (80 mmol, 8.0 equive) and phosphorus oxychloride (40 mmol, 4.0 equive) was stirred at 0 °C for 30 min. To this solution, 2-hydroxyacetophenone **14** (10 mmol, 1.0 equive) was added dropwise at 0 °C. The mixture was stirred at room temperature for 4 h. After completion of the reaction, as indicated by TLC, the reaction mixture was diluted with dichloromethane (40 mL). The mixture was cooled to 0 °C and hydroxylamine hydrochloride (30 mmol, 3.0 equive) in DMF (10 mL) was then added. The resulting mixture was stirred at room temperature and the reaction progress was monitored by TLC. After completion of the reaction, the mixture solution was diluted with cold water (100 mL) and extracted with DCM (3 × 50 mL). The combined organic phases were washed with water (3 × 50 mL), saturated $NaHCO_3$ solution (10 mL) and finally with water (50 mL). The combined extracts were dried over anhydrous Na_2SO_4. The solvent was removed in vacuo and the residual solid was purified via flash chromatography or recrystallization to give the desired product **1**.



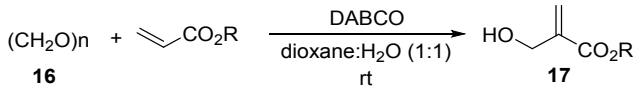
15 **1m**

Thionyl chloride (165 mmol, 31.0 equive) was added dropwise to a stirred solution of methanol (60 mL) at room temperature. After the mixture cooled again to room temperature and turned into a slightly yellowish solution (30 min), the chromone acid **15** (5.3 mmol, 1.0 equive) was added. The resulting

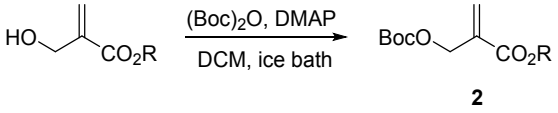
mixture was stirred at room temperature for 24 h. The orange solution was concentrated in vacuo and purified by flash column chromatography, producing **1m** as an off-white solid.

4.2 Synthesis of Unsubtituted MBH Carbonates

Unsubstituted MBH alcohols were prepared by following the reported literature procedure.[113] The analytical data are in agreement with those reported in the literature.



To a solution of paraformaldehyde **16** (20 mmol, 1.0 equive) in dioxane:water (1:1, 20 mL) was added acrylate (60 mmol, 3.0 equive) followed by addition of DABCO (20 mmol, 1.0 equive) and the resulting mixture was stirred at room temperature. Upon completion monitored by TLC, the mixture was extracted with EtOAc three times and the combined organic layer was dried over anhydrous Na_2SO_4 and concentrated in vacuo. The crude product was purified by flash column chromatography to afford the desired Morita-Baylis-Hillman alcohol **17**.



The solution of Morita-Baylis-Hillman alcohols (1.0 equive) and 4-dimethylaminopyridine (10 mol %) in DCM (0.6 M) was stirred at 0 °C for 10 minutes. To the cooled solution, a DCM solution of Boc_2O was then added dropwise (1.1 equive) at 0 °C. The resulting solution was stirred at room temperature for 2 h and then stirred at room temperature for specified time. Subsequently the solvent was removed in vacuo and the crude mixture was purified by column chromatography to afford pure Morita-Baylis-Hillman carbonates **2**.

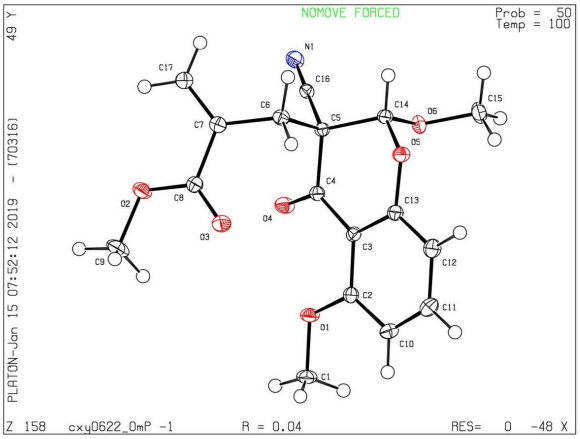
5. General Procedure for Synthesis of 3-allyl-2-alkoxychromanones

To an oven-dried vial was added chromone substrates **1** (0.2 mmol, 1.0 equiv) and catalyst PPh_3 (0.01 mmol 0.05 equiv) in alcohol (2.0 mL). The resulting solution was stirred for 5 minutes and then was added MBH carbonates **2** (1.38 g, 6 mmol, 1.5 equiv) under Ar at room temperature. Then, the reaction mixture was stirred at 50 °C for 12-48 hours monitored by TLC. After the reaction was complete, the mixture solution was concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc as eluent) to give the targeted products **4**.

General Procedure for the Gram-scale Reaction. To an oven-dried 100 mL Schlenk tube was added chromone substrates **1a** (685 mg, 4 mmol, 1.0 equiv) and catalyst PPh_3 (0.2 mmol 0.05 equiv) in alcohol (20.0 mL). The resulting solution was stirred for 5 minutes and then was added MBH carbonates **2** (1.38 g, 6 mmol, 1.5 equiv) under Ar at room temperature. Then, the reaction mixture was stirred at 50 °C for 12 hours monitored by TLC. After the reaction was complete, the mixture solution was concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel (petroleum ether/EtOAc as eluent) to give the targeted products **4aba** (1.14 g, 91% yield, >20:1 dr).

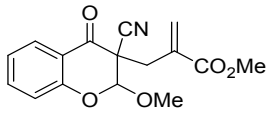
6. X-Ray Crystallography of the Product 4kaa

The configuration of the product **4kaa** was determined by single crystal X-ray diffraction and assigned to all other products by analogy.



Identification code	cxy0622_0m
Empirical formula	$C_{17}H_{17}NO_6$
Formula weight	331.31
Temperature/K	100
Crystal system	triclinic
Space group	P-1
a/Å	7.180(3)
b/Å	8.862(4)
c/Å	12.266(6)
α/°	84.056(17)
β/°	84.296(15)
γ/°	84.884(14)
Volume/Å^3	770.0(6)

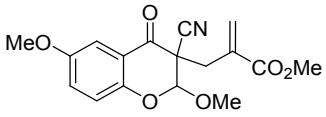
7. Analytic Data for the Products



4aaa

Methyl 2-((3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4aaa)

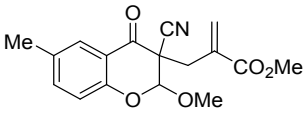
The compound was prepared according to the general procedure as off-white solid (58.4 mg, 97% yield). m.p. 84-86 °C. FTIR (KBr) 2951, 2920, 2841, 1719, 1699, 1608, 1460, 1297, 1196, 1160, 1110, 1004, 965, 765, 674 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.91 (d, *J* = 7.8 Hz, 1H), 7.63–7.59 (m, 1H), 7.16 (t, *J* = 7.6 Hz, 1H), 7.06 (dd, *J* = 8.3, 1.2 Hz, 1H), 6.49 (s, 1H), 5.90 (s, 1H), 5.37 (s, 1H), 3.71 (s, 3H), 3.51 (s, 3H), 3.12–2.95 (m, 2H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 183.9, 166.2, 155.1, 137.2, 132.8, 131.8, 127.7, 123.1, 119.0, 118.2, 115.4, 102.9, 57.0, 55.0, 52.2, 33.8. HRMS (ESI) *m/z*: $[M+H]^+$ calcd for $C_{16}H_{16}NO_5$, 302.1023; found 302.1026.



4baa

Methyl 2-((3-cyano-2,6-dimethoxy-4-oxochroman-3-yl)methyl)acrylate (4baa)

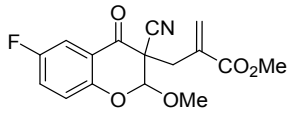
The compound was prepared according to the general procedure as off-white solid (62.3 mg, 94% yield). m.p. 101-103 °C. FTIR (KBr) 2951, 1704, 1600, 1598, 1466, 1422, 1289, 1196, 1102, 975, 830 cm^{-1}. ^1H NMR (500 MHz, Chloroform-*d*) δ 7.32 (d, *J* = 3.1 Hz, 1H), 7.19 (dd, *J* = 9.0, 3.1 Hz, 1H), 6.99 (d, *J* = 9.0 Hz, 1H), 6.48 (s, 1H), 5.90 (s, 1H), 5.32 (s, 1H), 3.82 (s, 3H), 3.72 (s, 3H), 3.49 (s, 3H), 3.11–2.96 (m, 2H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 184.04, 166.3, 155.2, 149.3, 132.8, 131.8, 125.9, 119.5, 118.9, 115.5, 108.4, 102.9, 56.9, 55.9, 54.9, 52.2, 33.9. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{17}H_{18}NO_6$, 332.1129; found 332.1132.



4caa

Methyl 2-((3-cyano-2-methoxy-6-methyl-4-oxochroman-3-yl)methyl)acrylate (4caa)

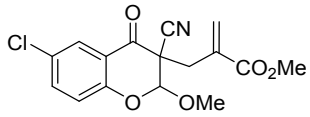
The compound was prepared according to the general procedure as off-white solid (59.9 mg, 95% yield). m.p. 98-100 °C. FTIR (KBr) 2951, 1722, 1702, 1618, 1445, 1289, 1152, 983, 825, 734 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.79 (d, *J* = 8.0 Hz, 1H), 6.98–6.86 (m, 1H), 6.86 (s, 1H), 6.48 (s, 1H), 5.90 (s, 1H), 5.34 (s, 1H), 3.71 (s, 3H), 3.51 (s, 3H), 3.10–2.93 (m, 2H), 2.41 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 183.6, 166.3, 155.1, 149.1, 132.8, 131.8, 127.6, 124.4, 118.3, 116.6, 115.6, 102.9, 57.0, 54.9, 52.2, 33.9, 22.1. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{17}H_{18}NO_5$, 316.1179; found 316.1184.



4daa

Methyl 2-((3-cyano-6-fluoro-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4daa)

The compound was prepared according to the general procedure as off-white solid (52.4 mg, 82% yield). m.p. 87-89 °C. FTIR (KBr) 2951, 1712, 1624, 1483, 1439, 1286, 1190, 1115, 998, 747 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.56 (dd, *J* = 7.9, 3.1 Hz, 1H), 7.32 (ddd, *J* = 9.0, 7.7, 3.2 Hz, 1H), 7.06 (dd, *J* = 9.0, 4.1 Hz, 1H), 6.50 (s, 1H), 5.93 (s, 1H), 5.36 (s, 1H), 3.71 (s, 3H), 3.51 (s, 3H), 3.13–2.91 (m, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 183.3, 166.2, 158.1 (d, J_{F-C} = 243.0 Hz), 151.1, 132.5, 132.1, 124.6, (d, J_{F-C} = 24.0 Hz), 120.0 (d, J_{F-C} = 7.0 Hz), 119.7 (d, J_{F-C} = 7.0 Hz), 115.2, 113.1 (d, J_{F-C} = 24.0 Hz), 103.1, 57.1, 55.0, 52.3, 33.8. ^{19}F NMR (375 MHz, $CDCl_3$) δ -118.6. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{16}H_{14}FNNaO_5^+$, 342.0748; found 342.0750.

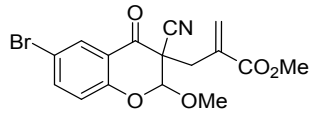


49eaa

Methyl 2-((6-chloro-3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4eaa)

The compound was prepared according to the general procedure as off-white solid (59.7 mg, 89% yield). m.p. 78-80 °C. FTIR (KBr) 2951, 1713, 1622, 1433, 1285, 1187, 1110, 997, 745 cm^{-1}. ^1H NMR (500 MHz, Chloroform-*d*) δ 7.86 (d, *J* = 2.6 Hz, 1H), 7.55 (dd, *J* = 8.8, 2.6 Hz, 1H), 7.04 (d, *J* = 8.8 Hz, 1H), 6.50 (s, 1H), 5.92 (s, 1H), 5.38 (s, 1H), 3.71 (s, 3H), 3.51 (s, 3H), 3.01 (dd, *J* = 79.1, 14.0 Hz, 2H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 183.0, 166.2, 153.4, 137.0, 132.4, 132.1, 128.8, 127.0, 119.9,

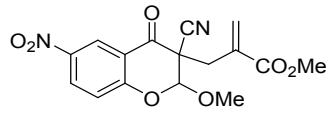
119.9, 115.1, 103.1, 57.2, 55.0, 52.3, 33.8. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{16}H_{14}ClNNaO_5^+$, 358.0453; found 358.0455.



4faa

Methyl 2-((6-bromo-3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4faa)

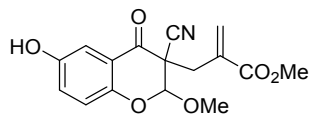
The compound was prepared according to the general procedure as off-white solid (63.1 mg, 83% yield). m.p. 97-99 °C. FTIR (KBr) 2951, 2855, 1707, 1598, 1423, 1279, 1221, 1110, 997, 975, 825 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 8.01 (d, *J* = 2.5 Hz, 1H), 7.69 (dd, *J* = 8.8, 2.5 Hz, 1H), 6.98 (d, *J* = 8.8 Hz, 1H), 6.50 (s, 1H), 5.92 (s, 1H), 5.38 (s, 1H), 3.71 (s, 3H), 3.51 (s, 3H), 3.10–2.91 (m, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 182.9, 166.2, 153.9, 139.8, 132.4, 132.2, 130.1, 120.3, 120.2, 115.9, 115.1, 103.0, 57.2, 55.0, 52.3, 33.8. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{16}H_{14}BrNNaO_5^+$, 401.9948; found 401.9951.



4gaa

Methyl 2-((3-cyano-2-methoxy-6-nitro-4-oxochroman-3-yl)methyl)acrylate (4gaa)

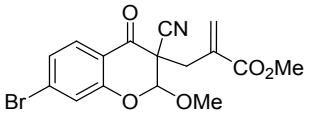
The compound was prepared according to the general procedure as off-white solid (42.2 mg, 61% yield). m.p. 112-114 °C. FTIR (KBr) 2951, 1723, 1645, 1466, 1422, 1289, 1196, 1123, 1110, 743 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 8.79 (d, *J* = 2.8 Hz, 1H), 8.47 (dd, *J* = 9.1, 2.8 Hz, 1H), 7.25 (d, *J* = 9.1 Hz, 1H), 6.53 (s, 1H), 5.99 (s, 1H), 5.50 (s, 1H), 3.71 (s, 3H), 3.56 (s, 3H), 3.01 (dd, *J* = 89.7, 13.9 Hz, 2H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 182.3, 166.2, 159.0, 143.5, 132.6, 131.9, 131.4, 124.1, 119.6, 119.2, 114.6, 103.7, 57.7, 55.4, 52.4, 33.8. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{16}H_{15}N_2O_7$, 347.0874; found 347.0478.



4haa

Methyl 2-((3-cyano-6-hydroxy-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4haa)

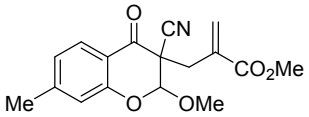
The compound was prepared according to the general procedure as off-white solid (50.8 mg, 80% yield). m.p. 62-64 °C. FTIR (KBr) 3434, 2956, 2915, 1697, 1511, 1251, 1189, 1091, 999, 962, 825, 752 cm^{-1}. ^1H NMR (500 MHz, Chloroform-*d*) δ 7.31 (d, *J* = 3.1 Hz, 1H), 7.13 (dd, *J* = 8.9, 3.1 Hz, 1H), 6.96 (d, *J* = 8.9 Hz, 1H), 6.49 (s, 1H), 5.91 (s, 1H), 5.62 (s, 1H), 5.32 (s, 1H), 3.72 (s, 3H), 3.49 (s, 3H), 3.03 (dd, *J* = 88.9, 14.0 Hz, 2H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 184.2, 166.5, 151.5, 149.0, 132.7, 132.1, 125.5, 119.5, 119.1, 115.5, 112.0, 102.9, 56.9, 55.1, 52.4, 33.9. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{16}H_{15}NNaO_6^+$, 340.0792; found 340.0793.



4iaa

Methyl 2-((7-bromo-3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4iaa)

The compound was prepared according to the general procedure as off-white solid (65.4 mg, 86% yield). m.p. 111-113 °C. FTIR (KBr) 2956, 2857, 1704, 1596, 1416, 1281, 1229, 1105, 996, 970, 820 cm^{-1}. ^1H NMR (500 MHz, Chloroform-*d*) δ 7.77 (d, *J* = 8.4 Hz, 1H), 7.32–7.27 (m, 2H), 6.50 (s, 1H), 5.92 (s, 1H), 5.38 (s, 1H), 3.71 (s, 3H), 3.53 (s, 3H), 3.09 (d, *J* = 13.9 Hz, 1H), 2.92 (d, *J* = 14.0 Hz, 1H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 183.2, 166.2, 155.3, 132.4, 132.1, 131.6, 128.9, 126.8, 121.5, 118.0, 115.1, 103.3, 57.3, 55.1, 52.3, 33.8. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $[M+Na]^+$ calcd for $C_{16}H_{14}BrNNaO_5^+$, 401.9948; found 401.9951.

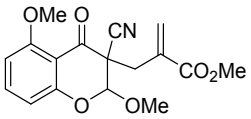


4jaa

Methyl 2-((3-cyano-2-methoxy-7-methyl-4-oxochroman-3-yl)methyl)acrylate (4jaa)

The compound was prepared according to the general procedure as off-white solid (60.5 mg, 96% yield). m.p. 78-80 °C. FTIR (KBr) 2951, 1721, 1708, 1615, 1440, 1331, 1278, 1112, 985, 826, 735 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.70 (d, *J* = 1.7 Hz, 1H), 7.41 (dd, *J* = 8.4, 2.2 Hz, 1H), 6.96 (d, *J* = 8.4 Hz, 1H), 6.48 (s, 1H), 5.89 (s, 1H), 5.34 (s, 1H), 3.72 (s, 3H), 3.49 (s, 3H), 3.10–2.95 (m, 2H), 2.35 (s, 3H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 184.1, 166.3, 153.0, 138.2, 132.8, 132.8,

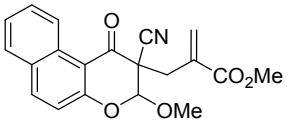
131.8, 127.3, 118.5, 118.0, 115.5, 102.8, 56.9, 55.0, 52.2, 33.8, 20.5. HRMS (ESI) m/z: $[M+Na]^+$ calcd for $C_{17}H_{17}NNaO_5^+$, 338.0999; found 338.1002.



4kaa

Methyl 2-((3-cyano-2,5-dimethoxy-4-oxochroman-3-yl)methyl)acrylate (4kaa)

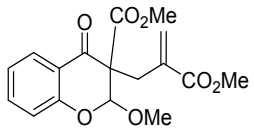
The compound was prepared according to the general procedure as off-white solid (63.6 mg, 96% yield). m.p. 85-87 °C. FTIR (KBr) 2951, 1712, 1606, 1587, 1455, 1410, 1232, 1167, 1101, 965, 823 cm^{-1}. ^1H NMR (500 MHz, Chloroform-*d*) δ 7.49 (t, *J* = 8.4 Hz, 1H), 6.66–6.63 (m, 2H), 6.47 (s, 1H), 5.90 (s, 1H), 5.29 (s, 1H), 3.92 (s, 3H), 3.73 (s, 3H), 3.51 (s, 3H), 3.07–2.95 (m, 2H). $^{13}C\{^1H\}$ NMR (126 MHz, $CDCl_3$) δ 181.7, 166.4, 161.2 156.8 137.2 133.1 131.6 115.6, 110.0, 108.9, 105.7, 102.2, 57.0, 56.2, 55.9, 52.2, 33.8. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{17}H_{18}NO_6$, 332.1129; found 332.1134.



4laa

Methyl 2-((2-cyano-3-methoxy-1-oxo-2,3-dihydro-1H-benzo[f]chromen-2-yl)methyl)-acrylate (4laa)

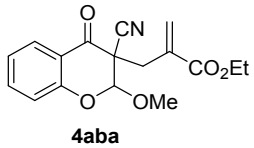
The compound was prepared according to the general procedure as off-white solid (62.5 mg, 89% yield). m.p. 101-103 °C. FTIR (KBr) 2945, 2852, 1717, 1689, 1590, 1512, 1434, 1349, 1200, 1115, 1007, 809, 749, 503 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 9.26 (d, *J* = 8.6 Hz, 1H), 8.06 (d, *J* = 8.9 Hz, 1H), 7.80 (d, *J* = 7.9 Hz, 1H), 7.66 (ddd, *J* = 8.5, 7.0, 1.3 Hz, 1H), 7.50–7.46 (m, 1H), 7.17 (d, *J* = 8.9 Hz, 1H), 6.47 (s, 1H), 5.89 (s, 1H), 5.43 (s, 1H), 3.56 (d, *J* = 7.4 Hz, 6H), 3.19–3.02 (m, 2H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 184.8, 166.3, 157.3, 138.9, 133.0, 131.7, 131.1, 130.3, 129.8, 128.6, 125.6, 125.5, 118.1, 115.6, 110.7, 102.9, 57.2, 56.1, 52.2, 34.2. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{20}H_{18}NO_5$, 352.1179; found 352.1182.



4maa

Methyl 2-methoxy-3-(2-(methoxycarbonyl)allyl)-4-oxochromane-3-carboxylate (4maa)

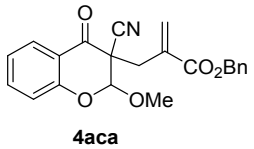
The compound was prepared according to the general procedure as off-white solid (54.8 mg, 82% yield). m.p. 107-109 °C. FTIR (KBr) 3532, 2950, 2841, 1725, 1691, 1610, 1462, 1437, 1299, 1195, 1154, 1086, 996, 757 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.91 (dd, *J* = 7.8, 1.6 Hz, 1H), 7.55–7.51 (m, 1H), 7.12–7.08 (m, 1H), 7.02–7.00 (m, 1H), 6.20 (d, *J* = 1.0 Hz, 1H), 5.62 (m, 1H), 5.33 (s, 1H), 3.75 (s, 3H), 3.65 (s, 3H), 3.45 (s, 3H), 3.25–3.06 (m, 2H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 187.8, 168.4, 166.9, 155.8, 136.1, 134.6, 129.7, 127.3, 122.5, 121.4, 118.0, 104.1, 61.6, 56.8, 52.6, 51.8, 33.8. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{17}H_{19}O_7$, 335.1125; found 335.1128.



4aba

Ethyl 2-((3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4aba)

The compound was prepared according to the general procedure as off-white solid (62.4 mg, 99% yield). m.p. 85-87 °C. FTIR (KBr) 2961, 1712, 1464, 1294, 1166, 1113, 989, 946, 757 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.91 (dd, *J* = 7.9, 1.7 Hz, 1H), 7.63–7.58 (m, 1H), 7.18–7.14 (m, 1H), 7.07–7.05 (m, 1H), 6.48 (s, 1H), 5.89 (s, 1H), 5.37 (s, 1H), 4.26–4.09 (m, 2H), 3.51 (s, 3H), 3.11–2.95 (m, 2H), 1.26 (t, *J* = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 183.9, 165.8, 155.1, 137.2, 133.0, 131.5, 127.7, 123.1, 119.0, 118.2, 115.5, 102.9, 61.3, 57.0, 55.1, 33.7, 14.0. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{17}H_{18}NO_5$, 316.1179; found 316.1183.

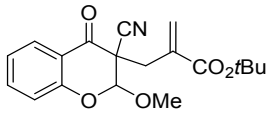


4aca

Benzyl 2-((3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4aca)

The compound was prepared according to the general procedure as off-white solid (74.7 mg, 99% yield). m.p. 99-101 °C. FTIR (KBr) 2940, 1720, 1699, 1605, 1460, 1296, 1167, 1091, 993, 962, 768,

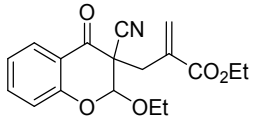
703 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.87 (dd, *J* = 7.9, 1.7 Hz, 1H), 7.60–7.56 (m, 1H), 7.34 (q, *J* = 4.9 Hz, 5H), 7.14–7.10 (m, 1H), 7.03–7.00 (m, 1H), 6.52 (s, 1H), 5.92 (s, 1H), 5.34 (s, 1H), 5.24–5.09 (m, 2H), 3.47 (s, 3H), 3.12–2.96 (m, 2H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 183.9, 165.7, 155.1, 137.2, 135.5, 132.8, 132.1, 128.5, 128.3, 128.2, 127.7, 123.1, 119.0, 118.1, 115.5, 102.8, 67.0, 57.0, 55.1, 33.7. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{22}H_{20}NO_5$, 378.1336; found 378.1339.



4ada

***tert*-Butyl 2-((3-cyano-2-methoxy-4-oxochroman-3-yl)methyl)acrylate (4ada)**

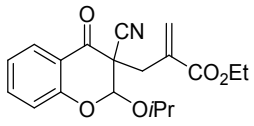
The compound was prepared according to the general procedure as off-white solid (61.8 mg, 90% yield). m.p. 89-91 °C. FTIR (KBr) 2982, 2945, 1706, 1611, 1466, 1297, 1157, 1115, 996, 768, 737 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.90 (dd, *J* = 7.9, 1.7 Hz, 1H), 7.60 (ddd, *J* = 8.4, 7.3, 1.7 Hz, 1H), 7.17–7.13 (m, 1H), 7.06–7.04 (m, 1H), 6.38 (d, *J* = 0.7 Hz, 1H), 5.81-5.80 (m, 1H), 5.37 (s, 1H), 3.50 (s, 3H), 3.10–3.07 (m, 1H), 2.92–2.89 (m, 1H), 1.46 (s, 9H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 184.0, 164.9, 155.1, 137.1, 134.3, 130.6, 127.7, 123.1, 119.1, 118.2, 115.6, 102.9, 81.7, 57.0, 55.2, 33.6, 27.8. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{19}H_{22}NO_5$, 344.1492; found 344.1495.



4abb

Ethyl 2-((3-cyano-2-ethoxy-4-oxochroman-3-yl)methyl)acrylate (4abb)

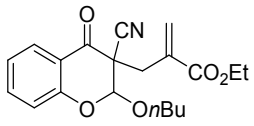
The compound was prepared according to the general procedure as off-white solid (62.6 mg, 95% yield). m.p. 88-90 °C. FTIR (KBr) 2960, 1708, 1464, 1292, 1170, 1115, 989, 947, 757, 736 cm^{-1}. ^1H NMR (400 MHz, Chloroform-*d*) δ 7.91 (dd, *J* = 7.9, 1.7 Hz, 1H), 7.59 (ddd, *J* = 8.8, 7.4, 1.7 Hz, 1H), 7.17–7.13 (m, 1H), 7.04–7.02 (m, 1H), 6.48 (s, 1H), 5.89 (s, 1H), 5.47 (s, 1H), 4.26–4.09 (m, 2H), 3.78 (ddq, *J* = 40.8, 9.8, 7.1 Hz, 2H), 3.11–3.07 (m, 2H), 1.25 (t, *J* = 7.1 Hz, 3H), 1.16 (t, *J* = 7.1 Hz, 3H). $^{13}C\{^1H\}$ NMR (101 MHz, $CDCl_3$) δ 184.1, 165.8, 155.3, 137.1, 133.1, 131.5, 127.7, 122.9, 119.0, 118.1, 115.6, 101.8, 65.9, 61.3, 55.3, 33.7, 14.5, 14.0. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{18}H_{20}NO_5$, 330.1336; found 330.1338.



4abc

Ethyl 2-((3-cyano-2-isopropoxy-4-oxochroman-3-yl)methyl)acrylate (4abc)

The compound was prepared according to the general procedure as off-white solid (59.8 mg, 87% yield). m.p. 93-95 °C. FTIR (KBr) 2961, 1706, 1611, 1465, 1180, 1111, 990, 764 cm^{-1}. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.90 (dd, *J* = 7.8, 1.7 Hz, 1H), 7.58 (ddd, *J* = 8.8, 7.4, 1.7 Hz, 1H), 7.15–7.11 (m, 1H), 7.00 (d, *J* = 8.3 Hz, 1H), 6.47 (s, 1H), 5.88 (s, 1H), 5.54 (s, 1H), 4.25–4.02 (m, 3H), 3.10–2.93 (m, 2H), 1.27–1.22 (m, 6H), 1.06 (d, *J* = 6.2 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 184.3, 165.8, 155.5, 137.0, 133.2, 131.4, 127.6, 122.8, 119.0, 118.1, 115.7, 100.9, 73.4, 61.3, 55.7, 33.8, 22.7, 21.4, 14.0. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{19}H_{22}NO_5$, 344.1492; found 344.1495.



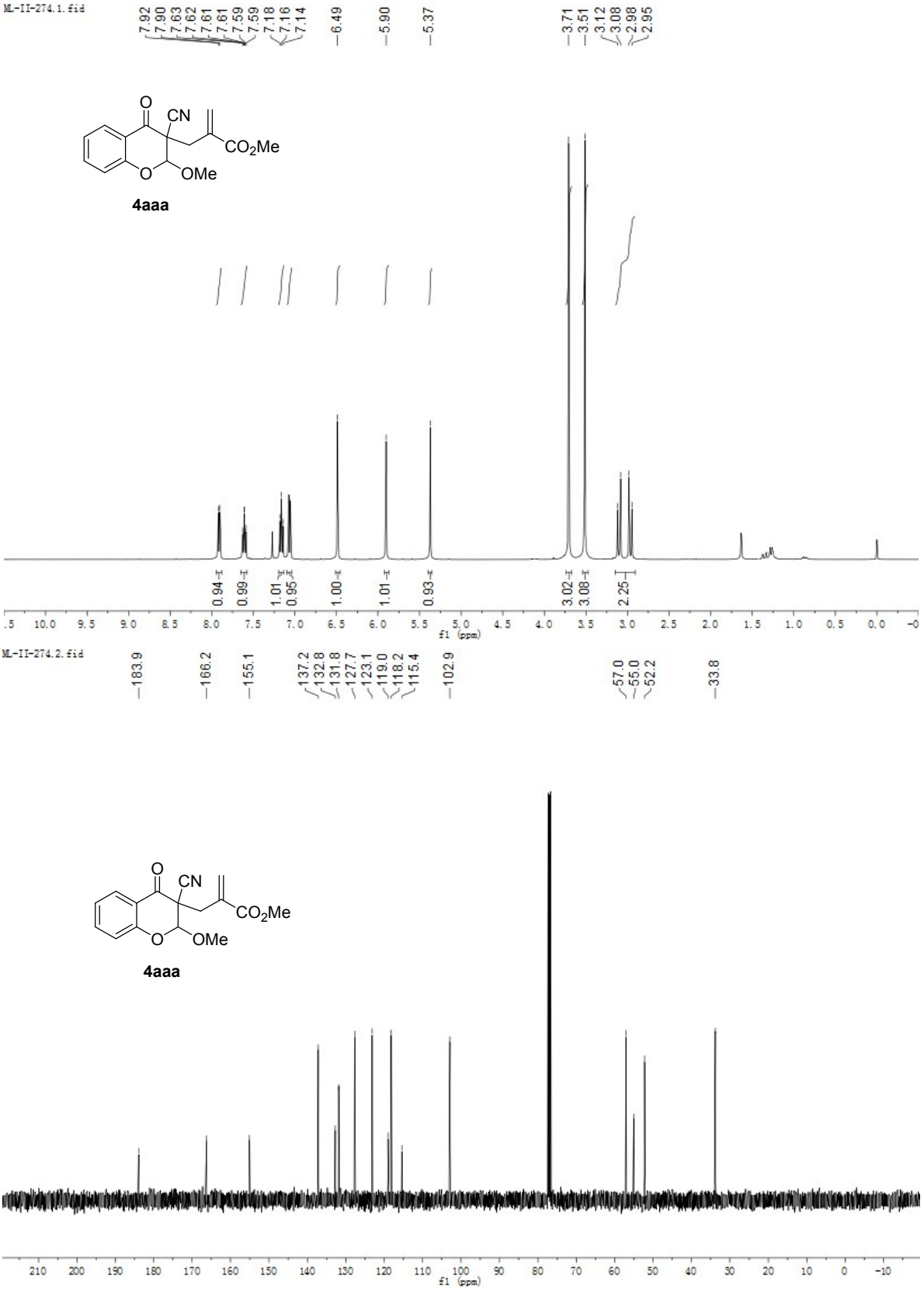
4abd

Ethyl 2-((2-butoxy-3-cyano-4-oxochroman-3-yl)methyl)acrylate (4abd)

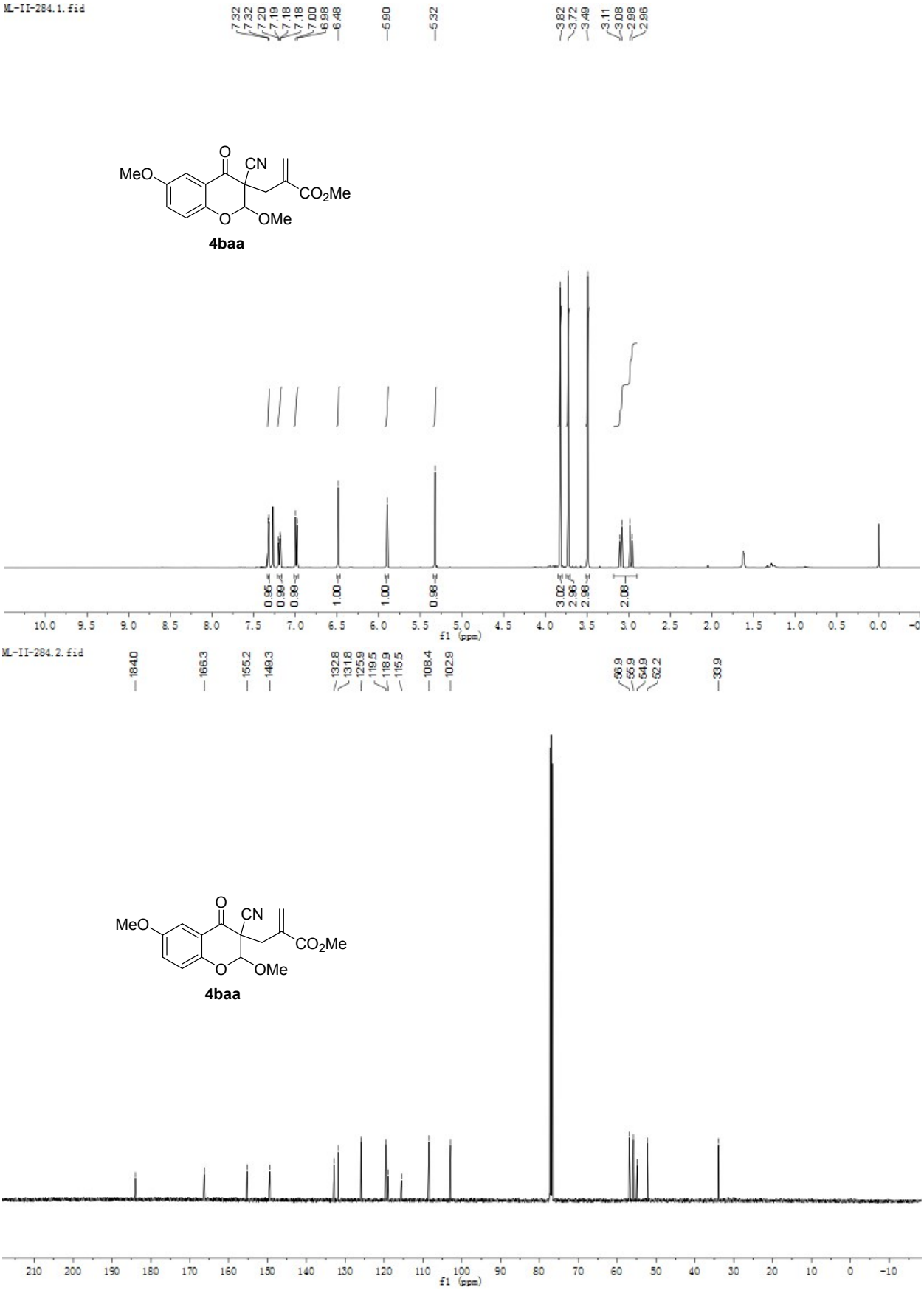
The compound was prepared according to the general procedure as off-white solid (65.7 mg, 92% yield). m.p. 96-98 °C. FTIR (KBr) 2961, 2873, 1704, 1608, 1463, 1297, 1177, 1110, 991, 770 cm^{-1}. ^{1}H NMR (400 MHz, Chloroform-*d*) δ 7.92 (dd, *J* = 7.8, 1.7 Hz, 1H), 7.60 (ddd, *J* = 8.7, 7.4, 1.7 Hz, 1H), 7.18–7.14 (m, 1H), 7.04 (d, *J* = 8.2 Hz, 1H), 6.49 (s, 1H), 5.90 (s, 1H), 5.47 (s, 1H), 4.27–4.10 (m, 2H), 3.73 (ddt, *J* = 43.3, 9.6, 6.4 Hz, 2H), 3.12–2.95 (m, 2H), 1.55–1.47 (m, 2H), 1.27 (t, *J* = 7.1 Hz, 5H), 0.81 (t, *J* = 7.4 Hz, 3H). $^{13}C\{^{1}H\}$ NMR (101 MHz, $CDCl_3$) δ 184.2, 165.8, 155.3, 137.0, 133.1, 131.5, 127.6, 122.9, 119.0, 118.1, 115.5, 101.9, 69.9, 61.3, 55.3, 33.7, 31.0, 18.8, 14.0, 13.5. HRMS (ESI) m/z: $[M+H]^+$ calcd for $C_{20}H_{24}NO_5$, 358.1649; found 358.1651.

8. ^{1}H NMR, $^{13}C\{^{1}H\}$ NMR spectra of Products

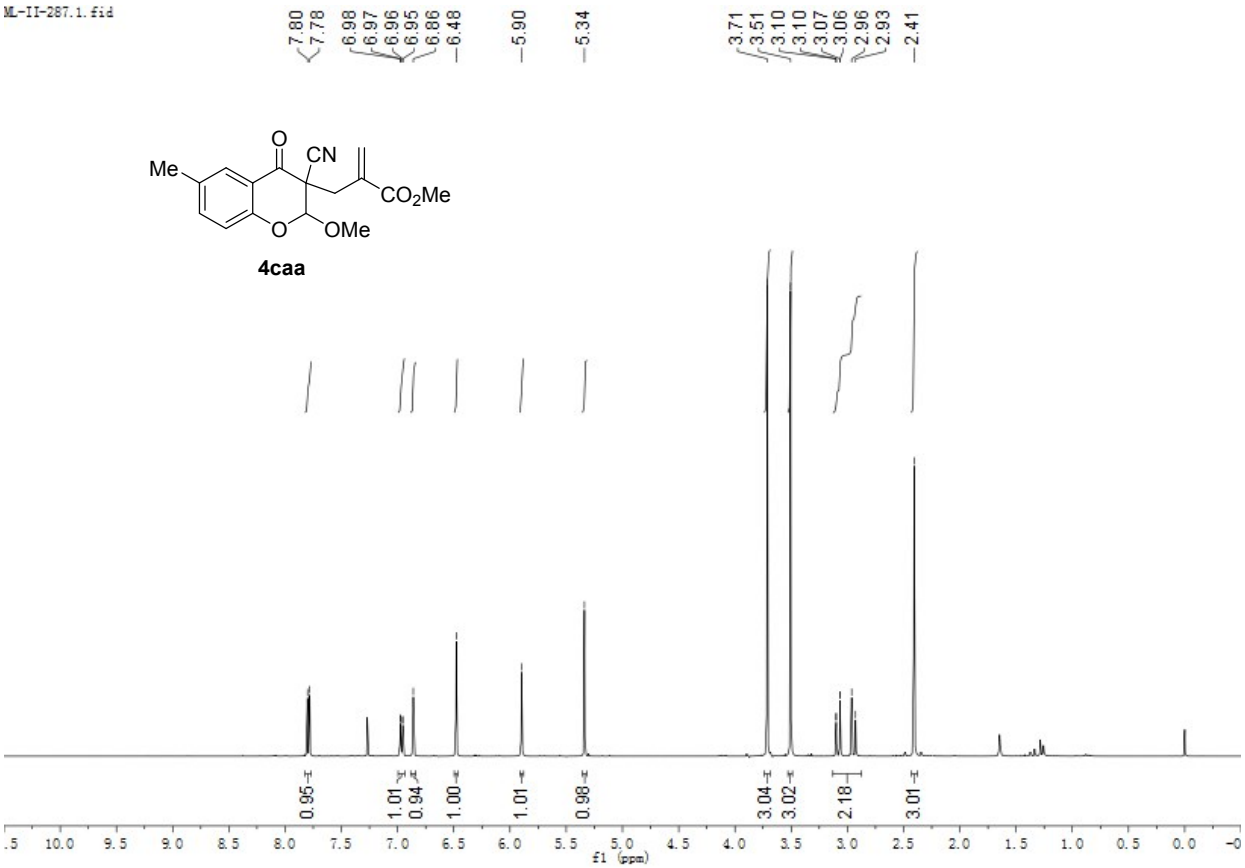
^{1}H, ^{13}C NMR spectra of **4aaa**

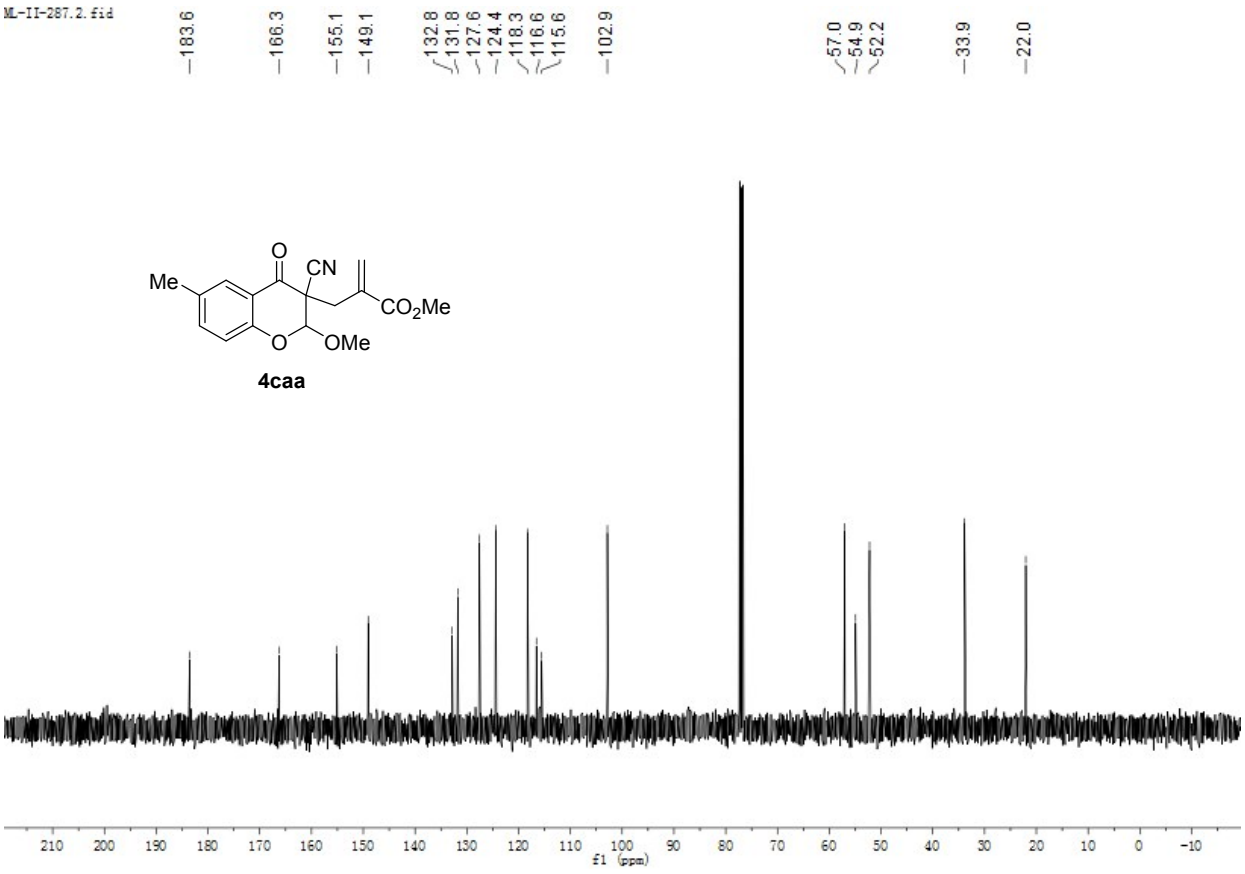


^{1}H, ^{13}C NMR spectra of **4baa**

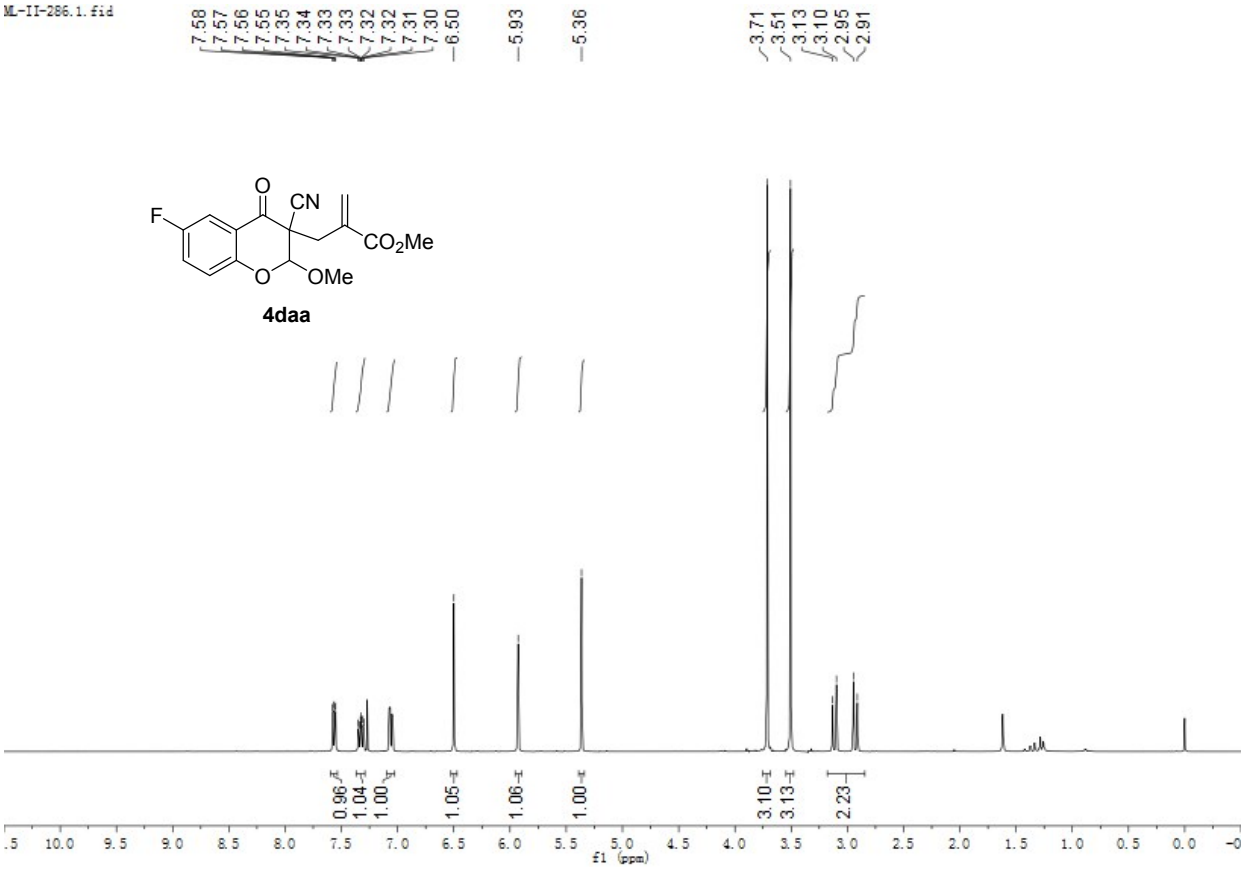


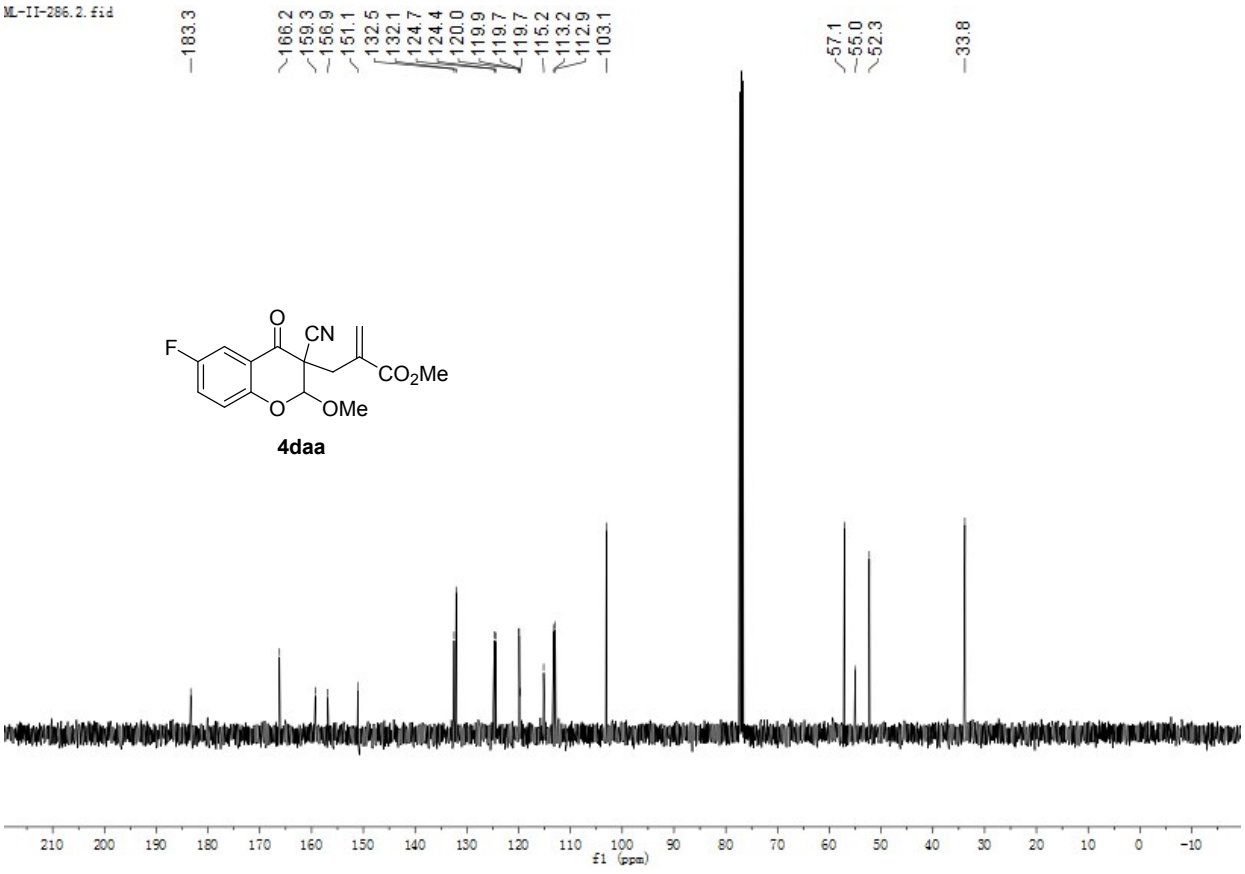
^{1}H, ^{13}C NMR spectra of **4caa**





^{1}H, ^{13}C, ^{19}F NMR spectra of **4daa**





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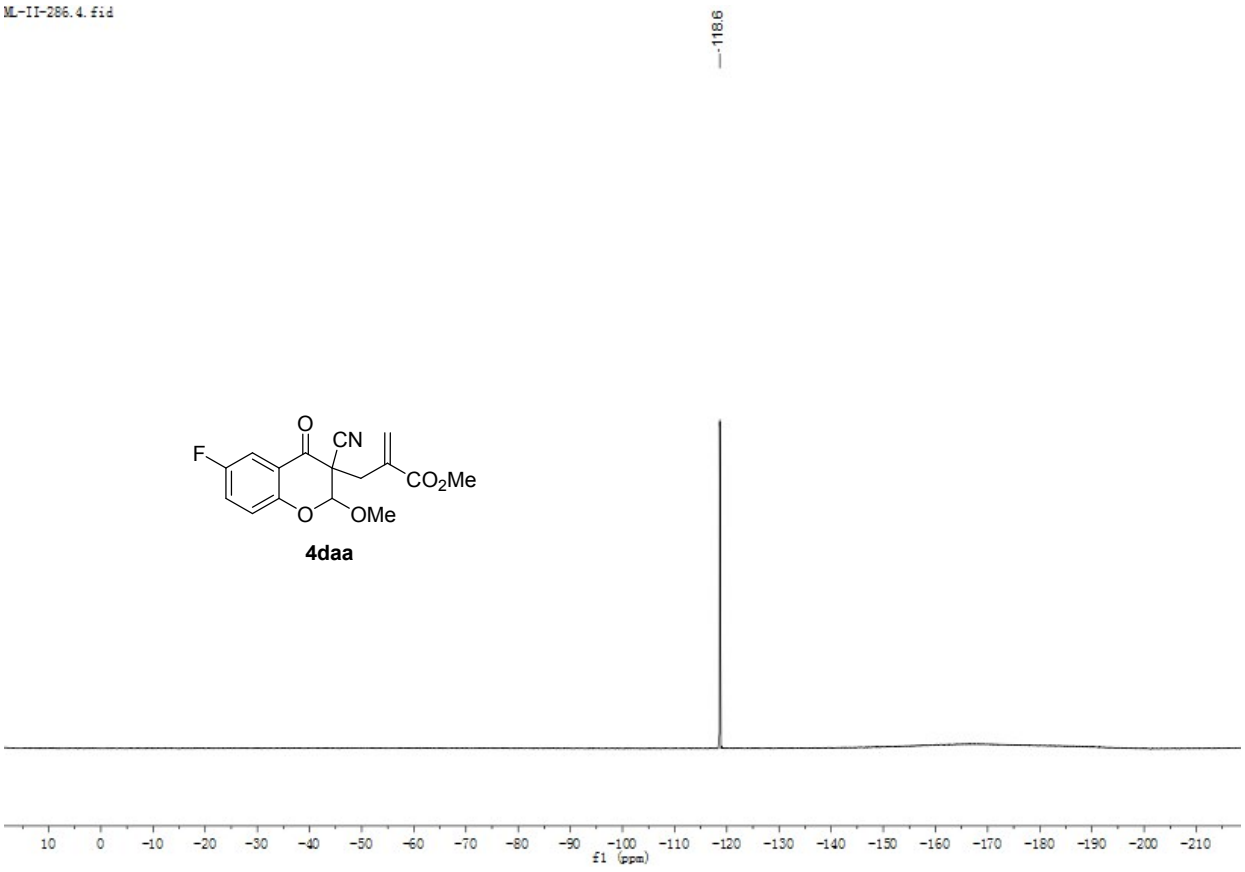
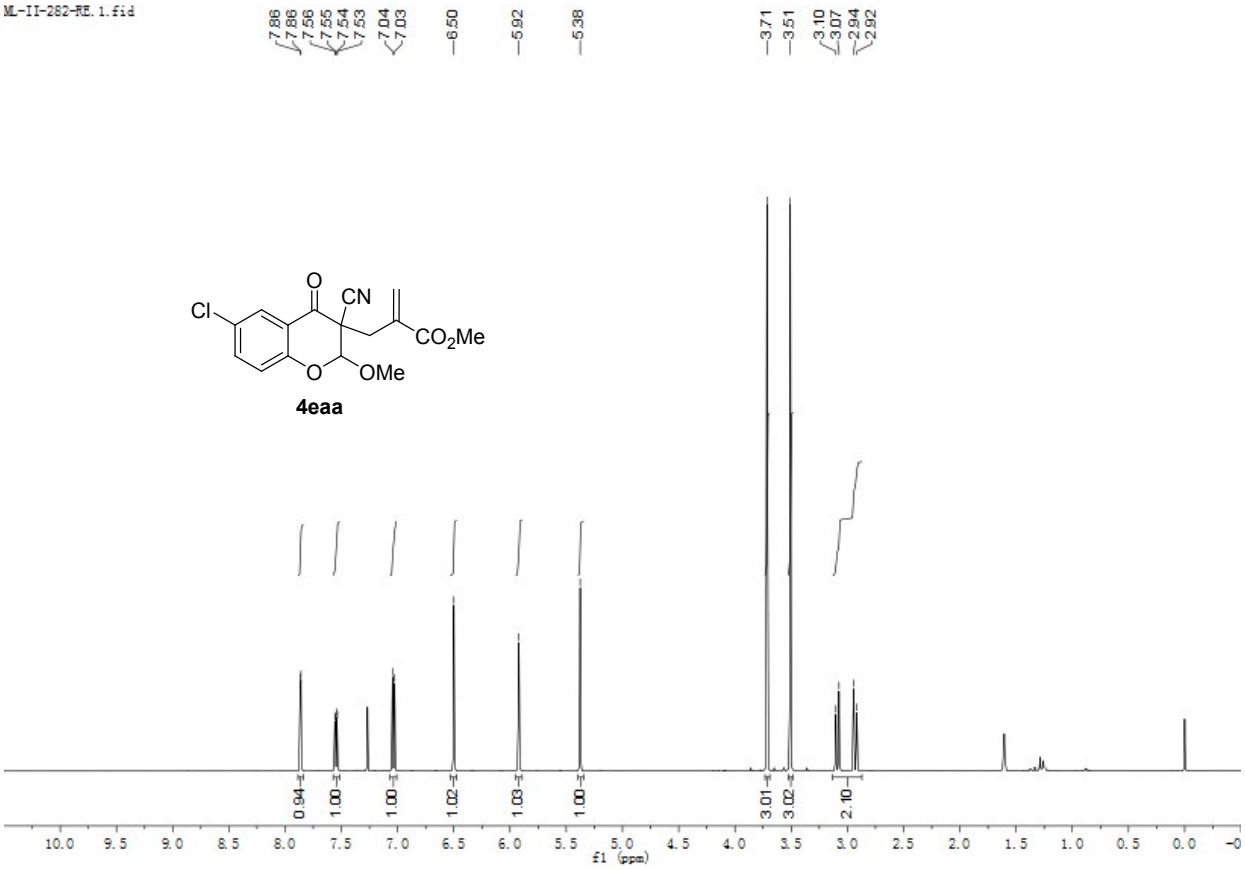
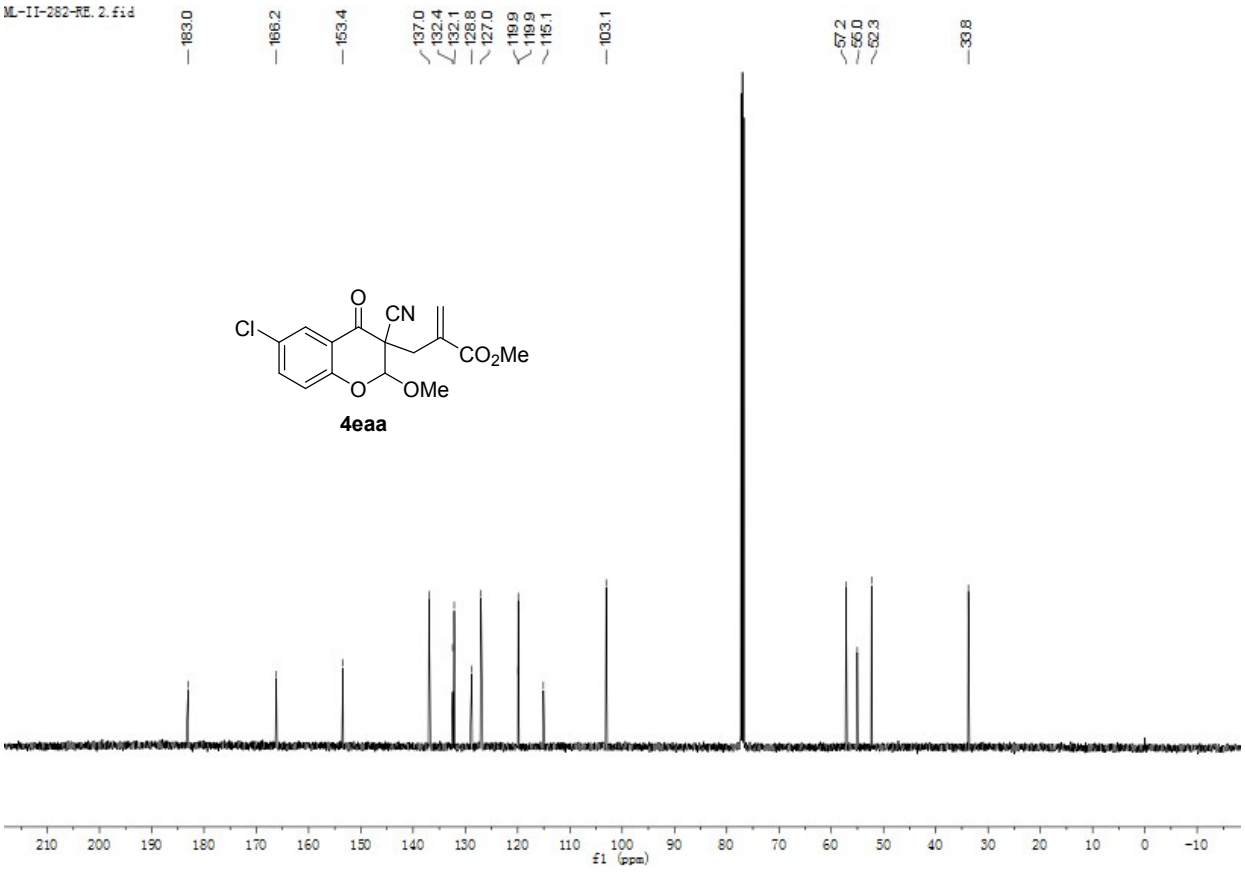


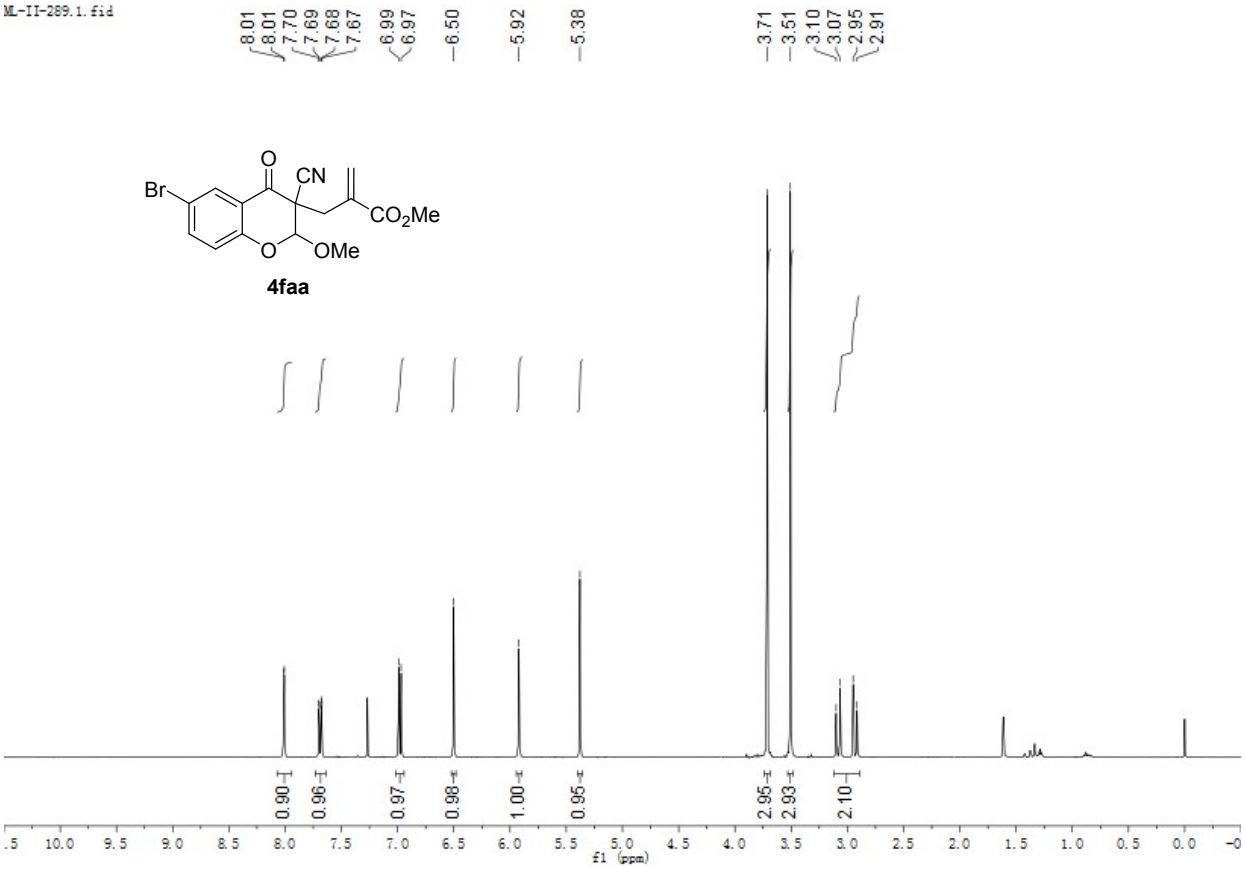
4daa

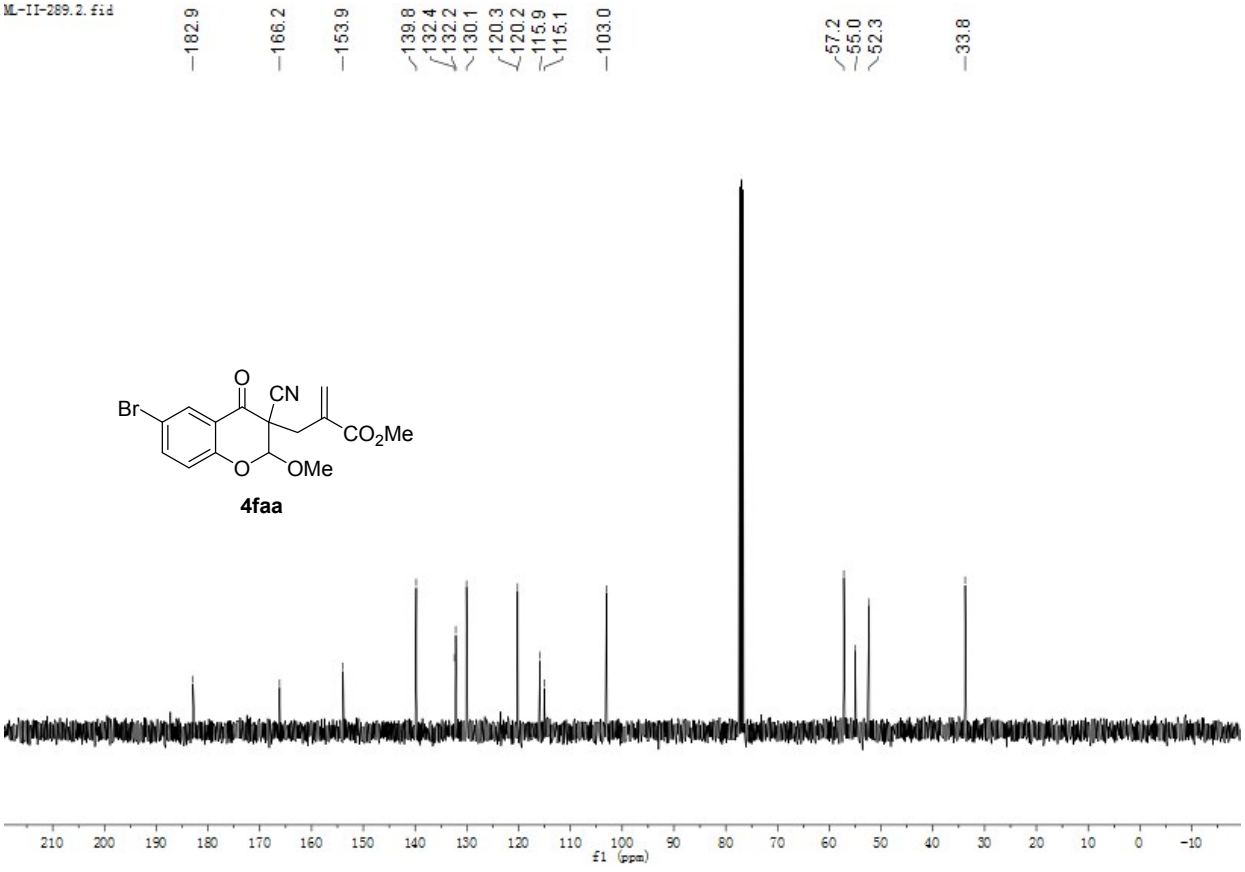
^{1}H, ^{13}C NMR spectra of **4eaa**



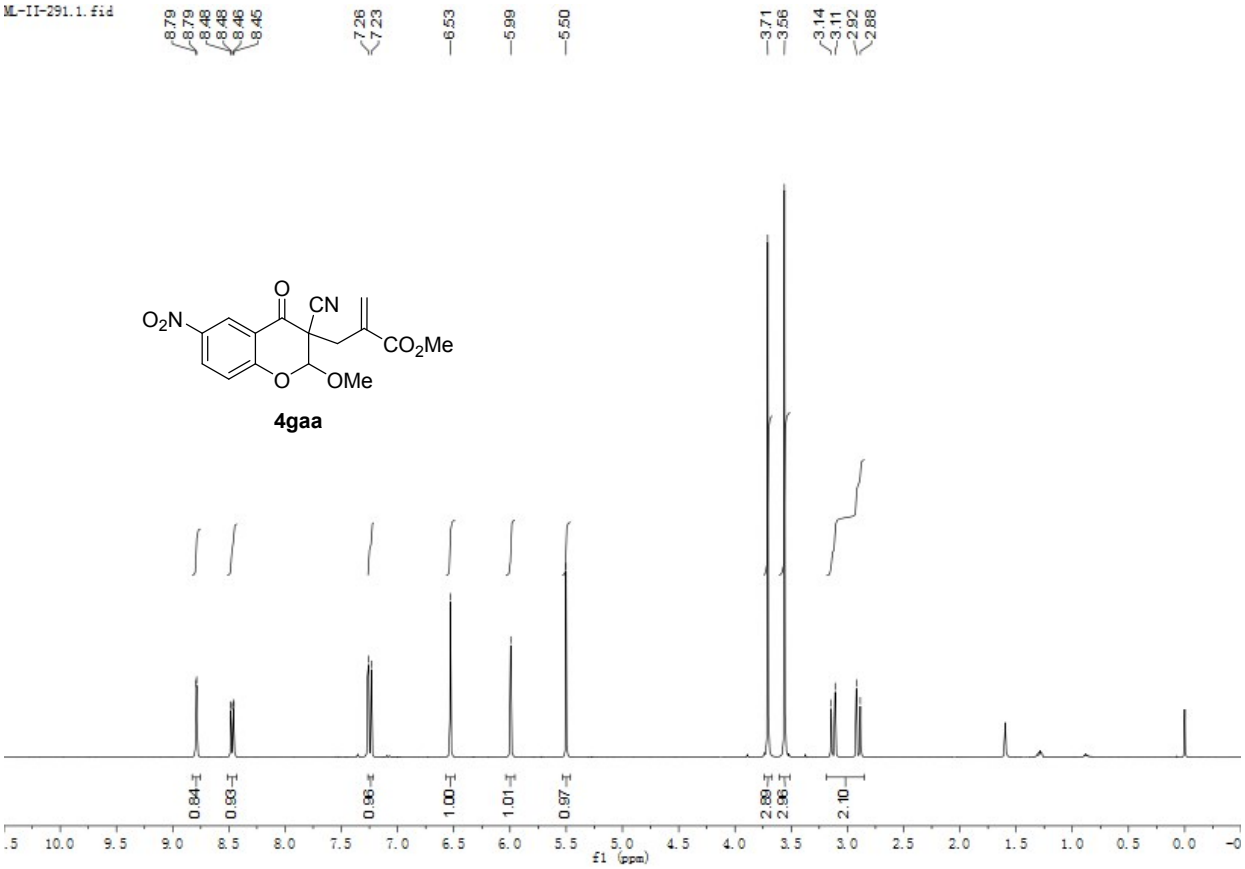


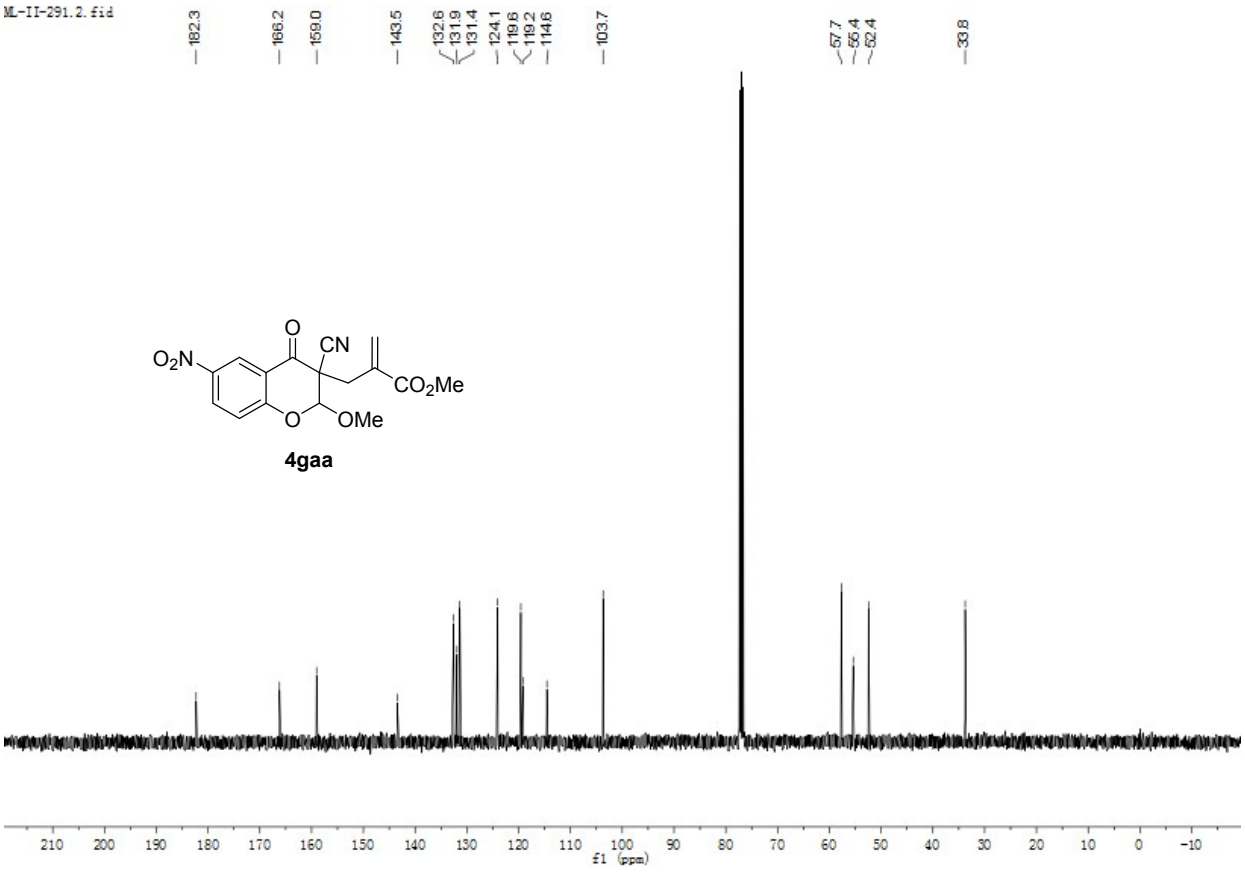
^{1}H, ^{13}C NMR spectra of **4faa**



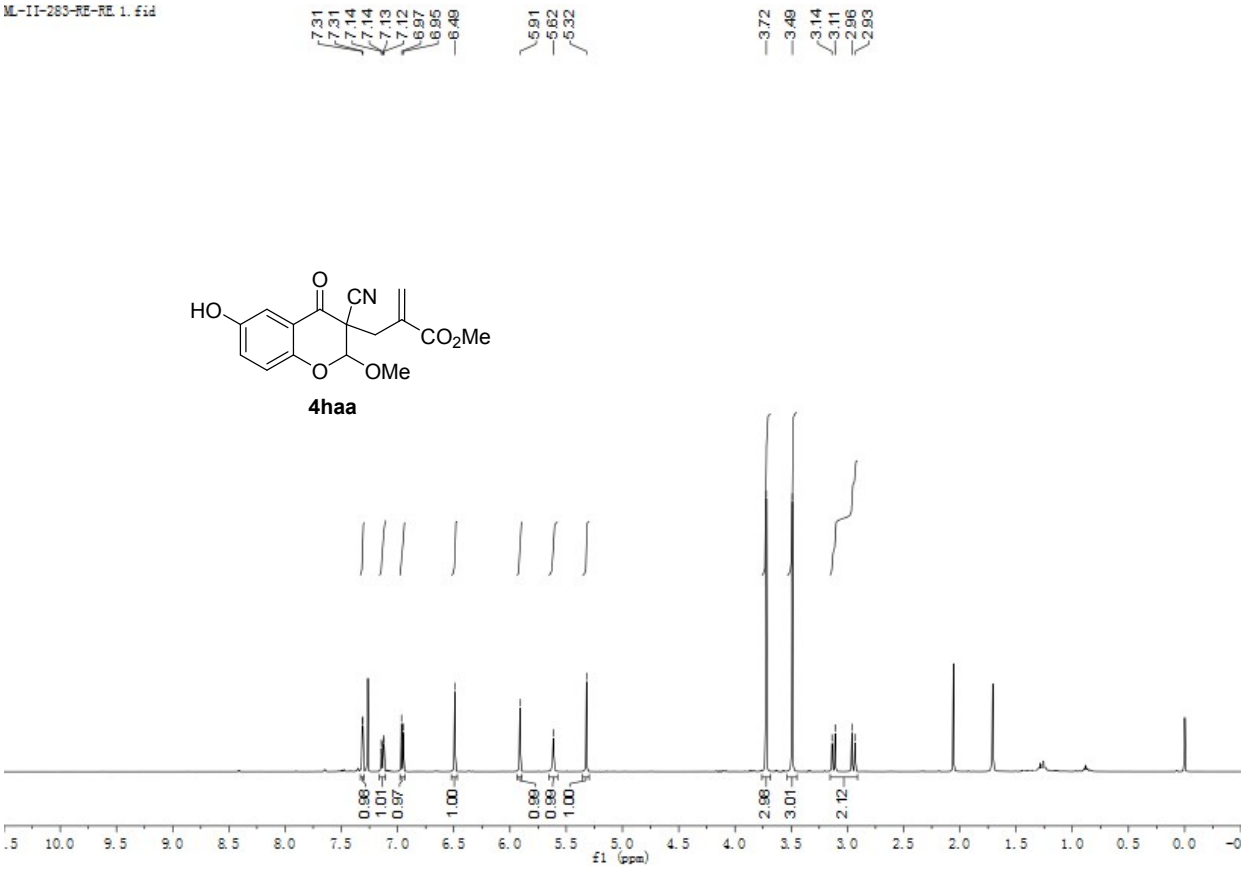


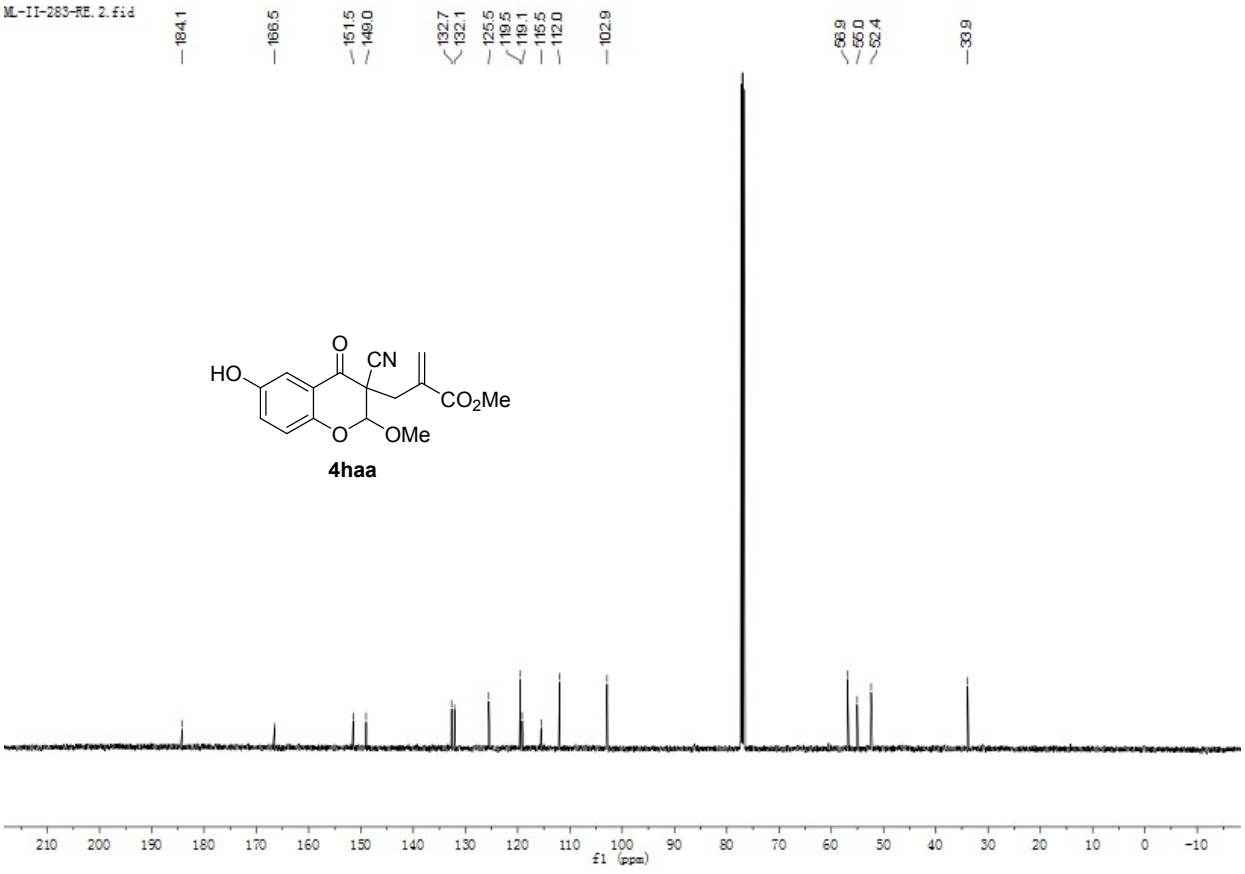
^{1}H, ^{13}C NMR spectra of **4gaa**



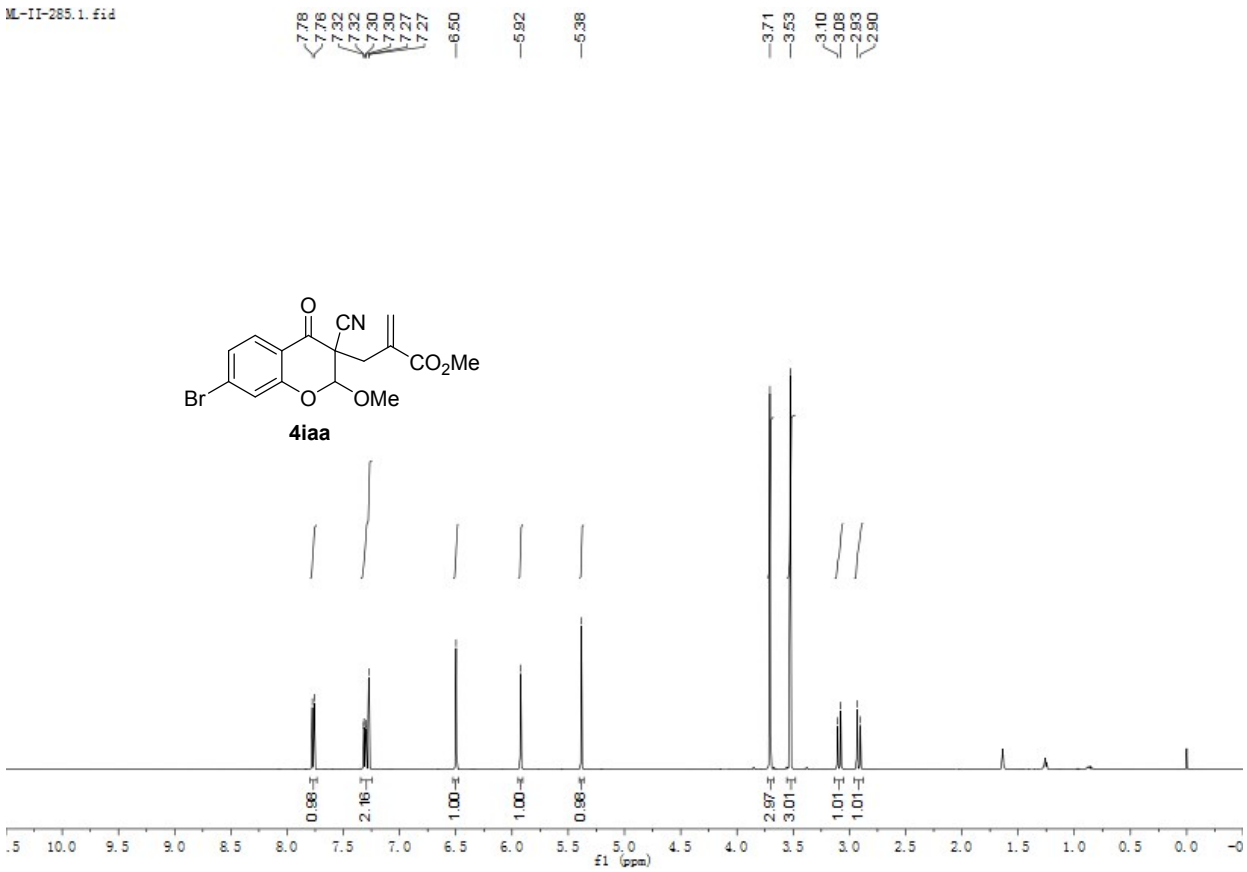


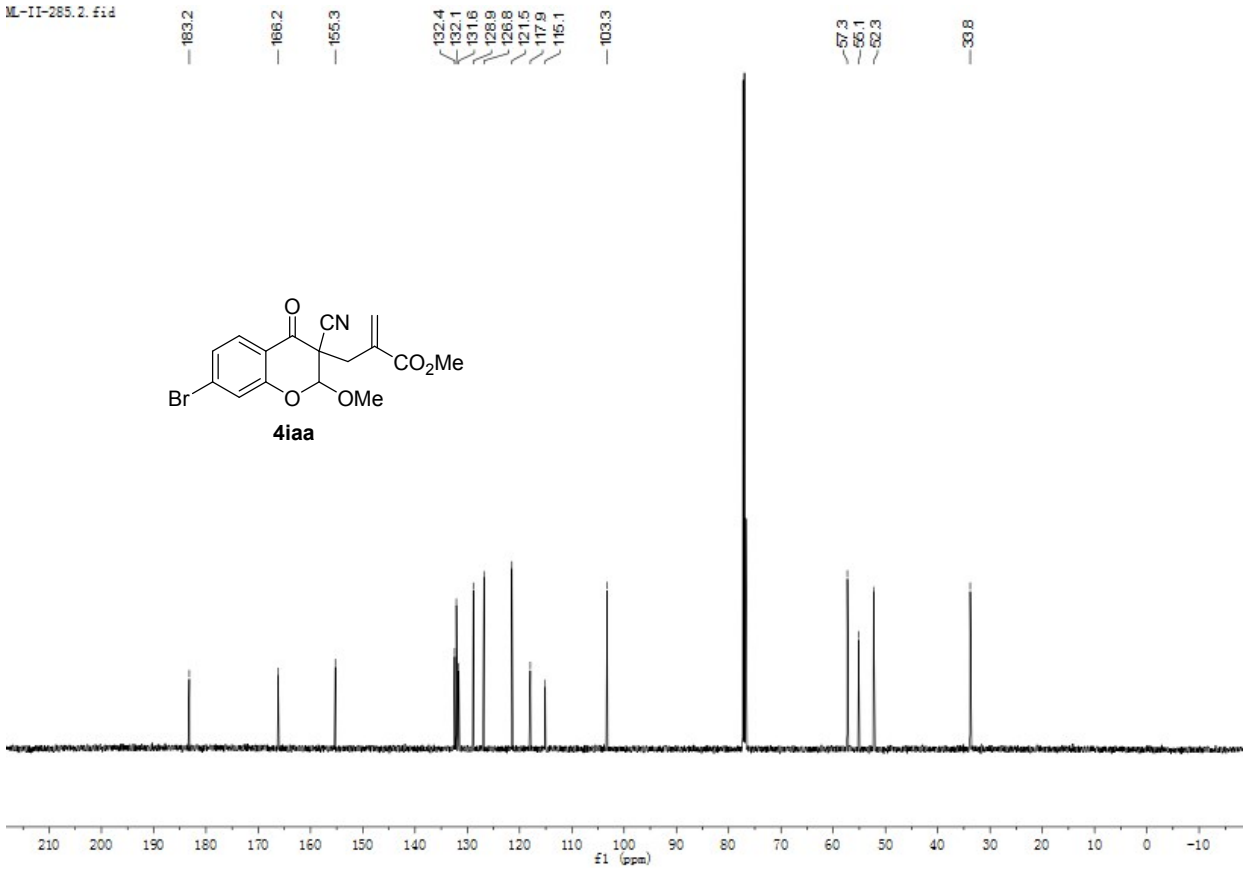
^{1}H, ^{13}C NMR spectra of **4haa**



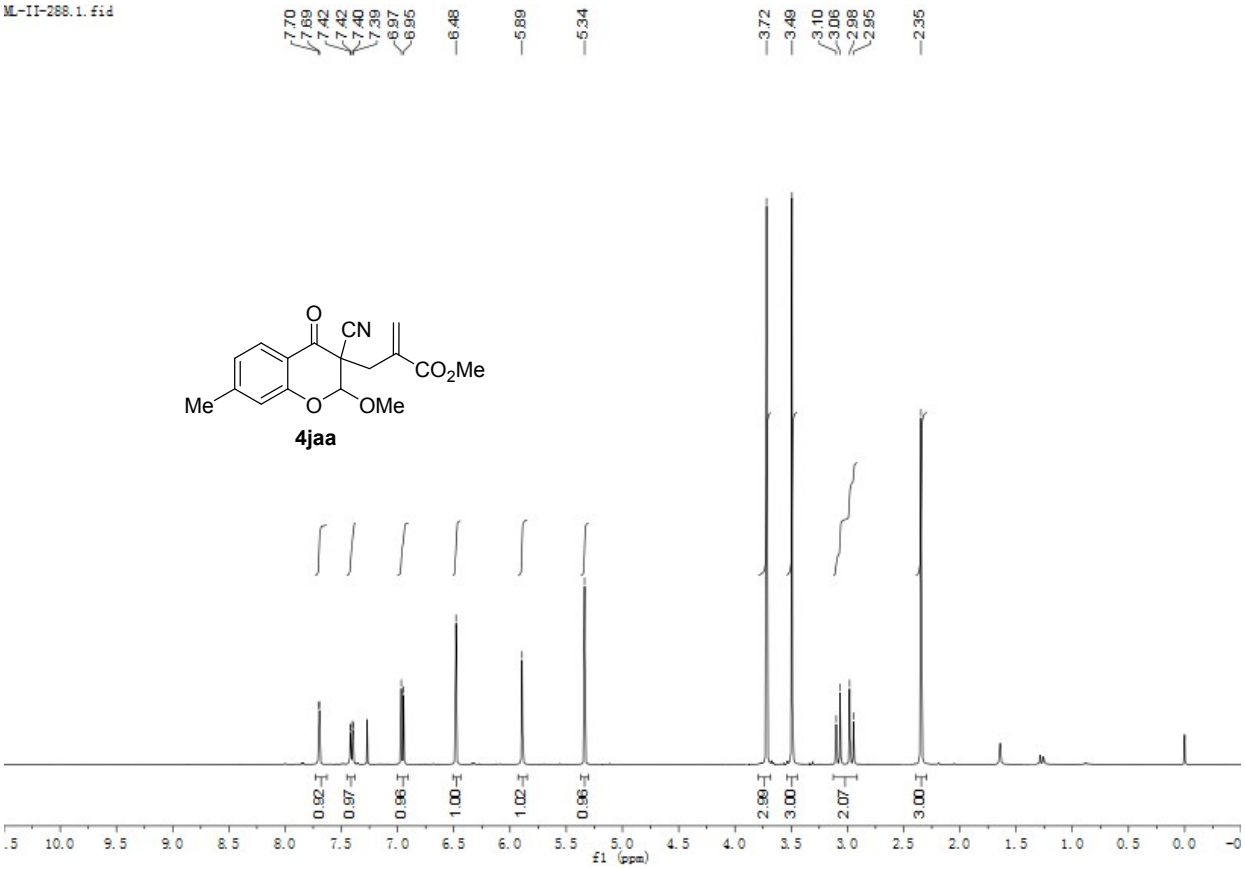


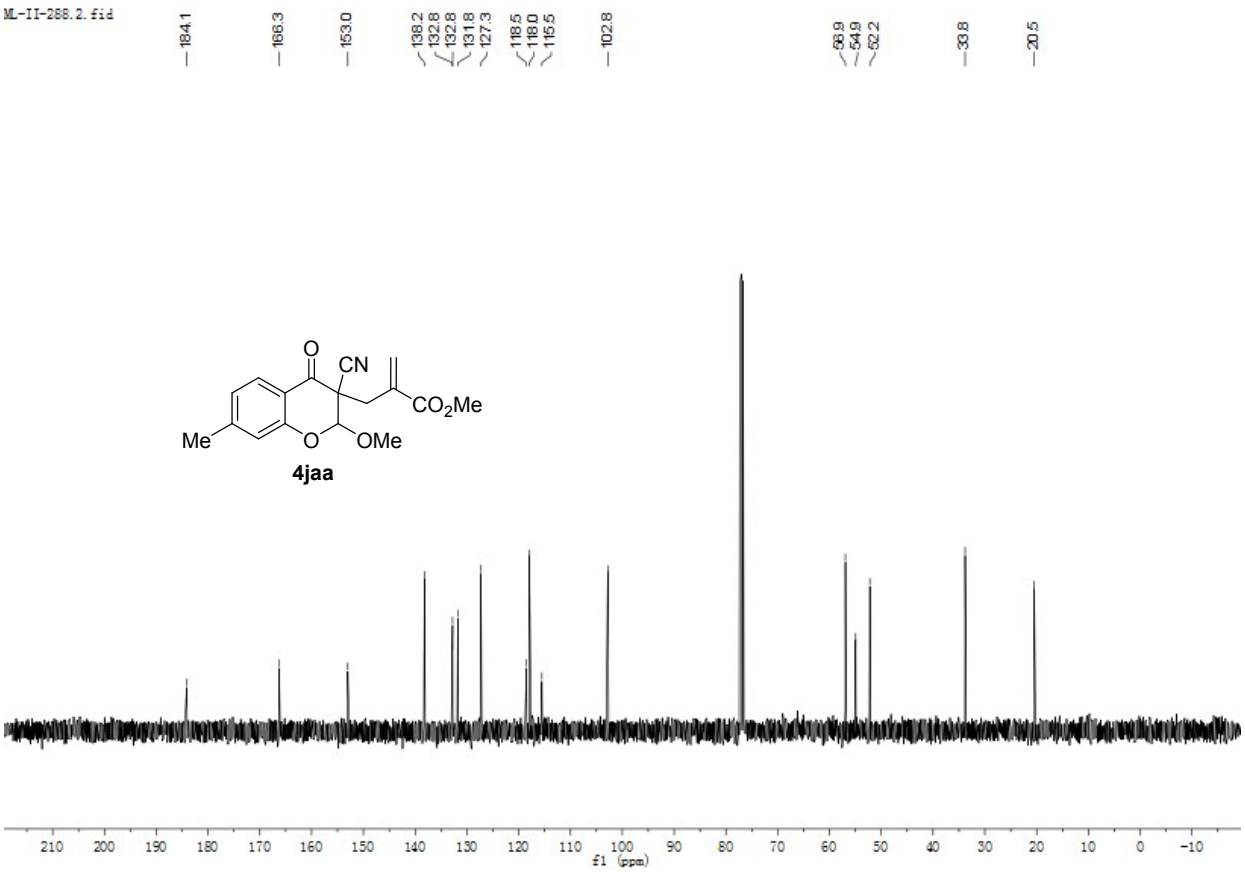
^{1}H, ^{13}C NMR spectra of **4iaa**



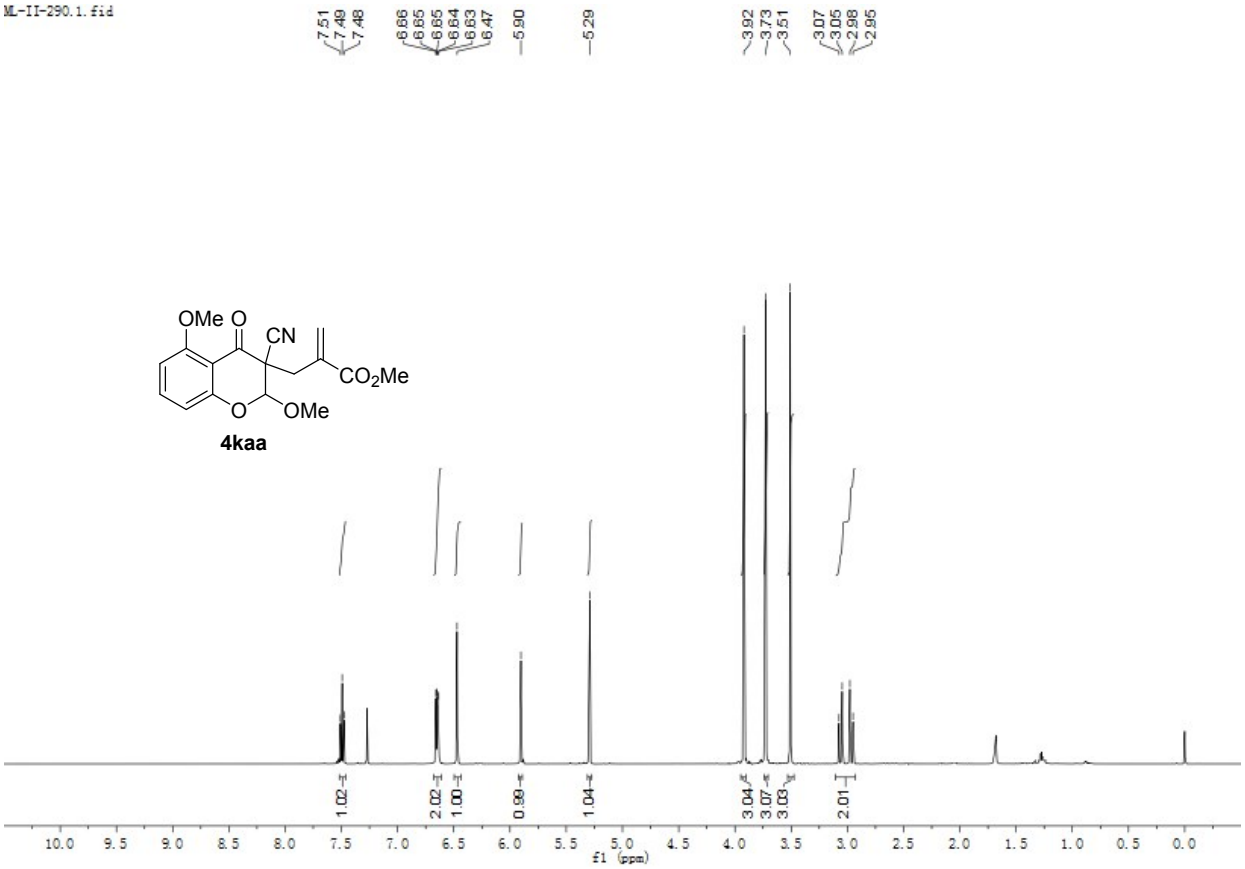


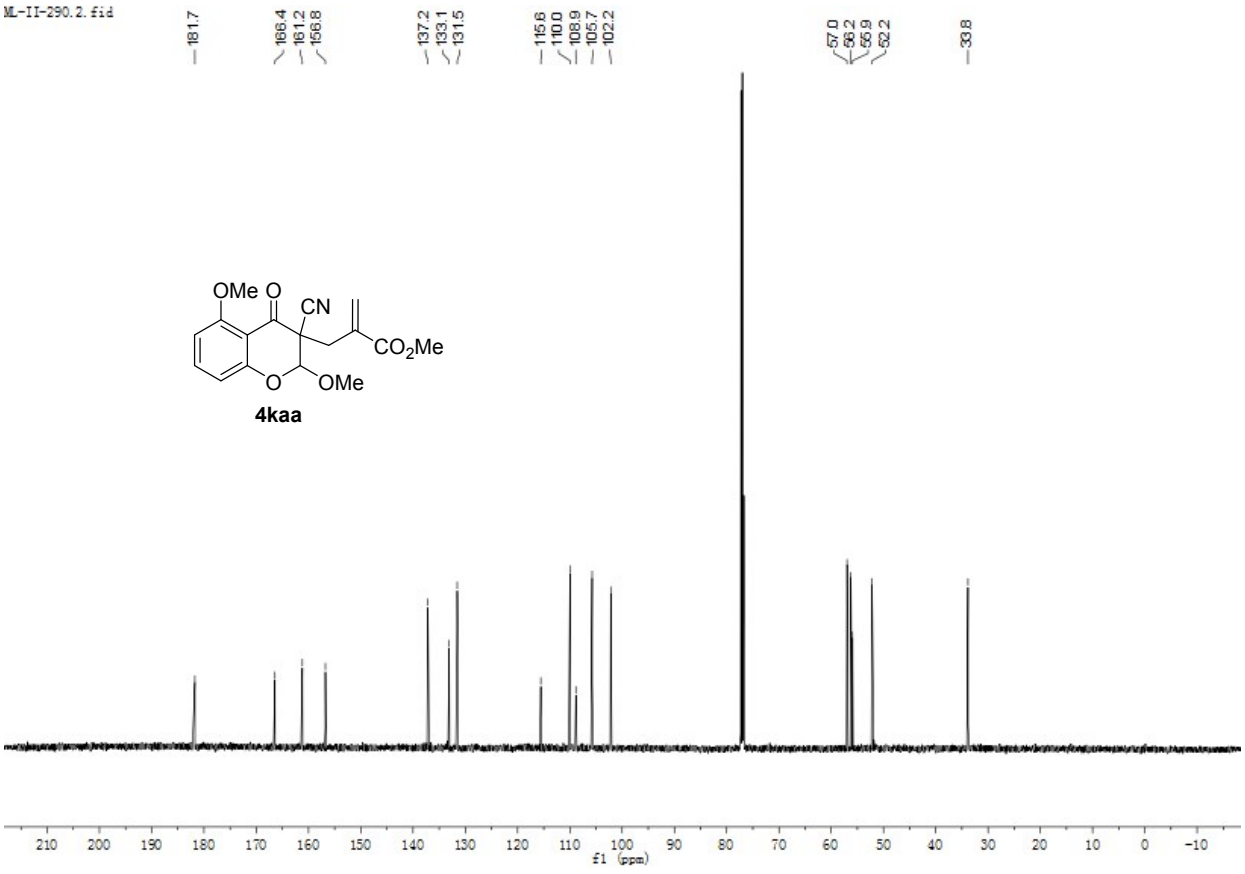
^{1}H, ^{13}C NMR spectra of **4jaa**



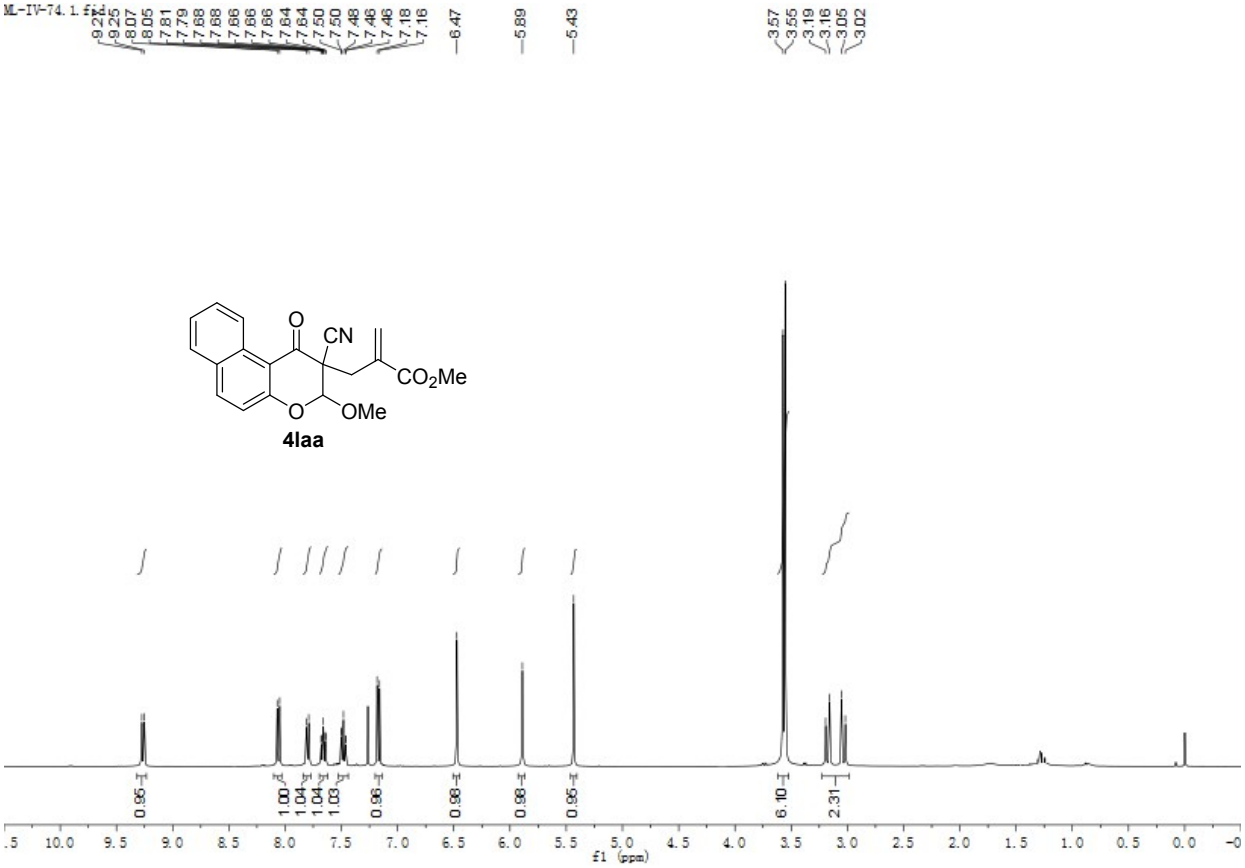


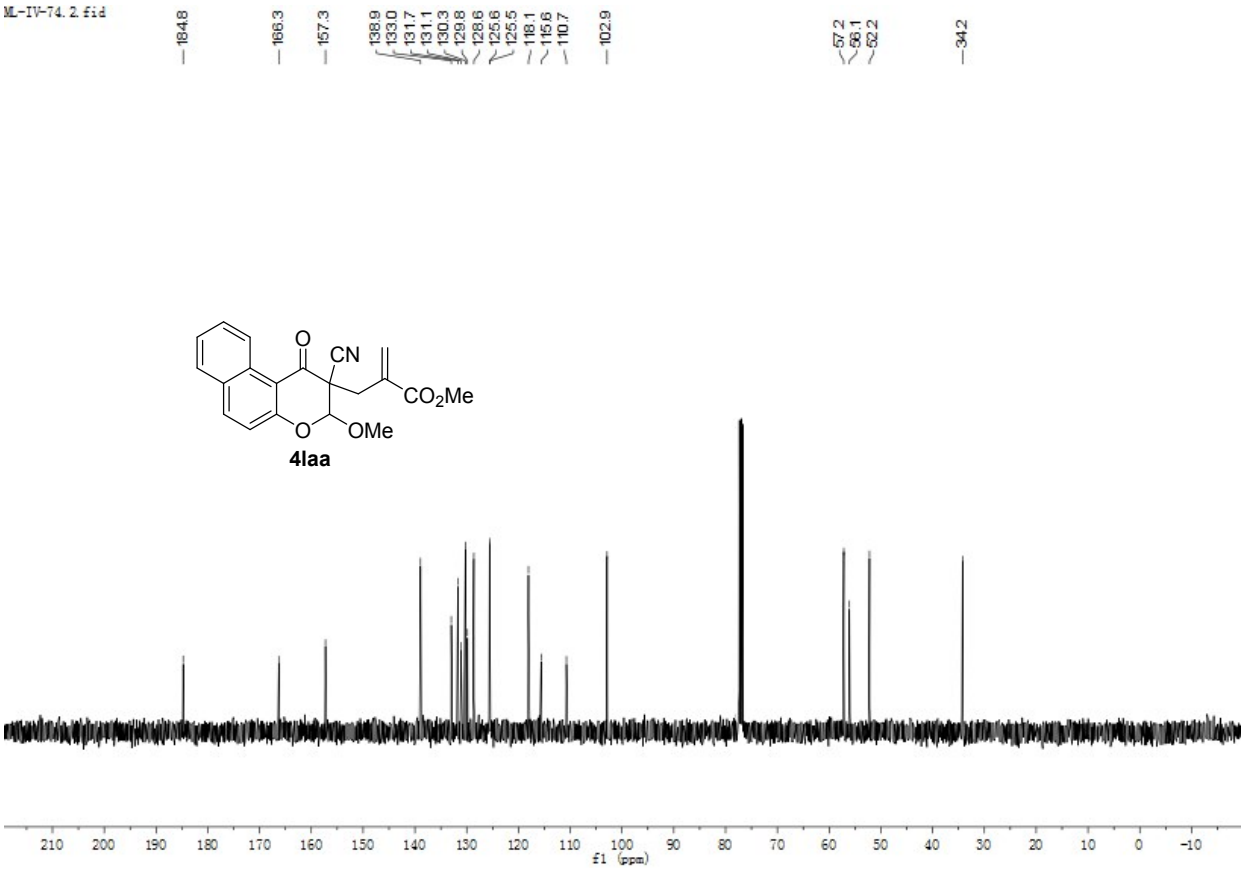
^{1}H, ^{13}C NMR spectra of **4kaa**



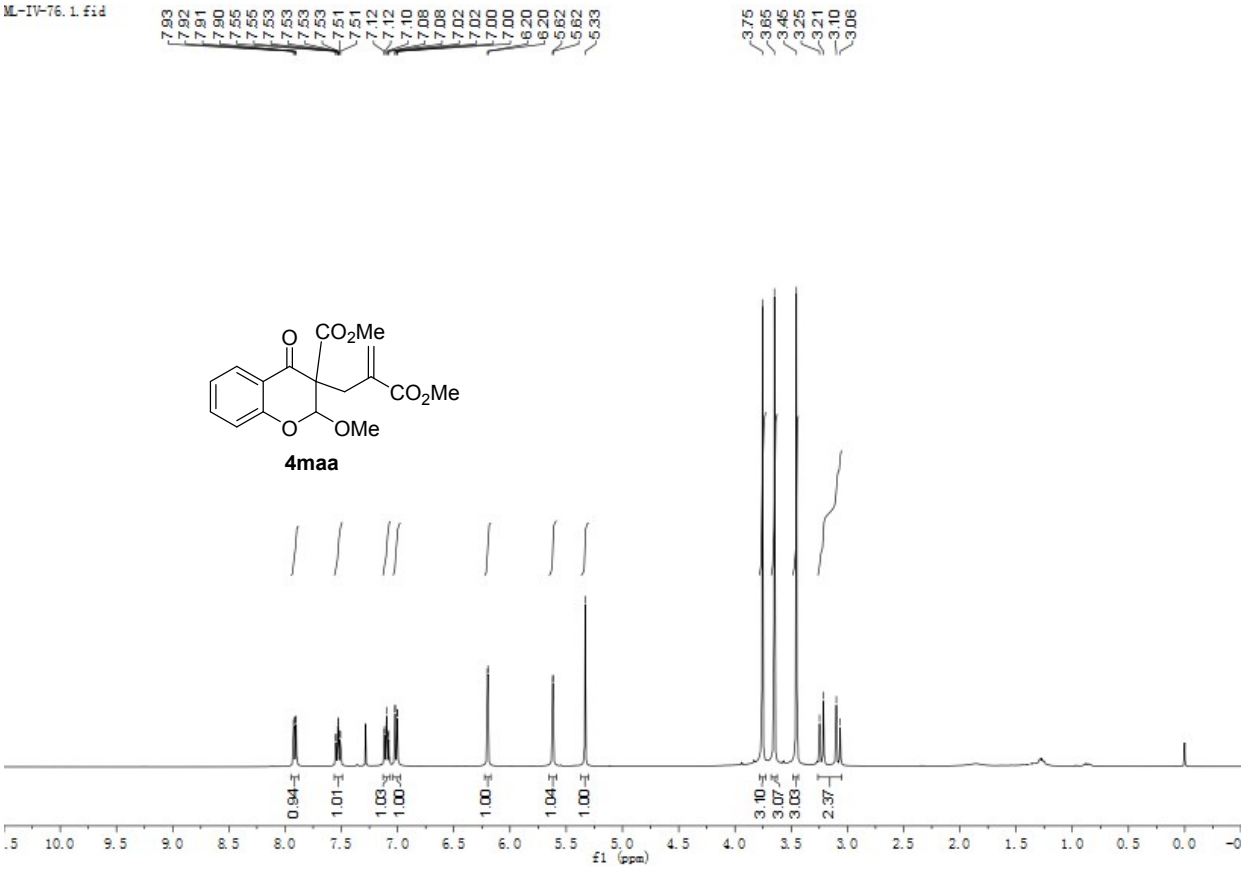


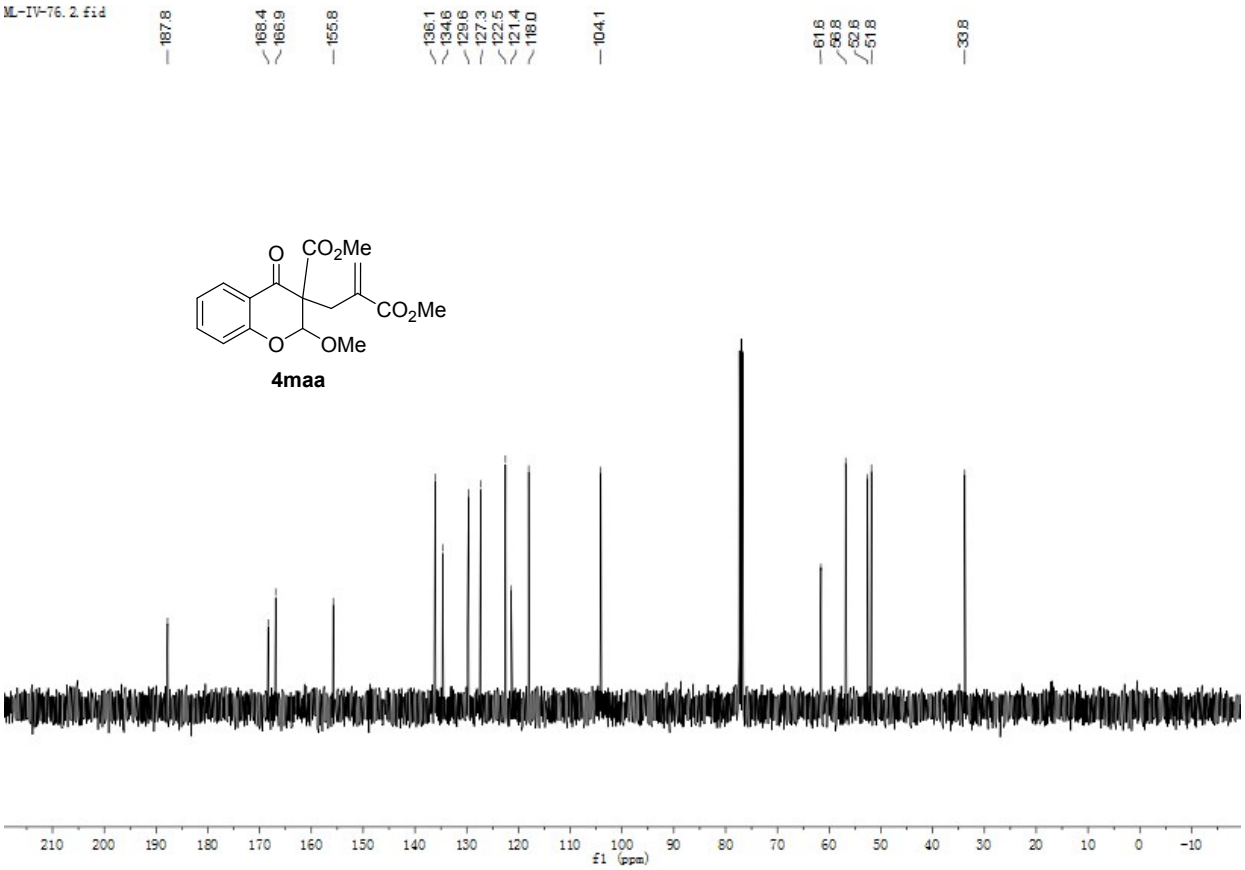
^{1}H, ^{13}C NMR spectra of **4laa**



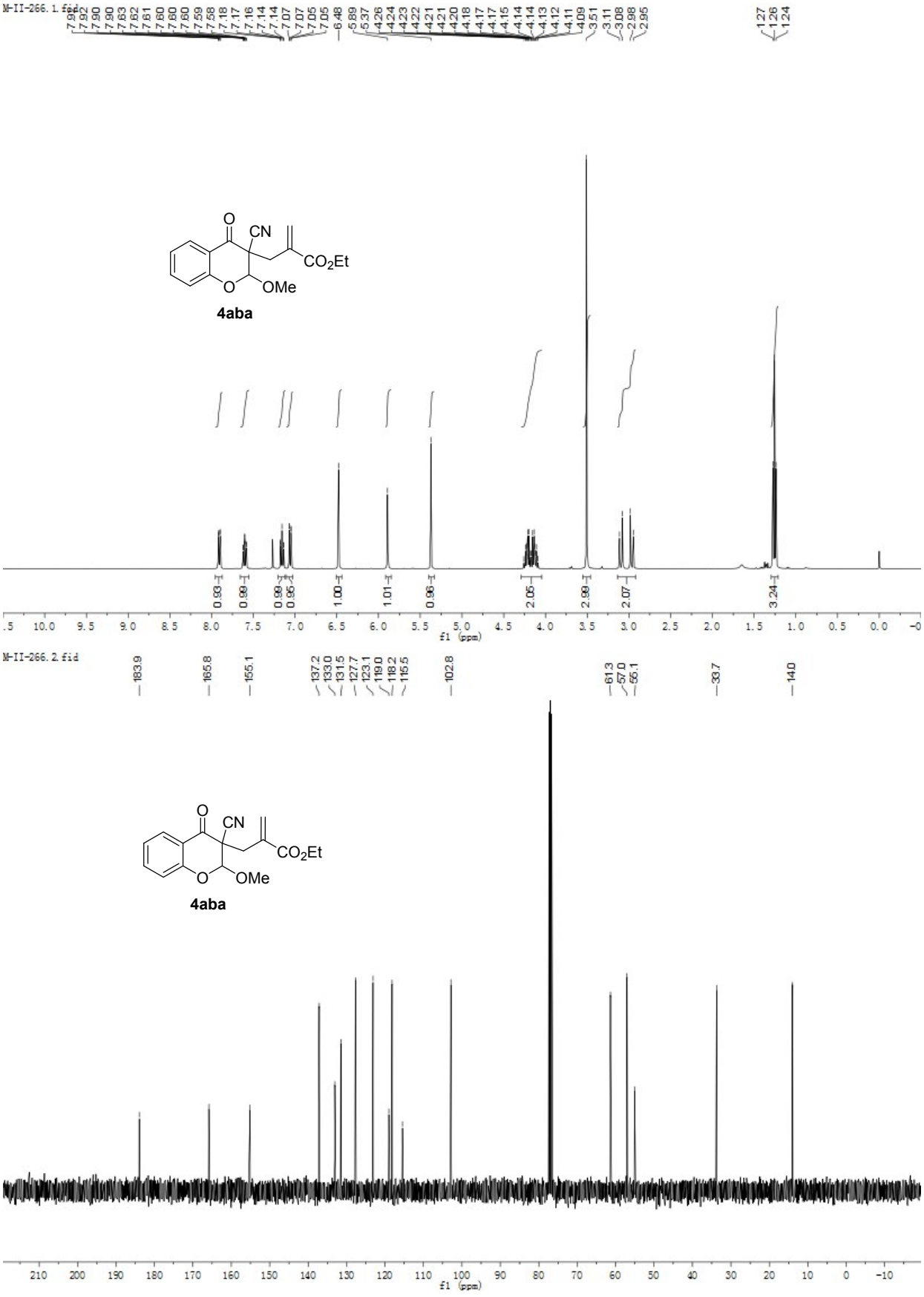


^{1}H, ^{13}C NMR spectra of **4maa**

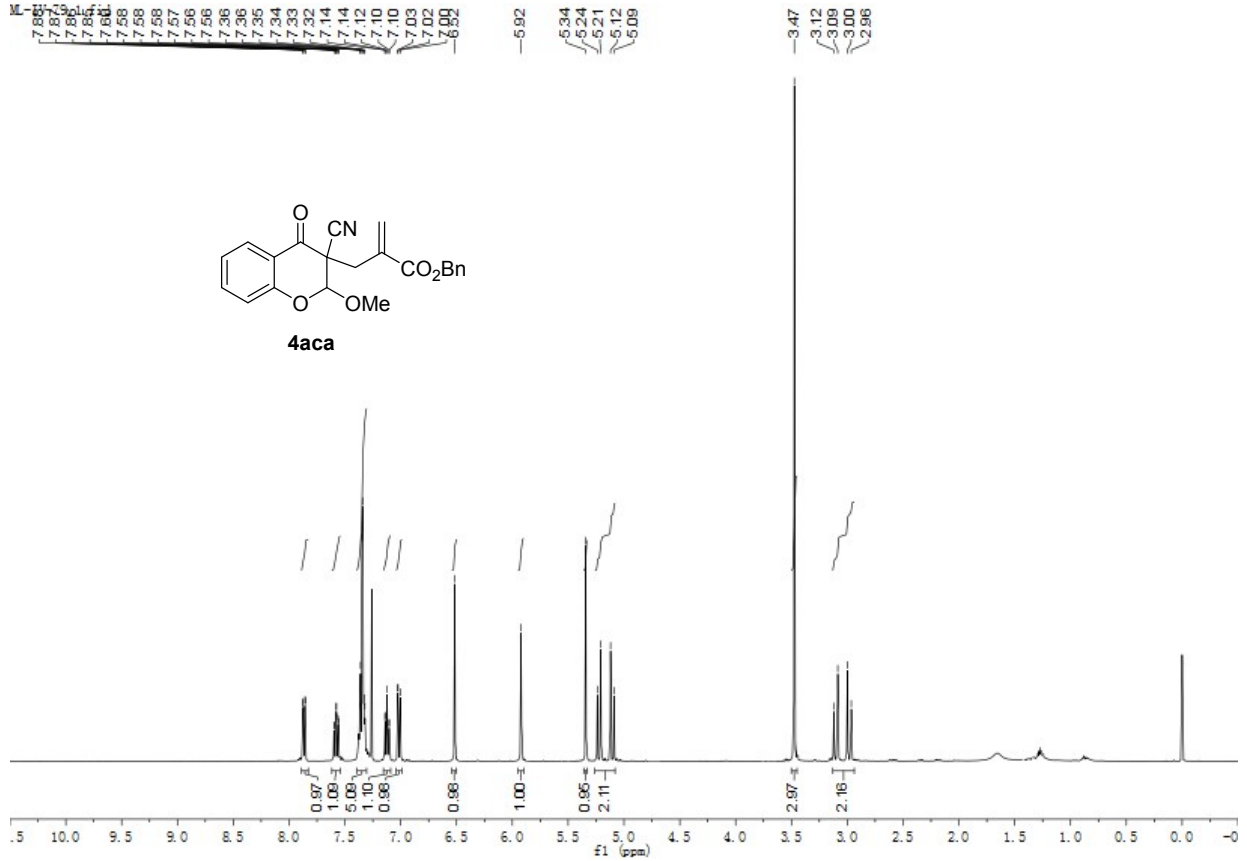


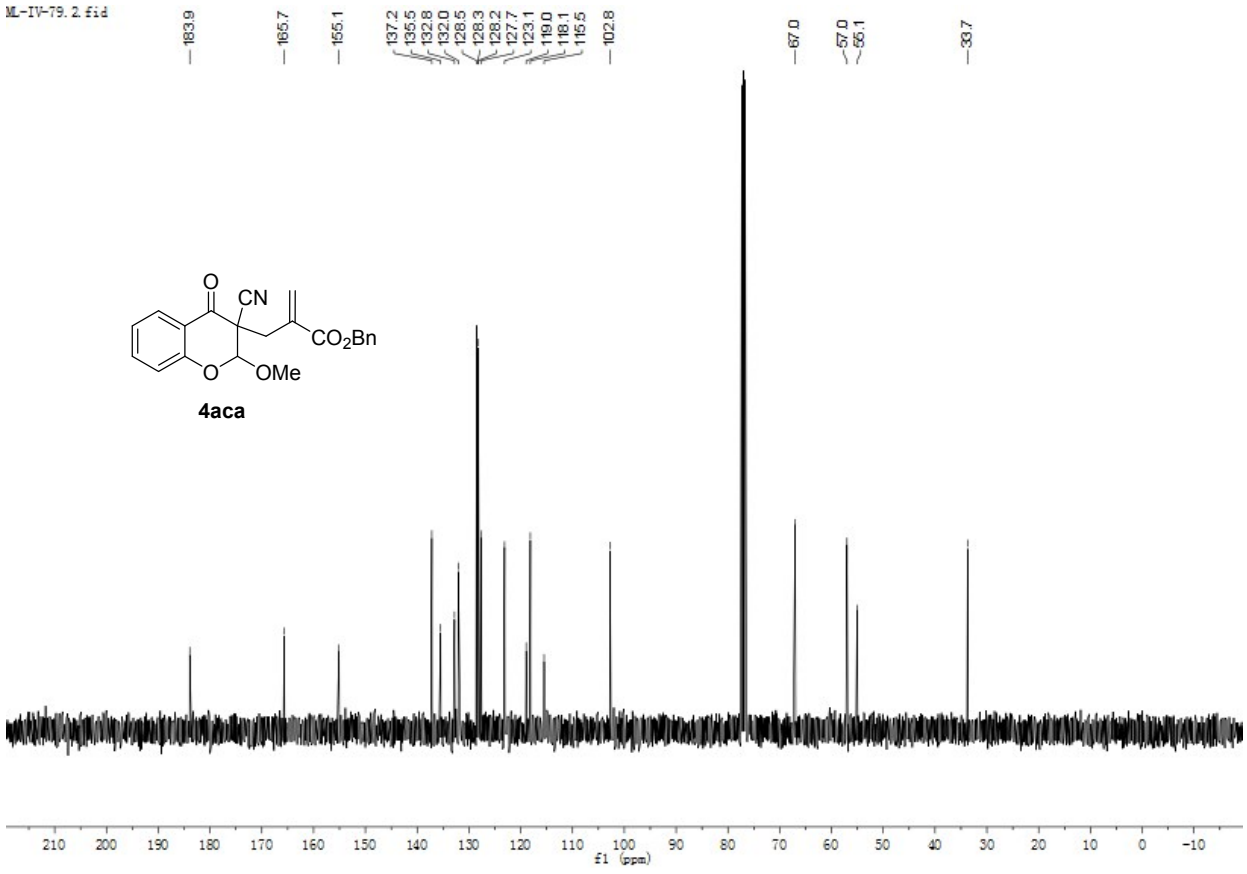


^{1}H, ^{13}C NMR spectra of **4aba**

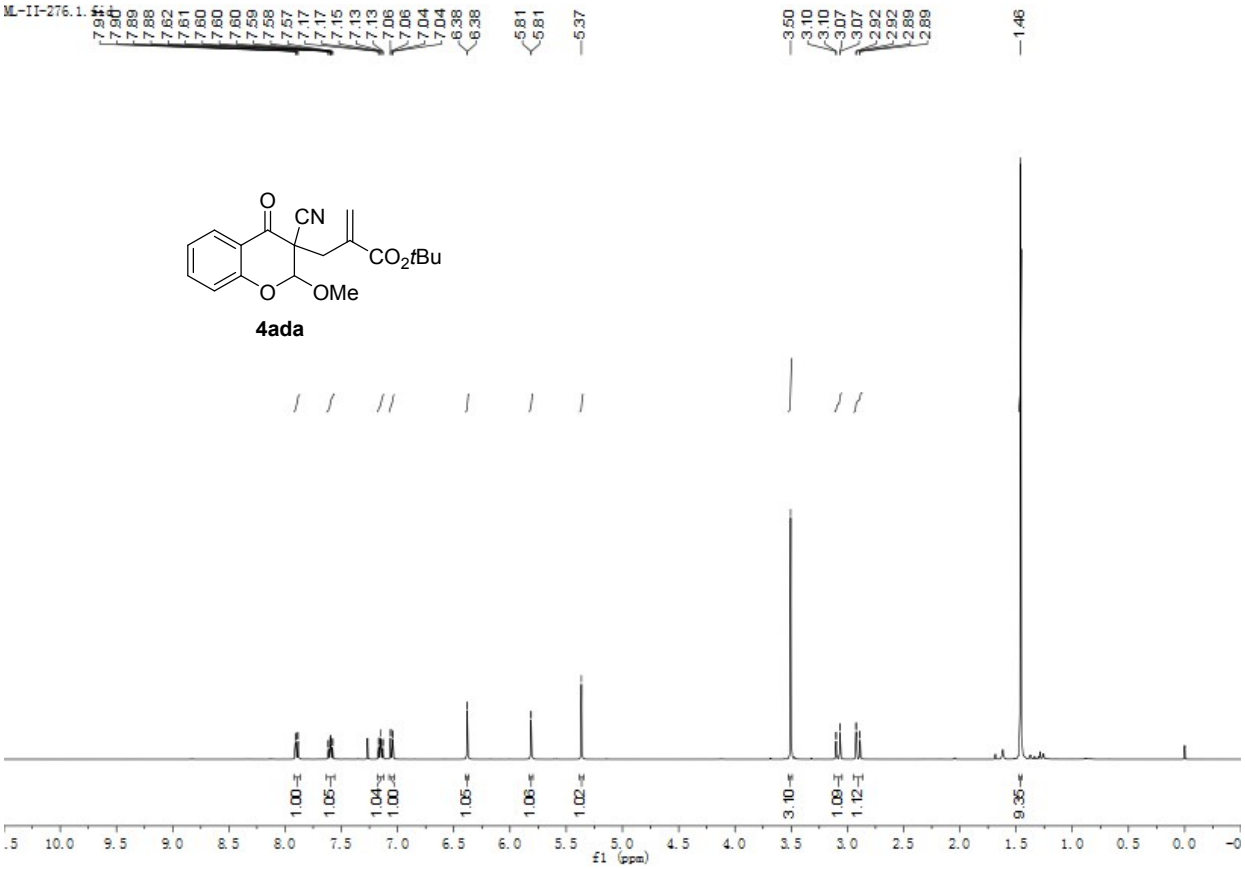


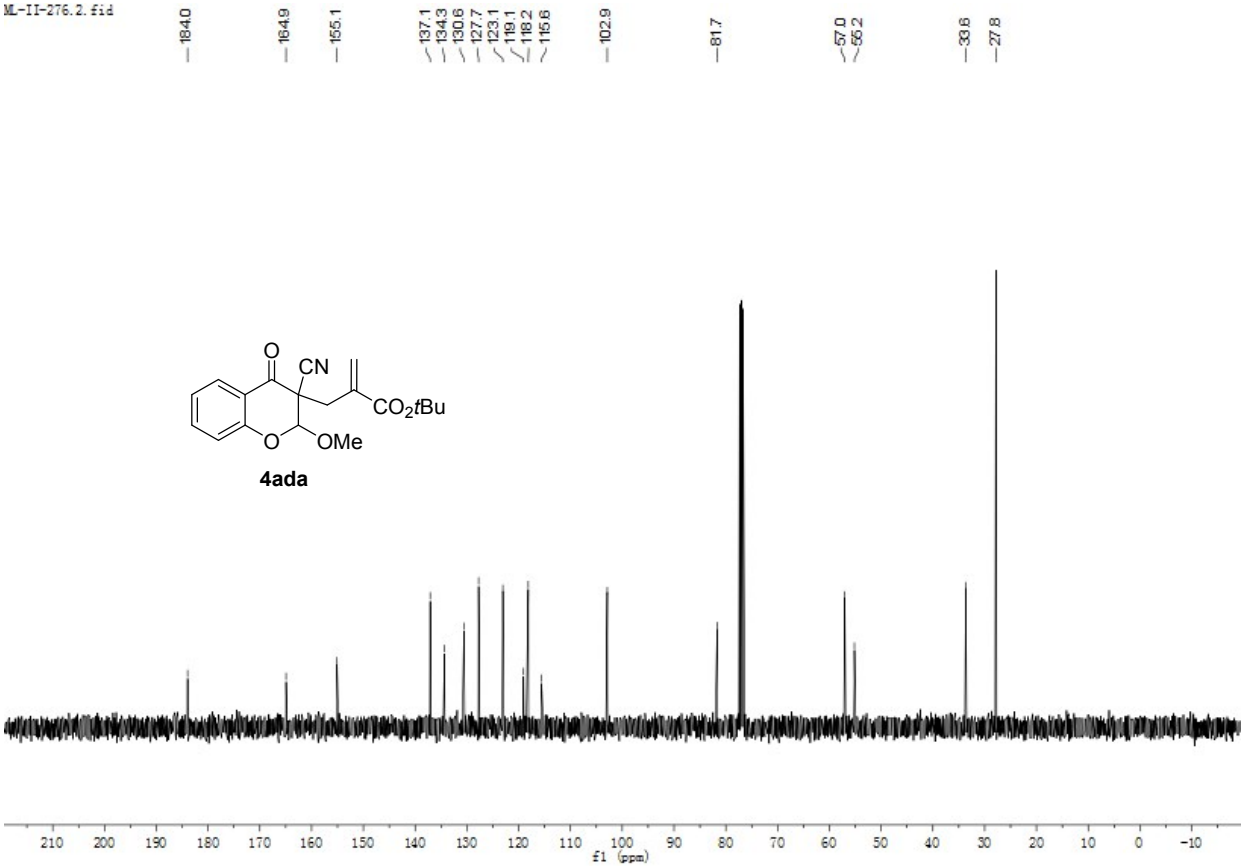
^{1}H, ^{13}C NMR spectra of **4aca**



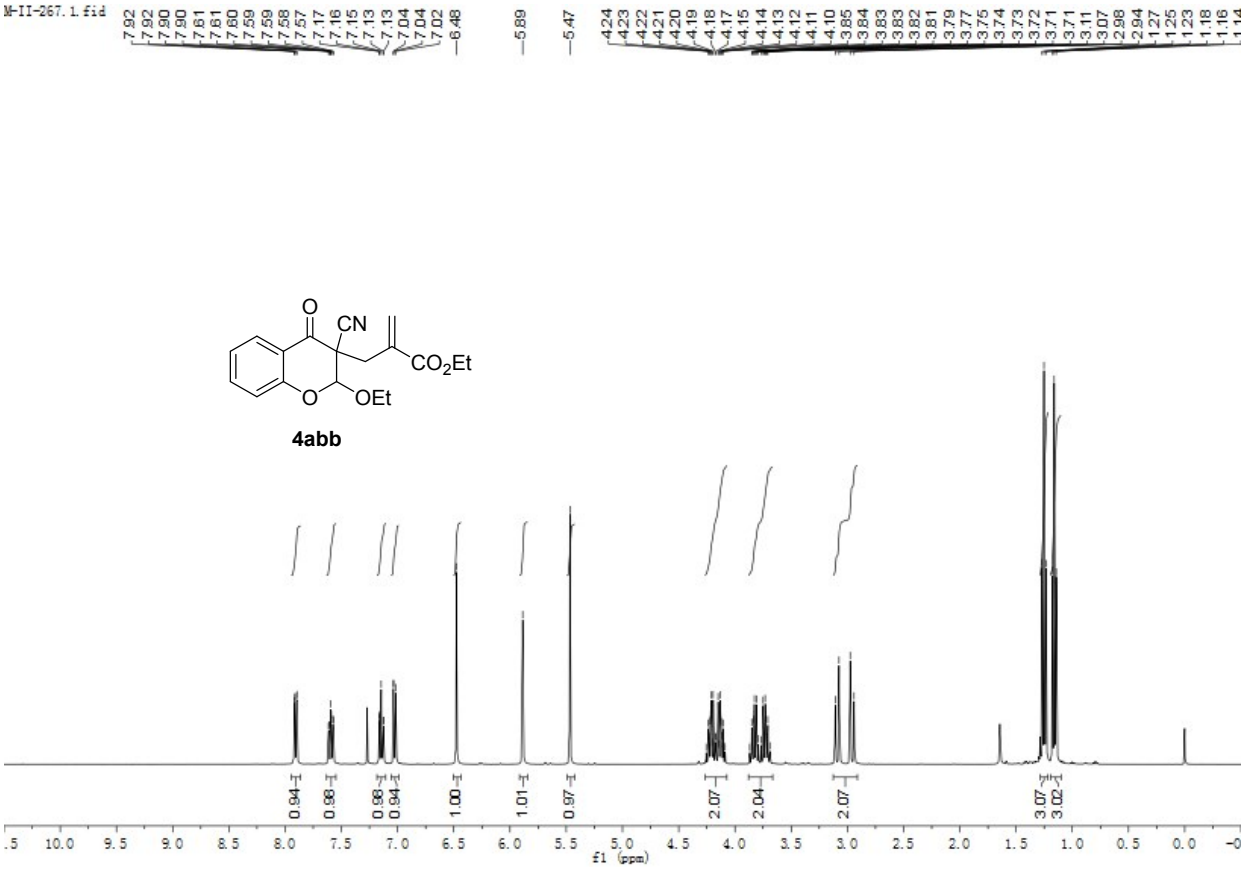


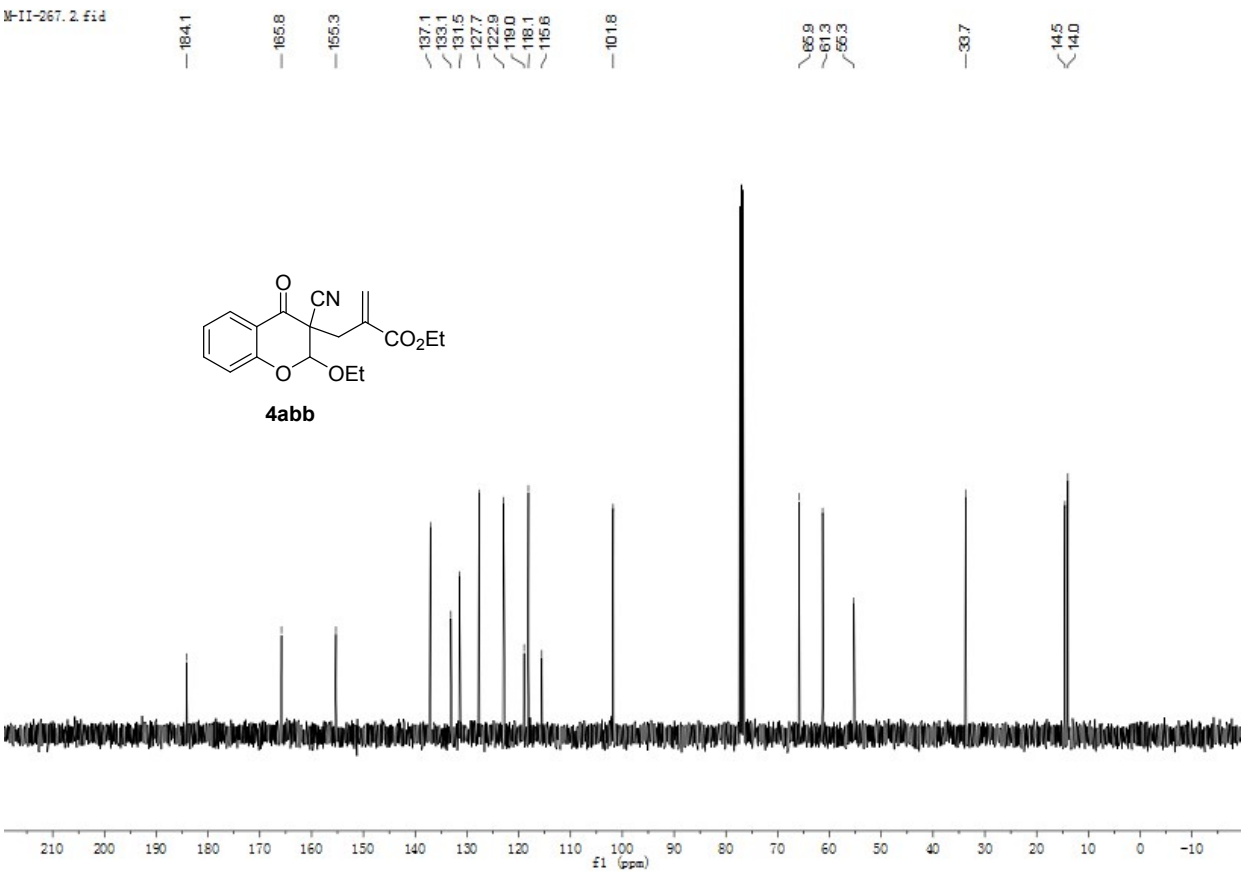
^{1}H, ^{13}C NMR spectra of **4ada**



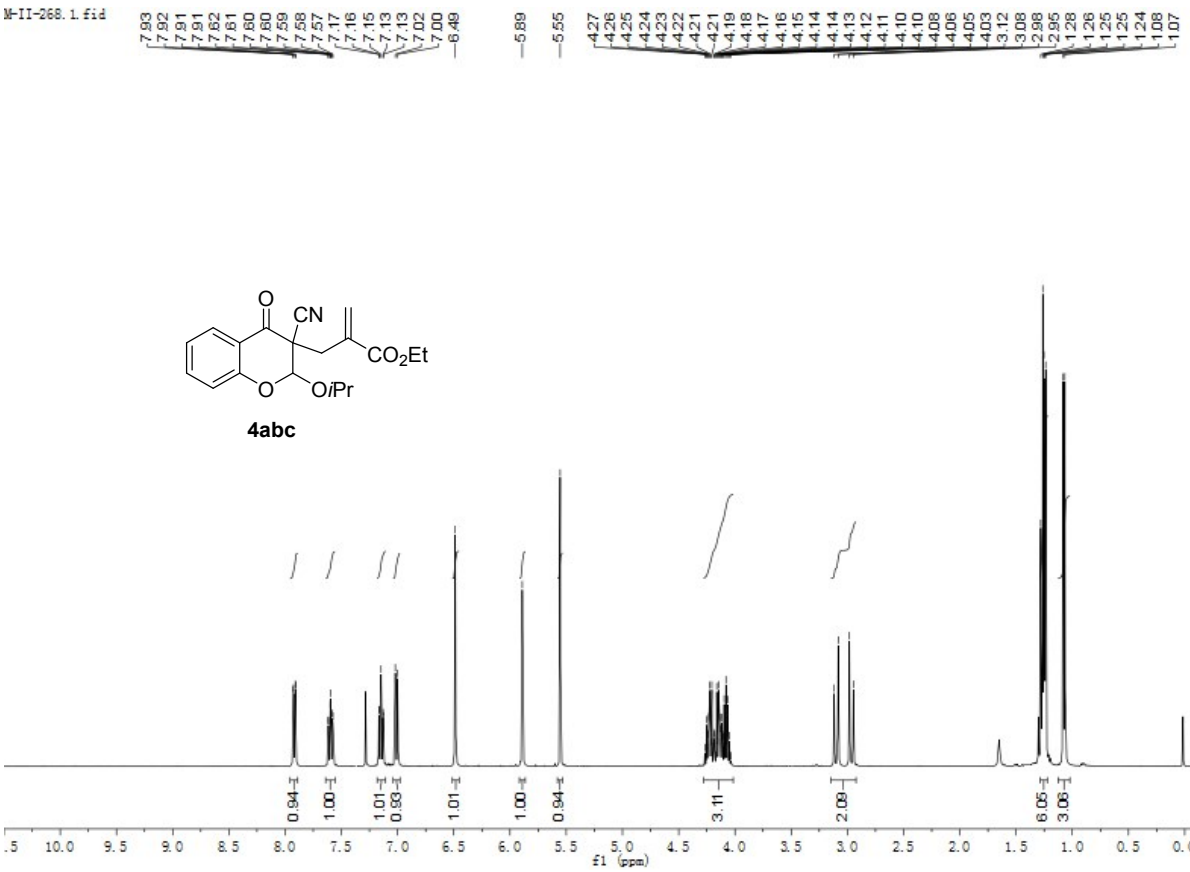


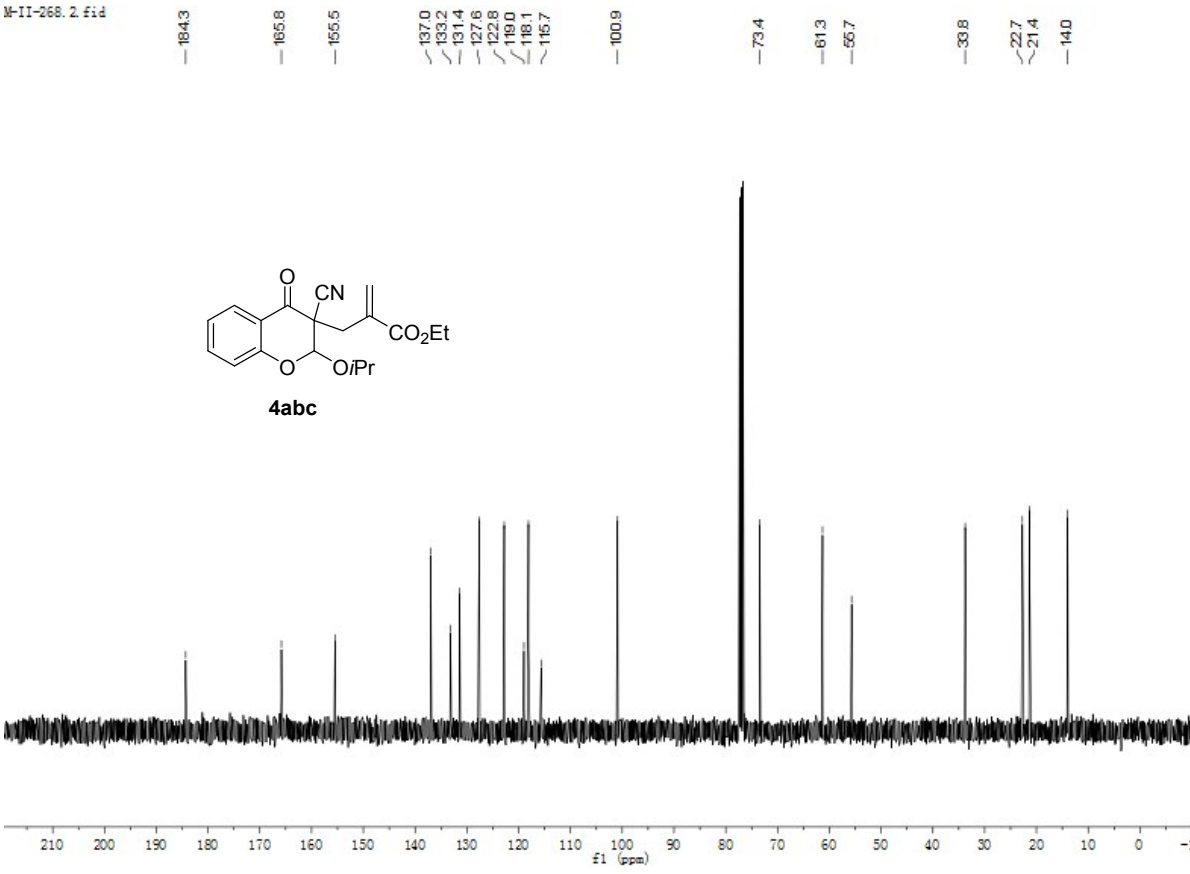
^{1}H, ^{13}C NMR spectra of **4abb**





^{1}H, ^{13}C NMR spectra of **4abc**





^{1}H, ^{13}C NMR spectra of **4abd**