Supporting information

An electrochemical tandem oxidative azidation and intramolecular cyclization strategy for the synthesis of quinoxaline derivatives

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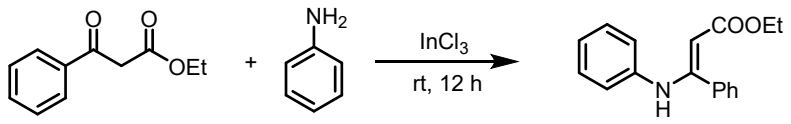
1. General information

All reagents were obtained from commercial sources and used without further purification unless otherwise indicated. Silica gel for column chromatography was purchased from Qingdao Haiyang Chemical Co., Ltd. Reactions were stirred using Teflon-coated magnetic stir bars. Thin-layer chromatography (TLC) was used to monitor the reaction. Melting points were determined using a Büchi B-540 capillary melting point apparatus. ^{1}H NMR (400 MHz), ^{13}C NMR (100 MHz) and ^{19}F NMR (376 MHz) spectra were recorded with $CDCl_3$. Chemical shifts are reported downfield from TMS (= 0) for ^{1}H NMR. For $^{13}C\{1H\}$ NMR, chemical shifts are reported in the scale relative to $CDCl_3$ (= 77.0). High resolution mass spectrometry (HRMS) analysis was performed on an Agilent 1290–6540 UHPLC Q-Tof HR-MS System (ESI) spectrometer.

2. Typical experimental procedure[1-4]

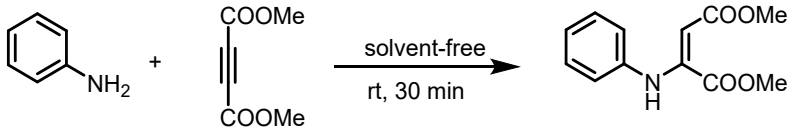
1aa

A 50 mL single-mouth flask was charged with ethyl trifluoroacetoacetate (5.0 mmol, 920.5 mg), aniline (7.5 mmol, 698.5 mg), DCM (3.0 mL), $Sc(OTf)_2$ (0.25 mmol, 123.0 mg). The reaction mixture was stirred at 40℃ for 9 hours and monitored by TLC during the reaction. When the reaction was finished, the solution was extracted with diethyl ether (2 × 10 mL). After the solvent was evaporated under vacuum, The crude products were separated by flash column chromatography on Et_3N pre-treated silica gel using petroleum ether: ethyl ether = (20:1, v/v) as eluent.



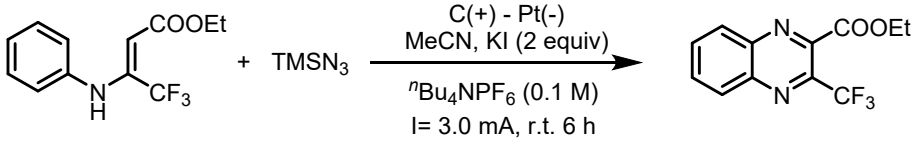
1ba

A 50 mL single-mouth flask was charged with ethyl benzoyl acetate (5 mmol, 961.1 mg), aniline (7.5 mmol, 698.5 mg), $InCl_3$ (0.5 mmol, 221.2 mg). The reaction mixture was stirred at room temperature for 12 hours and monitored by TLC during the reaction. When the reaction was finished, the solution was extracted with diethyl ether (2 × 10 mL). After the solvent was evaporated under vacuum, The crude products were separated by flash column chromatography on Et_3N pre-treated silica gel using petroleum ether: ethyl ether = (20:1, v/v) as eluent.



1ca

Take a 50 mL single-necked round-bottomed flask that was dried in the oven in advance, add aniline (7.5 mmol, 698.5 mg), then slowly add dimethylacetylenedicarboxylate (5.0 mmol, 710.5 mg), and mix thoroughly to form a uniform paste. The reaction mixture was stirred at room temperature for 30 min and monitor the reaction process by TLC. After the reaction was completed, using petroleum ether/ethyl acetate = (15:1, v/v) as eluent to quickly purify by silica gel column pretreated with Et_3N to obtain the desired product.



1aa **3aa**

In an oven-dried undivided three-necked bottle added enamine ester **1aa** (0.5mmol，122.6 mg), MeCN (5.0 mL), $TMSN_3$ (1.0 mmol, 115.0 mg), $^nBu_4NPF_6$ (0.5 mmol, 193.5 mg), KI (1.0 mmol, 166.0 mg). The bottle was equipped with platinum plate (20 mm × 15 mm) as the anode and platinum plate (20 mm × 15 mm) as the cathode. The reaction mixture was stirred and electrolyzed at a constant current of 3.0 mA for 6 hours at room temperature. When the reaction was finished, the solution was extracted with diethyl ether (3 × 10 mL). After the solvent was evaporated under

vacuum, the residues were purified by flash column chromatography on silica gel (petroleum ether: ethyl ether = 10:1, v/v) to give the desired product.

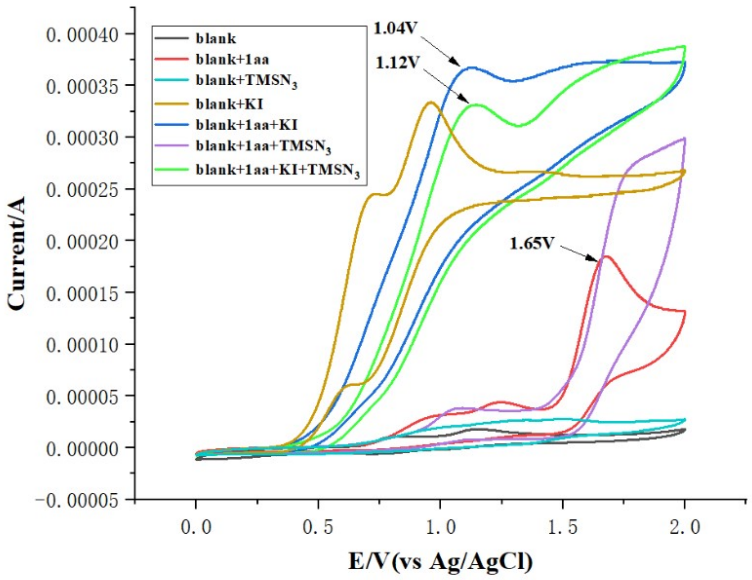
Figure S1. Electrolysis setup

3. Large-scale experimental procedure

In an oven-dried undivided three-necked bottle added enamine ester **1aa** (5.0 mmol, 1.23 g), MeCN (20.0 mL), $TMSN_3$ (10.0 mmol, 1.12 g), $^{n}Bu_4NPF_6$ (5.0 mmol, 1.94 g), KI (10.0 mmol, 1.66 g). The bottle was equipped with platinum plate (20 mm × 15 mm) as the anode and platinum plate (20 mm × 15 mm) as the cathode. The reaction mixture was stirred and electrolyzed at a constant current of 6.0 mA for 16 hours at room temperature. When the reaction was finished, the solution was extracted with diethyl ether (3 × 20 mL). After the solvent was evaporated under vacuum, the residues were purified by flash column chromatography on silica gel (petroleum ether: ethyl ether = 10:1, v/v) to give the desired product.

4. Cyclic voltammetry experiments

Cyclic voltammetry was performed in a three-electrode bottle (10.0 mL) by electrochemical analyzer at room temperature. The working electrode was a steady glassy carbon disk electrode, the counter electrode a platinum wire. The reference was an Ag/AgCl electrode submerged in saturated aqueous KCl solution. In all experiments, 10 mL of CH_3CN containing 0.1 M $^{n}Bu_4NPF_6$ were poured into the electrochemical cell. The scan rate is 0.04 V/s, ranging from 0.0 V to 2.0 V.



5. References

1. J. S. Yadav, V. N. Kumar, R. S. Rao, A. D. Priyadarshini, P. P. Rao, B. V. S. Reddy and K. Nagaiah, *J. Mol. Catal. A: Chem.*, 2006, **256**, 234-237.

2. D. Ramanathan and K. Pitchumani, *Eur. J. Org. Chem.*, 2015, **2015**, 463-467.

3. H. Ma, D. Li and W. Yu, *Org. Lett.*, 2016, **18**, 868-871.

4. G. Choudhary and R. K. Peddinti, *Green Chem.*, 2011, **13**, 3290-3299.

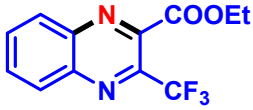
6. Analytical data of the synthesized derivatives

ethyl -4,4,4-trifluoro-2-imino-3-(phenylimino)butanoate (2aa)

Yellow oil; ^{1}H NMR (400 MHz, $CDCl_3$) δ 12.06 (s, 1H), 7.32 (t, J = 7.7 Hz, 2H), 7.20 (t, J = 7.4 Hz, 1H), 6.93 (d, J = 7.4 Hz, 2H), 4.04 (q, J = 7.2 Hz, 2H), 1.09 (t, J = 7.2 Hz, 3H).^{13}C NMR (100 MHz, $CDCl_3$) δ 162.0, 157.1, 152.4 (q, $^{2}J_{C-F}$ = 35.7 Hz), 145.9, 129.1, 127.1, 120.6, 118.8 (q, $^{1}J_{C-F}$ = 279.1 Hz), 63.4, 13.5. ^{19}F NMR (376 MHz, $CDCl_3$) δ -69.61.

HRMS-ESI (m/z): calcd for $C_{12}H_{12}F_3N_2O_2^+$ $[M+H]^+$ 273.0845, found 273.0846.

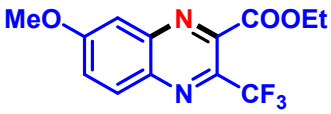
ethyl 3-(trifluoromethyl)quinoxaline-2-carboxylate (3aa)



White solid; m.p.= 48.3-49.5 ℃; 70% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (m, 2H), 7.98 (m, 2H), 4.58 (q, J = 7.2 Hz, 1H), 1.48 (t, J = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.2, 143.6, 141.7, 140.5, 140.2 (q, $^{2}J_{C-F}$ = 36.6 Hz), 133.2, 132.8, 129.8, 129.6, 120.6 (q, $^{1}J_{C-F}$ = 275.8 Hz), 63.2, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.4.

HRMS-ESI (m/z): calcd for $C_{12}H_{10}F_3N_2O_2^+$ $[M+H]^+$ 271.0689, found 271.0691

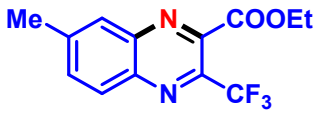
ethyl 7-methoxy-3-(trifluoromethyl)quinoxaline-2-carboxylate (3ab)



Yellow viscous oil; 74% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.04 (d, J = 9.2 Hz, 1H), 7.51 (dd, J = 9.2, 3.0 Hz, 1H), 7.42 (d, J = 2.8 Hz, 1H), 4.48 (q, J = 7.2 Hz, 2H), 3.93 (s, 2H), 1.39 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.4, 163.3, 143.9, 143.7, 137.8 (q, $^{2}J_{C-F}$ = 36.2 Hz, CF_3), 137.0, 130.7, 126.8, 122.3 (q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 106.3, 63.1, 56.2, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.0.

HRMS-ESI (m/z): calcd for $C_{13}H_{12}F_3N_2O_3^+$ $[M+H]^+$ 301.0795, found 301.0796

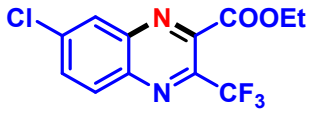
ethyl 7-methyl-3-(trifluoromethyl)quinoxaline-2-carboxylate (3ac)



Yellow viscous oil; 72% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.06 (m, 1H), 7.95 (s, 1H), 7.72 (m, 2H), 4.49 (q, J = 7.2 Hz, 2H), 2.59 (s, 3H), 1.39 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.4, 144.6, 143.6, 141.8, 140.8 (q, $^{2}J_{C-F}$ = 36.0 Hz, CF_3), 139.1, 135.2, 129.3, 128.3, 122.2 (q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 63.1, 22.1, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.3.

HRMS-ESI (m/z): calcd for $C_{13}H_{12}F_3N_2O_2^+$ $[M+H]^+$ 285.0845, found 285.0846

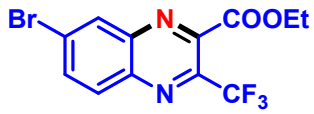
ethyl 7-chloro-3-(trifluoromethyl)quinoxaline-2-carboxylate (3ad)



Yellow oil; 46% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.22 – 8.09 (m, 2H), 7.85 (m, 1H), 4.50 (q, J = 7.2 Hz, 2H), 1.40 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.8, 144.5, 142.0, 140.6 (q, $^{2}J_{C-F}$ = 36.7 Hz, CF_3), 139.6, 139.1, 134.0, 131.0, 128.5, 120.5 (q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 63.4, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.5.

HRMS-ESI (m/z): calcd for $C_{12}H_9ClF_3N_2O_2^+$ $[M+H]^+$ 305.0299, found 305.0298

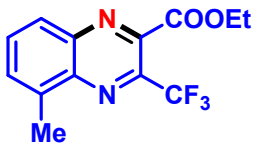
ethyl 7-bromo-3-(trifluoromethyl)quinoxaline-2-carboxylate (3ae)



Yellow oil; 48% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.46 (d, J = 2.6 Hz, 1H), 8.16 – 8.00 (m, 2H), 4.57 (q, J = 7.2 Hz, 2H), 1.47 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.8, 144.5, 142.1, 140.6 (q, $^{2}J_{C-F}$ = 36.7 Hz, CF_3), 139.3, 136.5, 131.9, 131.0, 128.0, 120.5 (q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 63.4, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.5.

HRMS-ESI (m/z): calcd for $C_{12}H_9BrF_3N_2O_2^+$ $[M+H]^+$ 348.9794, found 348.9795

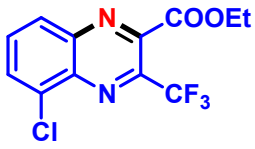
ethyl 5-methyl-3-(trifluoromethyl)quinoxaline-2-carboxylate (3af)



Yellow oil; 46% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.02 (d, J = 8.4 Hz, 1H), 7.79 (t, J = 7.8 Hz, 1H), 7.71 (d, J = 7.2 Hz, 1H), 4.50 (q, J = 7.2 Hz, 2H), 2.77 (s, 3H), 1.40 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.4, 143.1, 141.9, 139.8, 139.2 (q, $^{2}J_{C-F}$ = 36.0 Hz, CF_3), 139.0, 133.0, 132.5, 127.3, 120.8 (q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 63.1, 16.9, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.3.

HRMS-ESI (m/z): calcd for $C_{13}H_{12}F_3N_2O_2^+$ $[M+H]^+$ 285.0845, found 284.0846

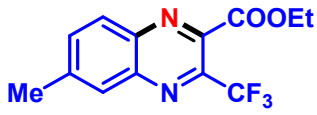
ethyl 5-chloro-3-(trifluoromethyl)quinoxaline-2-carboxylate (3ag)



Yellow oil; 41% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.20 (d, J = 8.4 Hz, 1H), 8.08 (d, J = 7.6 Hz, 1H), 7.90 (t, J = 8.2 Hz, 1H), 4.58 (q, J = 7.4 Hz, 2H), 1.47 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 163.8, 144.3, 142.7, 140.2 (q, $^{2}J_{C-F}$ = 36.2 Hz, CF_3), 137.6, 134.3, 132.9, 132.5, 128.5, 120.5(q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 63.4, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -64.3.

HRMS-ESI (m/z): calcd for $C_{12}H_9ClF_3N_2O_2^+$ $[M+H]^+$ 305.0299, found 305.0298

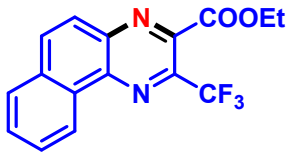
ethyl 6-methyl-3-(trifluoromethyl)quinoxaline-2-carboxylate (3ah)



Yellow solid; m.p.= 58.2-59.3 °C; 43% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.81 (d, J = 2.0 Hz, 1H), 7.73 (d, J = 7.6 Hz, 1H), 7.35 – 7.25 (m, 1H), 4.39 (q, J = 7.2 Hz, 2H), 2.38 (s, 3H), 1.38 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 159.3, 148.2, 139.0, 135.6 (q, $^{2}J_{C-F}$ = 35.6 Hz, CF_3), 131.4, 128.8, 127.8, 127.2, 123.2, 120.8 (q, $^{1}J_{C-F}$ = 269.1 Hz, CF_3), 62.3, 21.2, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -61.1.

HRMS-ESI (m/z): calcd for $C_{13}H_{12}F_3N_2O_2^+$ $[M+H]^+$ 285.0845, found 285.0846

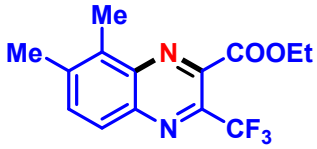
ethyl 2-(trifluoromethyl)benzo[f]quinoxaline-3-carboxylate (3aj)



Yellow viscous oil; 47% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 9.31 – 9.21 (m, 1H), 8.22 (d, J = 9.0 Hz, 1H), 8.09 – 7.97 (m, 2H), 7.90 – 7.83 (m, 2H), 4.59 (q, J = 7.2 Hz, 2H), 1.49 (t, J = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.5, 135.6 (q, $^{2}J_{C-F}$ = 35.6 Hz, CF_3), 135.3, 134.0, 133.1, 130.6, 129.9, 128.9, 128.9, 128.7, 128.3, 125.8, 125.4, 120.8 (q, $^{1}J_{C-F}$ = 269.1 Hz), 63.2, 14.0. ^{19}F NMR (376 MHz, $CDCl_3$) δ -63.9.

HRMS-ESI (m/z): calcd for $C_{16}H_{12}F_3N_2O_2^+$ $[M+H]^+$ 321.0845, found 321.0844

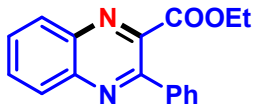
ethyl 7,8-dimethyl-3-(trifluoromethyl)quinoxaline-2-carboxylate (3al)



Yellow viscous oil; 41% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.00 (d, J = 8.6 Hz, 1H), 7.78 (d, J = 8.7 Hz, 1H), 4.56 (q, J = 7.2 Hz, 2H), 2.77 (s, 4H), 2.59 (s, 4H), 1.47 (t, J = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.5, 144.7, 144.2, 142.8 (q, $^{2}J_{C-F}$ = 36.0 Hz, CF_3), 129.9, 129.7, 128.6, 128.5, 125.2 (q, $^{1}J_{C-F}$ = 275.8 Hz, CF_3), 119.5, 117.2, 63.1, 20.7, 20.6, 13.9. ^{19}F NMR (376 MHz, $CDCl_3$) δ -67.3.

HRMS-ESI (m/z): calcd for $C_{14}H_{14}F_3N_2O_2^+$ $[M+H]^+$ 299.1002, found 299.1004

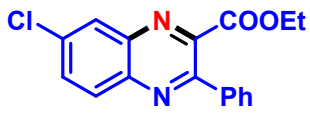
ethyl 3-phenylquinoxaline-2-carboxylate (3ba)



Yellow solid; m.p.= 65.1-66.7 °C; 71% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.2 (dd, J = 13.7, 8.2 Hz, 2H), 7.9 – 7.7 (m, 4H), 7.5 (q, J = 2.9, 2.4 Hz, 3H), 4.3 (q, J = 7.2 Hz, 2H), 1.2 – 1.1 (m, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.6, 152.3, 145.7, 142.2, 139.9, 137.8, 131.7, 130.5, 129.6, 129.3, 128.6, 128.5, 62.4, 13.7.

HRMS-ESI (m/z): calcd for $C_{17}H_{15}N_2O_2^+$ $[M+H]^+$ 279.1128, found 279.1127

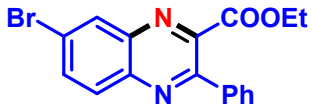
ethyl 7-chloro-3-phenylquinoxaline-2-carboxylate (3bd)



Yellow solid; m.p.= 91.1-92.8 °C; 59% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.21 (d, J = 2.3 Hz, 1H), 8.12 (d, J = 9.0 Hz, 1H), 7.80 (dd, J = 9.0, 2.3 Hz, 1H), 7.76 – 7.71 (m, 2H), 7.55 – 7.49 (m, 3H), 4.34 (q, J = 7.1 Hz, 2H), 1.18 (t, J = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.3, 152.3, 146.5, 140.7, 140.1, 137.3, 136.4, 132.7, 130.5, 129.8, 128.7, 128.5, 128.3, 62.5, 13.7.

HRMS-ESI (m/z): calcd for $C_{17}H_{14}ClN_2O_2^+$ $[M+H]^+$ 313.0738, found 313.0736

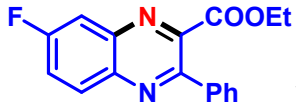
ethyl 7-bromo-3-phenylquinoxaline-2-carboxylate (3be)



Yellow solid; m.p.= 103.1-104.8 °C; 58% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.40 (d, *J* = 2.2 Hz, 1H), 8.05 (d, *J* = 9.0 Hz, 1H), 7.93 (dd, *J* = 9.0, 2.1 Hz, 1H), 7.74 (ddt, *J* = 5.2, 3.0, 1.4 Hz, 2H), 7.57 – 7.48 (m, 3H), 4.34 (q, *J* = 7.0 Hz, 2H), 1.19 (t, *J* = 7.0 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.3, 152.4, 146.5, 141.0, 140.4, 137.3, 135.2, 131.7, 130.6, 129.8, 128.7, 128.5, 124.5, 62.5, 13.6.

HRMS-ESI (m/z): calcd for $C_{17}H_{14}BrN_2O_2^+$ $[M+H]^+$ 357.0233, found 357.0235

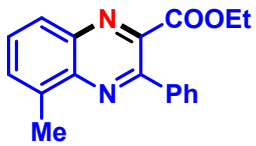
ethyl 7-fluoro-3-phenylquinoxaline-2-carboxylate (3bm)



Yellow solid; m.p.= 76.2-77.3 °C; 57% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.20 (dd, *J* = 9.2, 5.7 Hz, 1H), 7.84 (dd, *J* = 8.9, 2.8 Hz, 1H), 7.80 – 7.60 (m, 3H), 7.55 – 7.49 (m, 3H), 4.34 (q, *J* = 7.2 Hz, 2H), 1.18 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.4, 163.0 (d, *J* = 253.8 Hz), 151.6, 151.5, 146.5, 140.7, 140.6, 139.5, 137.4, 131.5, 131.4, 129.7, 128.7, 128.5, 122.4, 122.1, 113.1, 112.8, 62.5, 13.7.

HRMS-ESI (m/z): calcd for $C_{17}H_{14}FN_2O_2^+$ $[M+H]^+$ 297.1034, found 297.1033

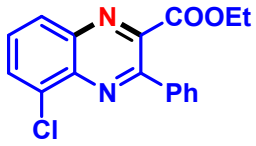
ethyl 5-methyl-3-phenylquinoxaline-2-carboxylate (3bf)



Yellow oil; 58% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 – 8.00 (m, 1H), 7.84 – 7.75 (m, 2H), 7.74 – 7.65 (m, 2H), 7.57 – 7.46 (m, 3H), 4.34 (q, *J* = 7.1 Hz, 2H), 2.85 (s, 3H), 1.19 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 167.0, 150.7, 145.1, 141.4, 139.9, 138.1, 137.8, 131.4, 130.2, 129.5, 128.8, 128.5, 127.3, 62.3, 17.1, 13.7.

HRMS-ESI (m/z): calcd for $C_{18}H_{17}N_2O_2^+$ $[M+H]^+$ 293.1285, found 293.1286

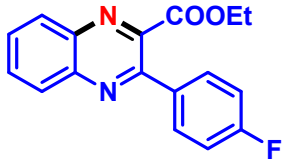
ethyl 5-chloro-3-phenylquinoxaline-2-carboxylate (3bg)



Yellow solid; m.p. = 117.5–120.3 ℃; 57% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (dd, *J* = 8.4, 1.3 Hz, 1H), 7.96 (dd, *J* = 7.6, 1.3 Hz, 1H), 7.83 (dd, *J* = 6.6, 2.9 Hz, 2H), 7.74 (t, *J* = 8.0 Hz, 1H), 7.53 (q, *J* = 2.9 Hz, 3H), 4.36 (q, *J* = 7.1 Hz, 2H), 1.20 (t, *J* = 7.1 Hz, 3H). ^{13}C NMR (101 MHz, $CDCl_3$) δ 166.4, 152.3, 146.3, 140.7, 139.0, 137.2, 133.4, 131.4, 130.1, 130.0, 128.9, 128.7, 128.5, 62.6, 13.7.

HRMS-ESI (m/z): calcd for $C_{17}H_{14}ClN_2O_2^+$ $[M+H]^+$ 313.0738, found 313.0737

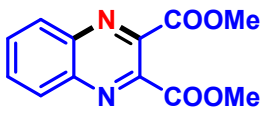
ethyl 3-(4-fluorophenyl)quinoxaline-2-carboxylate (3bn)



Yellow solid; m.p.= 147.1-148.9 ℃; 55% yield;^{1}H NMR (400 MHz, $CDCl_3$) δ 8.20 (ddd, *J* = 19.6, 8.2, 1.8 Hz, 1H), 7.91 – 7.80 (m, 1H), 7.78 – 7.72 (m, 1H), 7.21 (t, *J* = 8.6 Hz, 1H), 4.37 (q, *J* = 7.2 Hz, 1H), 1.24 (t, *J* = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 166.5, 163.8 (d, *J* = 250.0 Hz), 151.1, 145.5, 142.2, 139.9, 133.9, 131.8, 130.6, 130.6, 129.6, 129.3, 115.9, 115.6, 62.5, 13.8. ^{19}F NMR (376 MHz, $CDCl_3$) δ -111.3.

HRMS-ESI (m/z): calcd for $C_{17}H_{14}FN_2O_2^+$ $[M+H]^+$ 297.1034, found 297.1035

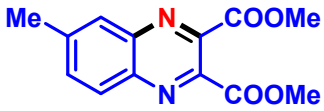
dimethyl quinoxaline-2,3-dicarboxylate (3ca)



White solid; m.p.= 122.1-124.5 ℃; 66% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 (dd, *J* = 6.4, 3.4 Hz, 2H), 7.96 (dd, *J* = 6.4, 3.4 Hz, 2H), 4.10 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.1, 143.8, 141.4, 132.7, 129.9, 53.6.

HRMS-ESI (m/z): calcd for $C_{12}H_{11}N_2O_4^+$ $[M+H]^+$ 247.0713, found 247.0715

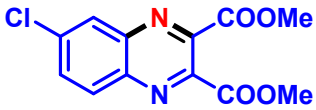
dimethyl 6-methylquinoxaline-2,3-dicarboxylate (3cc)



Yellow solid; m.p.= 84.4-85.4 ℃; 69% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.14 (d, J = 8.6 Hz, 1H), 8.01 (dt, J = 1.8, 0.8 Hz, 1H), 7.77 (dd, J = 8.6, 1.8 Hz, 1H), 4.09 (s, 6H), 2.65 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.3, 165.1, 144.0, 143.9, 142.5, 141.4, 139.8, 135.0, 129.2, 128.4, 53.4, 53.4, 22.0.

HRMS-ESI (m/z): calcd for $C_{13}H_{13}N_2O_4^+$ $[M+H]^+$ 261.0870, found 261.0869

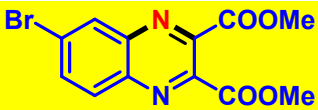
dimethyl 6-chloroquinoxaline-2,3-dicarboxylate (3cd)



Brown white solid; m.p.= 78.1-80.3 ℃; 68% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.27 – 8.16 (m, 2H), 7.88 (dd, *J* = 9.0, 2.2 Hz, 1H), 4.09 (d, *J* = 1.0 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.9, 164.7, 144.9, 143.5, 141.6, 139.9, 139.0, 133.8, 131.0, 128.6, 53.6.

HRMS-ESI (m/z): calcd for $C_{12}H_{10}ClN_2O_4^+$ $[M+H]^+$ 281.0324, found 281.0327

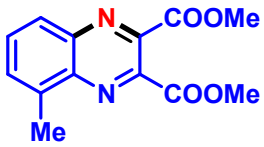
dimethyl 6-bromoquinoxaline-2,3-dicarboxylate (3ce)



Yellow solid; m.p.= 99.6-100.3 ℃; 65% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.44 (d, *J* = 2.0 Hz, 1H), 8.13 (d, *J* = 9.0 Hz, 1H), 8.01 (dd, *J* = 9.0, 2.0 Hz, 1H), 4.09 (s, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.9, 164.8, 144.8, 143.7, 141.8, 140.1, 136.3, 132.1, 131.0, 127.4, 53.7.

HRMS-ESI (m/z): calcd for $C_{12}H_{10}BrN_2O_4^+$ $[M+H]^+$ 324.9818, found 324.9816

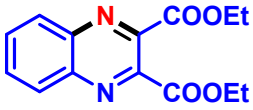
dimethyl 5-methylquinoxaline-2,3-dicarboxylate (3cf)



Yellow solid; m.p.= 111.9-112.8 ℃ ℃; 61% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.08 (dd, *J* = 8.4, 1.6 Hz, 1H), 7.85 – 7.73 (m, 2H), 4.08 (d, *J* = 3.0 Hz, 6H), 2.84 (s, 3H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 165.7, 165.1, 143.4, 142.4, 141.4, 140.7, 138.6, 132.5, 132.2, 127.6, 53.5, 53.3, 17.0.

HRMS-ESI (m/z): calcd for $C_{13}H_{13}N_2O_4^+$ $[M+H]^+$ 261.0870, found 261.0869

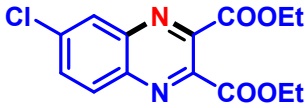
diethyl quinoxaline-2,3-dicarboxylate (3da)



White solid; m.p.= 128.3-130.6 ℃; 65% yield;^{1}H NMR (400 MHz, $CDCl_3$) δ 8.3 (dt, *J* = 6.5, 3.2 Hz, 2H), 7.9 (dq, *J* = 6.4, 3.0 Hz, 2H), 4.6 (q, *J* = 7.1 Hz, 4H), 1.5 (t, *J* = 7.2 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.7, 144.1, 141.3, 132.4, 129.8, 62.8, 14.0.

HRMS-ESI (m/z): calcd for $C_{14}H_{15}N_2O_4^+$ $[M+H]^+$ 275.1026, found 275.1027

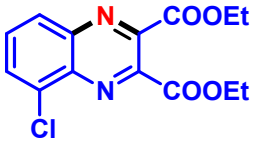
diethyl 6-chloroquinoxaline-2,3-dicarboxylate (3dd)



Brown solid; m.p.= 118.6-120.7 ℃; 69% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.16 – 7.07 (m, 2H), 6.63 – 6.56 (m, 2H), 4.25 – 4.11 (m, 4H), 1.25 (t, *J* = 7.2 Hz, 6H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.5, 164.4, 145.3, 144.0, 141.6, 139.9, 138.7, 133.5, 131.0, 128.6, 63.0, 14.1,14.0.

HRMS-ESI (m/z): calcd for $C_{14}H_{14}ClN_2O_4^+$ $[M+H]^+$ 309.0637, found 309.0638

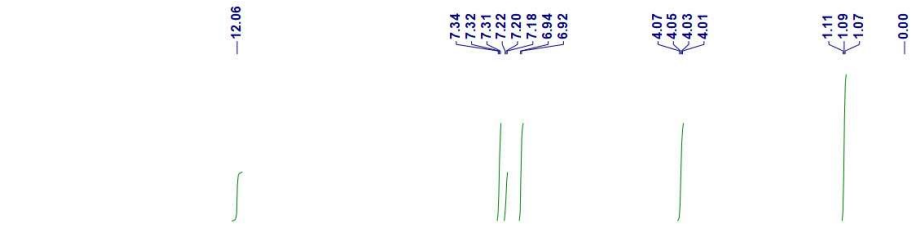
diethyl 5-chloroquinoxaline-2,3-dicarboxylate (3dg)

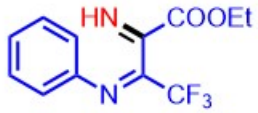


Brown solid; m.p.= 90.5-92.7 ℃; 67% yield; ^{1}H NMR (400 MHz, $CDCl_3$) δ 8.2 (dd, *J* = 8.4, 1.2 Hz, 0H), 8.0 (dd, *J* = 7.6, 1.4 Hz, 0H), 7.8 (dd, *J* = 8.4, 7.6 Hz, 0H), 4.6 (q, *J* = 7.2 Hz, 1H), 1.5 (t, *J* = 7.2 Hz, 1H). ^{13}C NMR (100 MHz, $CDCl_3$) δ 164.5, 164.3, 144.8, 144.4, 142.2, 138.3, 134.0, 132.3, 132.0, 128.8, 63.0, 62.9, 14.1, 14.0.

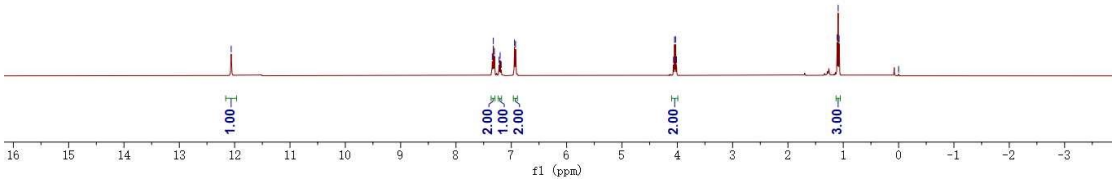
HRMS-ESI (m/z): calcd for $C_{14}H_{14}ClN_2O_4^+$ $[M+H]^+$ 309.0637, found 309.0639

7. NMR spectra of products

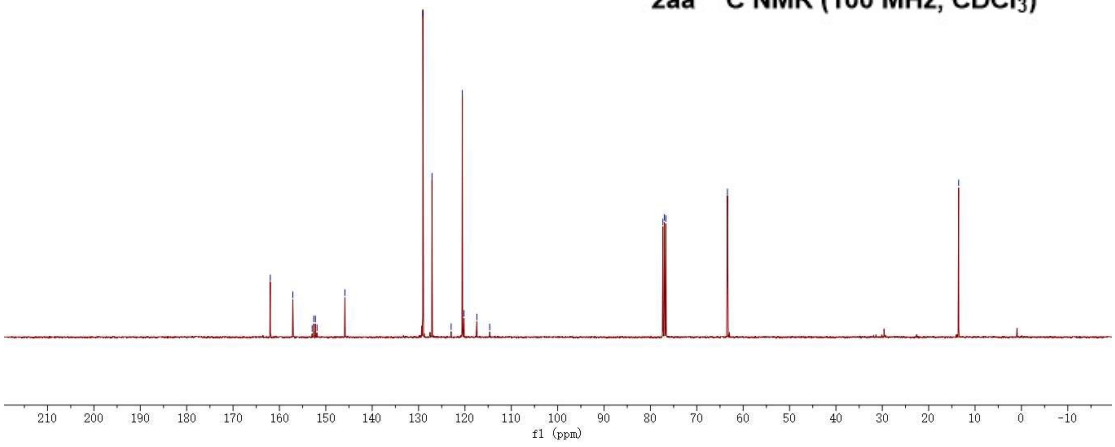


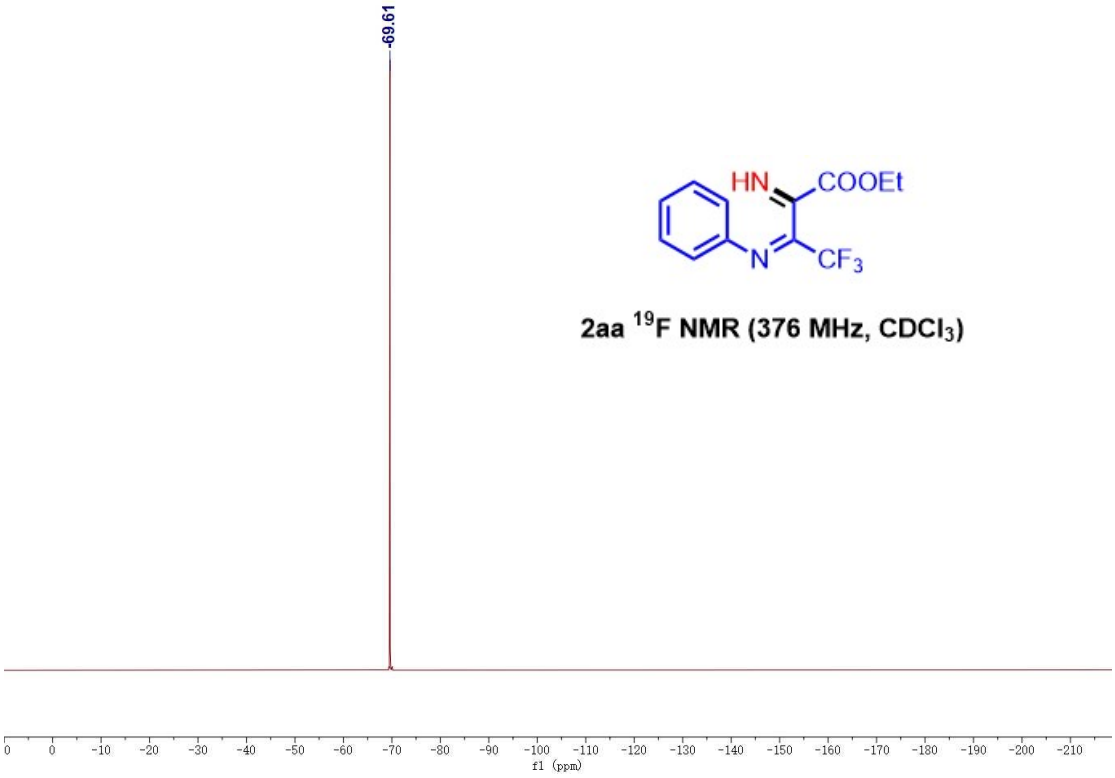


2aa ^{1}H NMR (400 MHz, $CDCl_3$)

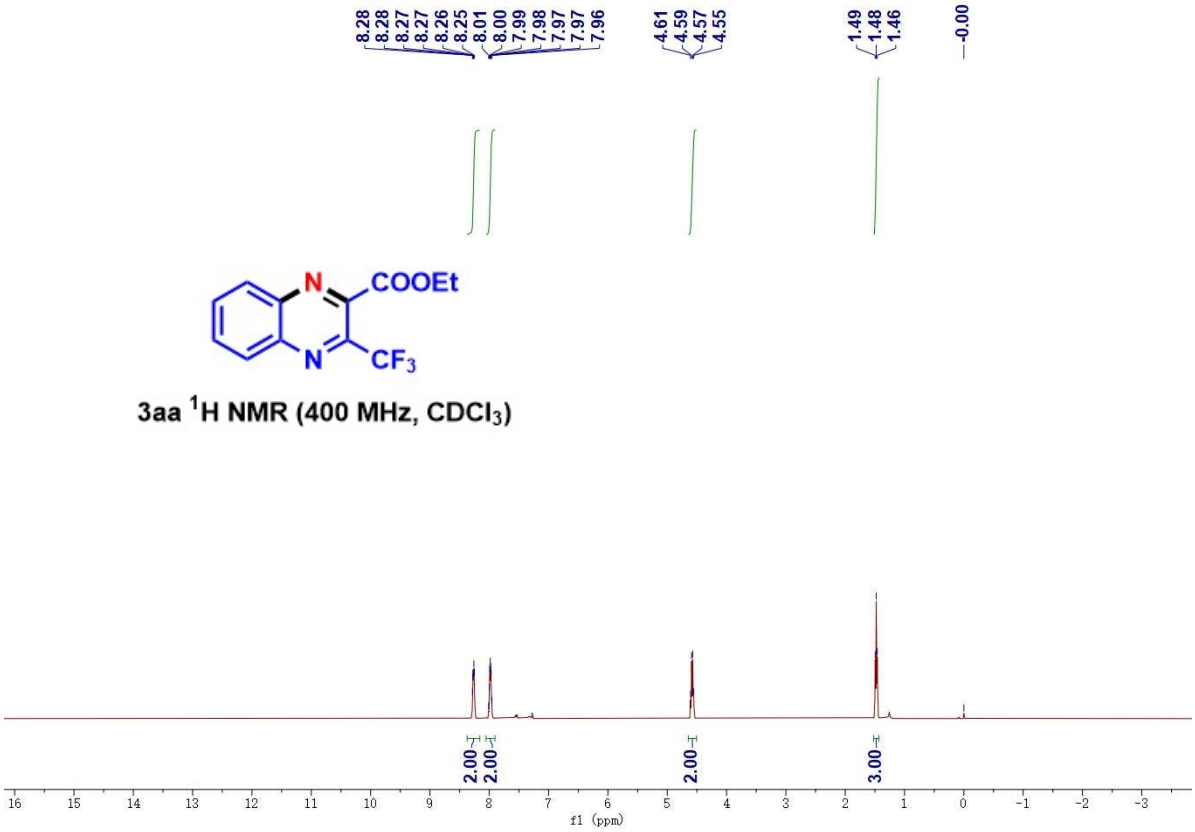


2aa ^{13}C NMR (100 MHz, $CDCl_3$)

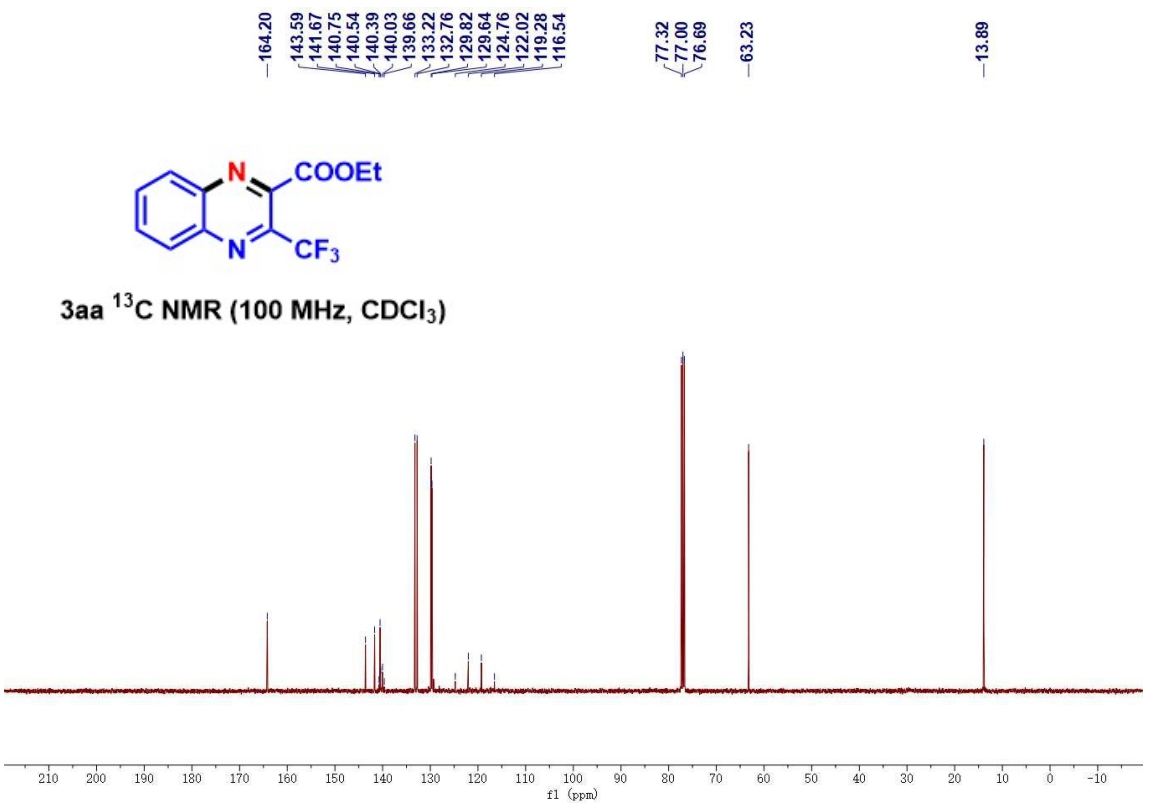


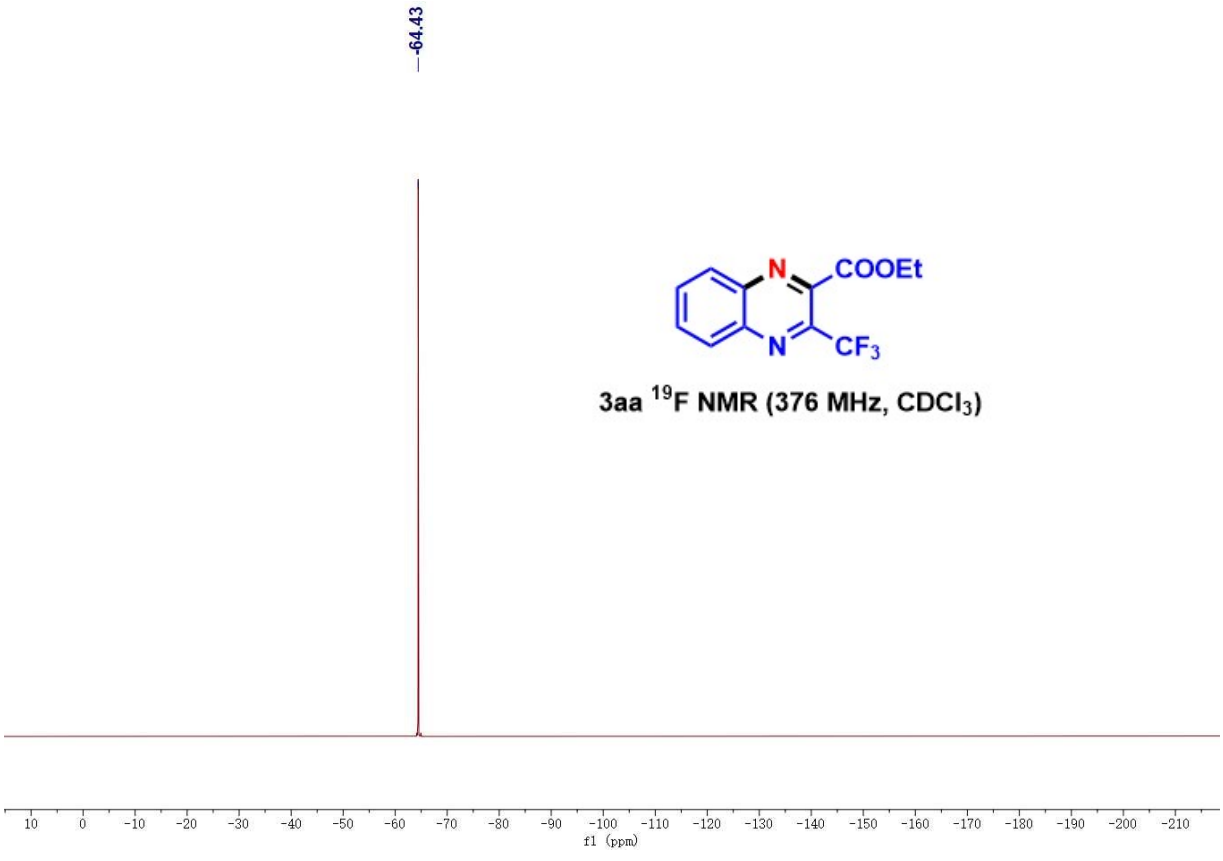


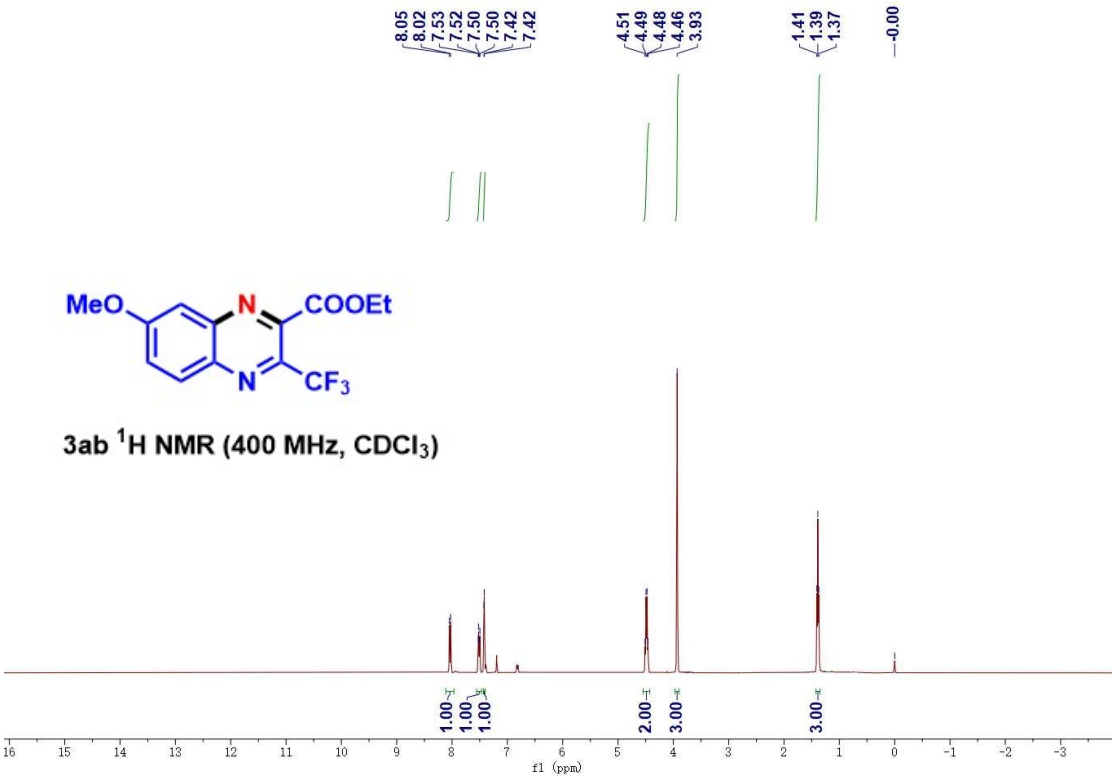
2aa ^{19}F NMR (376 MHz, $CDCl_3$)

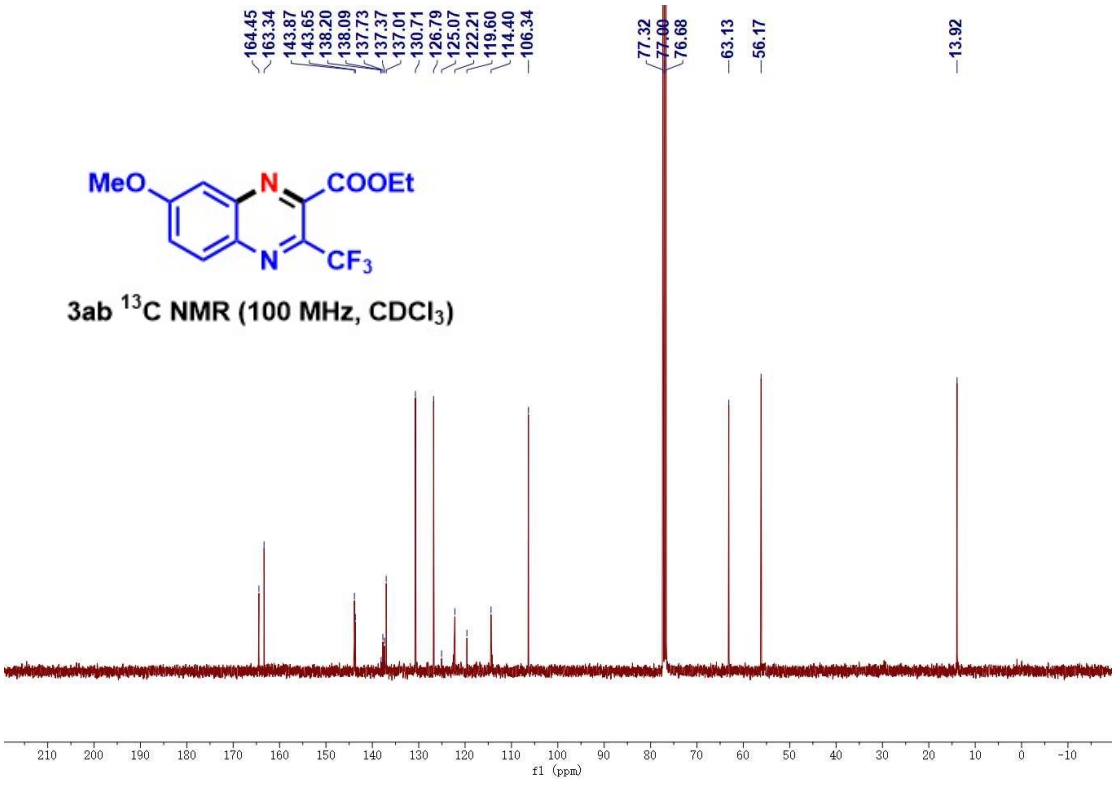


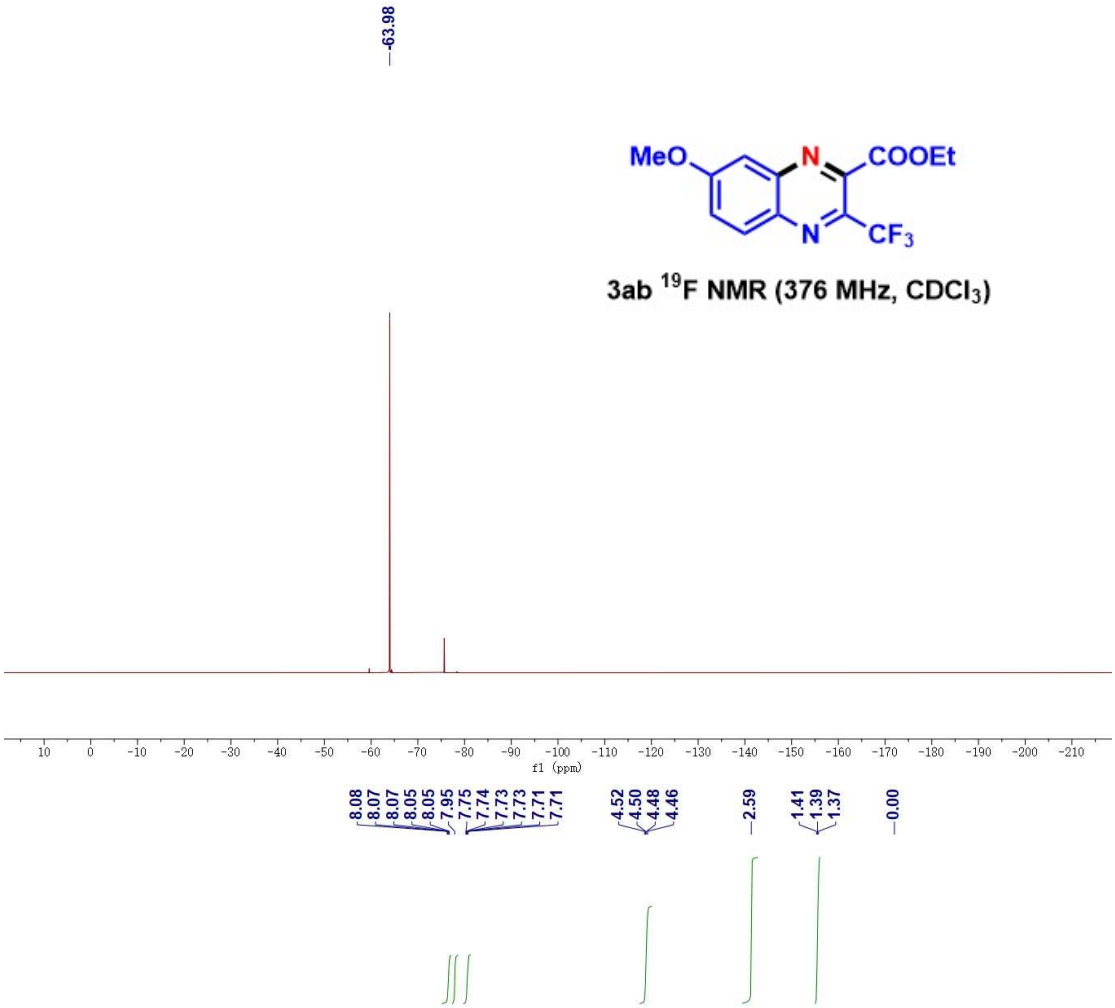
3aa ^{1}H NMR (400 MHz, $CDCl_3$)


164.20
143.59
141.67
140.75
140.54
140.39
140.03
139.66
133.22
132.76
129.82
129.64
124.76
122.02
119.28
116.54
77.32
77.00
76.69
63.23
13.89
COOEt
CF3
3aa 13C NMR (100 MHz, CDCl3)
f1 (ppm)

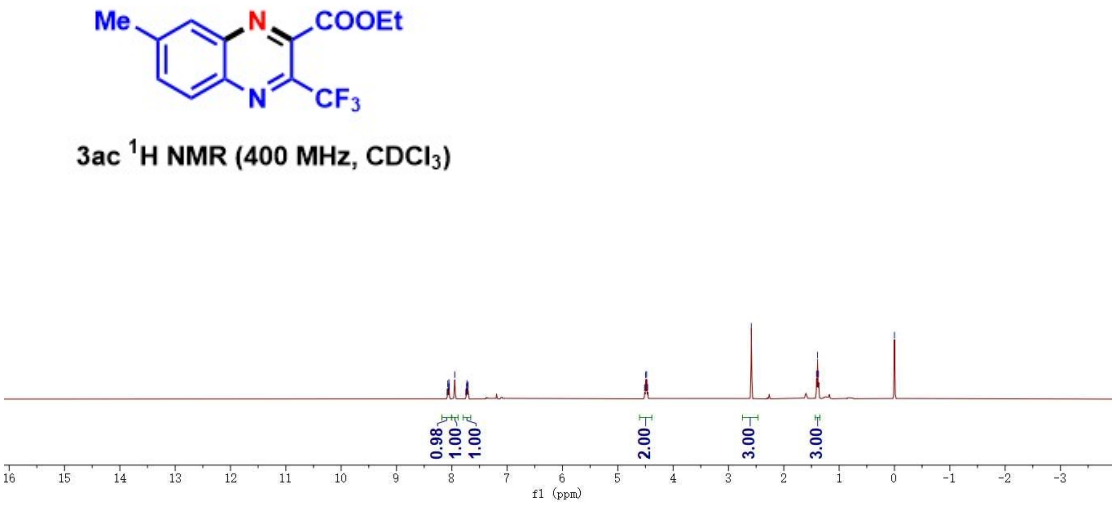

-64.43
COOEt
CF3
3aa 19F NMR (376 MHz, CDCl3)
f1 (ppm)


8.05
8.02
7.53
7.52
7.50
7.50
7.42
7.42
4.51
4.49
4.48
4.46
3.93
1.41
1.39
1.37
0.00
MeO
N
COOEt
N
CF3
3ab 1H NMR (400 MHz, CDCl3)
1.00
1.00
1.00
2.00
3.00
3.00
f1 (ppm)

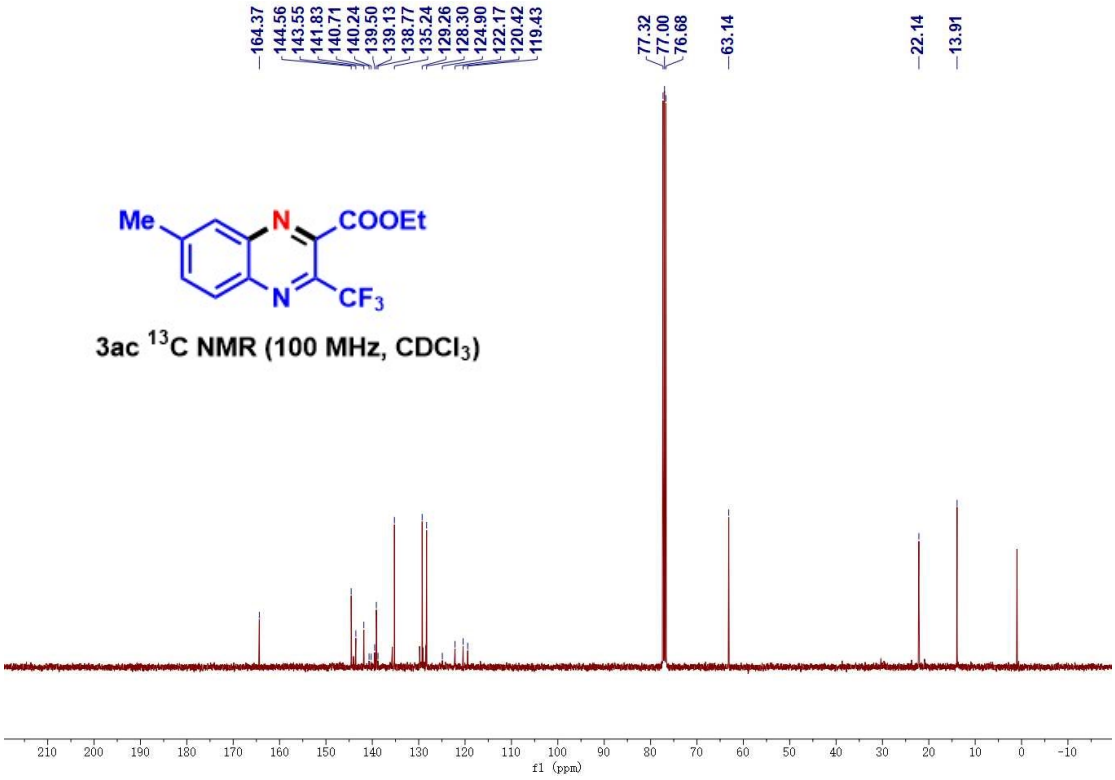

164.45
163.34
143.87
143.65
138.20
138.09
137.73
137.37
137.01
130.71
126.79
125.07
122.21
119.60
114.40
106.34
77.32
77.00
76.68
63.13
56.17
13.92
MeO
N
COOEt
N
CF3
3ab 13C NMR (100 MHz, CDCl3)
f1 (ppm)



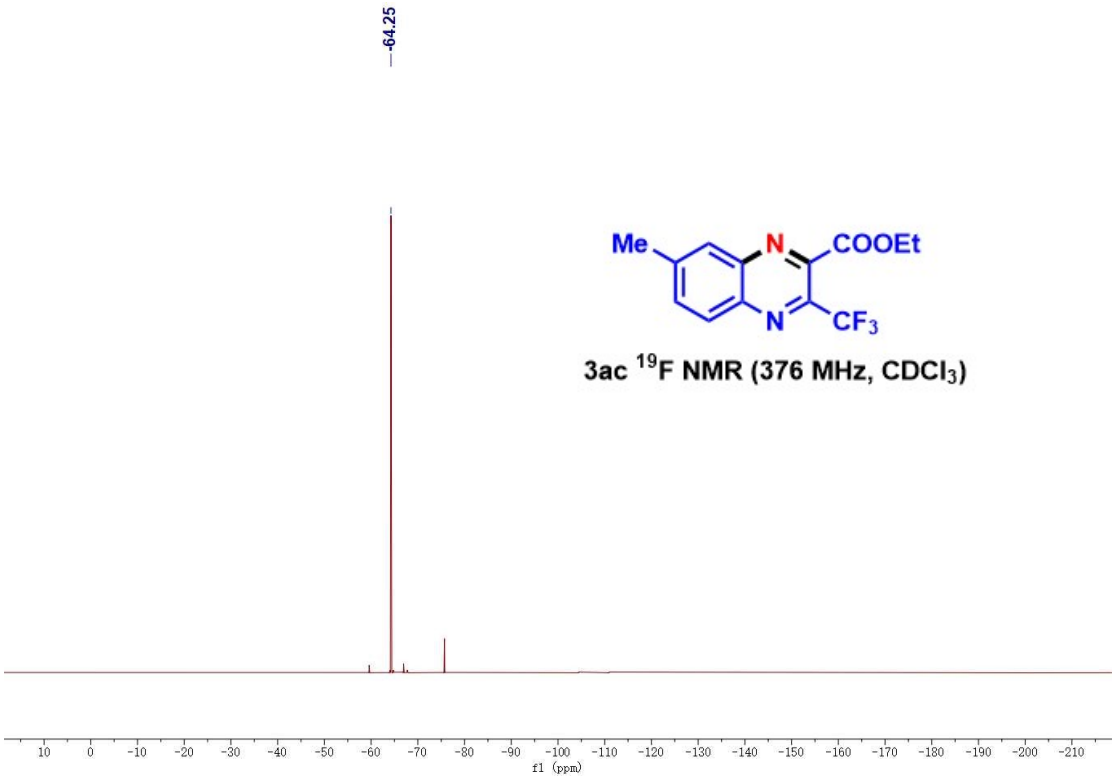
3ab ^{19}F NMR (376 MHz, $CDCl_3$)



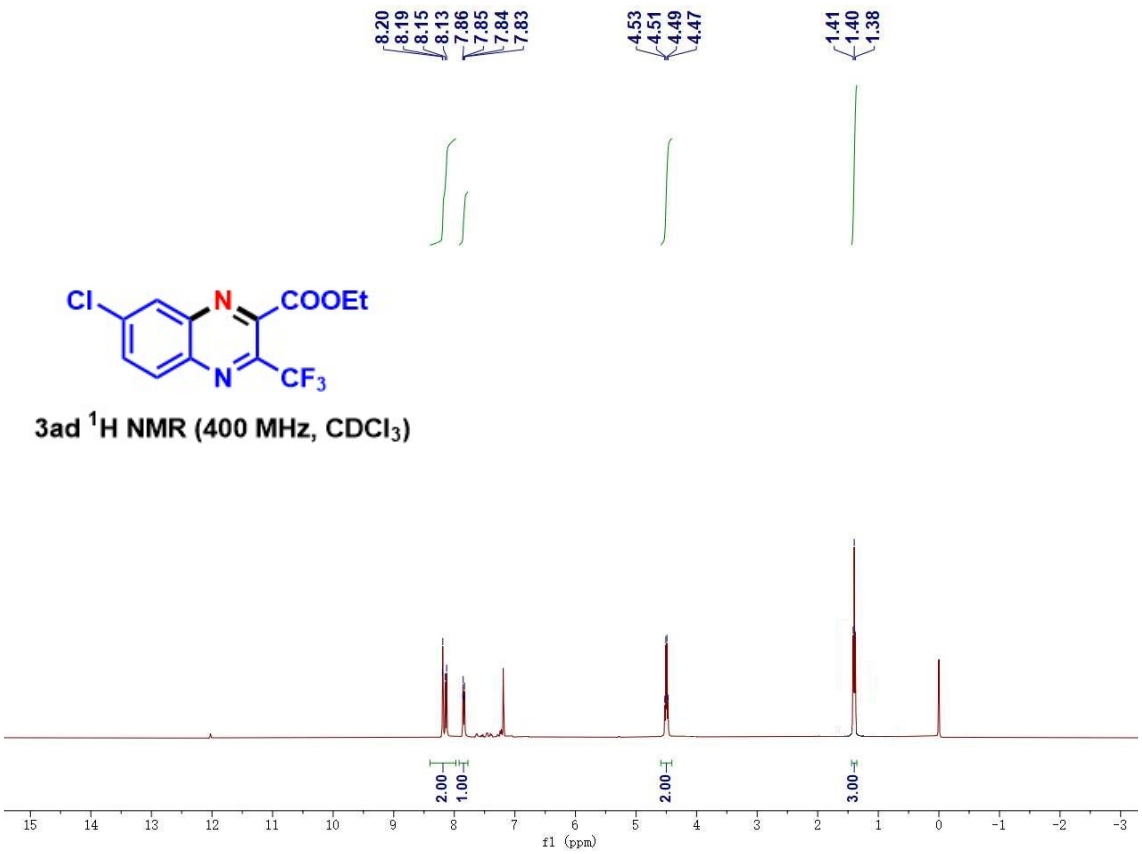
3ac ^{1}H NMR (400 MHz, $CDCl_3$)



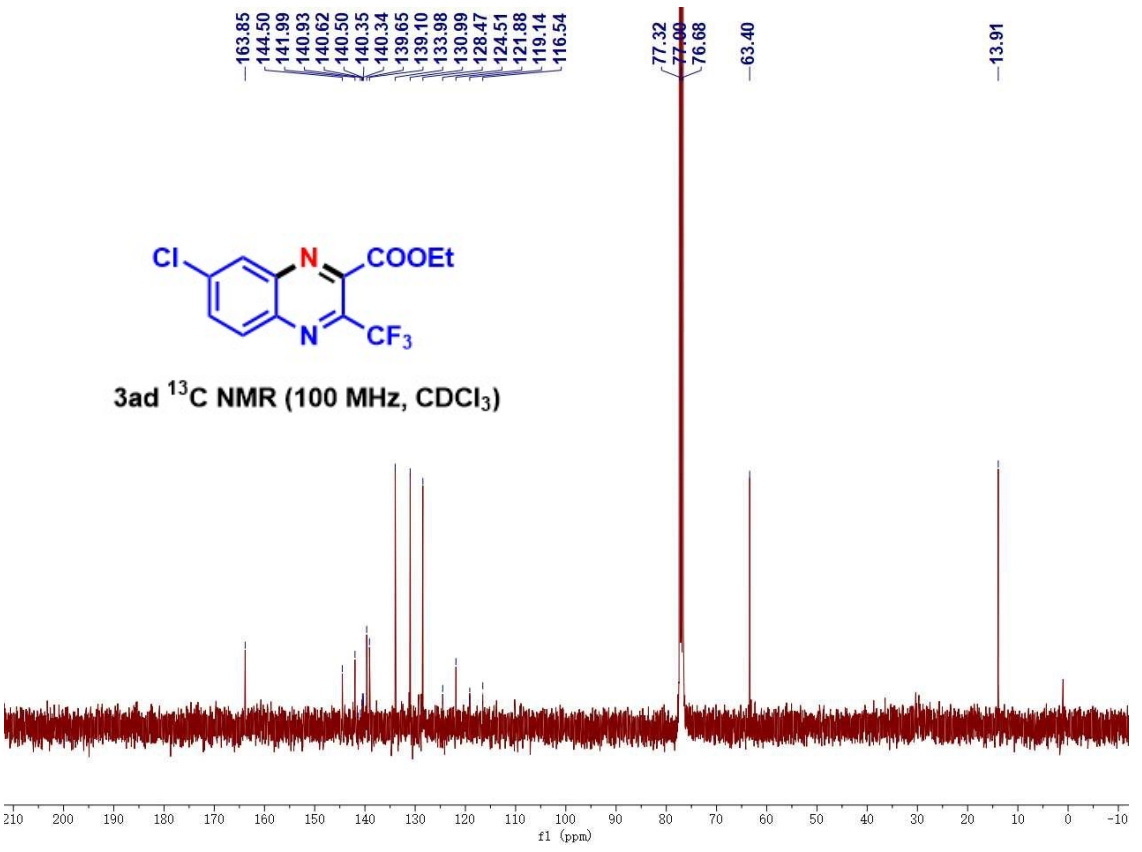
3ac ^{13}C NMR (100 MHz, $CDCl_3$)



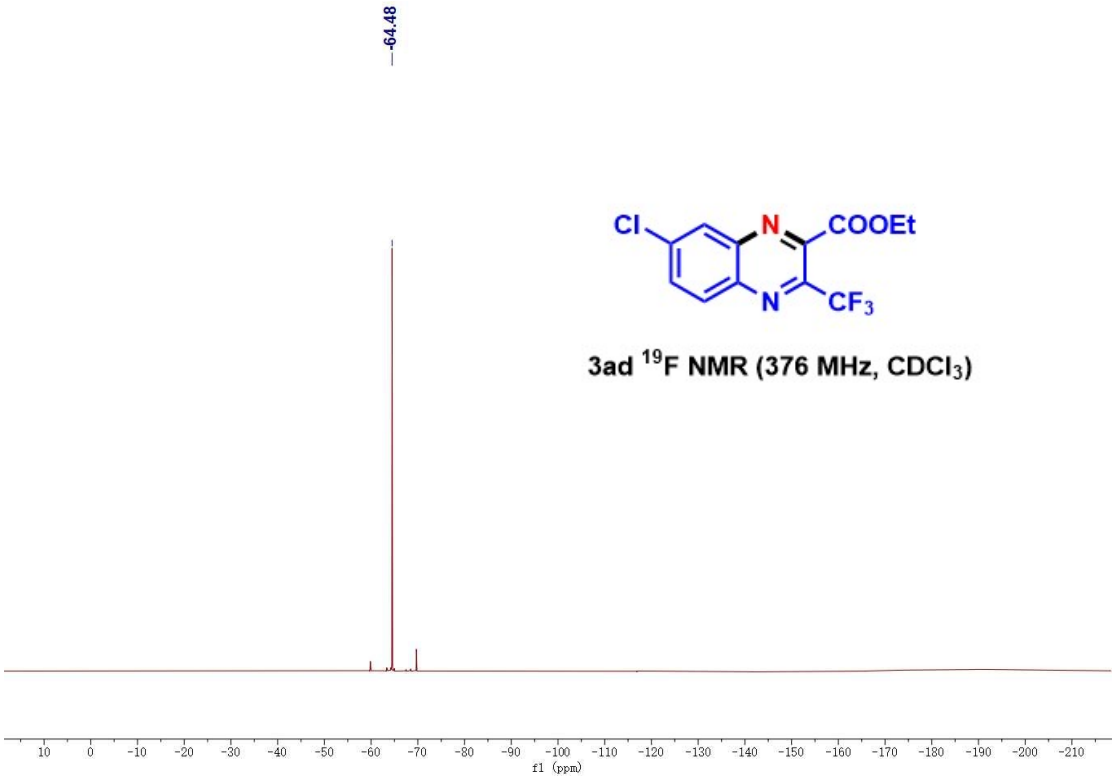
3ac ^{19}F NMR (376 MHz, $CDCl_3$)



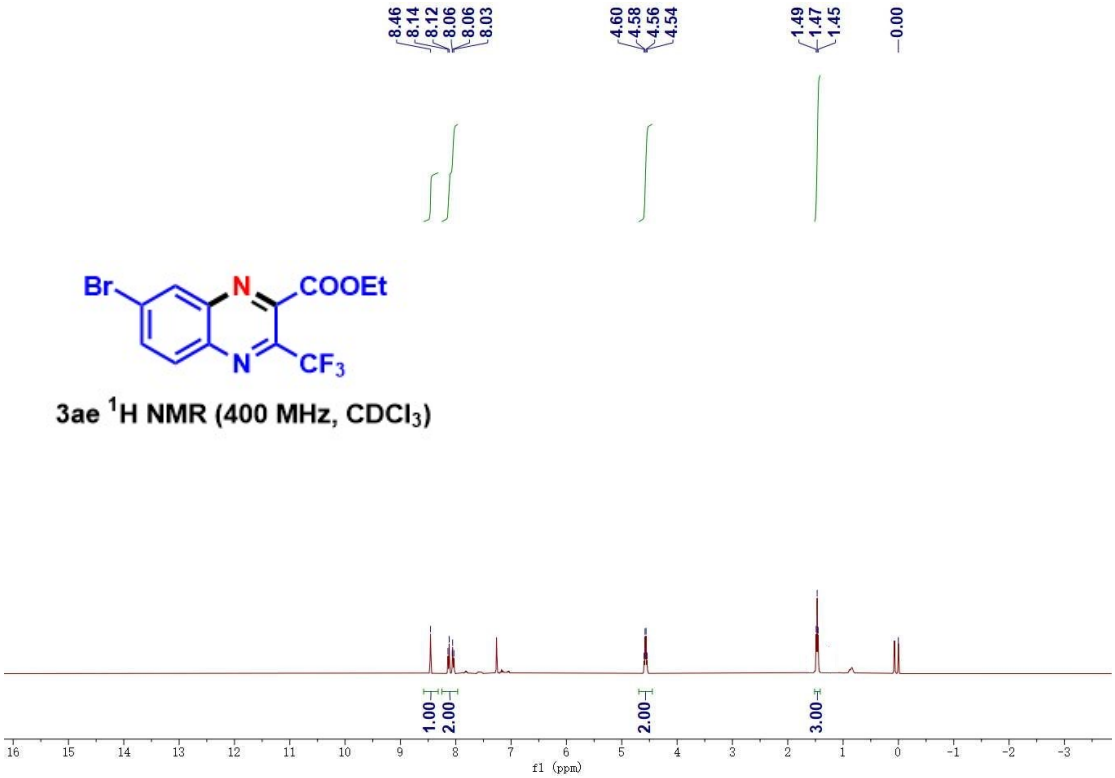
3ad ^{1}H NMR (400 MHz, $CDCl_3$)



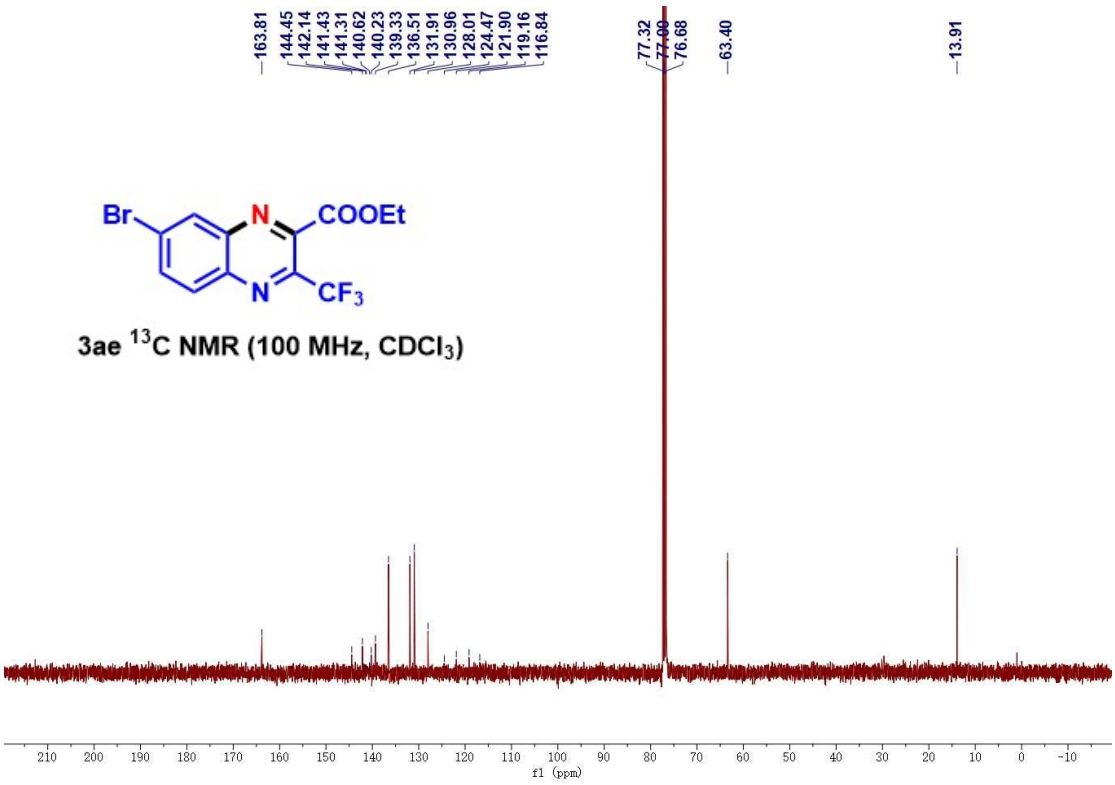
3ad ^{13}C NMR (100 MHz, $CDCl_3$)



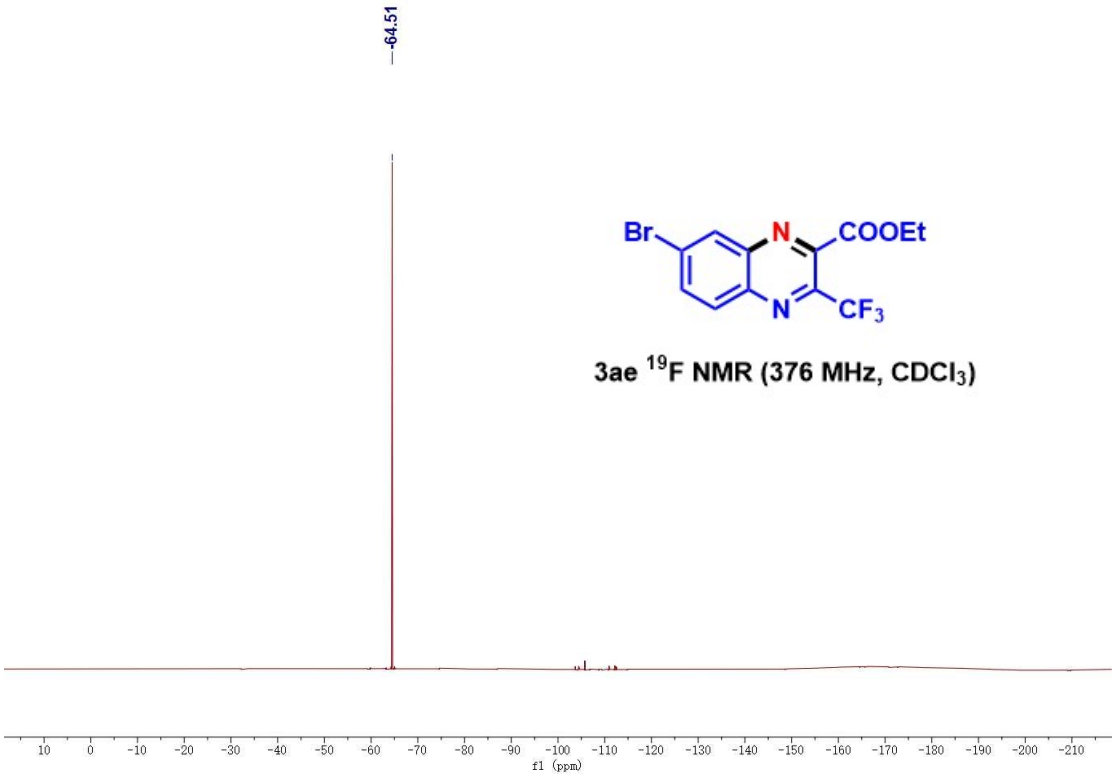
3ad ^{19}F NMR (376 MHz, $CDCl_3$)



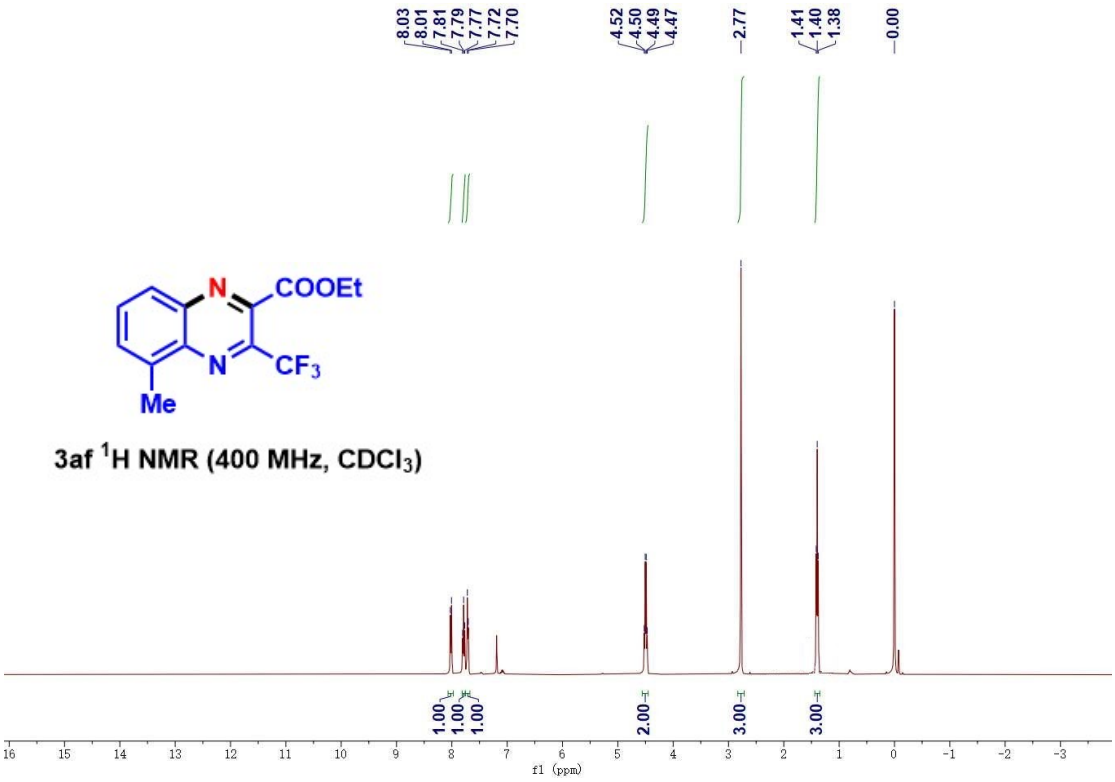
3ae ^{1}H NMR (400 MHz, $CDCl_3$)



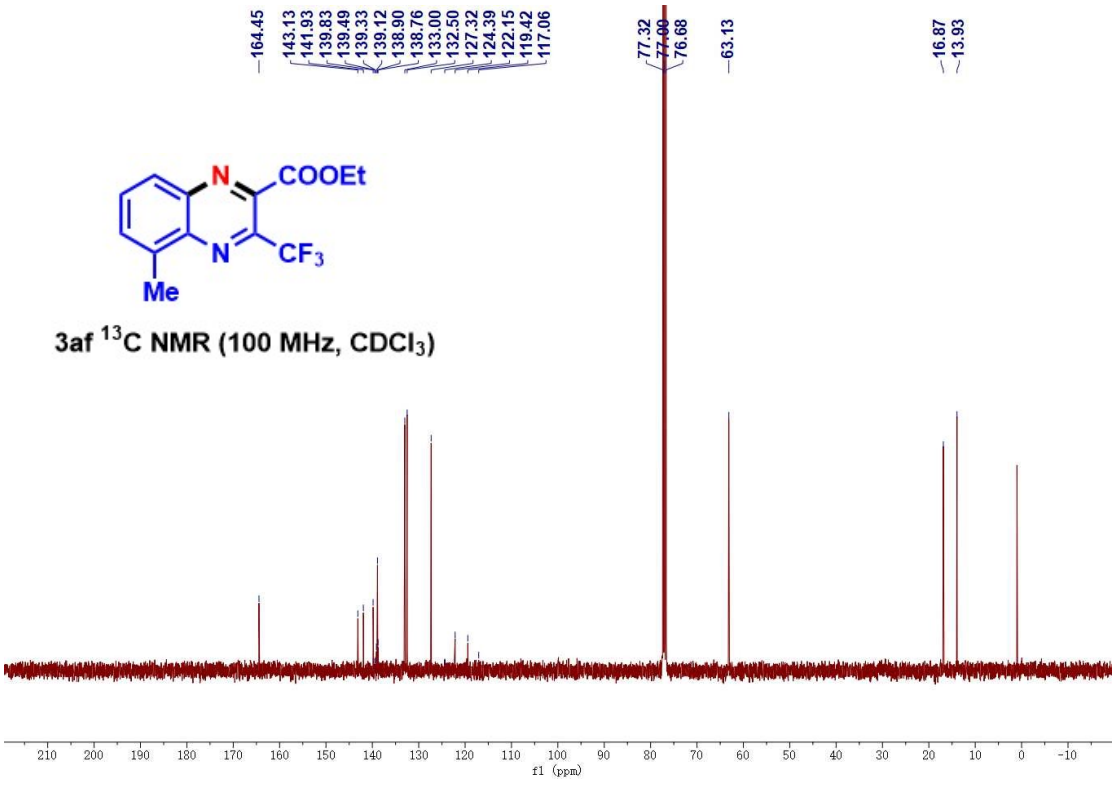
3ae ^{13}C NMR (100 MHz, $CDCl_3$)



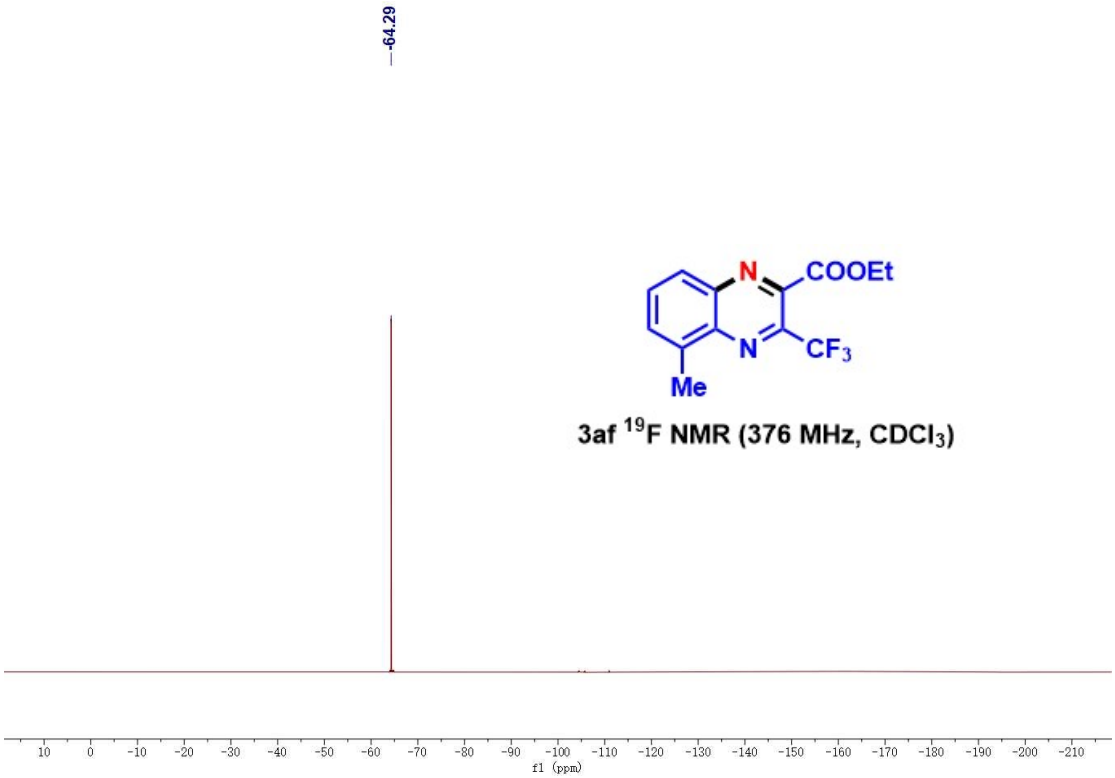
3ae ^{19}F NMR (376 MHz, $CDCl_3$)



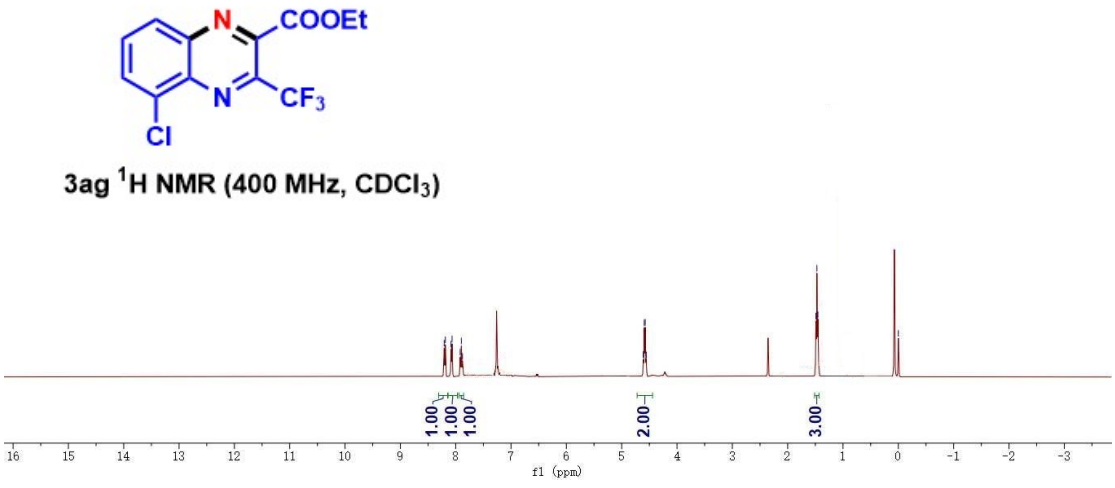
3af ^{1}H NMR (400 MHz, $CDCl_3$)



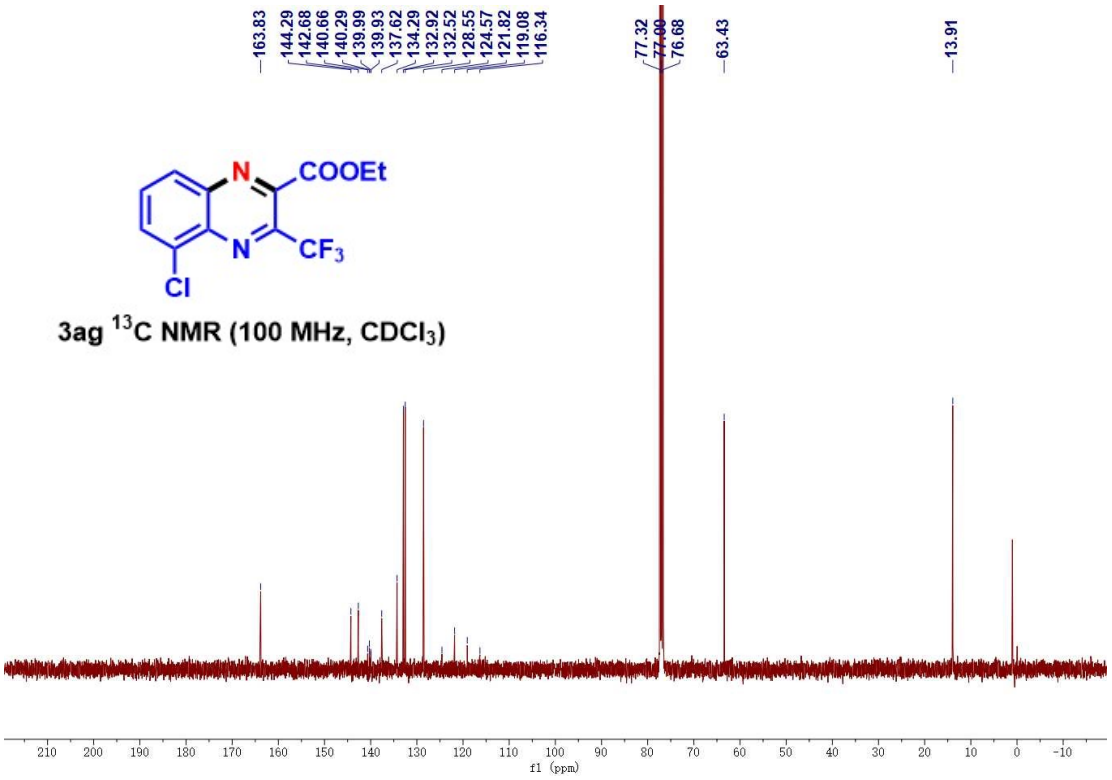
3af ^{13}C NMR (100 MHz, $CDCl_3$)



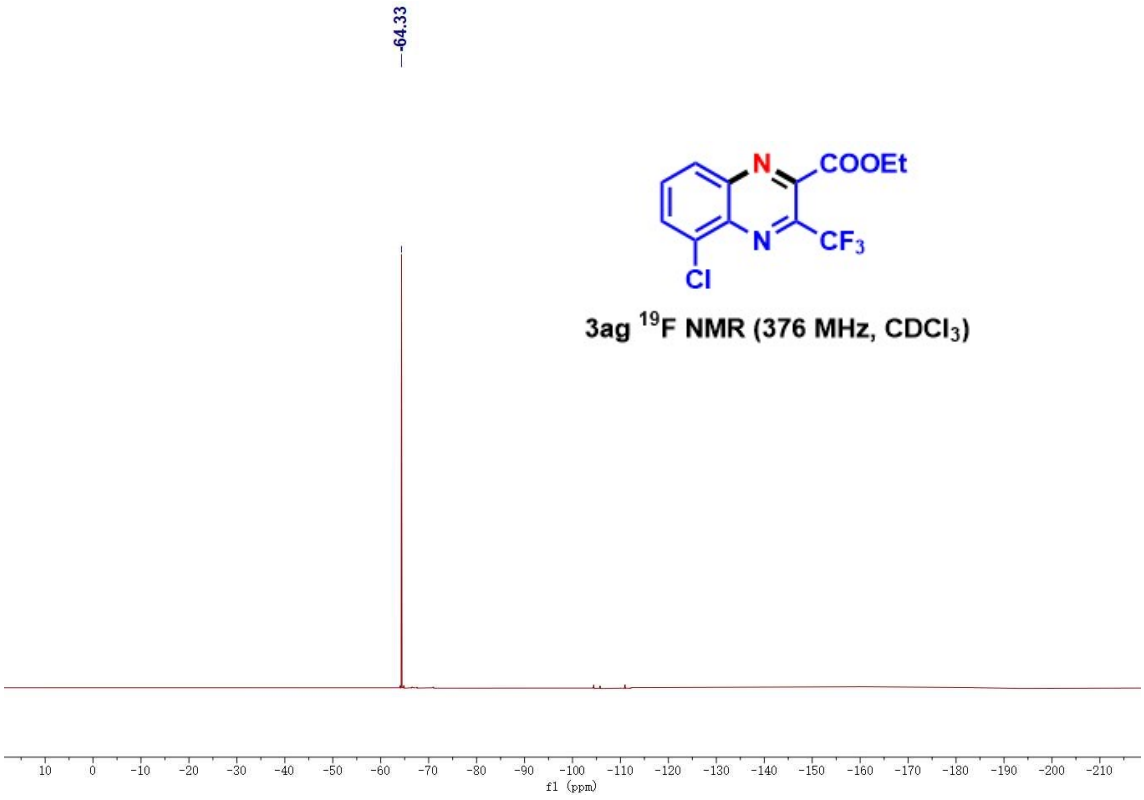
3af ^{19}F NMR (376 MHz, $CDCl_3$)



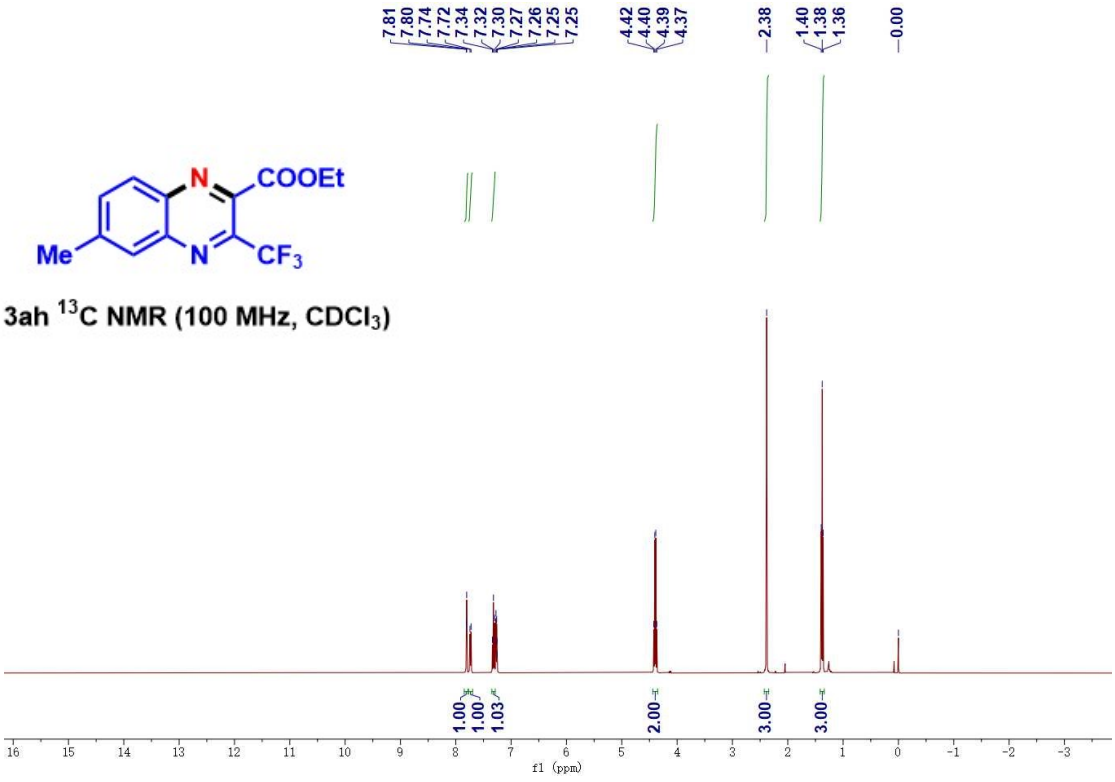
3ag ^{1}H NMR (400 MHz, $CDCl_3$)



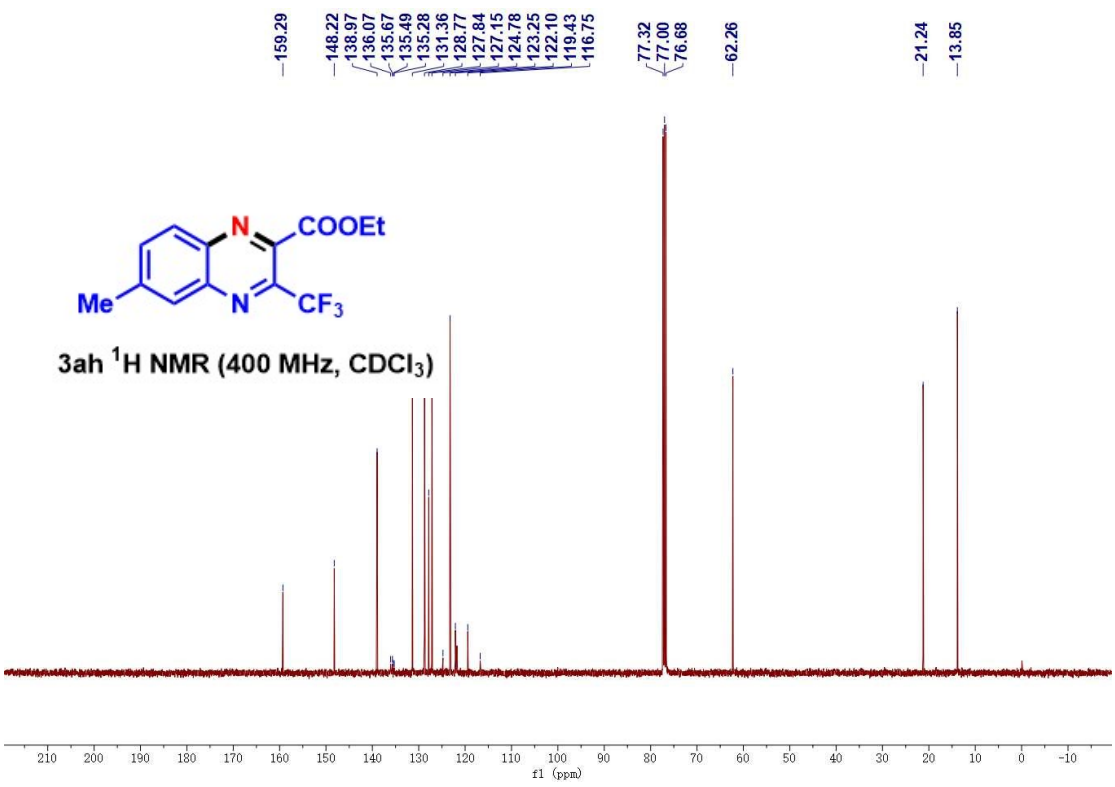
3ag ^{13}C NMR (100 MHz, $CDCl_3$)



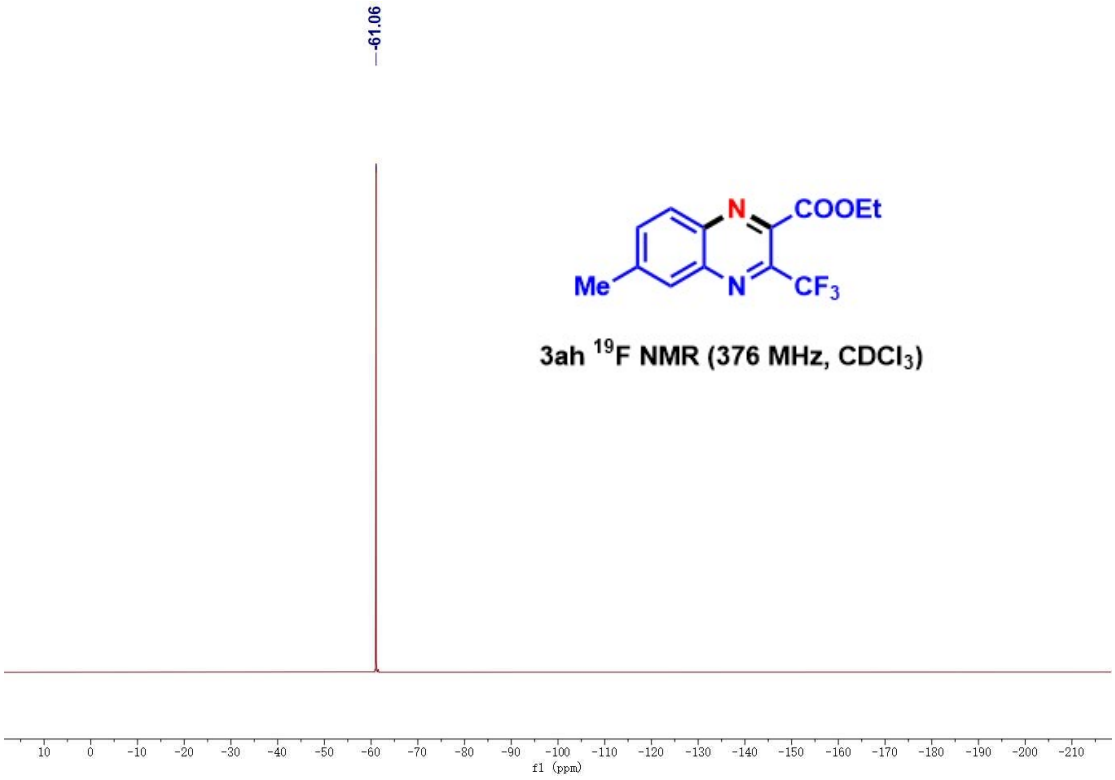
3ag ^{19}F NMR (376 MHz, $CDCl_3$)



3ah ^{13}C NMR (100 MHz, $CDCl_3$)



3ah ^{1}H NMR (400 MHz, $CDCl_3$)



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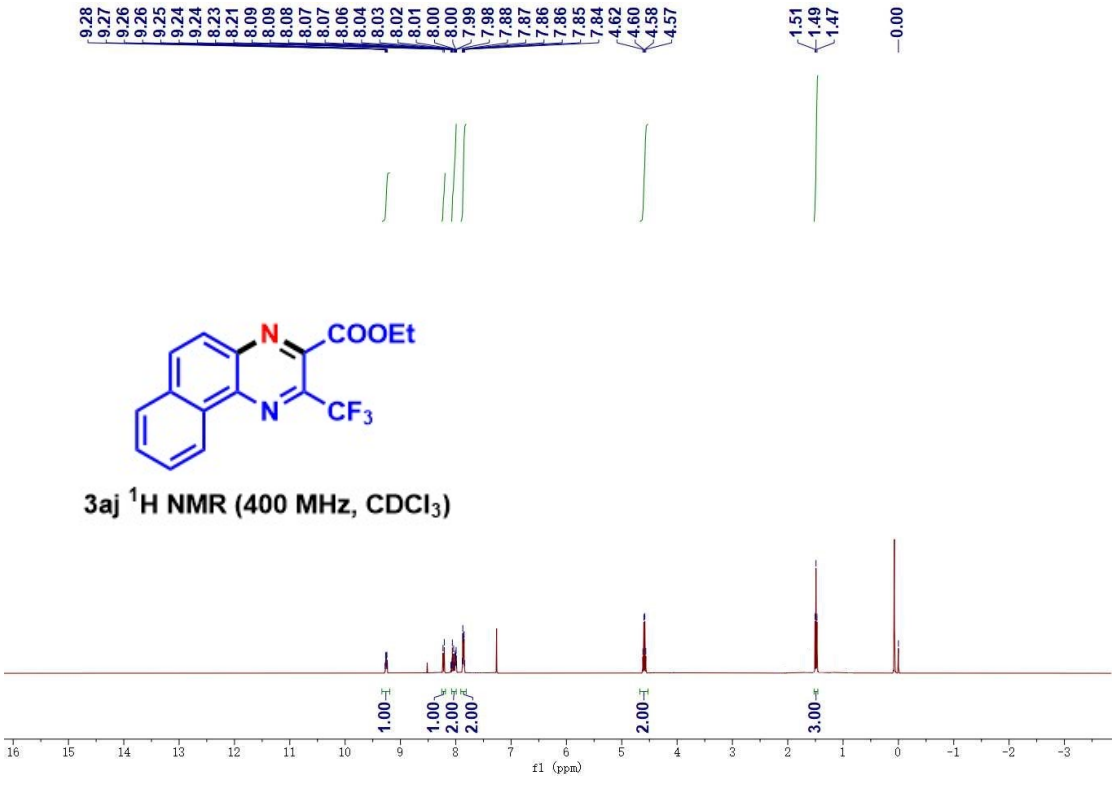
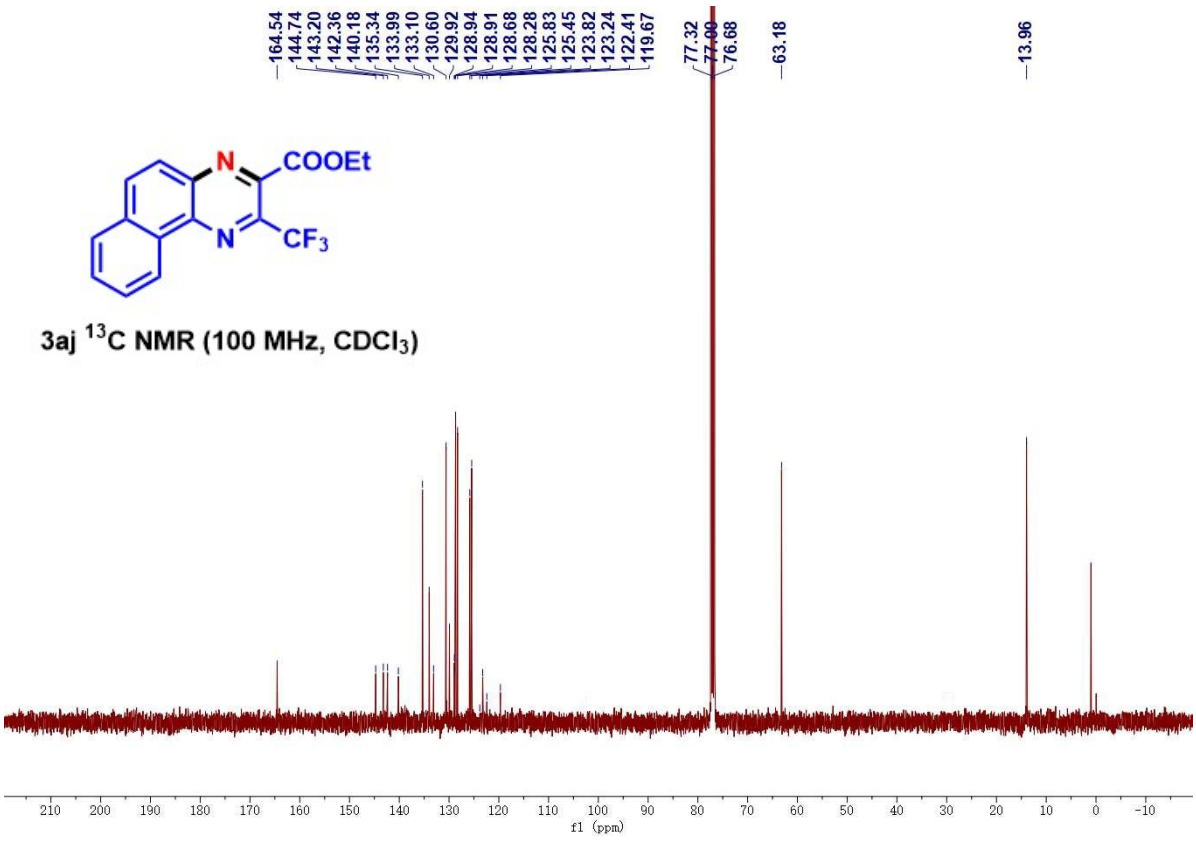
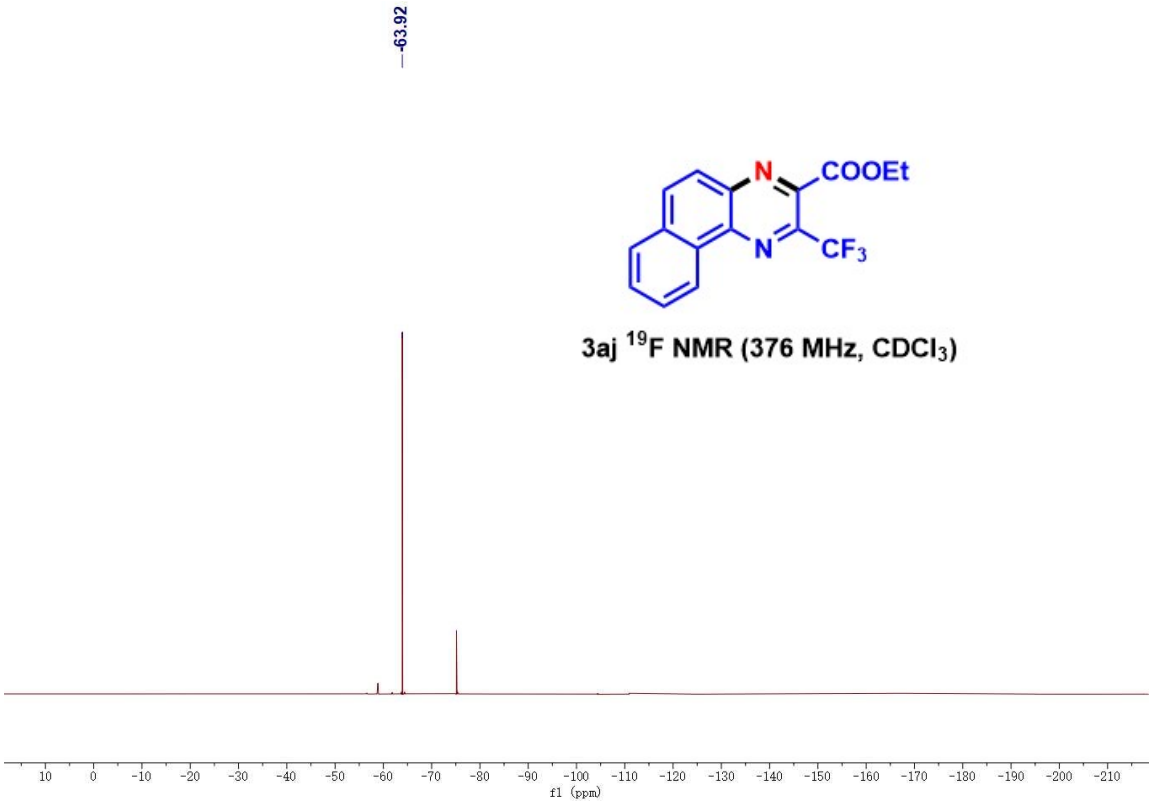


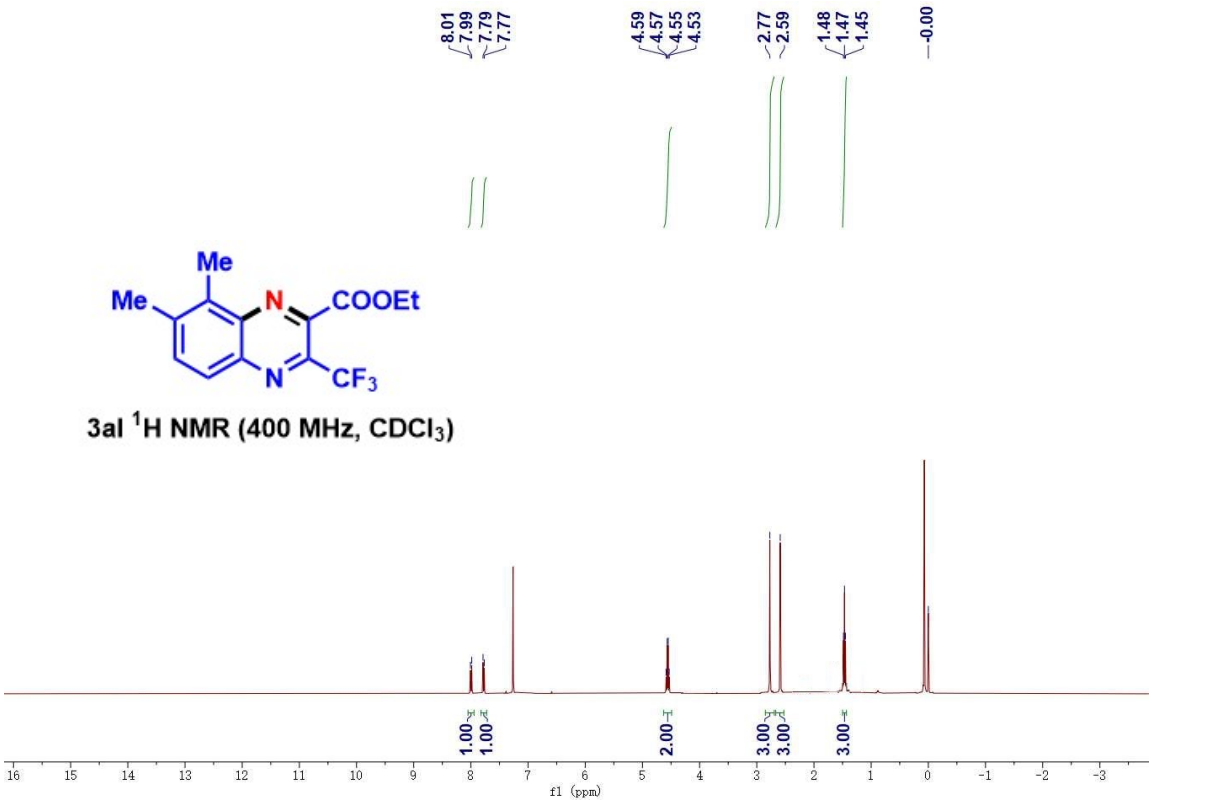
3aj ^{1}H NMR (400 MHz, $CDCl_3$)



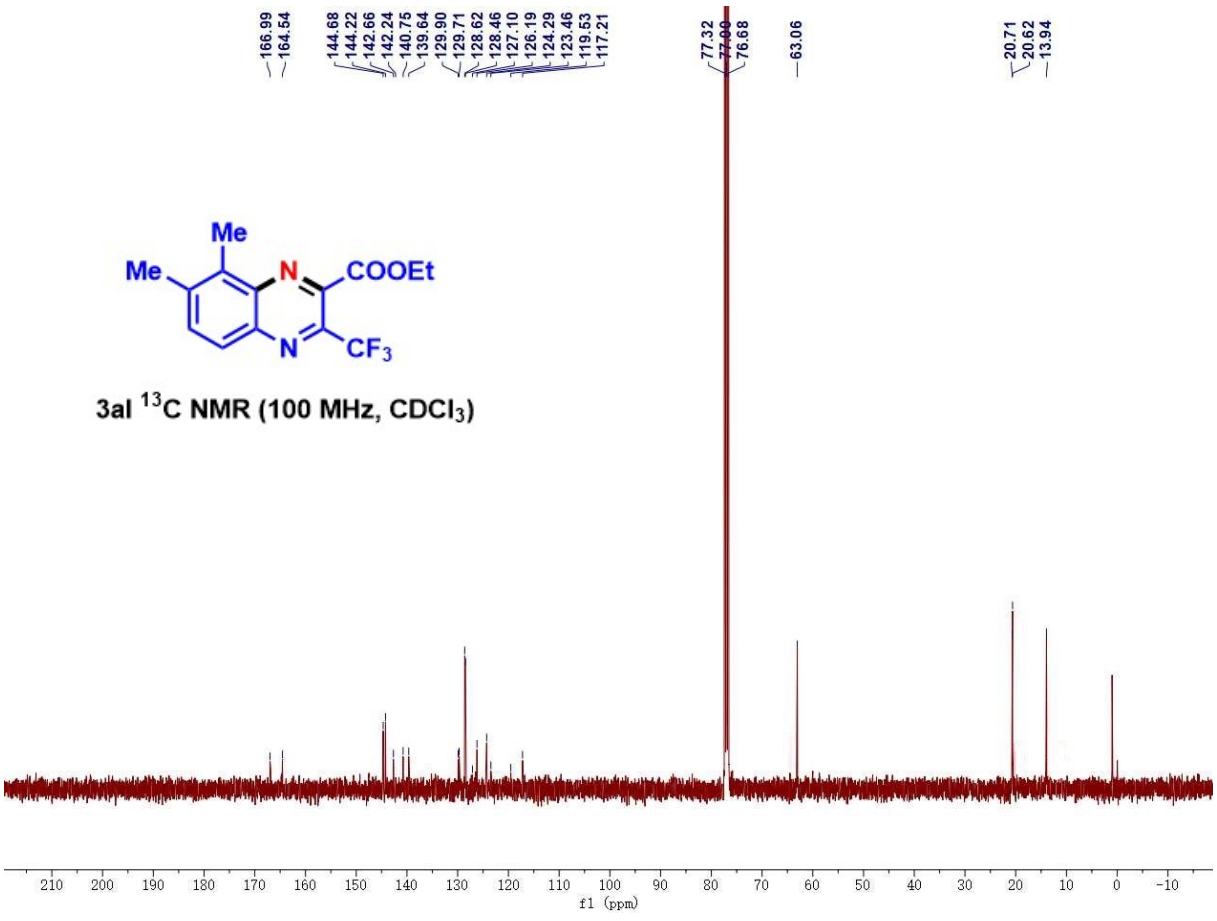
3aj ^{13}C NMR (100 MHz, $CDCl_3$)



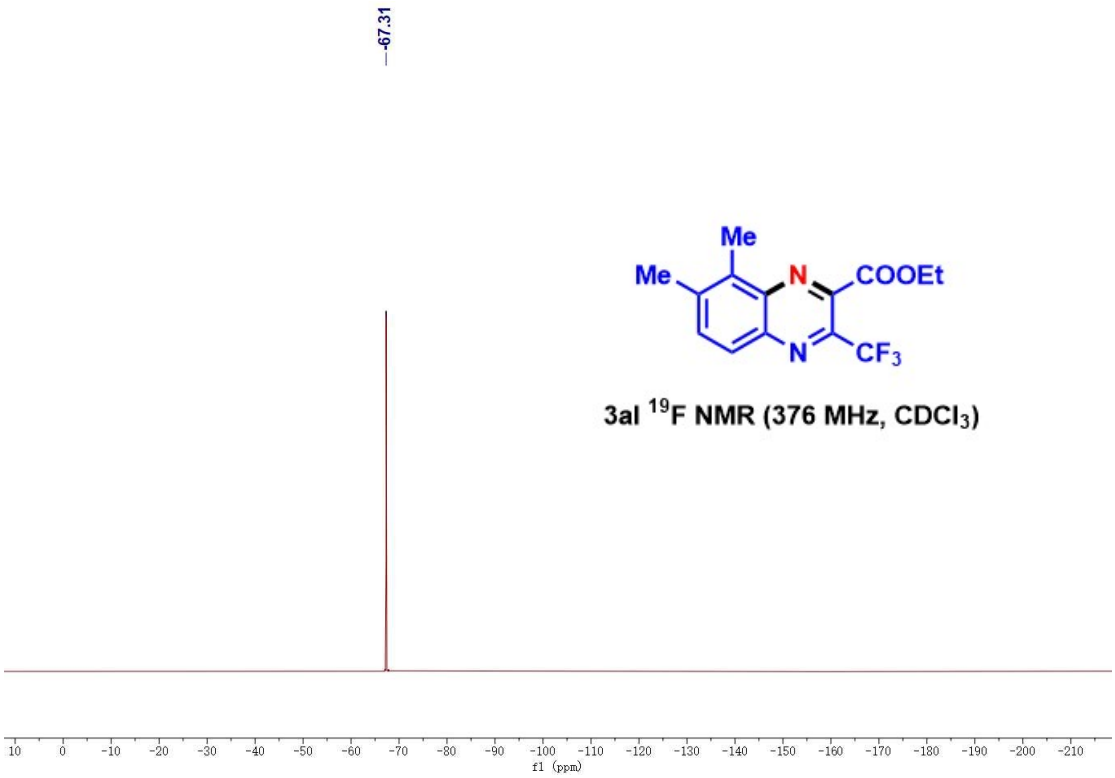
3aj ^{19}F NMR (376 MHz, $CDCl_3$)



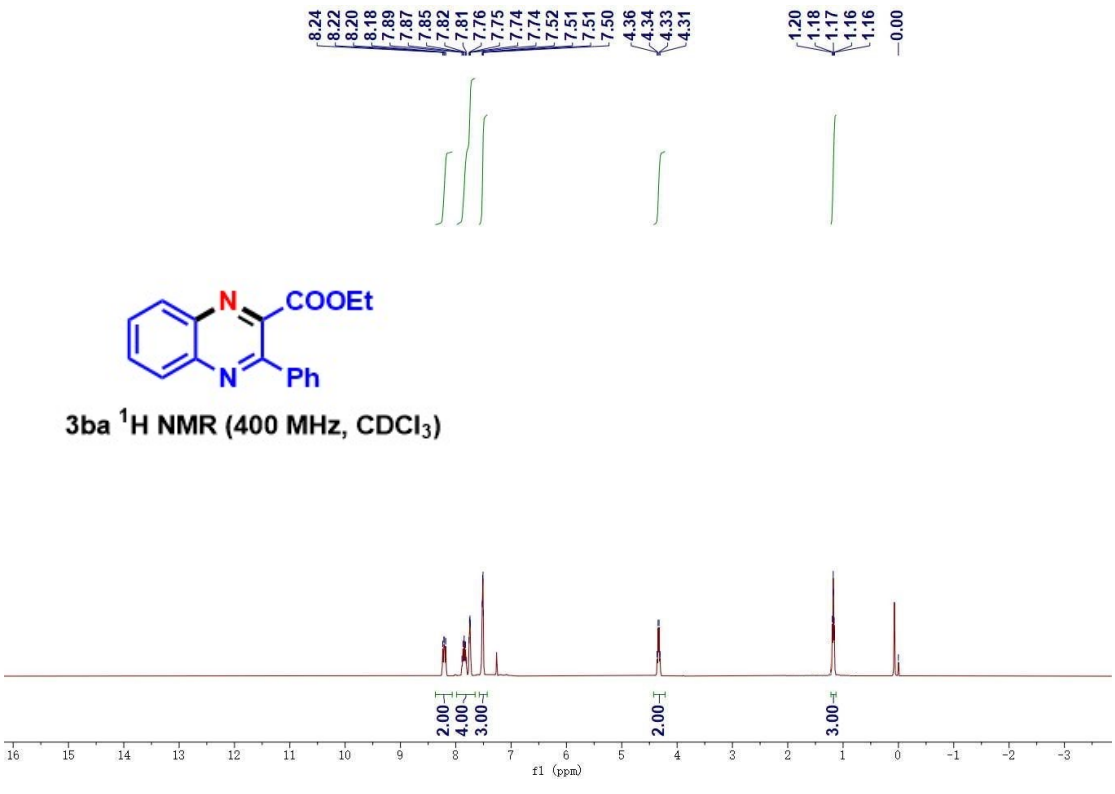
3al ^{1}H NMR (400 MHz, $CDCl_3$)



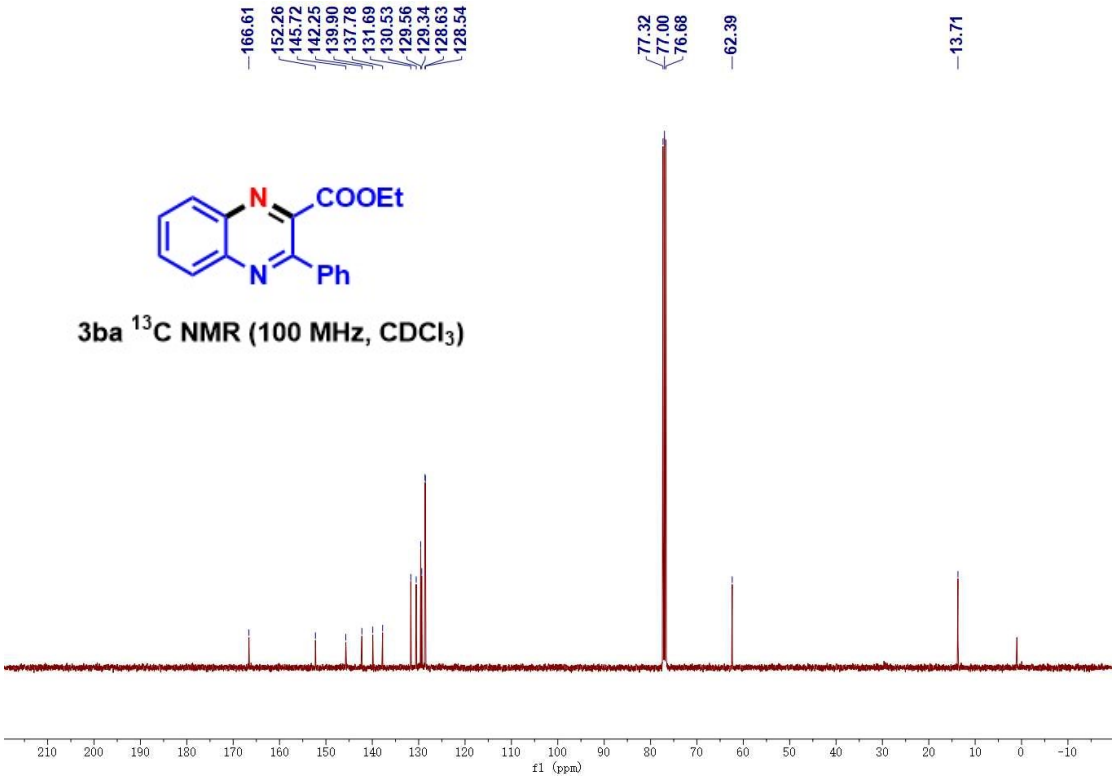
3al ^{13}C NMR (100 MHz, $CDCl_3$)



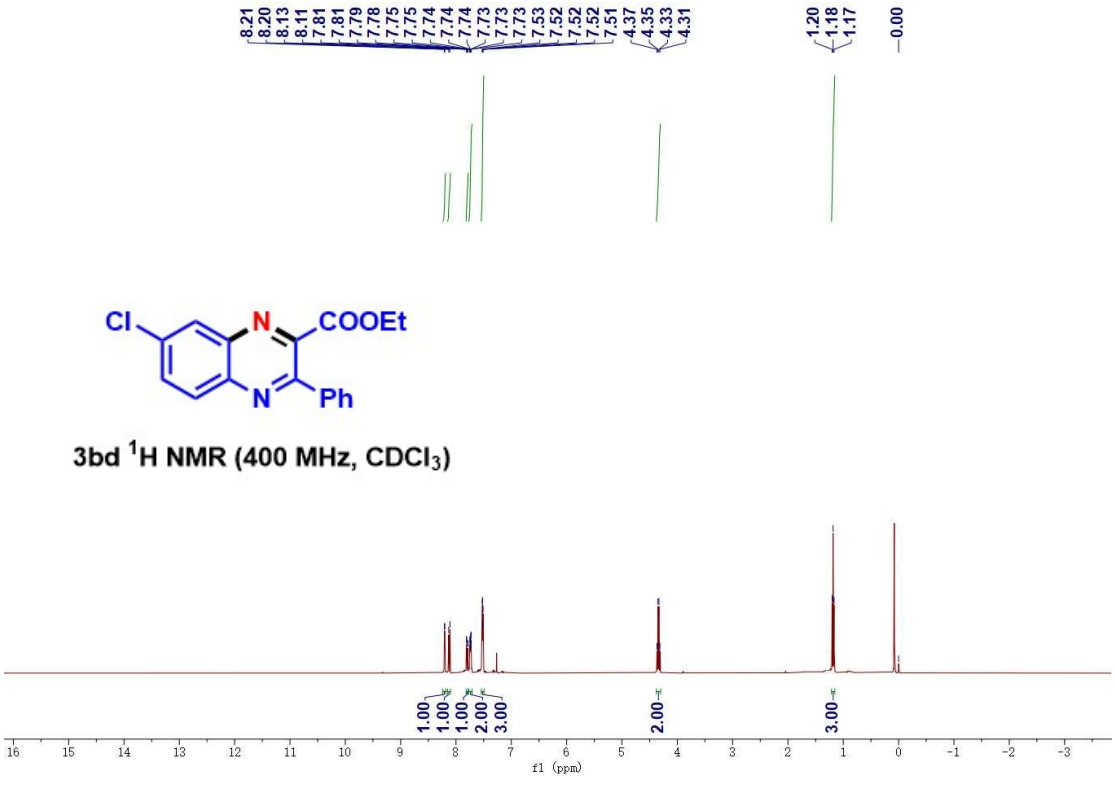
3al ^{19}F NMR (376 MHz, $CDCl_3$)



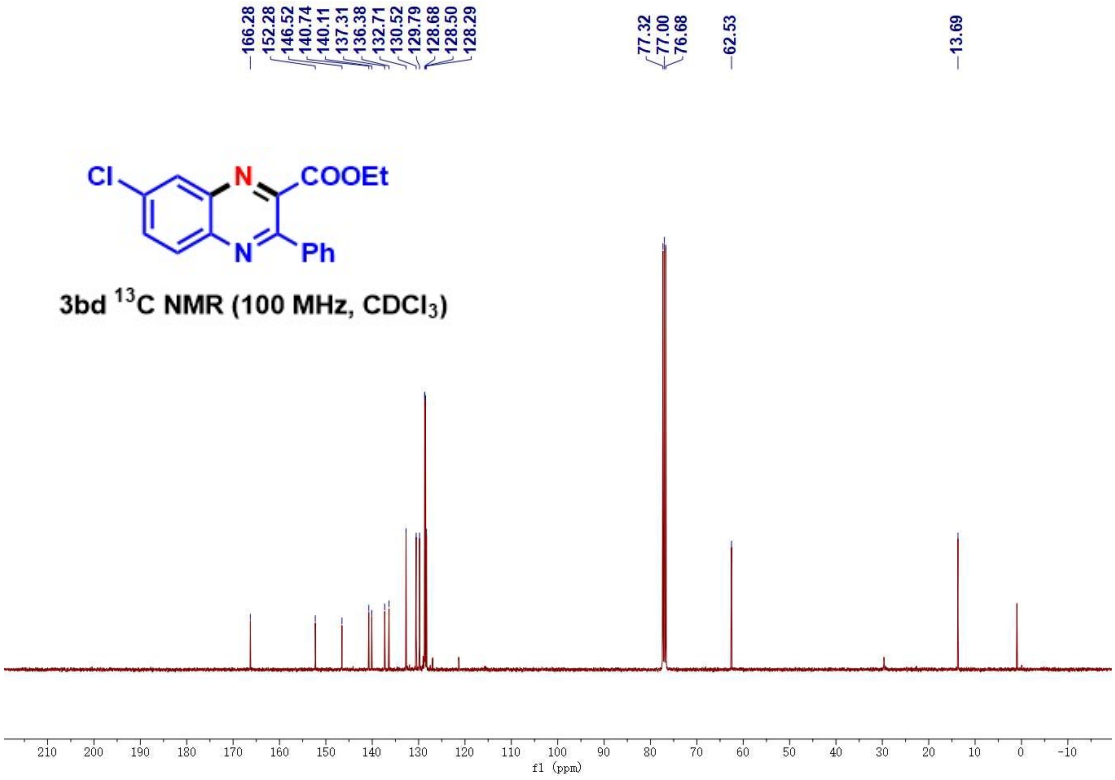
3ba ^{1}H NMR (400 MHz, $CDCl_3$)



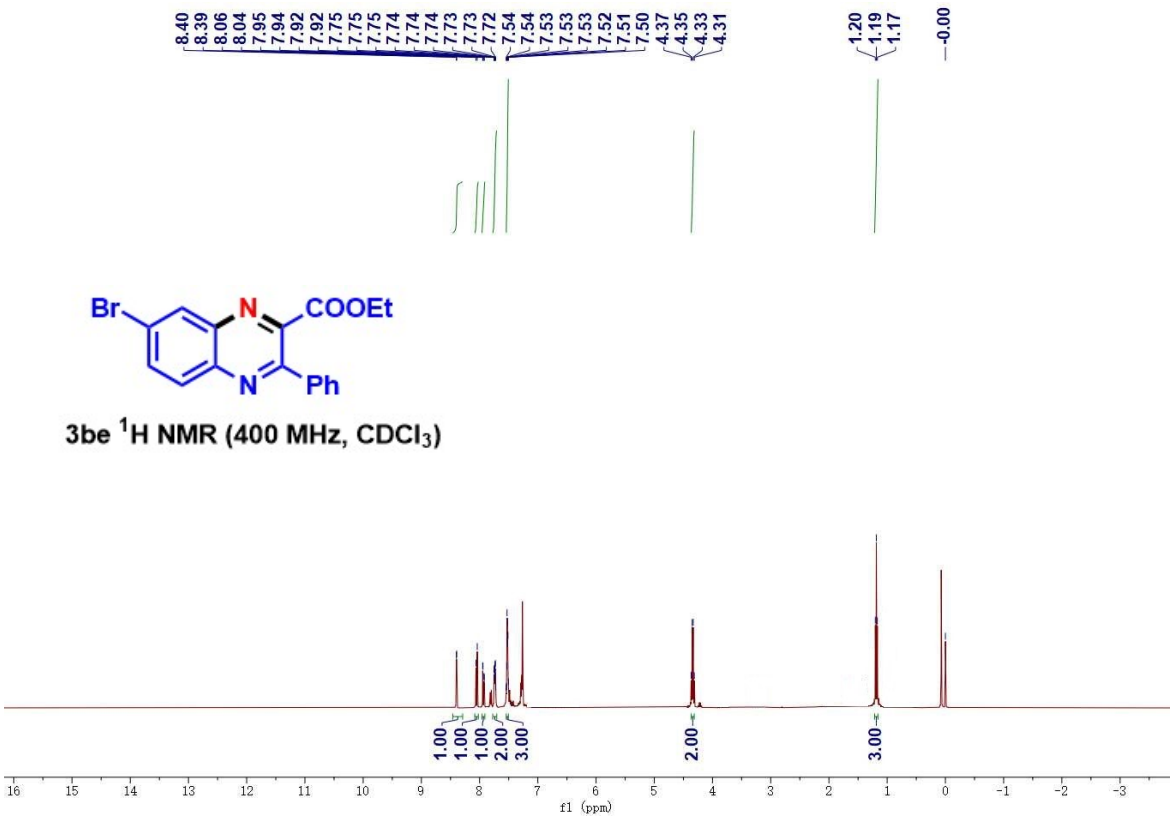
3ba ^{13}C NMR (100 MHz, $CDCl_3$)



3bd ^{1}H NMR (400 MHz, $CDCl_3$)



3bd ^{13}C NMR (100 MHz, $CDCl_3$)



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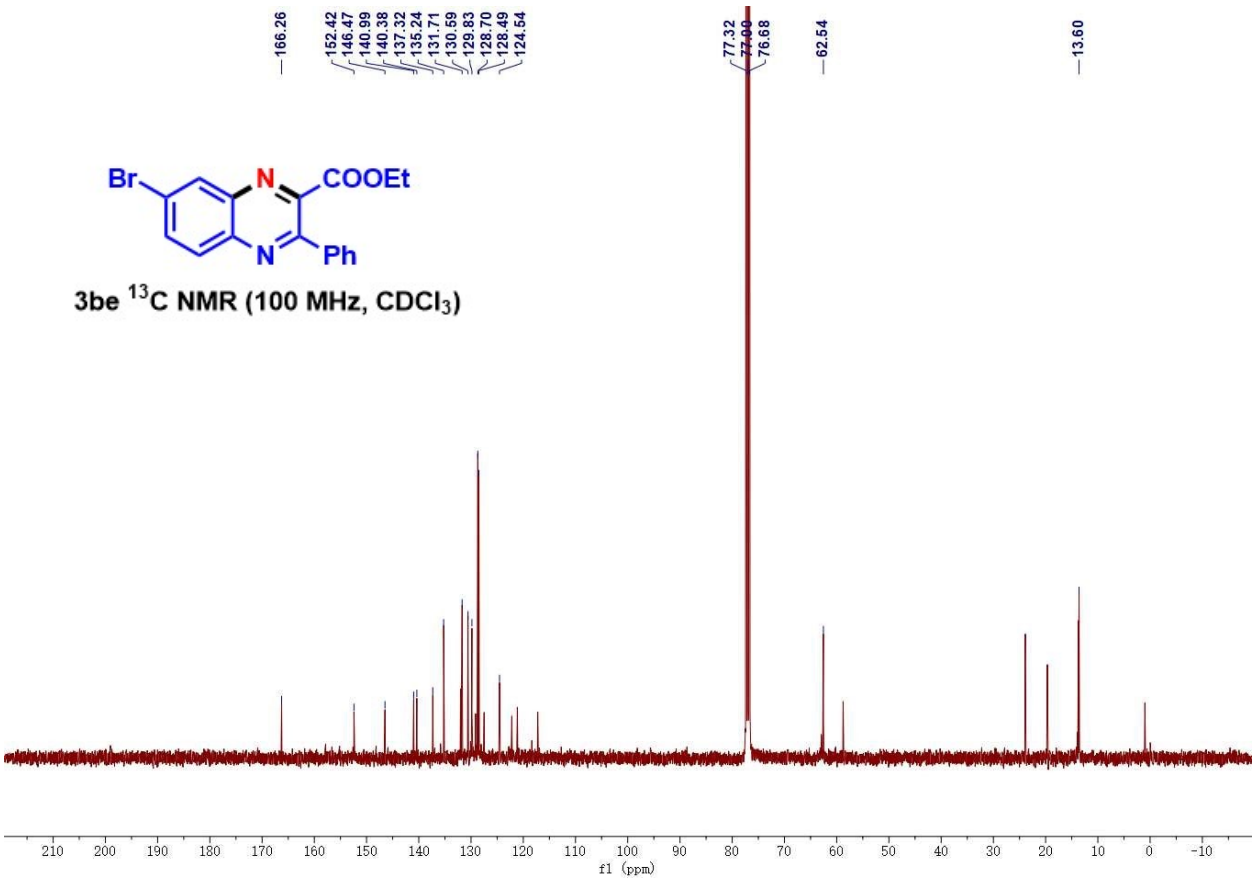
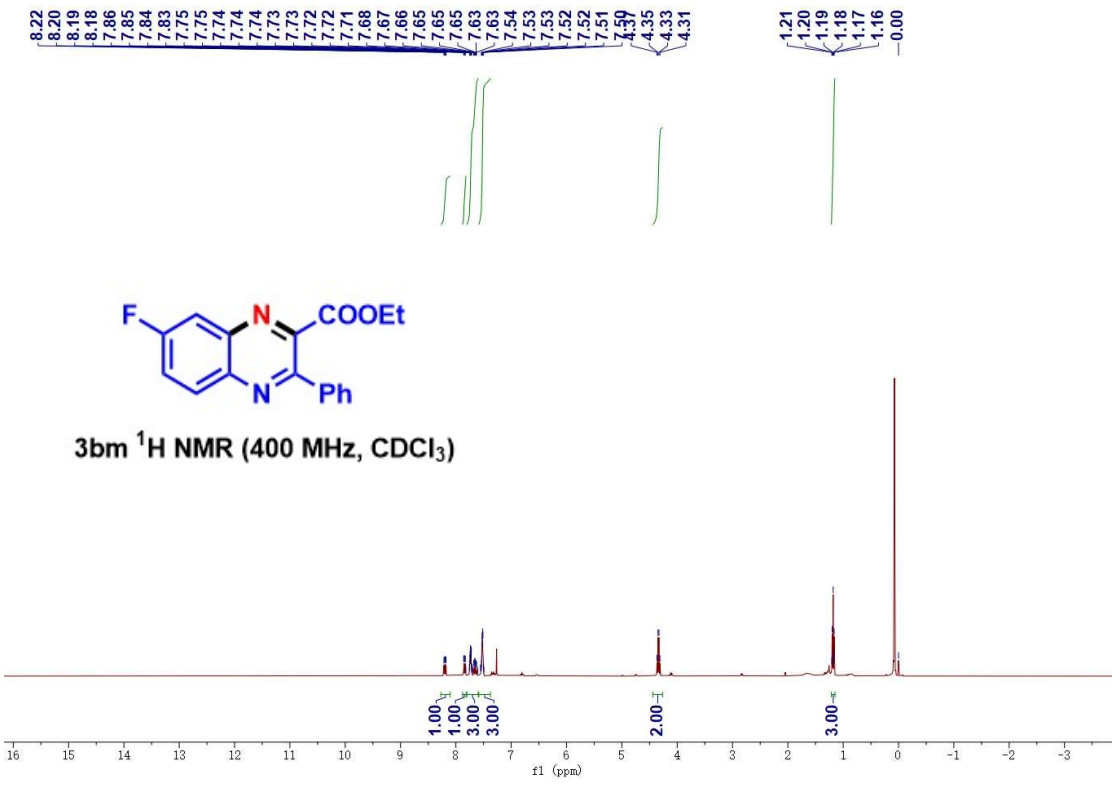
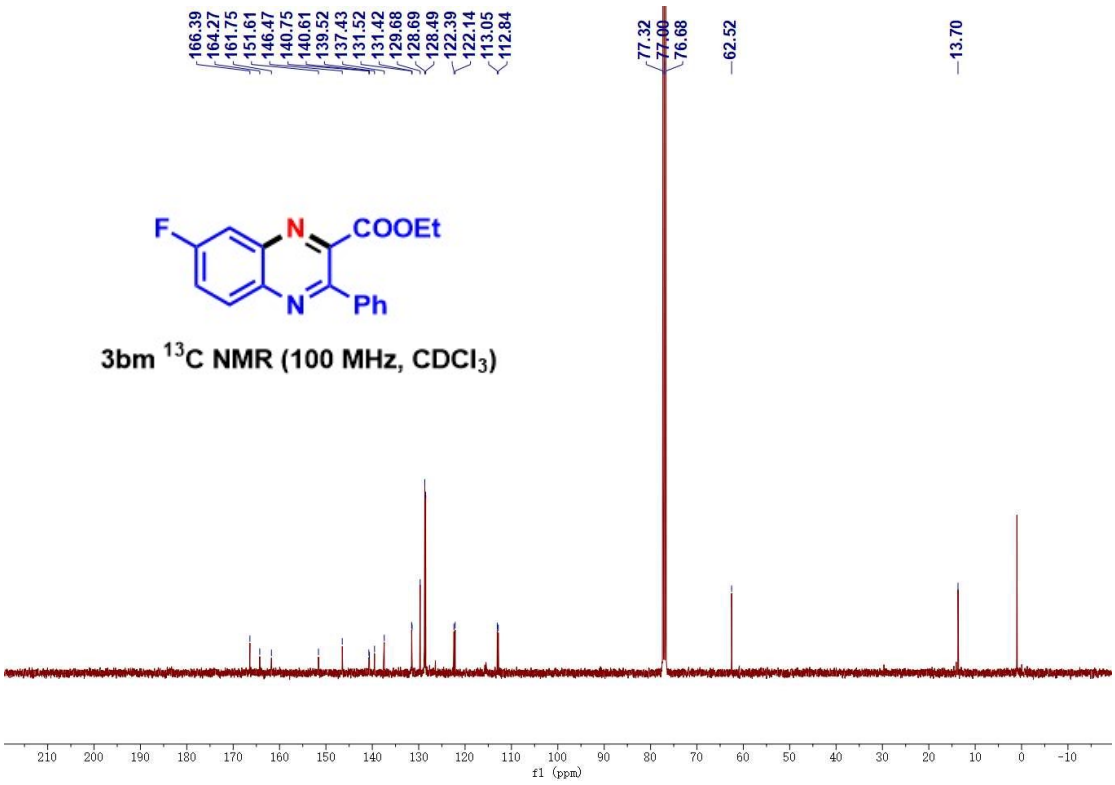


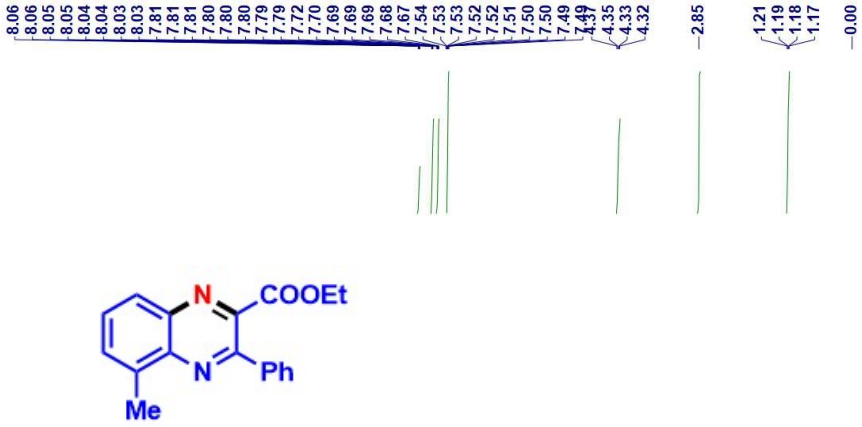
3be ^{13}C NMR (100 MHz, $CDCl_3$)



3bm ^{1}H NMR (400 MHz, $CDCl_3$)



3bm ^{13}C NMR (100 MHz, $CDCl_3$)



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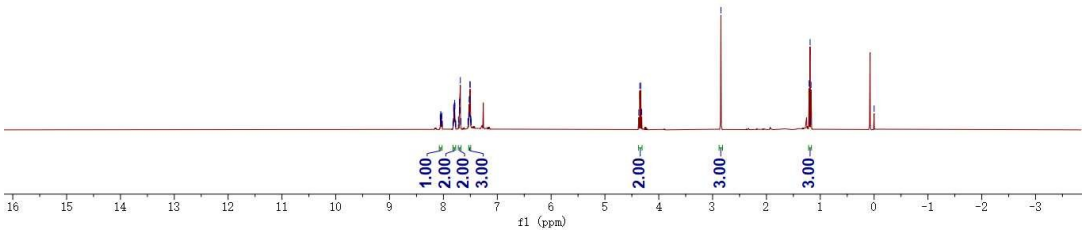

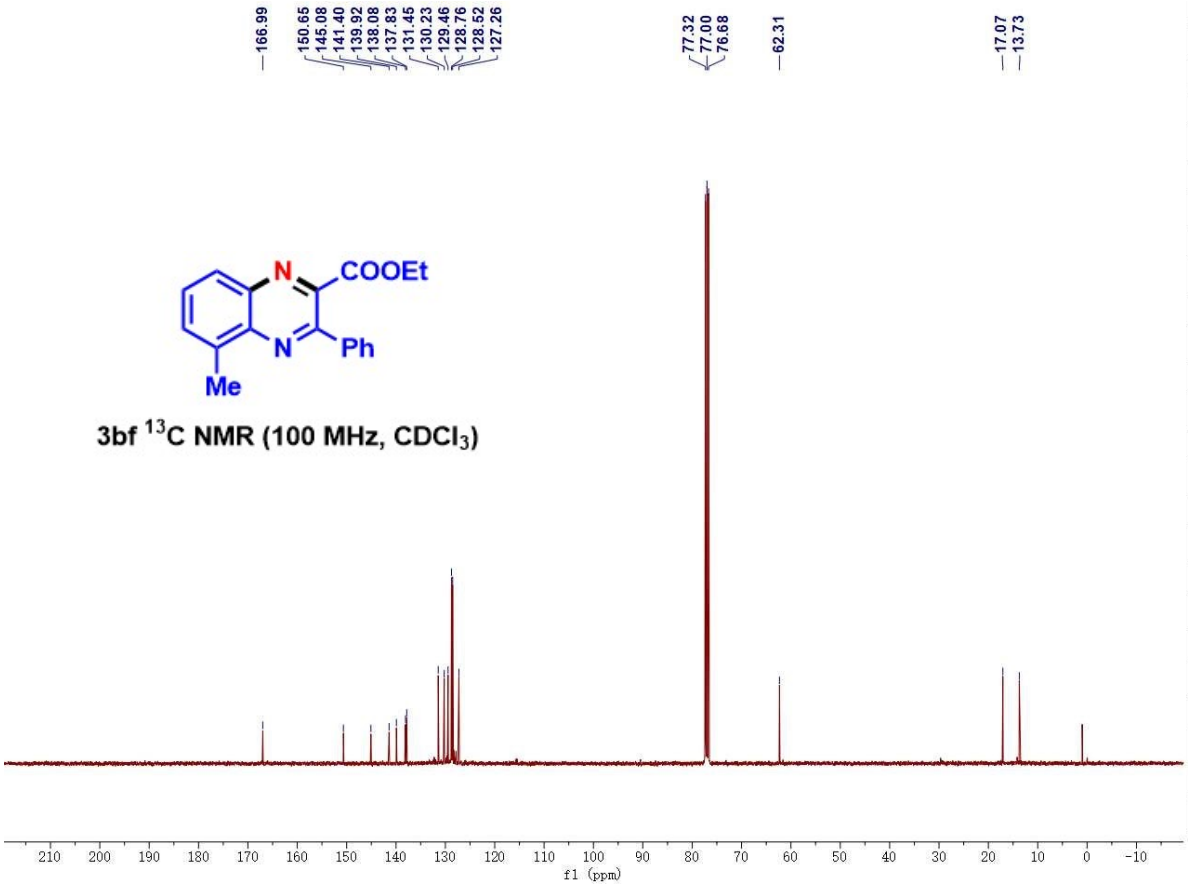

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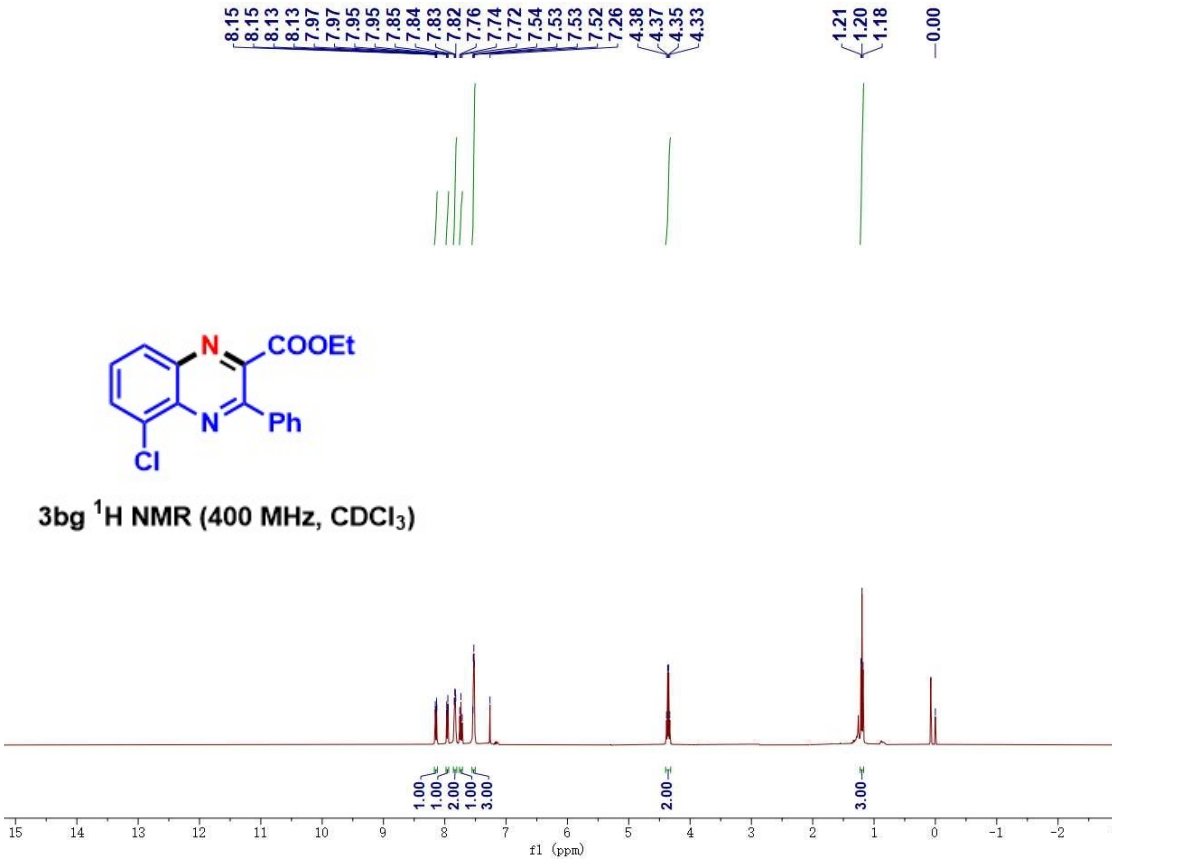

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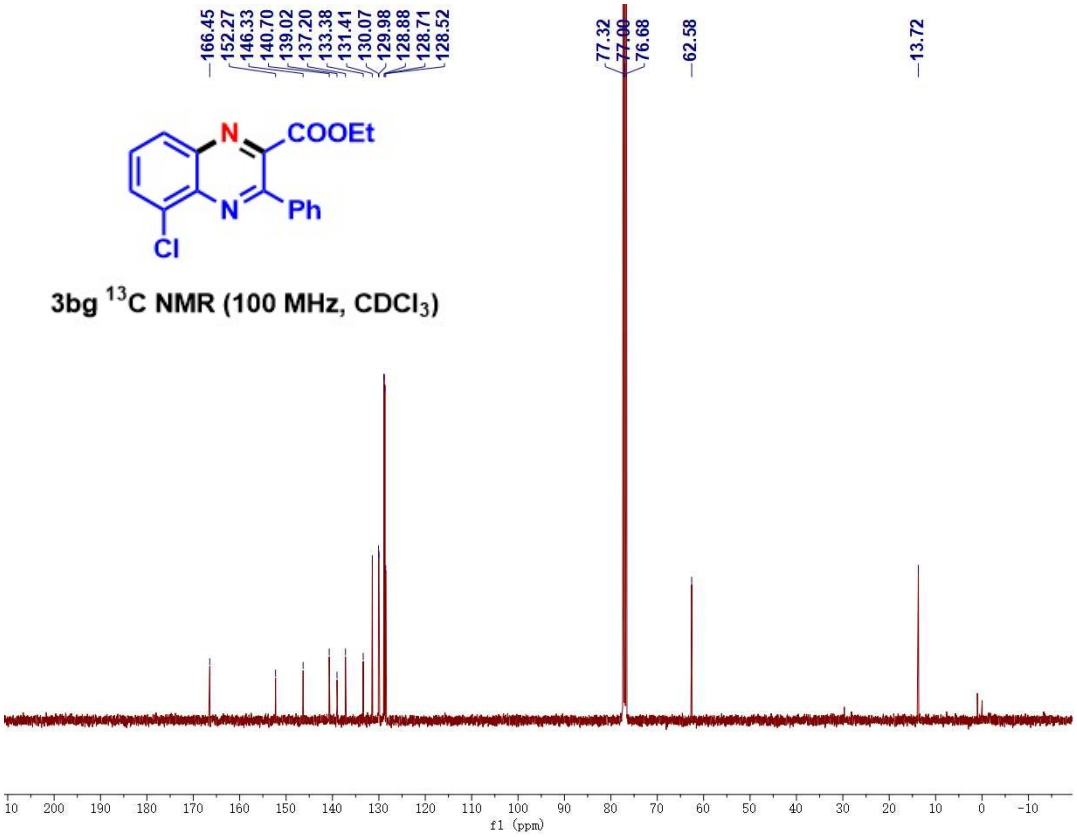
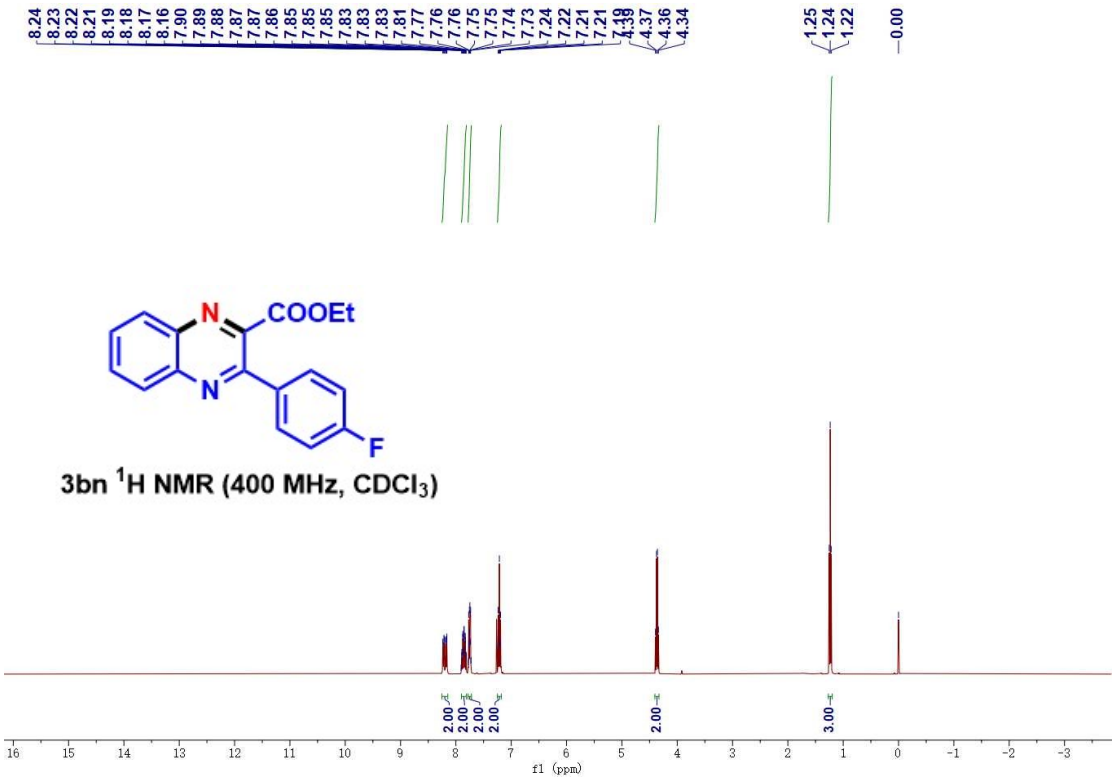
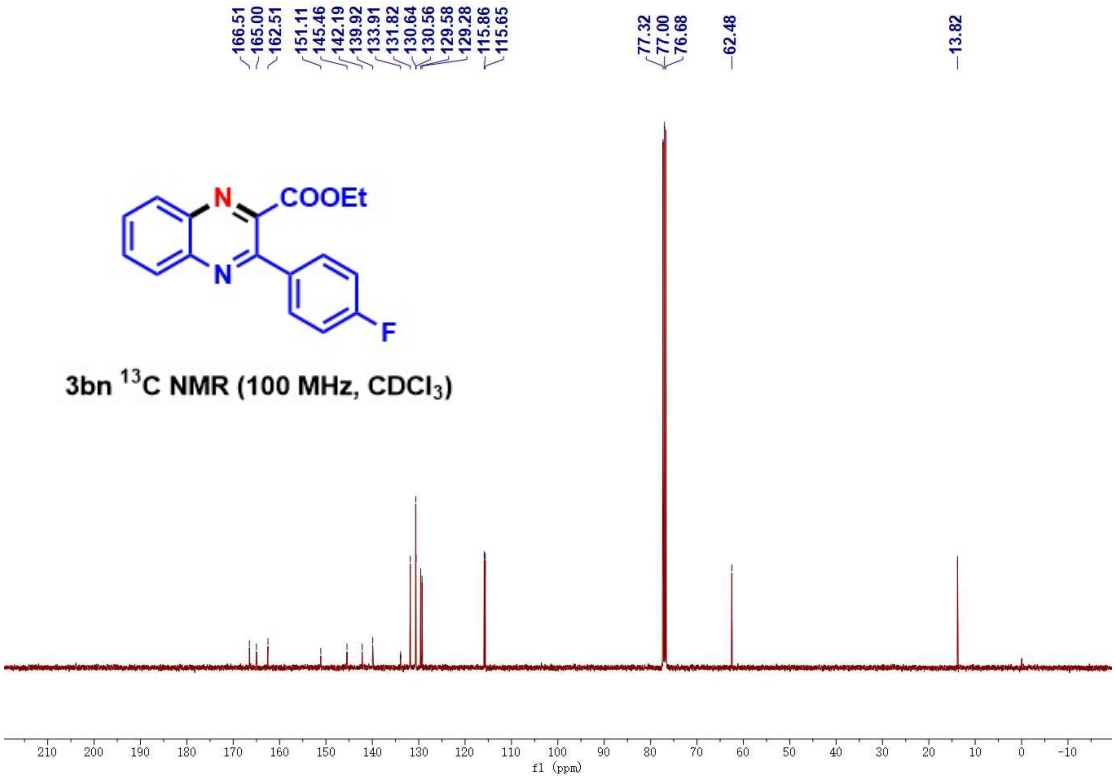


3bg ^{13}C NMR (100 MHz, $CDCl_3$)



3bn ^{1}H NMR (400 MHz, $CDCl_3$)



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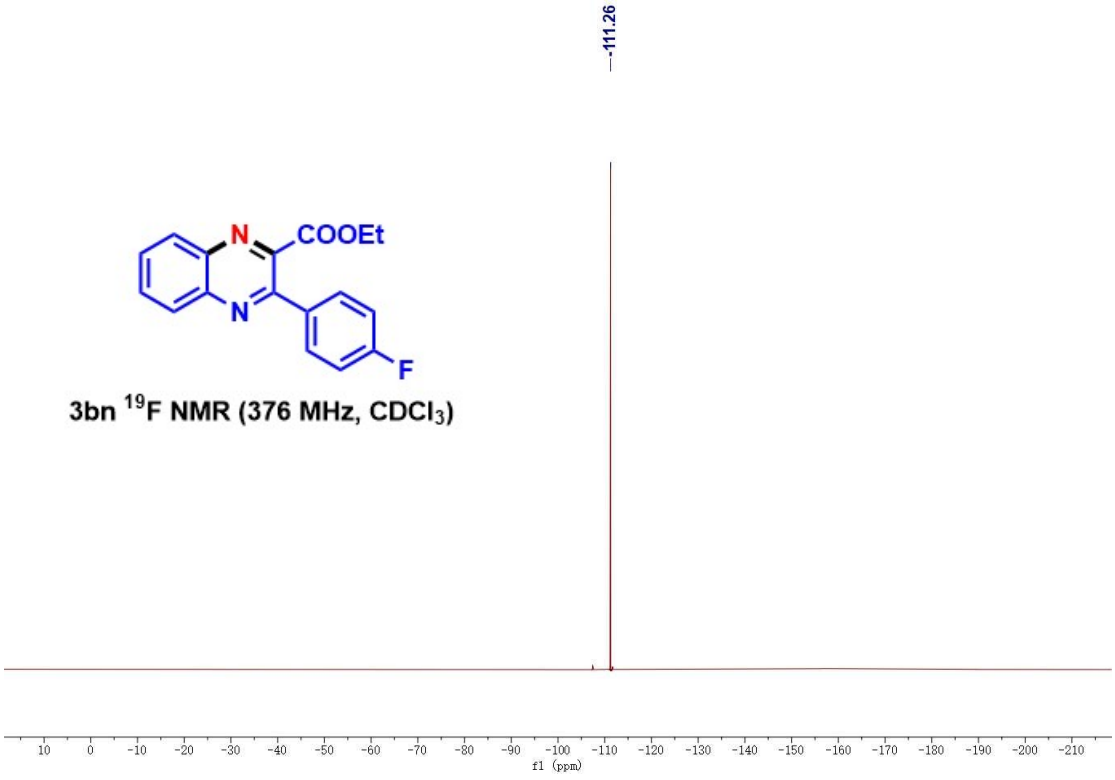
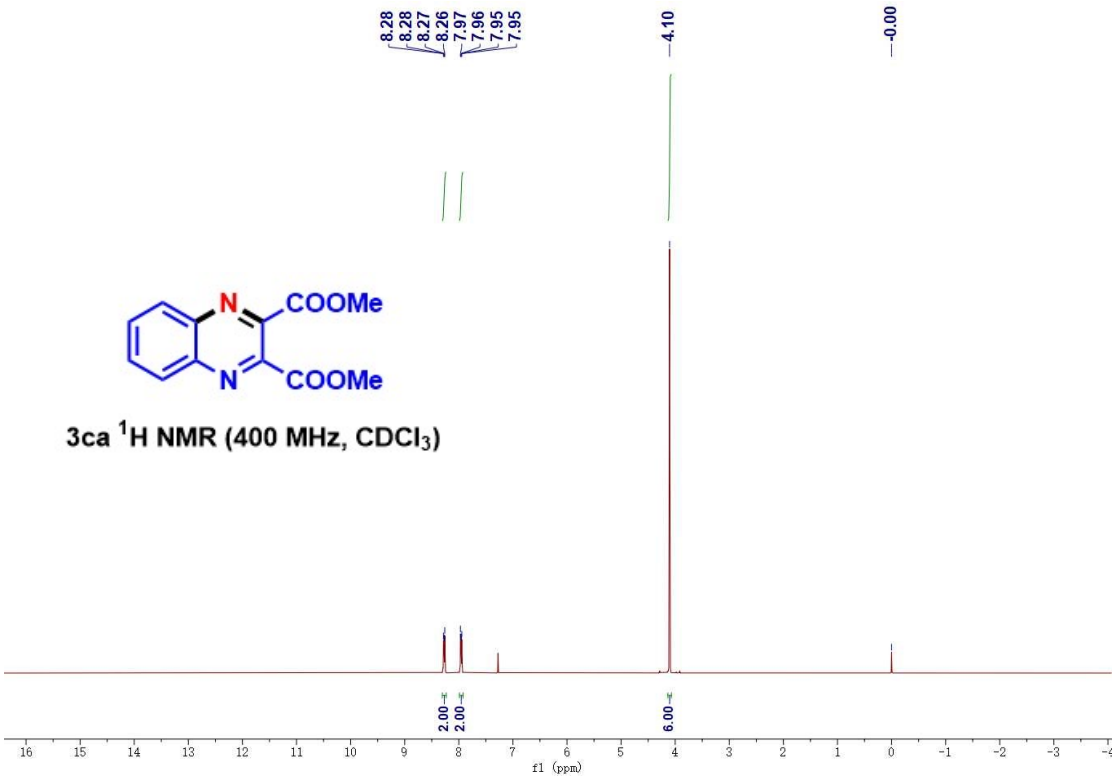
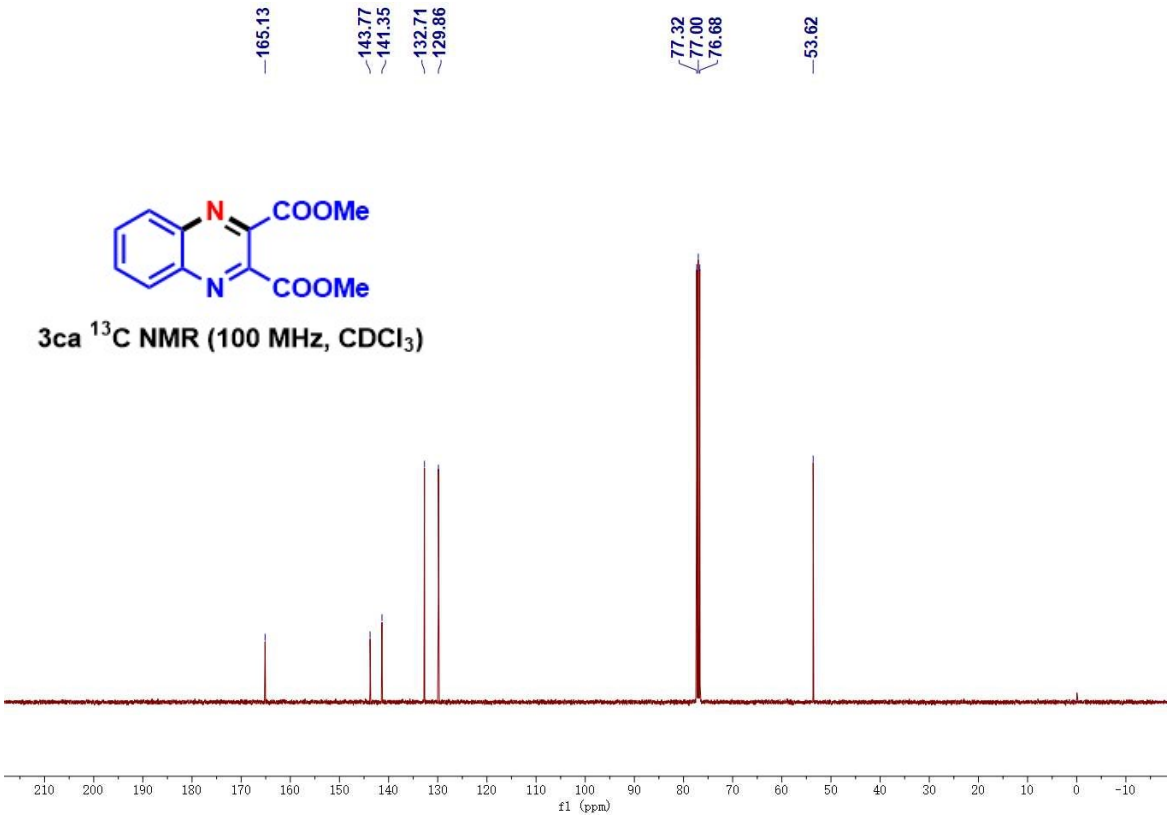


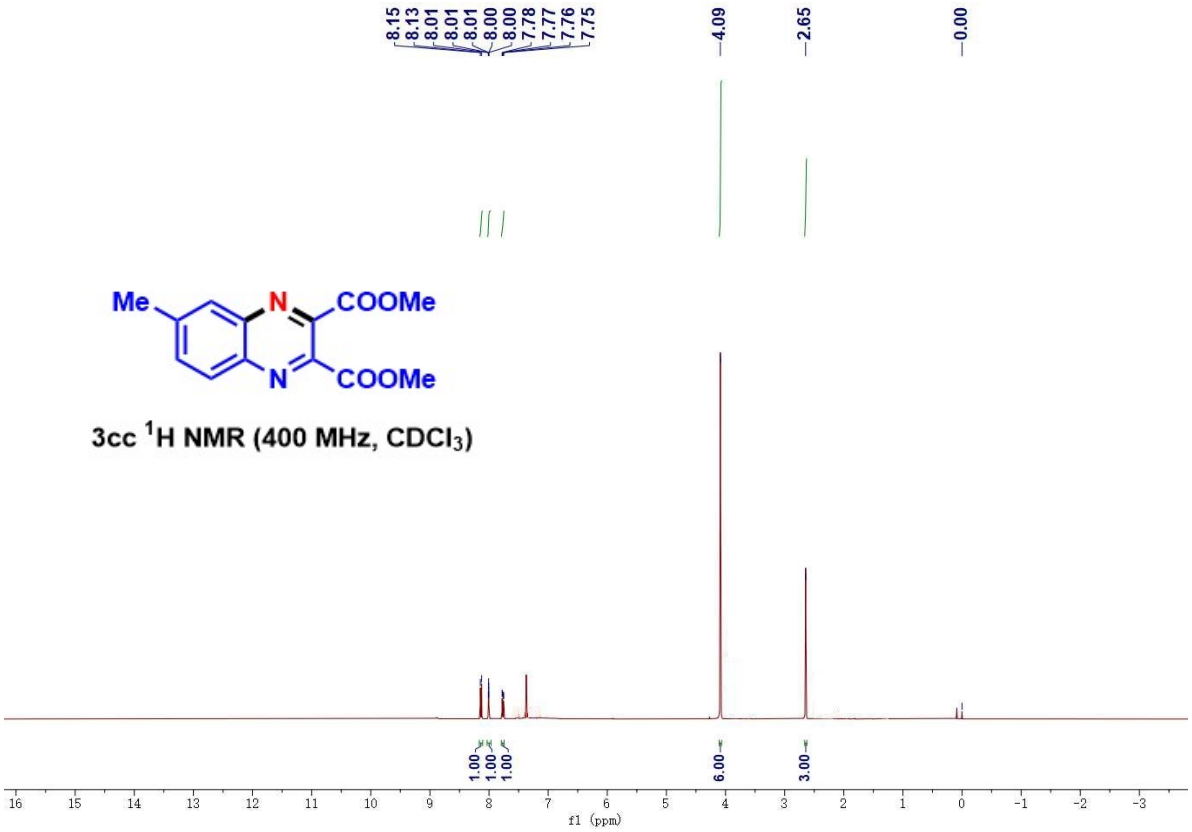
3bn ^{19}F NMR (376 MHz, $CDCl_3$)



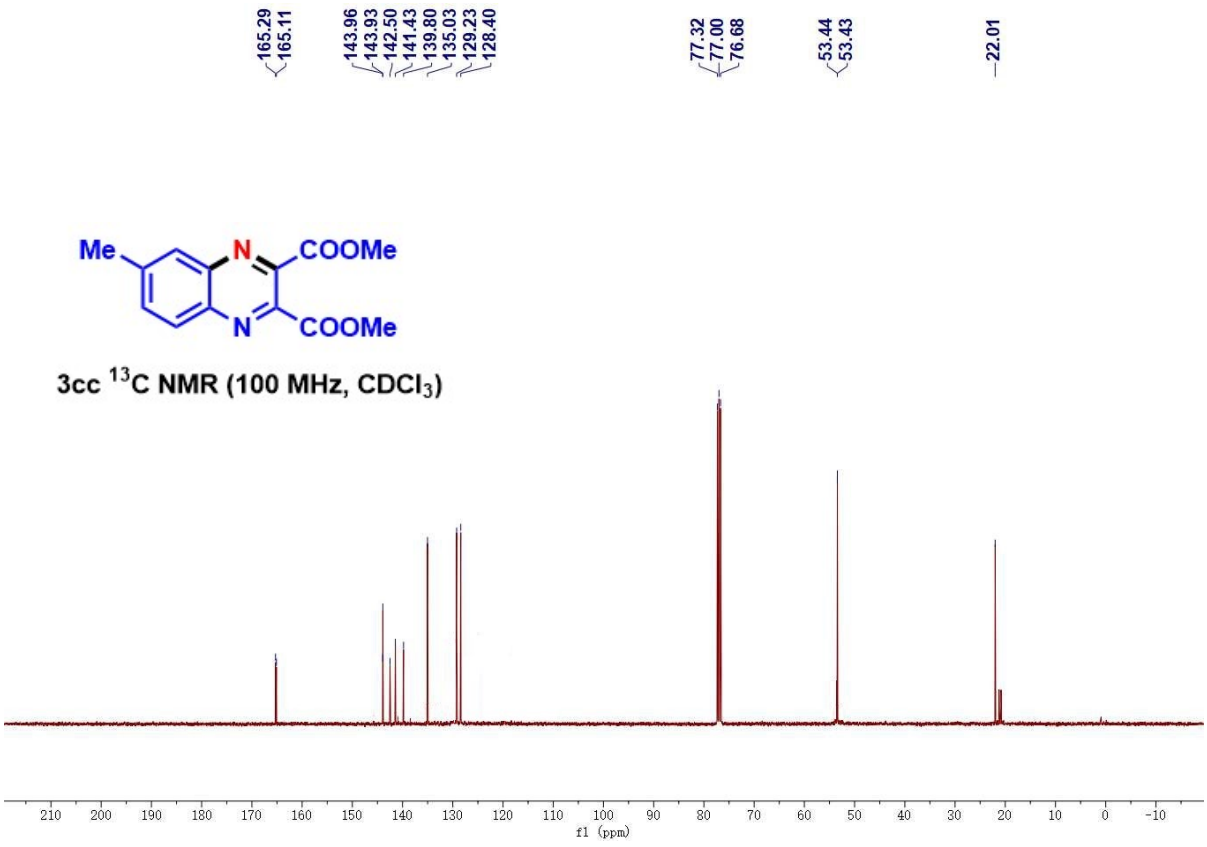
3ca ^{1}H NMR (400 MHz, $CDCl_3$)



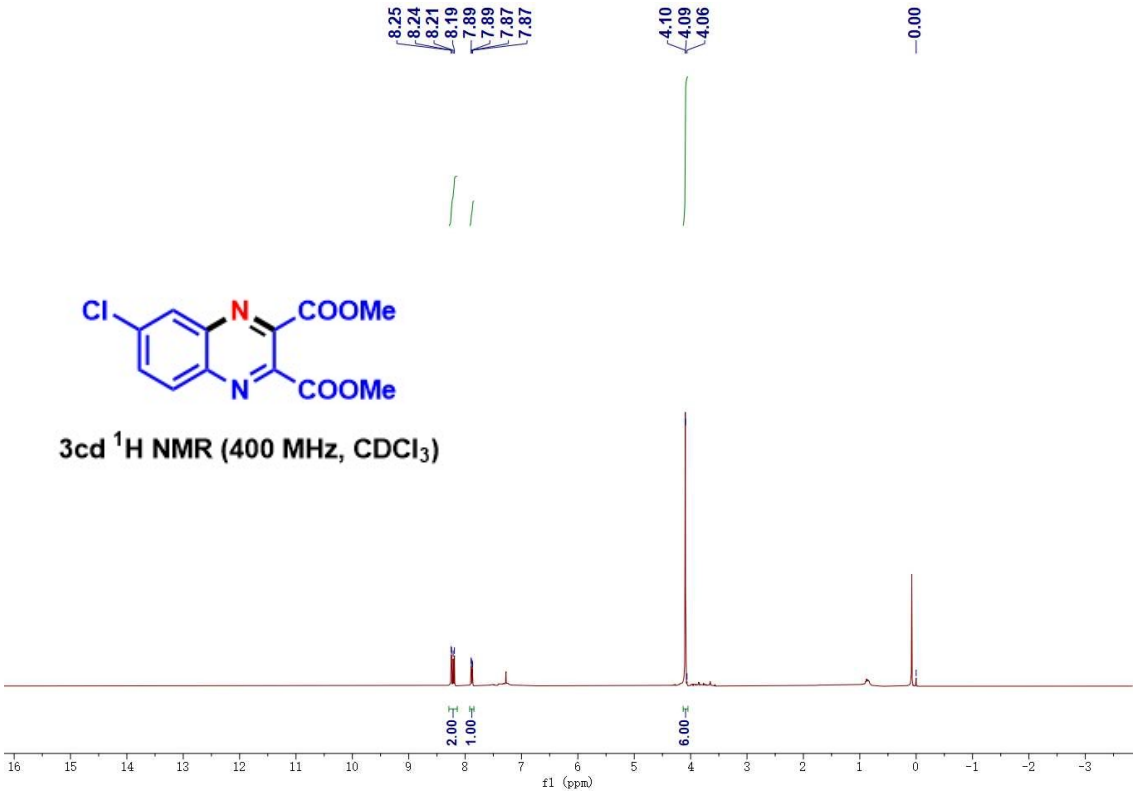
3ca ^{13}C NMR (100 MHz, $CDCl_3$)



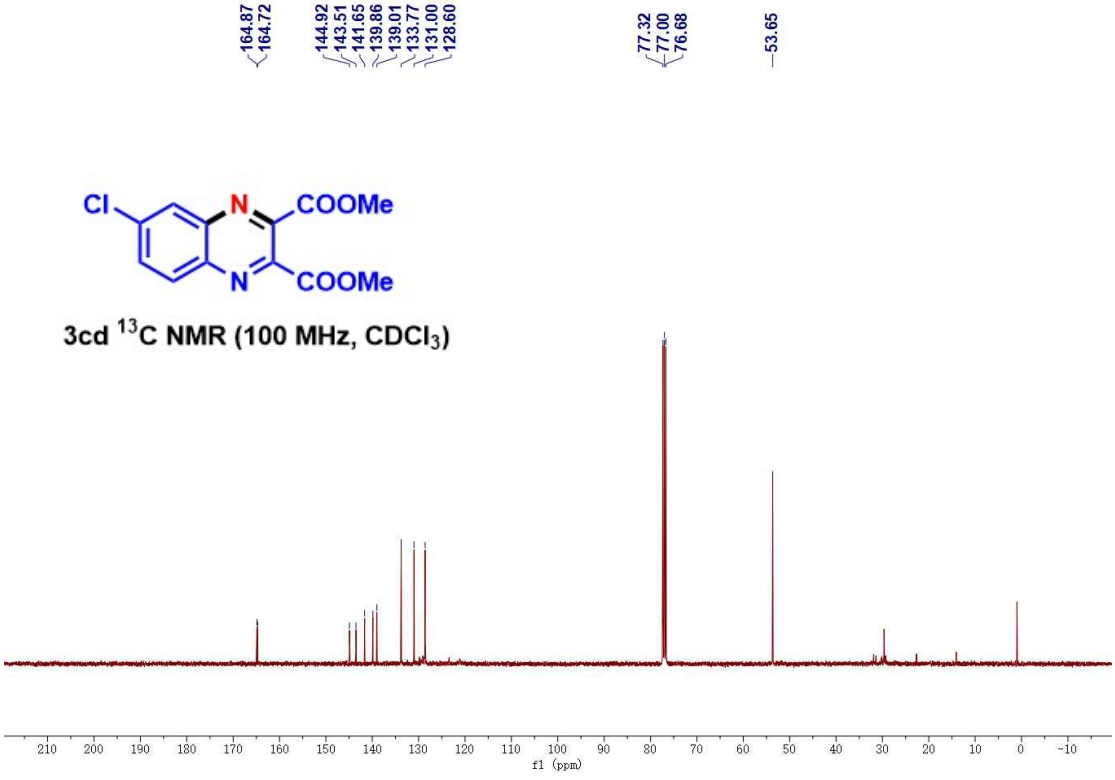
3cc ^{1}H NMR (400 MHz, $CDCl_3$)



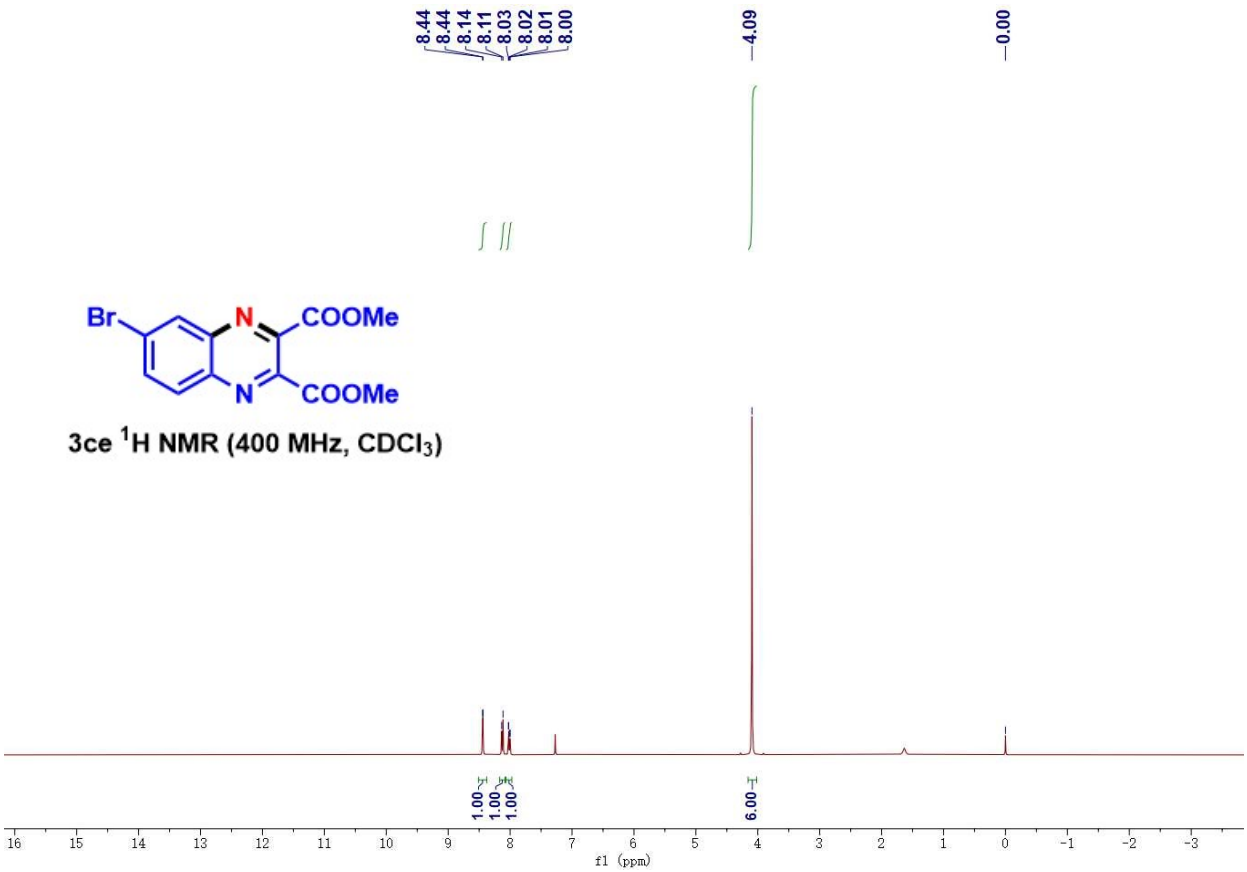
3cc ^{13}C NMR (100 MHz, $CDCl_3$)



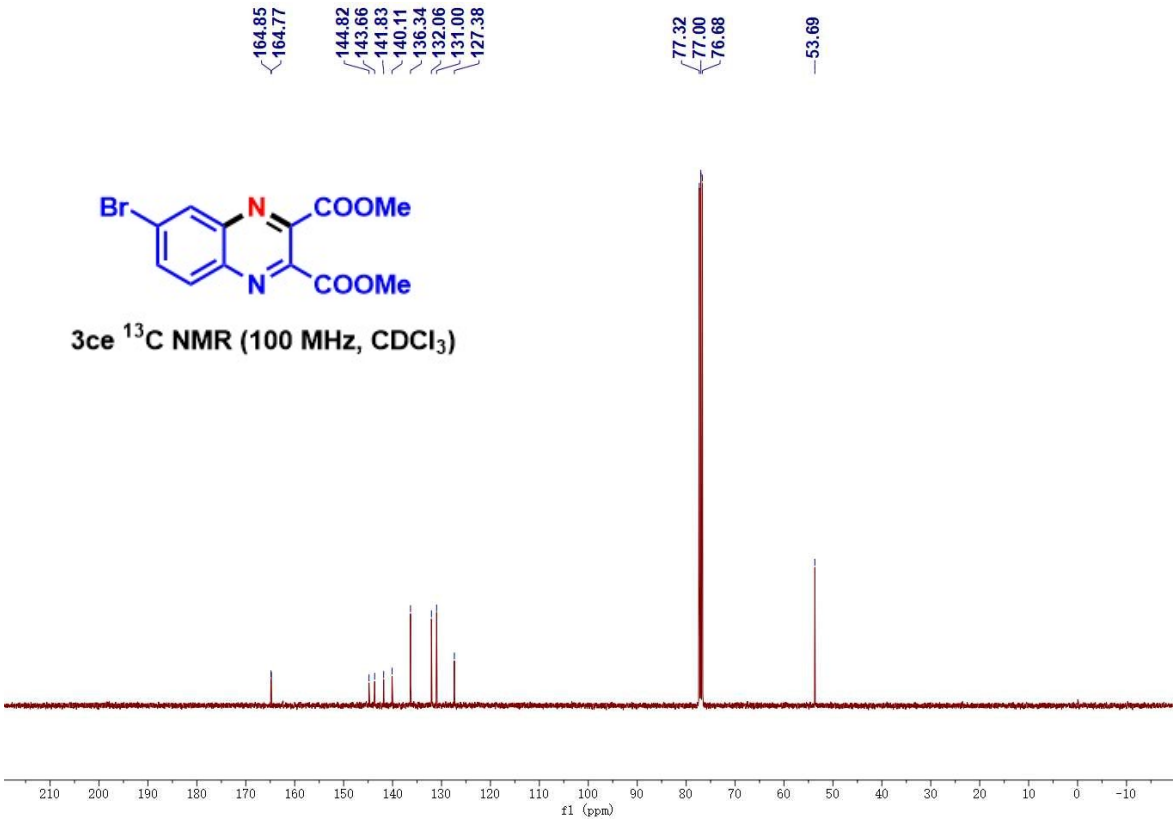
3cd ^{1}H NMR (400 MHz, $CDCl_3$)



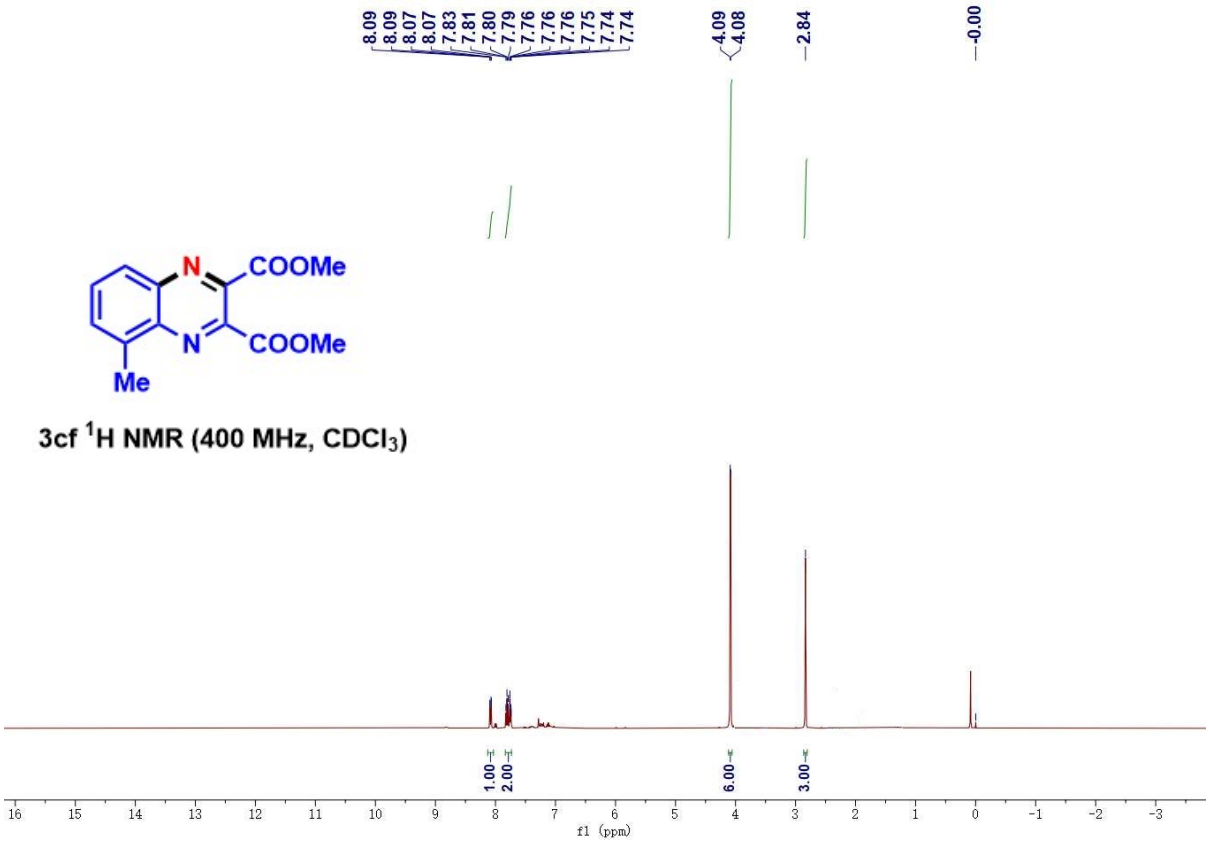
3cd ^{13}C NMR (100 MHz, $CDCl_3$)



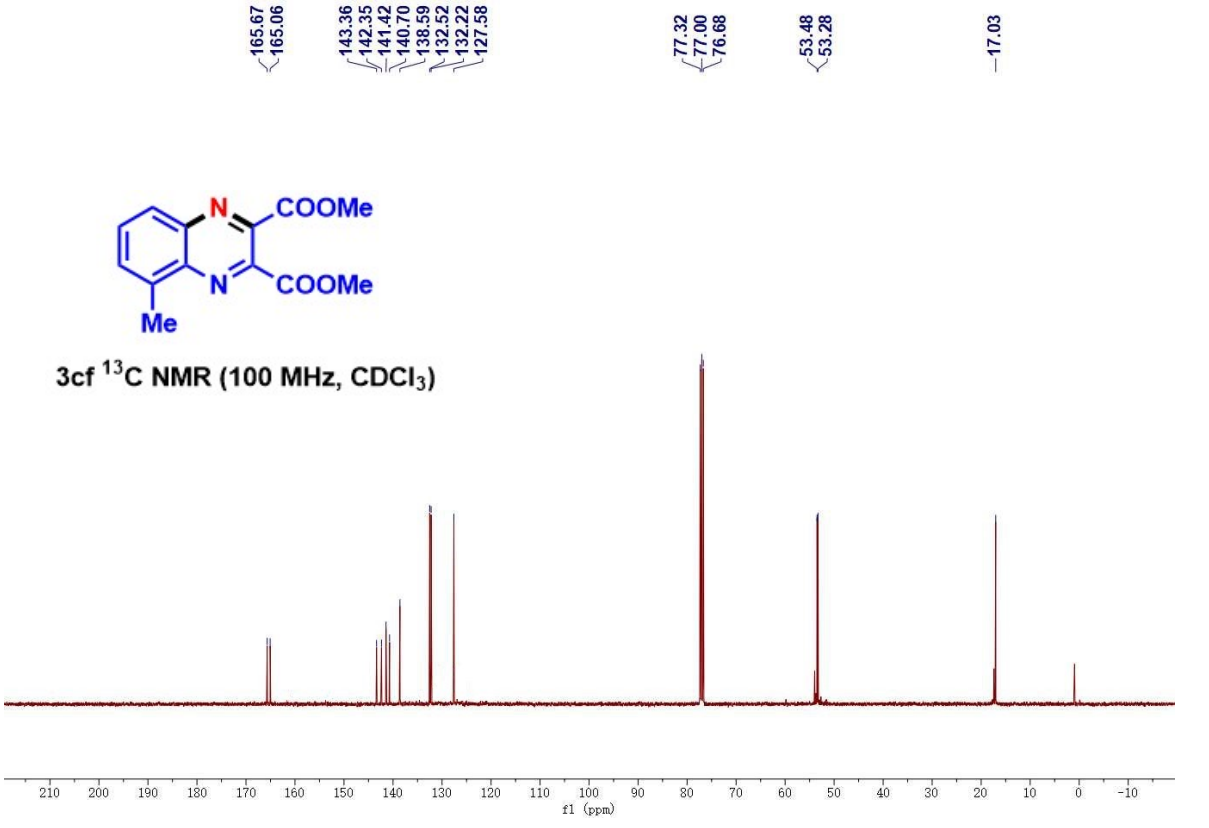
3ce ^{1}H NMR (400 MHz, $CDCl_3$)



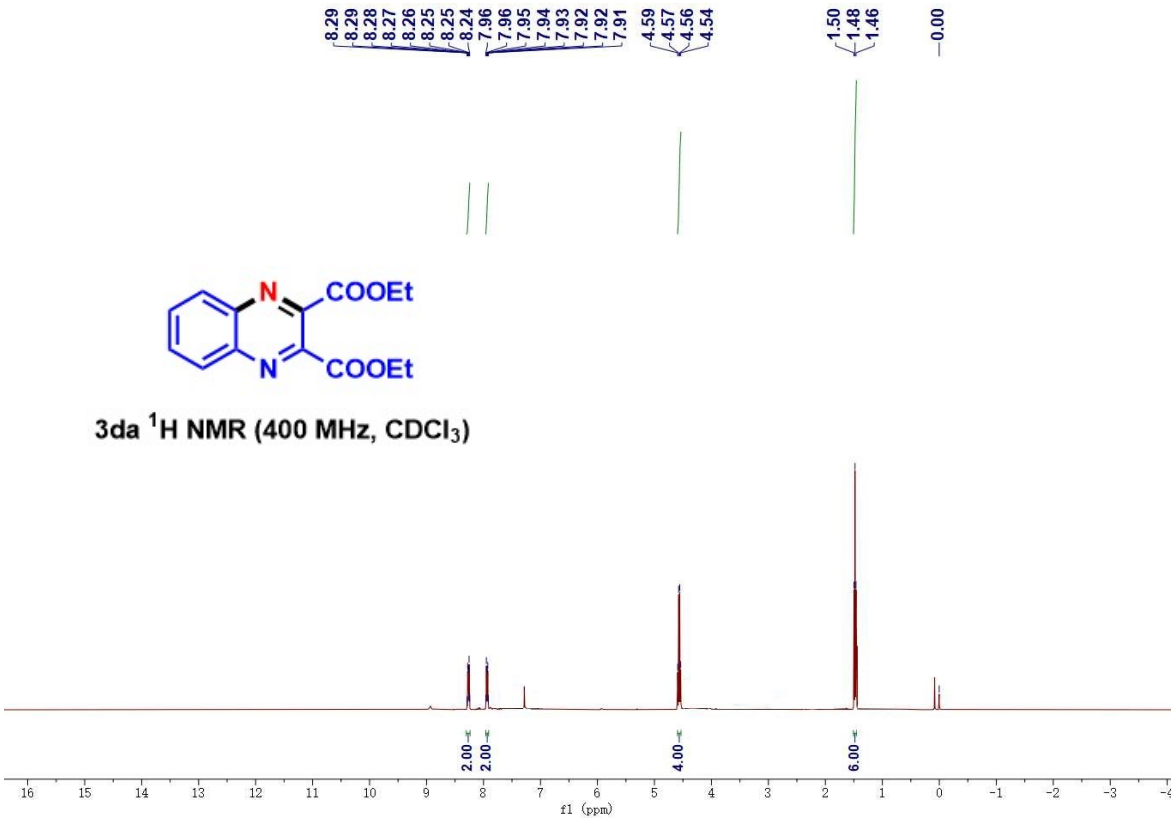
3ce ^{13}C NMR (100 MHz, $CDCl_3$)



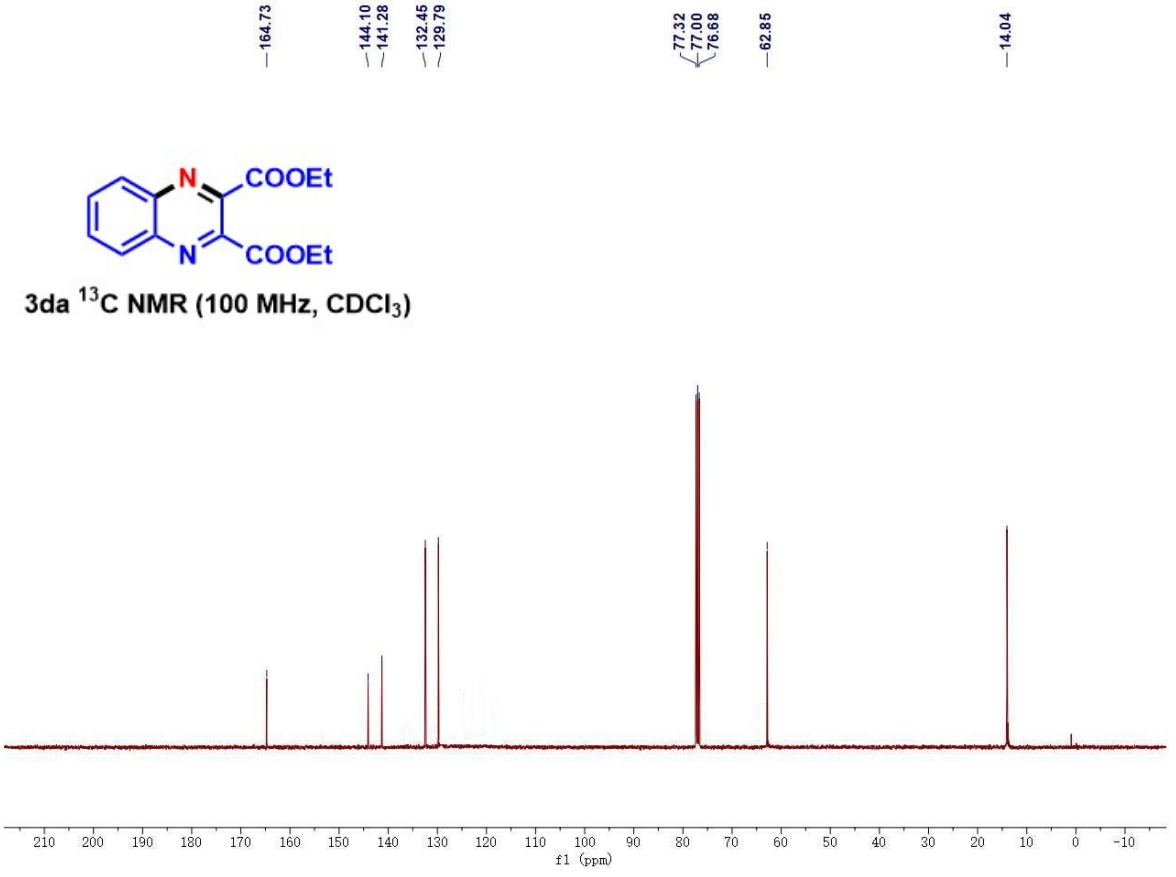
3cf ^{1}H NMR (400 MHz, $CDCl_3$)



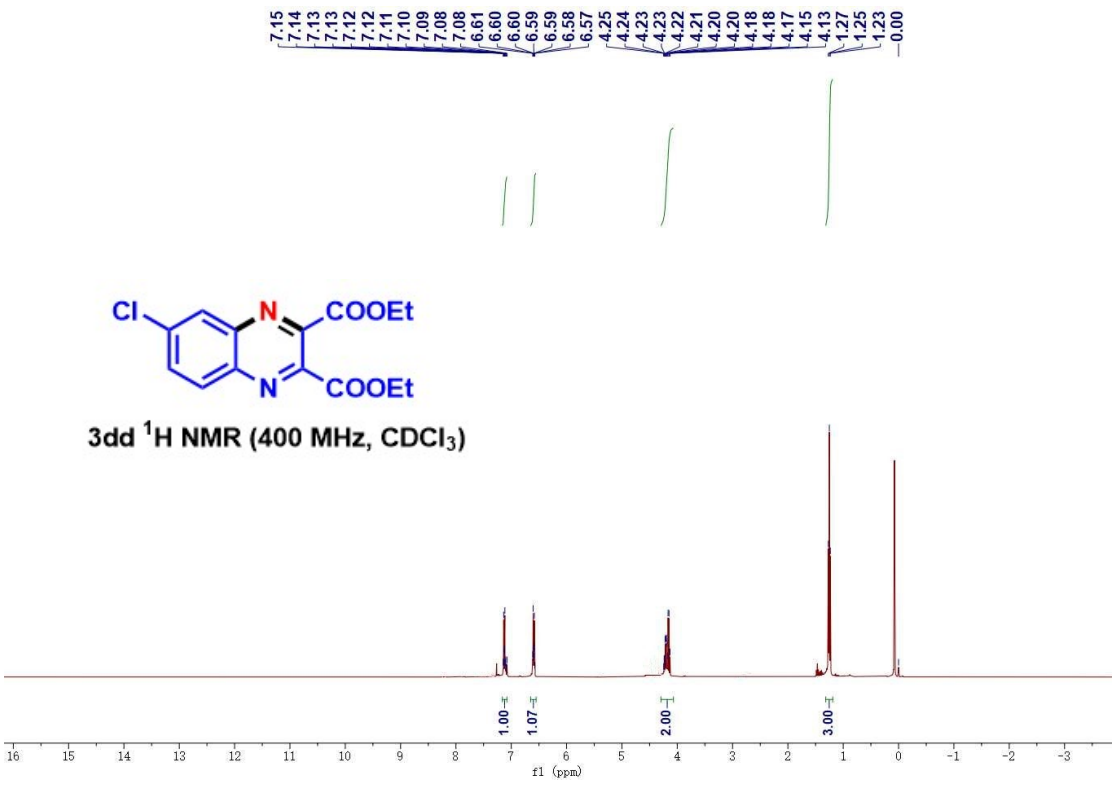
3cf ^{13}C NMR (100 MHz, $CDCl_3$)



3da ^{1}H NMR (400 MHz, $CDCl_3$)



3da ^{13}C NMR (100 MHz, $CDCl_3$)


7.15
7.14
7.13
7.13
7.12
7.12
7.11
7.10
7.09
7.08
7.08
6.61
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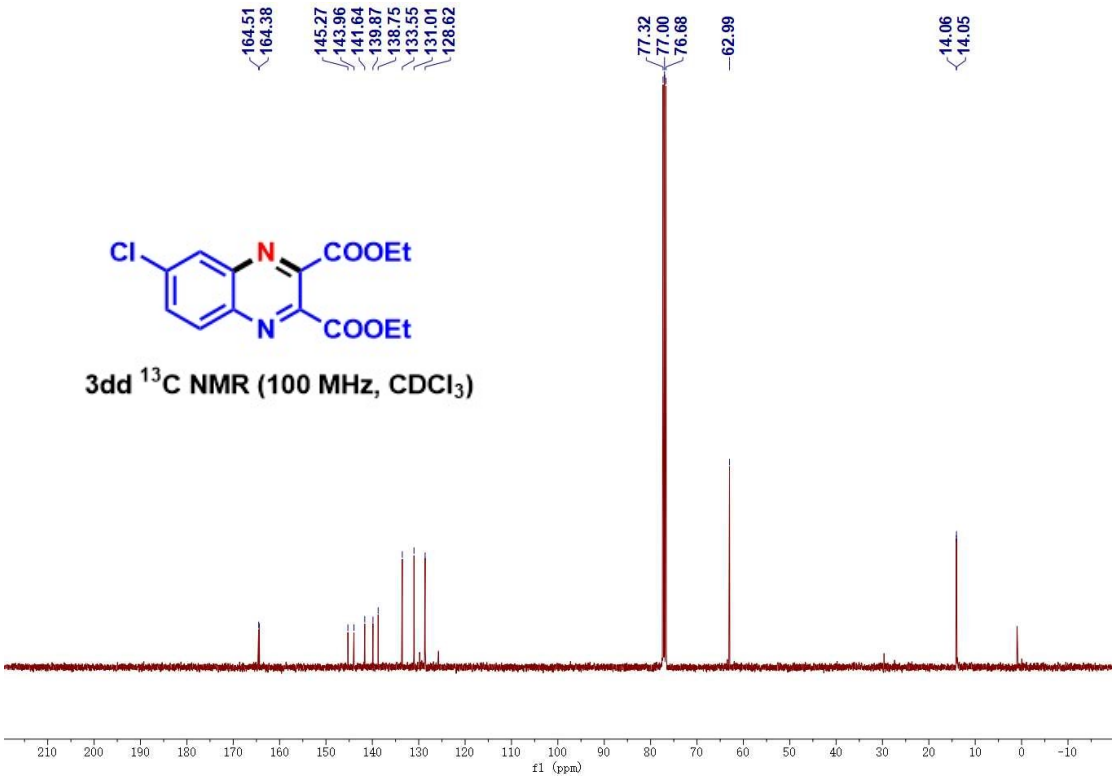
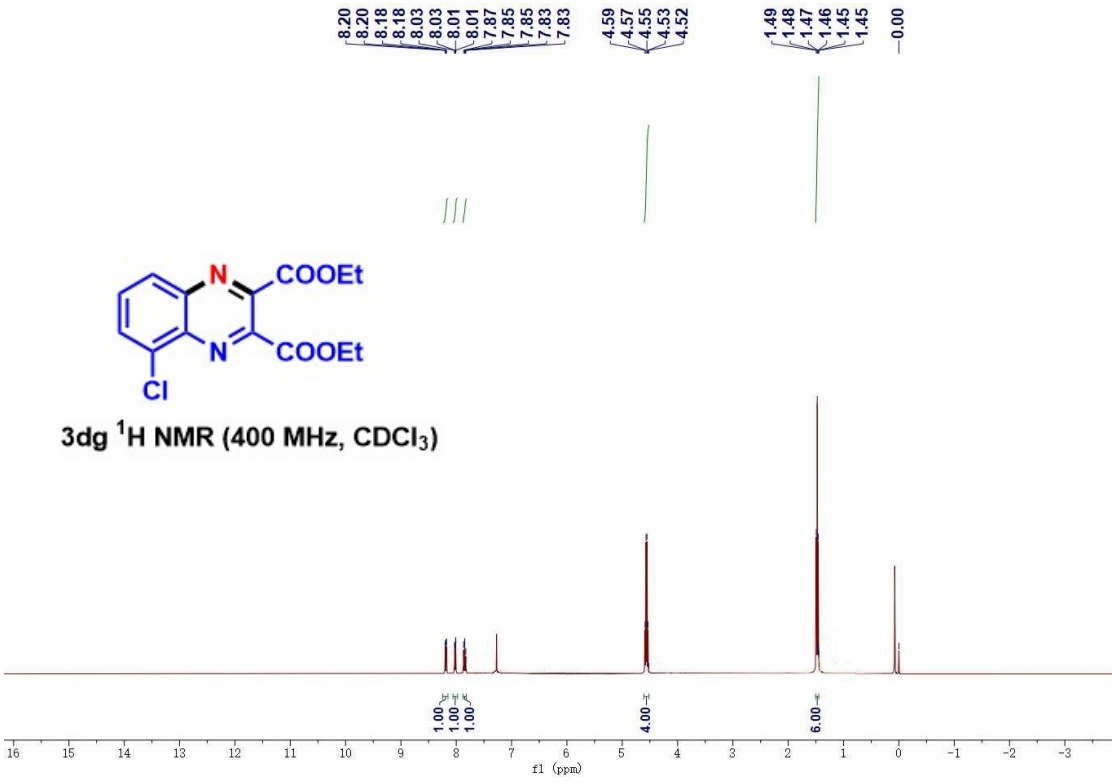
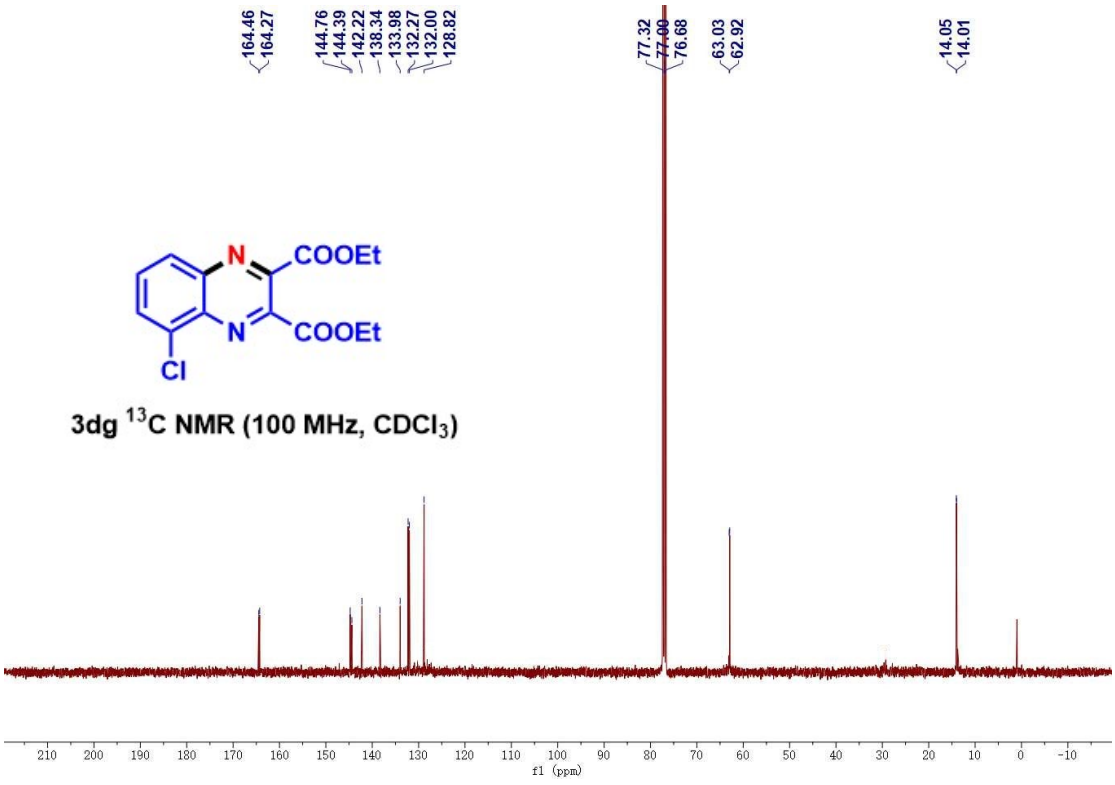
6.60
6.59
6.59
6.58
6.57
4.25
4.24
4.23
4.23
4.22
4.21
4.20
4.20
4.18
4.18
4.17
4.15
4.13
1.27
1.25
1.23
0.00
Cl
N
COOEt
N
COOEt
3dd ^{1}H NMR (400 MHz, $CDCl_3$)
1.00
1.07
2.00
3.00
f1 (ppm)


164.51
164.38
145.27
143.96
141.64
139.87
138.75
133.55
131.01
128.62
77.32
77.00
76.68
62.99
14.06
14.05
Cl
N
COOEt
N
COOEt
3dd ^{13}C NMR (100 MHz, $CDCl_3$)
f1 (ppm)



3dg ^{1}H NMR (400 MHz, $CDCl_3$)



3dg ^{13}C NMR (100 MHz, $CDCl_3$)