Supporting information

Base and copper (I) catalyzed Mannich, alkyne hydroamination cascades for the direct synthesis of 2-methylenepyrrolidines

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1. General Experimental

All reactions were performed under an atmosphere of nitrogen unless otherwise stated. All glass apparatus was oven dried and cooled under vacuum before use.

1) Solvents and Reagents

Bulk solutions were evaporated under reduced pressure using a Büchi rotary evaporator. Reagents used were obtained from commercial suppliers or redistilled. Petroleum ether refers to distilled light petroleum of fraction (40-65 °C). Anhydrous dichloromethane, toluene were purified by distillation over calcium hydride. Anhydrous tetrahydrofuran was freshly distilled from sodium-benzophenone. Anhydrous MeOH was purified by distillation over magnesium power.

2) Chromatography

In all cases of chromatography, distilled solvents were used as eluents. Flash column chromatography was carried out using Merck Kiesegal 60 silica gel (230-400 mesh). Thin-layer chromatography (TLC) was carried out using Merck Kiesegal 60 F254 (230-400 mesh) fluorescent treated silica which were visualised under UV light (250nm) or by staining with aqueous potassium permanganate solutions as appropriate.

3) Spectra

All ^{1}H and ^{13}C NMR spectra were recorded using a Bruker 400 MHz spectrometers and use ppm for measurement against a TMS internal standard. Chemical shifts (δ) are given in parts per million (ppm), and coupling constants (*J*) are given in Hertz (Hz). Melting points were determined on an XT-4 melting point apparatus and were uncorrected. HRMS were performed on Bruker Apex II mass instrument (ESI). MS were measured on a VG-7070E spectrometer (EI at 70 eV); Infrared spectra were recorded on an ATI Mattson: Genesis Series FTIR spectrometer from a thin film deposited onto a sodium chloride plate

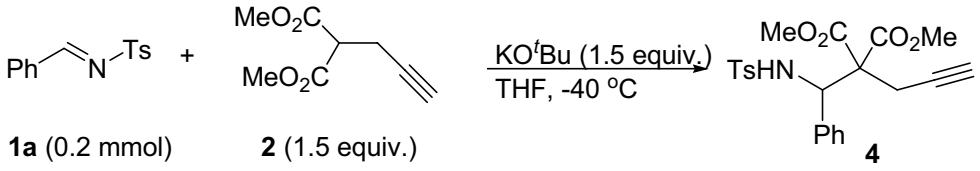
4) starting materials

Starting material **2** was synthesized by the reaction of dimethyl malonate and propargyl bromide in a solution of sodium in MeOH[S1]. Starting materials **1a-p** were synthesized by the reaction of the corresponding aromatic aldehyde and *p*-toluenesulfonamide with titanium tetrachloride and anhydrous triethylamine in dry dichloromethane[S2]. The starting material **1q** was synthesized by condensation of *p*-toluenesulfonamide with butyraldehyde mediated by sulfamic acid in aqueous media [S3].

2. Practical experimental

2.1 Cu(I) catalyzed cascade

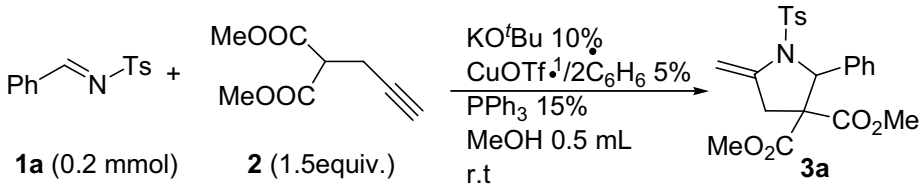
*2.1.1 Synthesis and characterization of intermediate **4***



1a (0.2 mmol) **2** (1.5 equiv.)

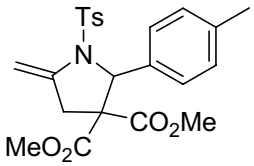
Dimethyl 2-(phenyl(tosylamino)methyl)-2-(prop-2-ynyl)malonate (4). Under a N_2 atmosphere, malonate **2** (46 μL, 0.3 mmol) was dissolved in dry THF (3 mL) at -40 ^oC. Then KO^{t}Bu (33.6 mg, 0.3 mmol) in THF (1 mL) was added to the solution . After 30 minutes, **1a** (51.8 mg, 0.2 mmol) was added. The reaction was stirred at -40 ^oC for 10 h. Subsequently, aqueous 10% HCl was added to the mixture to quench the reaction. The reaction was warmed up to room temperature, washed with saturated aqueous $NaHCO_3$, water, dried ($MgSO_4$) and concentrated to give the crude product. The crude product was purified by column chromatography to yield desired compound **4** (0.037 g, 43%) as a white solid; **mp** 78–79 ^oC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.41 (d, *J* = 8.0 Hz, 2H), 7.27–7.04 (m, 5H), 6.99 (d, *J* = 8.0 Hz, 2H), 6.48 (d, *J* = 9.5 Hz, 1H), 5.15 (d, *J* = 9.5 Hz, 1H), 3.76 (s, 3H), 3.73 (s, 3H), 2.64 (dd, *J* = 2.0 Hz, 16.8 Hz, 1H), 2.52 (dd, *J* = 2.0 Hz, 16.8 Hz, 1H), 2.94 (s, 3H), 2.13 (s, 1H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.1, 168.6, 142.6, 137.7, 135.0, 129.0, 128.3, 128.2, 127.9, 126.9, 78.4, 72.4, 62.0, 60.5, 53.1, 53.0, 23.9, 21.3; **IR**: ν_{max} (film)/cm^{-1} 3293, 3059, 2954, 1742, 1598, 1495, 1434, 1330, 1279, 1216, 1162, 1091, 1059, 913, 877, 733, 704, 670, 558; **MS:** m/z 365 (0.1), 259 (8.0), 195 (2.1), 155 (47.0), 111 (28.9), 91 (100.0), 77 (22.0), 65 (28.0), 59 (19.0); **HRMS** (ESI): calcd. for $C_{22}H_{24}NO_6S$ [M + H^+] 430.1319, found 430.1324.

*2.1.2 Synthesis and characterization of compound **3a***



Dimethyl 5-methylene-2-phenyl-1-tosylpyrrolidine-3,3-dicarboxylate (3a). Under a N_2 atmosphere, dry MeOH (0.5 ml) was added to a mixture of CuOTf·^{1}/2C_6H_6 (2.5 mg, 0.01 mmol), PPh_3 (8.4 mg, 0.03 mmol). Then malonate **2** (46 μL, 0.3 mmol) and **1a** (51.8 mg, 0.2 mmol) were added consecutively to the catalyst solution. After 2 minutes, KO^{t}Bu (2.24 mg, 0.02 mmol) was added. The reaction was stirred at room temperature for 16 h. On completion, the reaction mixture was directly loaded onto a silica gel column and purified by flash chromatography (elution: diethyl ether: Et_3N) to afford the desired product **3a** (0.081 g, 94%) as a white solid; **mp** 120–121 ^oC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.69 (d, *J* = 8.4 Hz, 2H), 7.29–7.22 (m, 5H), 7.27 (d, *J* = 8.4 Hz, 2H), 6.07 (s, 1H), 4.90 (s, 1H), 4.32 (s, 1H), 3.68 (s, 3H), 3.64 (d, *J* = 16.8 Hz, 1H), 3.34 (s, 3H), 2.94 (d, *J* = 16.8 Hz, 1H), 2.41 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.5, 166.7, 144.0, 140.7, 137.4, 135.7, 129.1, 128.5, 128.4, 128.1, 127.1, 89.0, 69.4, 61.9, 53.4, 52.7, 37.3, 21.6; **IR**: ν_{max} (film)/cm^{-1} 3474, 3066, 2958, 1741, 1677, 1641, 1597, 1452, 1433, 1347, 1286, 1223, 1165, 1119, 1084, 1009, 952, 823, 701, 660; **MS:** m/z 429 (M^+, 1.41), 370 (7.4), 306 (14.5), 221 (29.6), 156 (21.2), 105 (62.3), 91 (100.0), 77 (19.1), 65 (45.1), 59 (25.7); **HRMS** (ESI): calcd. for $C_{22}H_{24}NO_6S$ [M + H^+] 430.1319, found 430.1322.

*2.1.3 Synthesis and characterization of compound **3b***

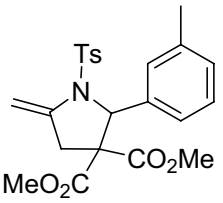


3b

Dimethyl 5-methylene-2-p-tolyl-1-tosylpyrrolidine-3,3-dicarboxylate (3b). This product was synthesized by the same method as for **3a.** The product **3b** (0.075 g, 85%) was isolated as a white solid after flash chromatography; **mp** 130–131 ^oC; **^{1}H NMR**

(400 MHz, $CDCl_3$): δ 7.70 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.4 Hz, 2H), 7.11 (d, *J* = 8.0 Hz, 2H), 7.08 (d, *J* = 8.0 Hz, 2H), 6.03 (s, 1H), 4.87 (s, 1H), 4.39 (s, 1H), 3.67 (s, 3H), 3.64 (d, *J* = 16.8 Hz, 1H), 3.33 (s, 3H), 2.93 (d, *J* = 16.8 Hz, 1H), 2.40 (s, 3H), 2.31 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.5, 166.7, 143.9, 140.6, 138.2, 135.7, 134.4, 129.1, 129.0, 128.1, 126.9, 88.8, 69.2, 61.8, 53.3, 52.6, 37.2, 21.5, 21.1; **IR**: ν_{max} (film)/cm^{-1} 3471, 3062, 2956, 1735, 1666, 1623, 1598, 1494, 1435, 1340, 1288, 1225, 1165, 1115, 1085, 1007, 962, 811, 656, 596; **MS:** m/z 443 (M^+, 2.8), 379 (6.2), 288 (7.1), 235 (45.3), 170 (24.8), 105 (61.5), 91 (100.0), 77 (9.9), 65 (47.8), 59 (21.7); **HRMS** (ESI): calcd. for $C_{23}H_{26}NO_6S$ [M + H^+] 444.1475, found 444.1474.

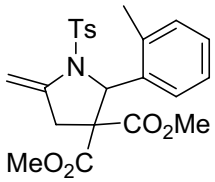
*2.1.4 Synthesis and characterization of compound **3c***



3c

Dimethyl 5-methylene-2-m-tolyl-1-tosylpyrrolidine-3,3-dicarboxylate (3c). This product was synthesized by the same method as for **3a.** The product **3c** (0.076 g, 86%) was isolated as a white solid after flash chromatography; **mp** 118–119 °C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.68 (d, *J* = 8.4 Hz, 2H), 7.22 (d, *J* = 8.4 Hz, 2H), 7.19 (dd, *J* = 7.6, 8.0 Hz, 1H), 7.07 (d, *J* = 7.6 Hz, 1H), 7.02 (d, *J* = 8.0 Hz, 1H), 6.96 (s, 1H), 6.03 (s, 1H), 4.91 (s, 1H), 4.31 (s, 1H), 3.68 (s, 3H), 3.65 (d, *J* = 16.8 Hz, 1H), 3.35 (s, 3H), 2.94 (d, *J* = 16.8 Hz, 1H), 2.40 (s, 3H), 2.27 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.5, 166.6, 143.9, 140.7, 137.9, 137.1, 135.7, 129.3, 129.1, 128.2, 128.1, 127.7, 124.2, 88.9, 69.3, 61.9, 53.4, 52.6, 37.3, 21.5, 21.4; **IR**: ν_{max} (film)/cm^{-1} 3475, 3023, 2956, 1740, 1678, 1642, 1599, 1491, 1433, 1348, 1281, 1221, 1165, 1118, 1085, 1008, 954, 811, 661, 595; **MS:** m/z 443 (M^+, 3.6), 384 (36.7), 288 (12.3), 198 (17.9), 170 (27.3), 117 (16.6), 91 (100.0), 65 (37.8), 59 (25.0); **HRMS** (ESI): calcd. for $C_{23}H_{26}NO_6S$ [M + H^+] 444.1475, found 444.1474.

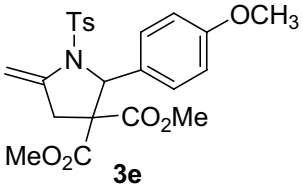
*2.1.5 Synthesis and characterization of compound **3d***



3d

Dimethyl 5-methylene-2-o-tolyl-1-tosylpyrrolidine-3,3-dicarboxylate (3d). This product was synthesized by the same method as for **3a.** The product **3d** (0.072 g, 81%) was isolated as a white solid after flash chromatography; **mp** 154–156 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.59 (d, *J* = 8.0 Hz, 2H), 7.26–7.11 (m, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 7.07–7.04 (m, 2H), 6.47 (s, 1H), 4.87 (s, 1H), 4.30 (s, 1H), 3.83 (d, *J* = 17.2 Hz, 1H), 3.71 (s, 3H), 3.24(s, 3H), 3.02 (d, *J* = 17.2 Hz, 1H), 2.50 (s, 3H), 2.38 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.8, 166.8, 143.9, 140.7, 136.1, 135.8, 135.6, 130.3, 129.0, 128.2, 128.0, 126.8, 126.2, 88.6, 65.0, 61.4, 53.5, 52.4, 38.0, 21.5, 19.3; **IR**: ν_{max} (film)/cm^{-1} 3472, 3062, 2956, 1735, 1666, 1624, 1494, 1435, 1340, 1288, 1224, 1166, 1115, 1085, 1007, 962, 812, 656, 597; **MS:** m/z 443 (M^+, 2.5), 384 (2.9), 320 (19.0), 288 (8.2), 235 (65.1), 170 (14.5), 117 (25.2), 91 (100.0), 65 (33.5), 59 (22.6); **HRMS** (ESI): calcd. for $C_{23}H_{26}NO_6S$ [M + H^+] 444.1475, found 444.1472.

*2.1.6 Synthesis and characterization of compound **3e***

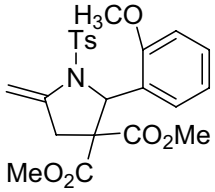


3e

Dimethyl 2-(4-methoxyphenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3e). This product was synthesized by the same method as for **3a.** The product **3e** (0.069 g, 75%) was isolated as a white solid after flash chromatography; **mp** 121–122 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.69 (d, *J* = 8.4 Hz, 2H), 7.23 (d, *J* = 8.4 Hz, 2H), 7.14 (d, *J* = 8.4 Hz, 2H), 6.80 (d, *J* = 8.4 Hz, 2H), 6.02 (s, 1H), 4.87 (s, 1H), 4.30 (s,

1H), 3.78 (s, 3H), 3.68 (s, 3H), 3.65 (d, *J* = 16.4 Hz, 1H), 3.37 (s, 3H), 2.94 (d, *J* = 16.4 Hz, 1H), 2.40 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.6, 166.7, 159.6, 143.9, 140.6, 135.7, 129.4, 129.1, 128.3, 128.1, 113.7, 88.9, 69.0, 61.8, 55.2, 53.4, 52.7, 37.2, 21.6; **IR**: ν_{max}(film)/cm^{-1} 3458, 3019, 2955, 1740, 1666, 1613, 1514, 1436, 1343, 1291, 1253, 1221, 1164, 1111, 1085, 1007, 954, 900, 811, 702, 660, 602, 543; **MS:** m/z 459(M^+, 2.4), 400 (27.4), 304 (2.6), 245 (25.8), 186 (26.0), 155 (13.7), 91 (100.0), 65 (39.5), 59 (25.8); **HRMS** (ESI): calcd. for $C_{23}H_{26}NO_7S$ [M + H^+] 460.1424, found 460.1427.

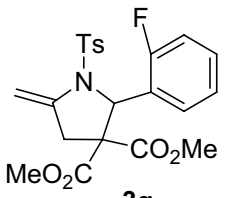
*2.1.7 Synthesis and characterization of compound **3f***



3f

Dimethyl 2-(2-methoxyphenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3f). This product was synthesized by the same method as for **3a.** The product **3f** (0.063 g, 69%) was isolated as a white solid after flash chromatography; **mp** 114–115 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.59 (d, *J* = 8.0 Hz, 2H), 7.26–7.12 (m, 2H), 7.19 (d, *J* = 8.0 Hz, 2H), 7.08–7.04 (m, 2H), 6.47 (s, 1H), 4.87 (s, 1H), 4.30 (s, 1H), 3.83 (d, *J* = 16.8 Hz, 1H),3.71 (s, 3H), 3.24 (s, 3H), 3.03 (d, *J* = 16.8 Hz, 1H), 2.51 (s, 3H), 2.39 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.8, 166.8, 143.9, 140.7, 136.1, 135.8, 135.6, 130.4, 129.1, 128.3, 128.0, 126.8, 88.6, 65.0, 61.4, 53.5, 52.4, 38.0, 21.5, 19.3; **IR**: ν_{max}(film)/cm^{-1} 3472, 3062, 2956, 1735, 1666, 1623, 1495, 1435, 1340, 1289, 1251, 1225, 1165, 1116, 1084, 1008, 962, 905, 812, 754, 655, 596, 542; **MS:** m/z 459(M^+, 2.8), 400 (30.0), 304 (7.1), 245 (26.3), 186 (26.0), 155 (14.6), 91 (100.0), 65 (37.9), 59 (25.8); **HRMS** (ESI): calcd. for $C_{23}H_{26}NO_7S$ [M + H^+] 460.1424, found 460.1431.

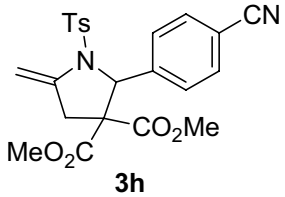
*2.1.8 Synthesis and characterization of compound **3g***



3g

Dimethyl 2-(2-fluorophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3g). This product was synthesized by the same method as for **3a.** The product **3g** (0.071 g, 79%) was isolated as a white solid after flash chromatography; **mp** 136–137 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.75 (d, *J* = 8.0 Hz, 2H), 7.35–7.25 (m, 2H), 7.26 (d, *J* = 8.0 Hz, 2H), 7.12–7.09 (m, 1H), 7.04–7.00 (m, 1H), 6.40 (s, 1H), 4.94 (s, 1H), 4.33 (s, 1H), 3.69 (d, *J* = 16.8 Hz, 1H), 3.65 (s, 3H), 3.38 (s, 3H), 2.97 (d, *J* = 16.8 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.3, 166.8, 159.6 (d, *J* = 257 Hz), 144.1, 140.6, 135.4, 130.2 (d, *J* = 8 Hz), 129.3, 128.7, 128.1, 125.3 (d, *J* = 13 Hz), 124.4 (d, *J* = 3 Hz), 115.3 (d, *J* = 21 Hz), 89.2, 61.3, 53.4, 52.8, 37.8, 21.6; **IR**: ν_{max}(film)/cm^{-1} 3479, 3003, 2953, 1740, 1646, 1594, 1490, 1452, 1438, 1343, 1282, 1250, 1220, 1167, 1117, 1089, 1006, 951, 901, 836, 799, 775, 705, 657, 601, 545, 523; **MS:** m/z 447 (M^+, 2.7), 388 (27.4), 324 (7.1), 202 (18.1), 174 (23.3), 155 (25.2), 91 (100.0), 65 (36.4), 59 (23.7); **HRMS** (ESI): calcd. for $C_{22}H_{23}FNO_6S$ [M + H^+] 448.1225, found 448.1233.

*2.1.9 Synthesis and characterization of compound **3h***

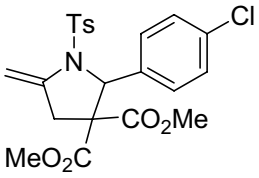


3h

Dimethyl 2-(4-cyanophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3h). This product was synthesized by the same method as for **3a.** The product **3h** (0.083 g, 91%) was isolated as a white solid after flash chromatography; **mp** 163–164 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.76 (d, *J* = 8.4 Hz, 2H), 7.62 (d, *J* = 8.0 Hz, 2H), 7.42 (d, *J* = 8.0 Hz, 2H), 7.29 (d, *J* = 8.4 Hz, 2H), 6.06 (s, 1H), 4.96 (s, 1H), 4.38 (s, 1H), 3.67 (s, 3H), 3.54 (d, *J* = 16.4 Hz, 1H), 3.36 (s, 3H), 2.91 (d, *J* = 16.4 Hz, 1H),

2.43 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.0, 166.4, 144.5, 143.3, 140.2, 135.0, 132.2, 129.4, 128.1, 127.8, 118.3, 112.4, 90.3, 68.8, 61.7, 53.6, 52.9, 37.2, 21.6; **IR**: ν_{max} (film)/cm^{-1} 3483, 3127, 2954, 2227, 1742, 1648, 1602, 1434, 1343, 1286, 1219, 1163, 1126, 1087, 1008, 958, 862, 835, 814, 663, 600; **MS:** m/z 454 (M^+, 1.1), 395 (11.0), 299 (8.3), 267 (2.7), 155 (45.5), 91 (100.0), 65 (33.7), 59 (30.0); **HRMS** (ESI): calcd. for $C_{23}H_{23}N_2O_6S$ [M + H^+] 455.1271, found 455.1280.

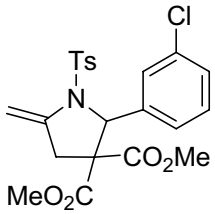
*2.1.10 Synthesis and characterization of compound **3i***



3i

Dimethyl 2-(4-chlorophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3i). This product was synthesized by the same method as for **3a.** The product **3i** (0.089 g, 96%) was isolated as a white solid after flash chromatography; **mp** 141–142 ^oC; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.71 (d, *J* = 8.4 Hz, 2H), 7.27 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.4 Hz, 2H), 7.18 (d, *J* = 8.4 Hz, 2H), 6.02 (s, 1H), 4.91 (s, 1H), 4.33 (s, 1H), 3.67 (s, 3H), 3.60 (d, *J* = 16.8 Hz, 1H), 3.37 (s, 3H), 2.93 (d, *J* = 16.8 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.3, 166.5, 144.2, 140.4, 136.2, 135.4, 134.4, 129.2, 128.6, 128.5, 128.0, 89.5, 68.7, 61.7, 53.5, 52.8, 37.2, 21.6; **IR**: ν_{max} (film)/cm^{-1} 3461, 3067, 2955, 1739, 1677, 1642, 1596, 1492, 1434, 1345, 1283, 1223, 1165, 1121, 1089, 1009, 953, 830, 661, 600; **MS:** m/z 465 (1.2), 463 (M^+, 3.0), 406 (14.0), 404 (35.1), 249 (6.7), 218 (16.1), 190 (16.7), 155 (39.6), 91 (100.0), 65 (36.3), 59 (25.5); **HRMS** (ESI): calcd. for $C_{22}H_{23}{}^{35}ClNO_6S$ [M + H^+] 464.0929, found 464.0936.

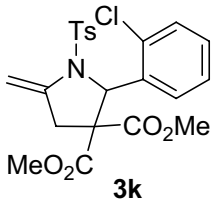
*2.1.11 Synthesis and characterization of compound **3j***



3j

Dimethyl 2-(3-chlorophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3j). This product was synthesized by the same method as for **3a.** The product **3j** (0.082 g, 82%) was isolated as a white solid after flash chromatography; **mp** 116–118 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.70 (d, *J* = 8.4 Hz, 2H), 7.26–7.24 (m, 2H), 7.25 (d, *J* = 8.4 Hz, 2H), 7.17–7.15 (m, 2H), 6.01 (s, 1H), 4.95 (s, 1H), 4.35 (s, 1H), 3.68 (s, 3H), 3.58 (d, *J* = 16.4 Hz, 1H), 3.40 (s, 3H), 2.93 (d, *J* = 16.4 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.2, 166.5, 144.3, 140.4, 139.5, 135.4, 134.3, 129.7, 129.3, 128.7, 128.0, 127.3, 125.2, 89.6, 68.7, 61.8, 53.5, 52.8, 37.2, 21.6; **IR**: ν_{max} (film)/cm^{-1} 3479, 3064, 2959, 1741, 1647, 1596, 1575, 1434, 1348, 1286, 1218, 1165, 1118, 1085, 1006, 944, 838, 840, 663, 590; **MS:** m/z 465 (1.4), 463 (M^+, 3.2), 406 (13.3), 404 (33.3), 308 (5.1), 218 (16.5), 190 (14.9), 155 (39.9), 91 (100.0), 65 (36.4), 59 (26.2); **HRMS** (ESI): calcd. for $C_{22}H_{23}{}^{35}ClNO_6S$ [M + H^+] 464.0929, found 464.0931.

*2.1.12 Synthesis and characterization of compound **3k***

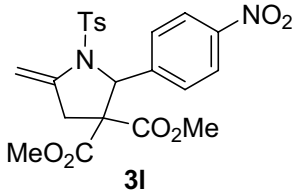


3k

Dimethyl 2-(2-chlorophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3k). This product was synthesized by the same method as for **3a.** The product **3k** (0.081 g, 87%) was isolated as a white solid after flash chromatography; **mp** 116–118 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.77 (d, *J* = 8.4 Hz, 2H), 7.36–7.20 (m, 4H), 7.23 (d, *J* = 8.4 Hz, 2H), 6.65 (s, 1H), 4.98 (s, 1H), 4.34 (s, 1H), 3.68 (d, *J* = 16.8 Hz, 1H), 3.67 (s, 3H), 3.36 (s, 3H), 3.01 (d, *J* = 16.8 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100

MHz, $CDCl_3$): δ 169.3, 166.8, 144.2, 140.6, 135.8, 135.2, 133.0, 129.5, 129.4, 129.2, 128.5, 128.1, 127.2, 89.1, 65.4, 61.2, 53.4, 52.6, 38.0, 21.6; **IR**: ν_{max} (film)/cm^{-1} 3468, 3004, 2952, 1736, 1643, 1596, 1473, 1436, 1341, 1287, 1220, 1168, 1113, 1088, 1005, 952, 833, 769, 657, 595; **MS:** m/z 465 (0.3), 463 (M^+, 1.0), 406 (3.0), 404 (7.6), 340 (6.9), 255 (17.4), 190 (8.2), 155 (21.2), 91 (100.0), 65 (40.3), 59 (25.8); **HRMS** (ESI): calcd. for $C_{22}H_{23}{}^{35}ClNO_6S$ [M + H^+] 464.0929, found 464.0936.

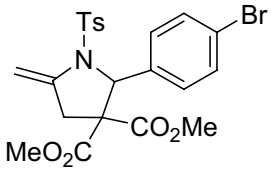
*2.1.13 Synthesis and characterization of compound **3l***



3l

Dimethyl 5-methylene-2-(4-nitrophenyl)-1-tosylpyrrolidine-3,3-dicarboxylate (3l). This product was synthesized by the same method as for **3a.** The product **3l** (0.087 g, 92%) was isolated as a white solid after flash chromatography; **mp** 187–189 °C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.18 (d, *J* = 8.8 Hz, 2H), 7.77 (d, *J* = 8.0 Hz, 2H), 7.49 (d, *J* = 8.8 Hz, 2H), 7.27 (d, *J* = 8.0 Hz, 2H), 6.10 (s, 1H), 4.98 (s, 1H), 4.40 (s, 1H), 3.68 (s, 3H), 3.56 (d, *J* = 16.8 Hz, 1H), 3.37 (s, 3H), 2.92 (d, *J* = 16.8 Hz, 1H), 2.43 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.0, 166.3, 147.8, 145.3, 144.6, 140.2, 134.9, 129.4, 128.0, 123.6, 90.5, 68.5, 53.6, 53.6, 52.9, 37.3, 21.6; **IR**: ν_{max}(film)/cm^{-1} 3480, 3119, 2955, 1740, 1646, 1603, 1523, 1434, 1405, 1347, 1286, 1246, 1217, 1163, 1122, 1087, 1009, 954, 906, 866, 815, 701, 680, 659, 599, 542; **MS:** m/z 447 (M^+, 0.2), 410 (0.9), 351 (5.9), 319 (1.8), 155 (18.3), 105 (60.1), 91 (100.0), 65 (32.0), 59 (26.6); **HRMS** (ESI): calcd. for $C_{22}H_{23}N_2O_8S$ [M + H^+] 475.1170, found 475.1162.

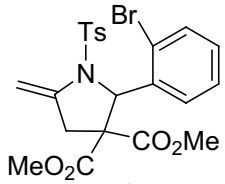
*2.1.14 Synthesis and characterization of compound **3m***



3m

Dimethyl 2-(4-bromophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3m). This product was synthesized by the same method as for **3a.** The product **3m** (0.086 g, 85%) was isolated as a white solid after flash chromatography; **mp** 158–159 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.71 (d, *J* = 8.4 Hz, 2H), 7.42 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.4 Hz, 2H), 7.12 (d, *J* = 8.4 Hz, 2H), 6.00 (s, 1H), 4.91 (s, 1H), 4.33 (s, 1H), 3.78 (s, 3H), 3.67 (d, *J* = 16.4 Hz, 1H), 3.38 (s, 3H), 2.93 (d, *J* = 16.4 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.3, 166.5, 144.2, 140.4, 136.7, 135.4, 131.5, 129.2, 128.8, 128.0, 122.6, 89.5, 68.7, 61.7, 53.5, 52.8, 37.2, 21.6; **IR**: ν_{max} (film)/cm^{-1} 3481, 3005, 2953, 1921, 1740, 1633, 1595, 1487, 1434, 1347, 1286, 1224, 1165, 1119, 1077, 1006, 959, 906, 855, 817, 702, 677, 659, 597, 541; **MS:** m/z 509 (2.9), 507 (M^+, 2.6), 450 (26.4), 448 (25.3), 264 (8.8), 262 (9.8), 155 (45.4), 91 (100.0), 65 (34.5), 59 (24.2); **HRMS** (ESI): calcd. for $C_{22}H_{23}{}^{79}BrNO_6S$ [M + H^+] 508.0424, found 508.0421.

*2.1.15 Synthesis and characterization of compound **3n***

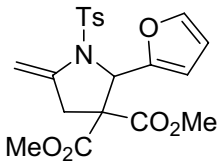


3n

Dimethyl 2-(2-bromophenyl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3n). This product was synthesized by the same method as for **3a.** The product **3n** (0.082 g, 81%) was isolated as a white solid after flash chromatography; **mp** 168–170 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.78 (d, *J* = 8.4 Hz, 2H), 7.54 (d, *J* = 8.0 Hz, 1H), 7.30 (d, *J* = 8.4 Hz, 2H), 7.27 (dd, *J* = 8.0, 8.0 Hz, 2H), 7.25 (d, *J* = 6.8 Hz, 1H), 7.14 (dd, *J* = 6.8, 8.0 Hz, 1H), 6.63 (s, 1H), 4.99 (s, 1H), 4.33 (s, 1H), 3.72 (d, *J* = 16.8 Hz, 1H), 3.64 (s, 3H), 3.36 (s, 3H), 3.01 (d, *J* = 16.8 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100

MHz, $CDCl_3$): δ 169.2, 166.8, 144.2, 140.6, 137.4, 135.2, 132.9, 129.8, 129.2, 128.7, 128.1, 127.8, 123.4, 89.1, 67.9, 61.2, 53.4, 52.6, 38.0, 21.6; **IR**: ν_{max}(film)/cm^{-1} 3469, 2993, 2952, 1939, 1736, 1640, 1593, 1496, 1469, 1437, 1350, 1288, 1219, 1166, 1110, 1087, 1005, 960, 943, 903, 825, 758, 707, 680, 656, 595, 543; **MS:** m/z 509 (1.4), 507 (M^+,1.0), 450 (5.7), 448 (5.6), 301 (18.8), 299 (19.3), 155 (26.8), 91 (100.0), 65 (43.2), 59 (27.0); **HRMS** (ESI): calcd. for $C_{22}H_{23}{}^{79}BrNO_6S$ [M + H^+] 508.0424, found 508.0421.

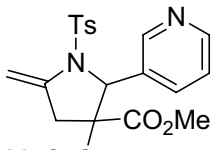
*2.1.16 Synthesis and characterization of compound **3o***



3o

Dimethyl 2-(furan-2-yl)-5-methylene-1-tosylpyrrolidine-3,3-dicarboxylate (3o). This product was synthesized by the same method as for **3a.** The product **3o** (0.074 g, 88%) was isolated as a white solid after flash chromatography; **mp** 114–115 °C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.52 (d, *J* = 8.4 Hz, 2H), 7.23 (d, *J* = 1.6 Hz, 1H), 7.20 (d, *J* = 8.4 Hz, 2H), 6.41 (d, *J* = 3.2 Hz, 1H), 6.32 (dd, *J* = 1.6, 3.2 Hz, 1H), 6.10 (s, 1H), 4.83 (s, 1H), 4.29 (s, 1H), 3.75 (d, *J* = 16.4 Hz, 1H), 3.72 (s, 3H), 3.50 (s, 3H), 3.01 (d, *J* = 16.4 Hz, 1H), 2.39 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 168.8, 166.4, 149.9, 143.8, 142.9, 140.0, 135.6, 129.2, 127.7, 110.4, 110.1, 89.1, 62.7, 60.6, 53.5, 53.0, 37.8, 21.5; **IR**: ν_{max}(film)/cm^{-1} 3464, 3013, 2956, 1921, 1741, 1668, 1622, 1596, 1498, 1436, 1350, 1283, 1216, 1166, 1111, 1085, 1009, 948, 890, 811, 758, 705, 662, 601, 533; **MS:** m/z 419 (M^+, 3.8), 360 (26.2), 264 (29.4), 204 (16.9), 155 (17.5), 146 (31.3), 91 (100.0), 65 (59.3), 59 (33.0); **HRMS** (ESI): calcd. for $C_{20}H_{22}NO_7S$ [M + H^+] 420.1111, found 420.1117.

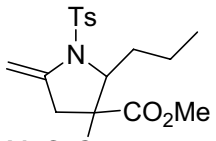
*2.1.17 Synthesis and characterization of compound **3p***



3p

Dimethyl 5-methylene-2-(pyridin-3-yl)-1-tosylpyrrolidine-3,3-dicarboxylate (3p). This product was synthesized by the same method as for **3a.** The product **3p** (0.071 g, 82%) was isolated as a white solid after flash chromatography; **mp** 96–97 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 8.54 (br, 2H), 7.74 (d, *J* = 8.4 Hz, 2H), 7.60 (d, *J* = 8.0 Hz, 1H), 7.27 (d, *J* = 8.4 Hz, 2H), 7.25 (d, *J* = 8.0 Hz, 1H), 6.06 (s, 1H), 4.96 (s, 1H), 4.37 (s, 1H), 3.67 (s, 3H), 3.59 (d, *J* = 16.4 Hz, 1H), 3.37 (s, 3H), 2.95 (d, *J* = 16.4 Hz, 1H), 2.42 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.0, 166.4, 149.7, 148.6, 144.3, 140.2, 135.1, 134.4, 133.5, 129.3, 128.0, 123.3, 89.9, 67.1, 61.6, 53.5, 52.9, 37.1, 21.6; **IR**: ν_{max}(film)/cm-1 3481, 3008, 2956, 1918, 1742, 1673, 1645, 1594, 1428, 1398, 1350, 1325, 1295, 1218, 1164, 1118, 1085, 1006, 957, 904, 830, 810, 709, 678, 656, 593, 542; **MS:** m/z 430 (M^+, 2.9), 366 (8.0), 307 (4.3), 275 (3.4), 155 (15.6), 105 (32.9), 91 (100.0), 65 (39.2), 59 (22.7); **HRMS** (ESI): calcd. for $C_{21}H_{23}N_2O_6S$ [M + H^+] 431.1271, found 431.1276.

*2.1.18 Synthesis and characterization of compound **3q***

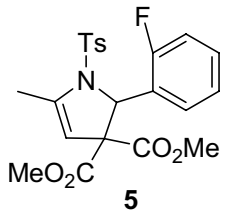


3q

Dimethyl 5-methylene-2-propyl-1-tosylpyrrolidine-3,3-dicarboxylate (3q). This product was synthesized by the same method as for **3a.** The product **3q** (0.025 g, 32%) was isolated as a colorless oil after flash chromatography; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.82 (d, *J* = 8.0 Hz, 2H), 7.28 (d, *J* = 8.0 Hz, 2H), 5.03 (t, *J* = 6.0 Hz, 2H), 4.86 (s, 1H), 4.26 (s, 1H), 3.74 (s, 3H), 3.51 (s, 3H), 3.44 (d, *J* = 16.8 Hz, 1H), 2.94 (d, *J* = 16.8 Hz, 1H), 2.42 (s, 3H), 1.75–1.43 (m, 5H), 0.95 (t, *J* = 7.2 Hz, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 169.5, 167.7, 143.9, 140.0, 135.5, 129.0, 128.5, 90.4, 66.4, 60.6,

53.2, 53.1, 37.7, 35.3, 21.6, 19.0, 14.2; **IR**: ν_{max}(film)/cm^{-1} 3394, 3003, 2959, 2874, 1737, 1616, 1437, 1329, 1272, 1221, 1163, 1086, 1044, 950, 909, 815, 706, 672, 549; **MS:** m/z 395 (M^+, 3.8), 336 (40.5), 288 (27.3), 180 (15.4), 155 (26.3), 91 (100.0), 65 (42.9), 59 (35.8); **HRMS** (ESI): calcd. for $C_{19}H_{26}NO_6S$ [M + H^+] 396.1475, found 396.1484.

*2.1.19 Synthesis and characterization of compound **5***



5

Dimethyl 2-(2-fluorophenyl)-1,2-dihydro-5-methyl-1-tosylpyrrole-3,3-dicarboxylate (5). The compound **3g** (18 mg, 0.04 mmol) was dissolved in $CDCl_3$ in NMR tube at r.t.. After 72 hrs, S.M. was almost isomerized to the desired product **5** (> 95% yield) by ^{1}H NMR. **mp** 45–47 ^{o}C; **^{1}H NMR** (400 MHz, $CDCl_3$): δ 7.74 (d, *J* = 8.0 Hz, 2H), 7.35–7.17 (m, 2H), 7.26 (d, *J* = 8.0 Hz, 2H), 7.11–7.07 (m, 1H), 7.03–7.00 (m, 1H), 6.43 (s, 1H), 5.00 (s, 1H), 3.55 (s, 3H), 3.10 (s, 3H), 2.41 (s, 3H), 2.22 (s, 3H); **^{13}C NMR** (100 MHz, $CDCl_3$): δ 168.5, 168.0, 159.4 (d, *J* = 247 Hz), 144.0, 143.6, 135.1, 129.9 (d, *J* = 8 Hz), 129.7, 128.6, 127.7, 125.6 (d, *J* = 12 Hz), 124.1, 114.9 (d, *J* = 22 Hz), 106.9, 67.8, 61.4, 53.1, 52.2 , 21.5, 15.5; **IR**: ν_{max}(film)/cm^{-1} 3441, 2954, 1740, 1662, 1595, 1492, 1454, 1437, 1347, 1275, 1223, 1168, 1094, 1067, 1040, 990, 901, 938, 810, 759, 659, 591, 542; **MS:** m/z 447 (M^+, 3.0), 388 (35.6), 202 (24.6), 174 (23.4), 155 (30.9), 91 (100.0), 65 (30.4), 59 (19.2); **HRMS** (ESI): calcd. for $C_{22}H_{23}FNO_6S$ [M + H^+] 448.1225, found 448.1233.

3. References

[S1] A. M. Gómez, M. D. Company, S. Valverde and J. C. López, *Org. Lett.*, 2002, **4**, 383.

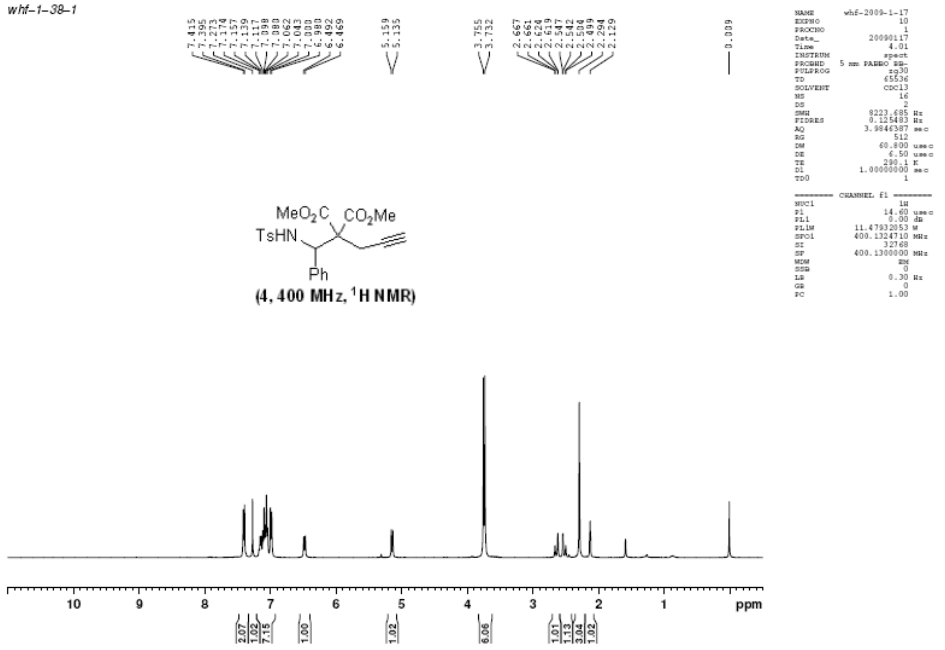
[S2] (a) W. B. Jennings, C. J. Lovely, *Tetrahedron,* 1991, **47**, 5561.
(b) W. B. Jennings, C. J. Lovely, *Tetrahedron Lett.,* 1988, **29**, 3725.

[S3] (a) F. Chemla, V. Hebbe and J.-F. Normant, *Synthesis*, 2000, 75.
(b) Zh.-J. Li, X.-H. Ren, P. Wei, H.-G. Wan, Y.-H. Shi and P.-K. Ouyang, *Green Chem.*, 2006, **8**, 433.

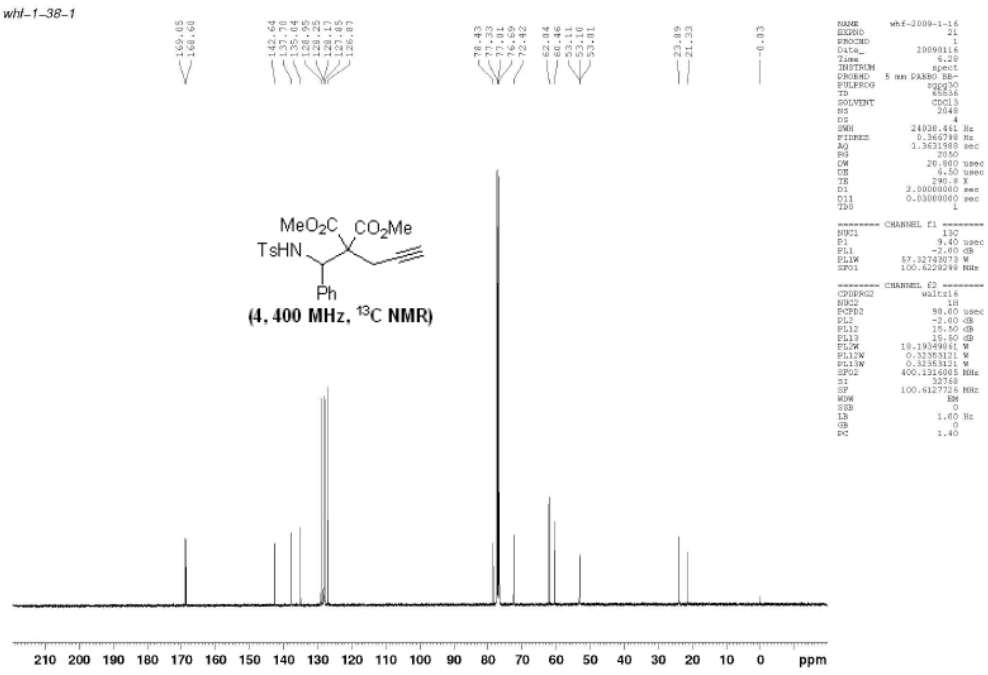
4. Spectra

*4.1 Spectra for compound **4***

^{1}H NMR:

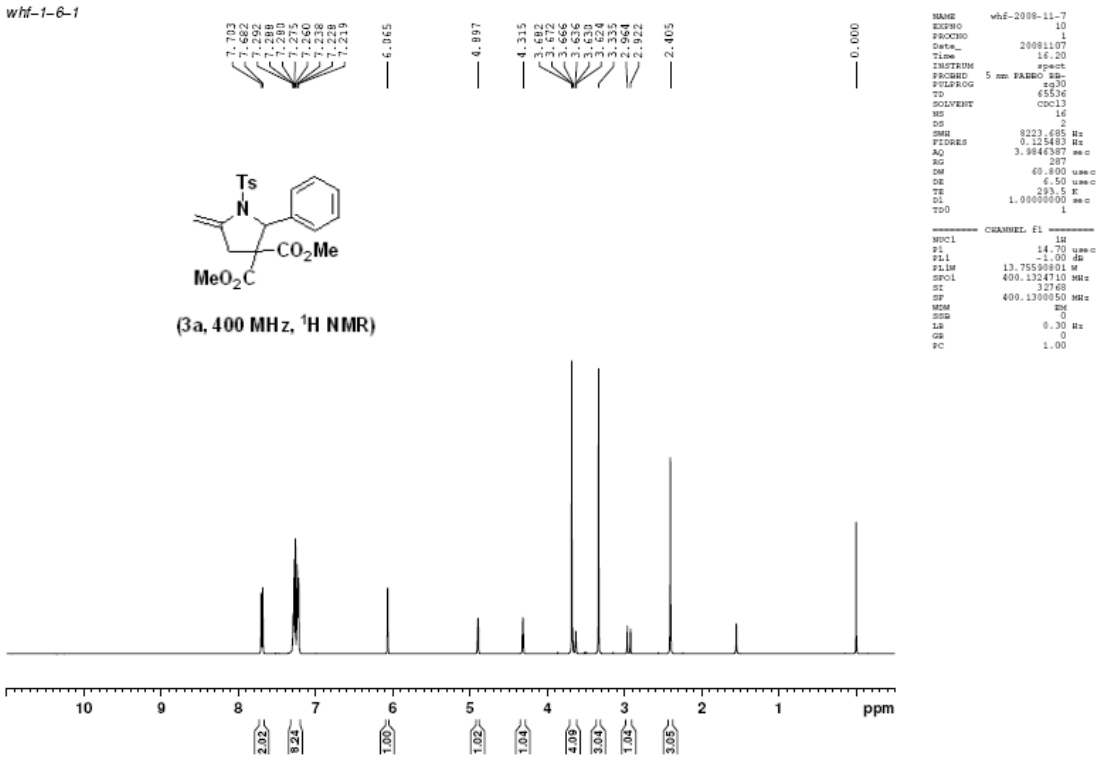


^{13}C NMR:

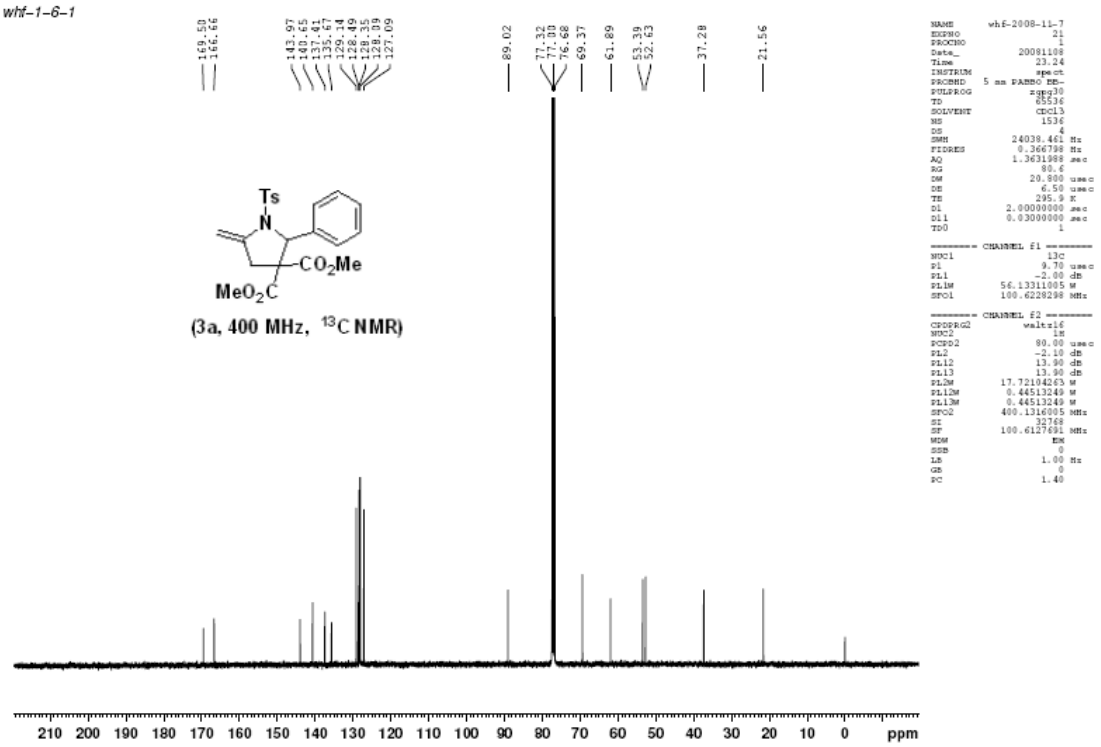


*4.2 Spectra for compound **3a***

^{1}H NMR:

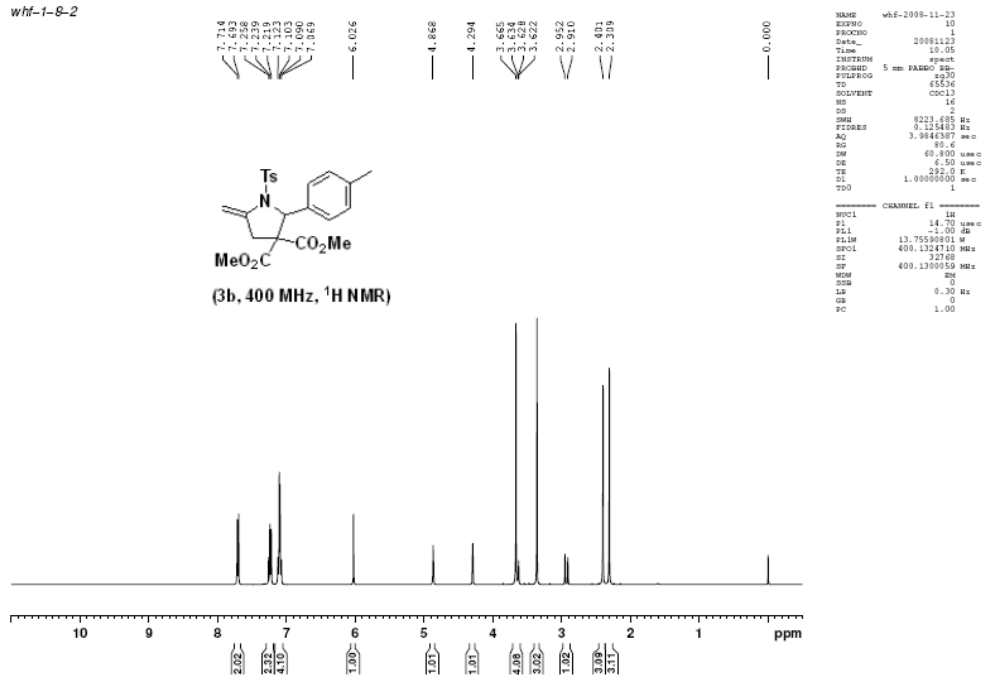


^{13}C NMR:

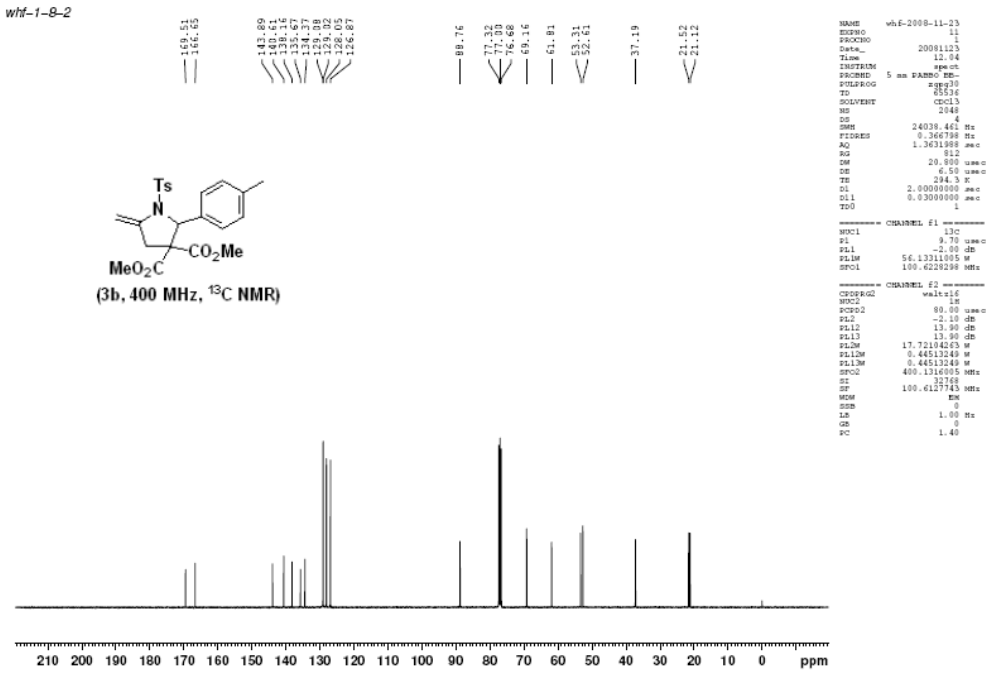


*4.3 Spectra for compound **3b***

^{1}H NMR:

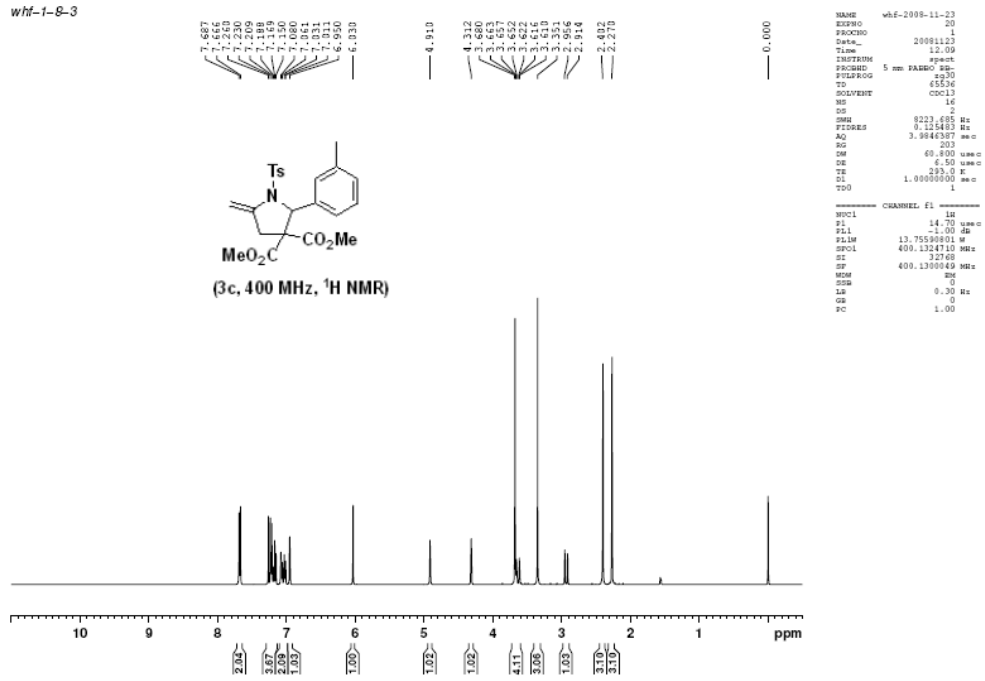


^{13}C NMR:

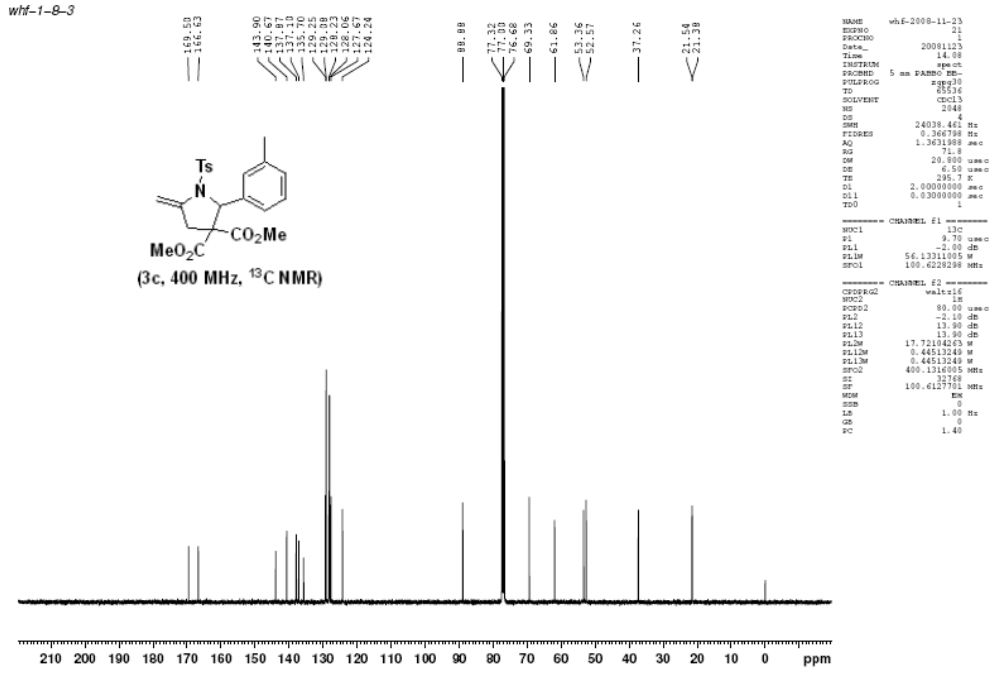


*4.4 Spectra for compound **3c***

^{1}H NMR:

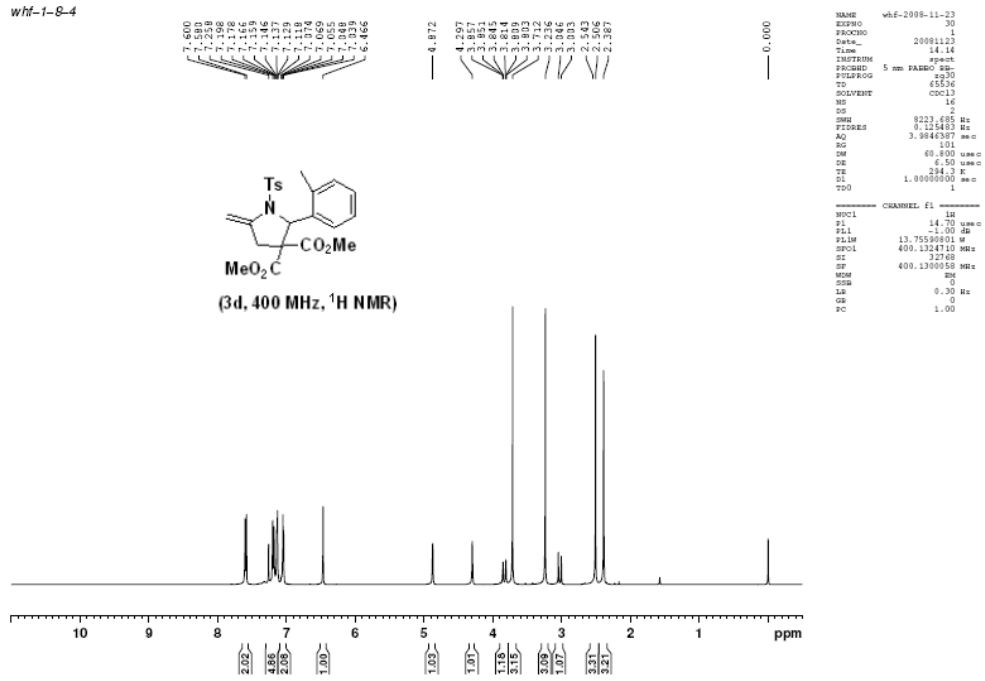


^{13}C NMR:

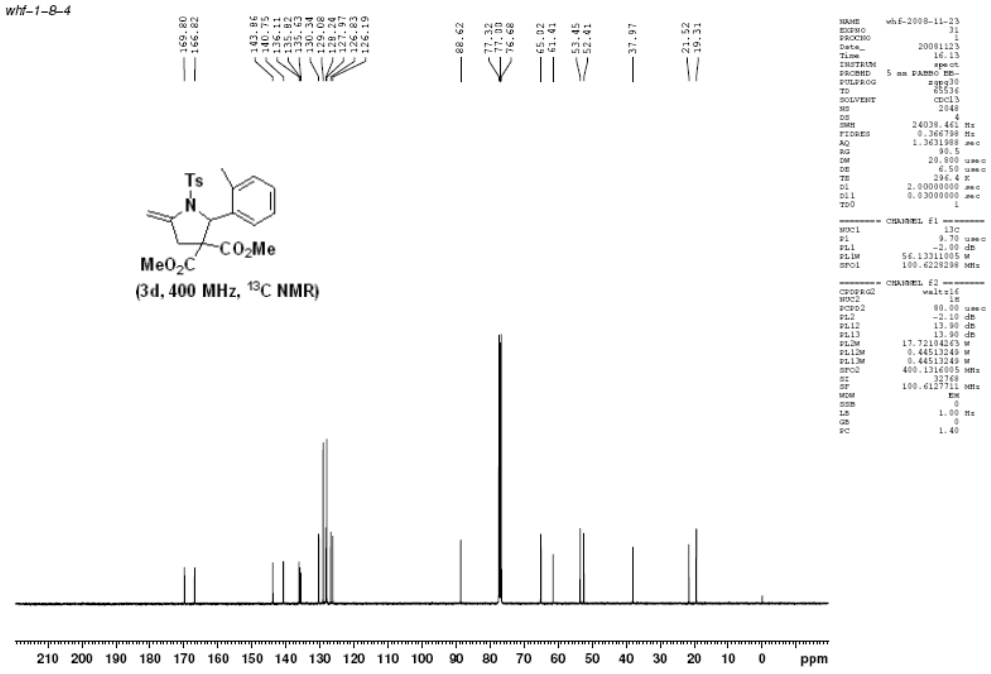


*4.5 Spectra for compound **3d***

^{1}H NMR:

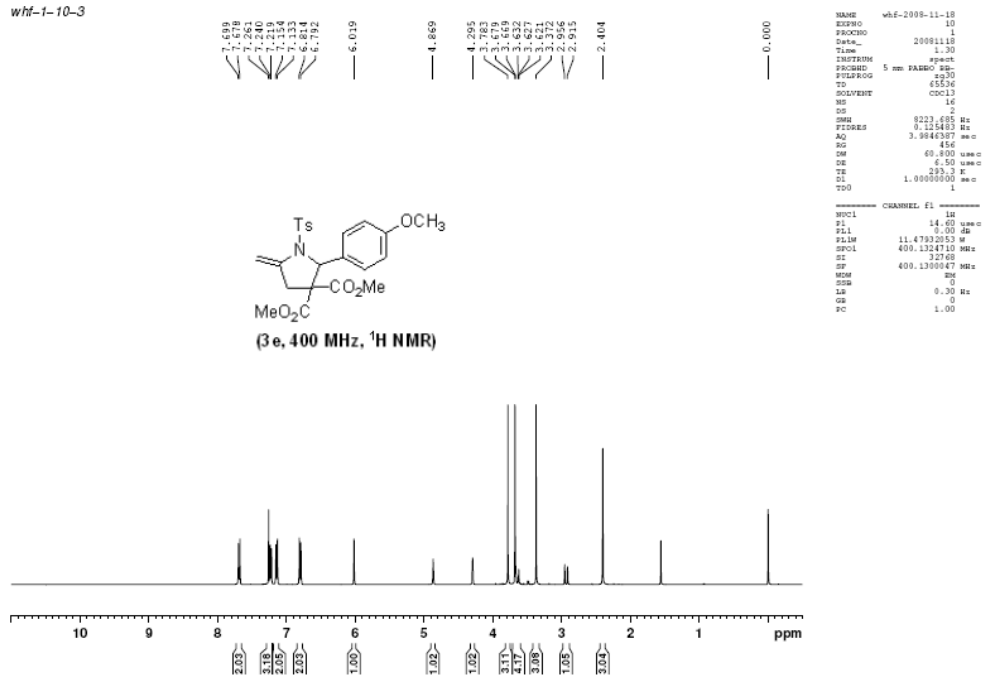


^{13}C NMR:

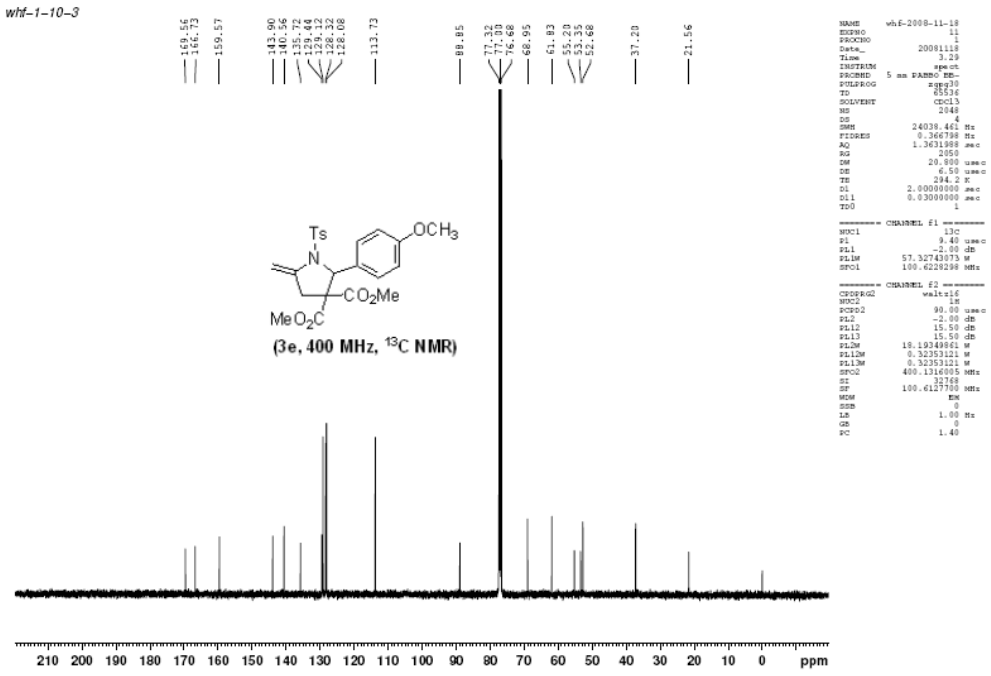


*4.6 Spectra for compound **3e***

^{1}H NMR:

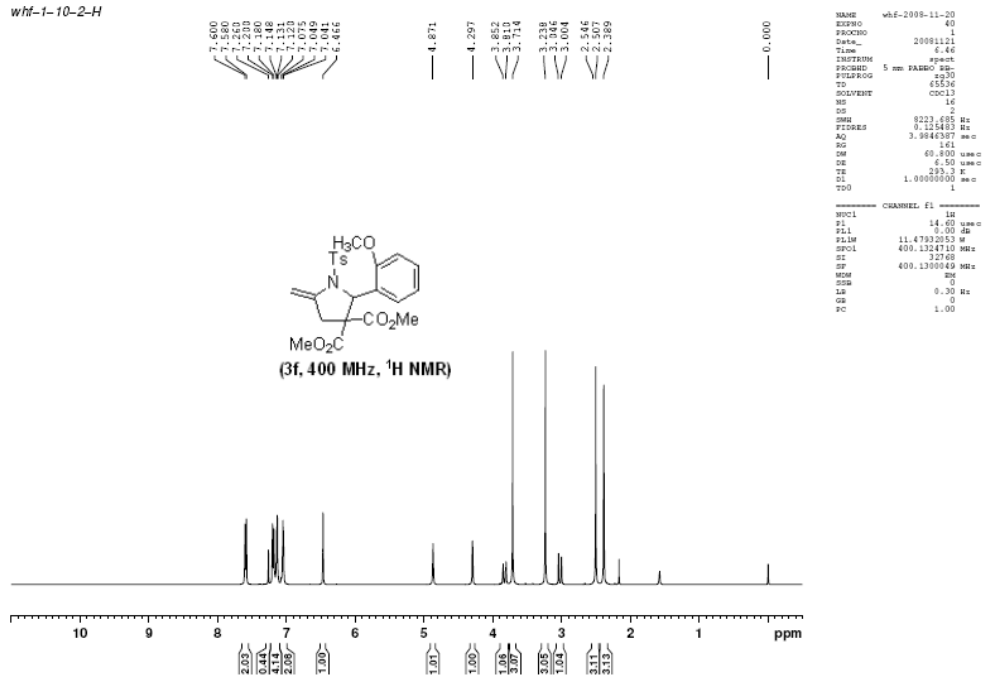


^{13}C NMR:

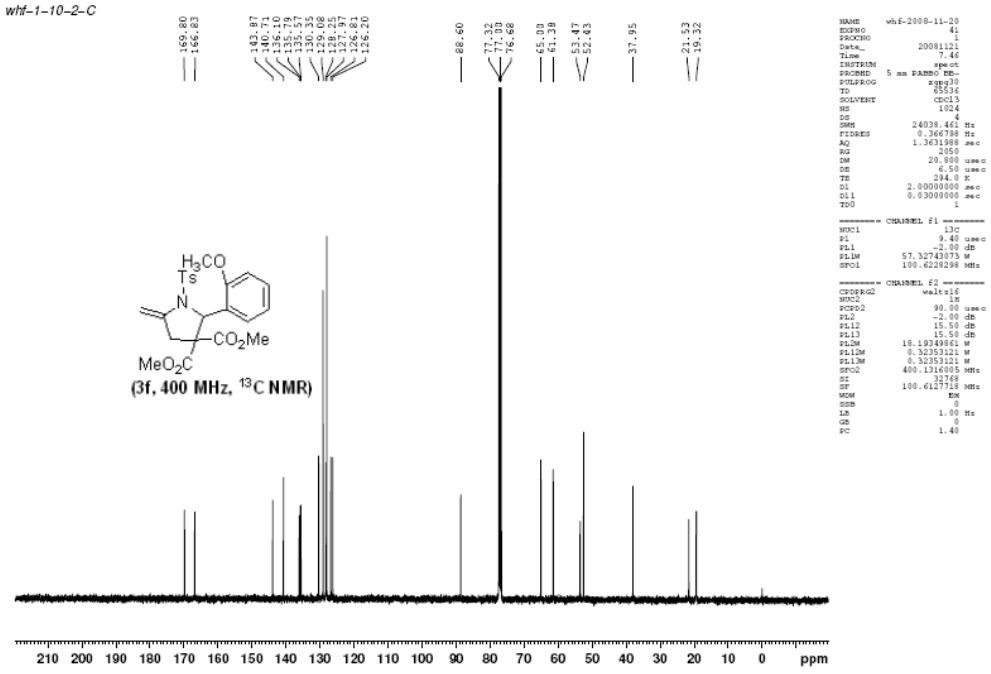


*4.7 Spectra for compound **3f***

^{1}H NMR:

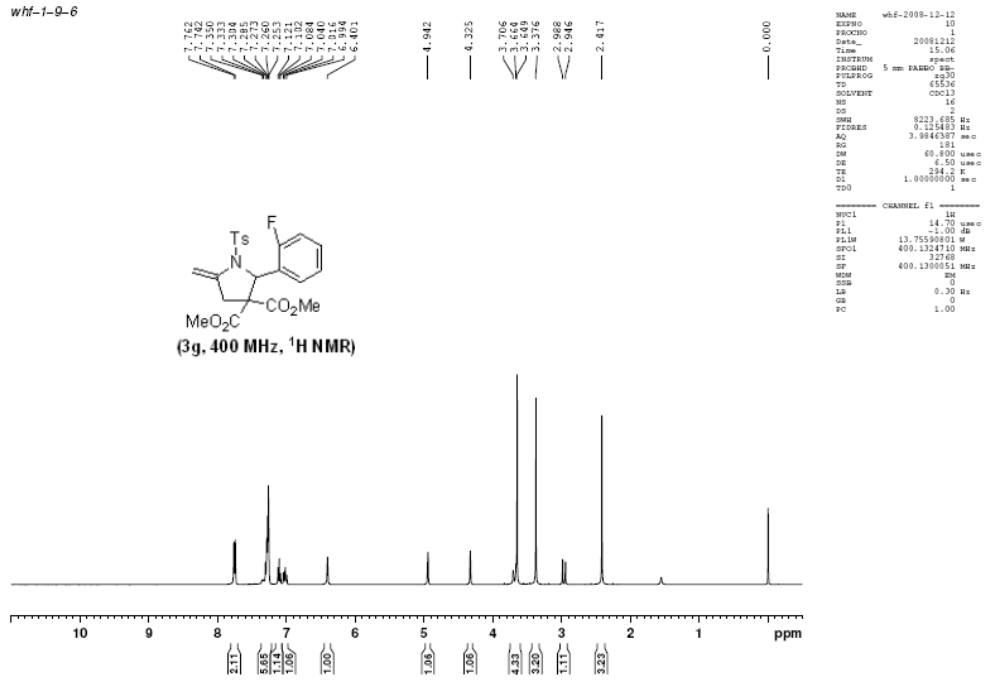


^{13}C NMR:

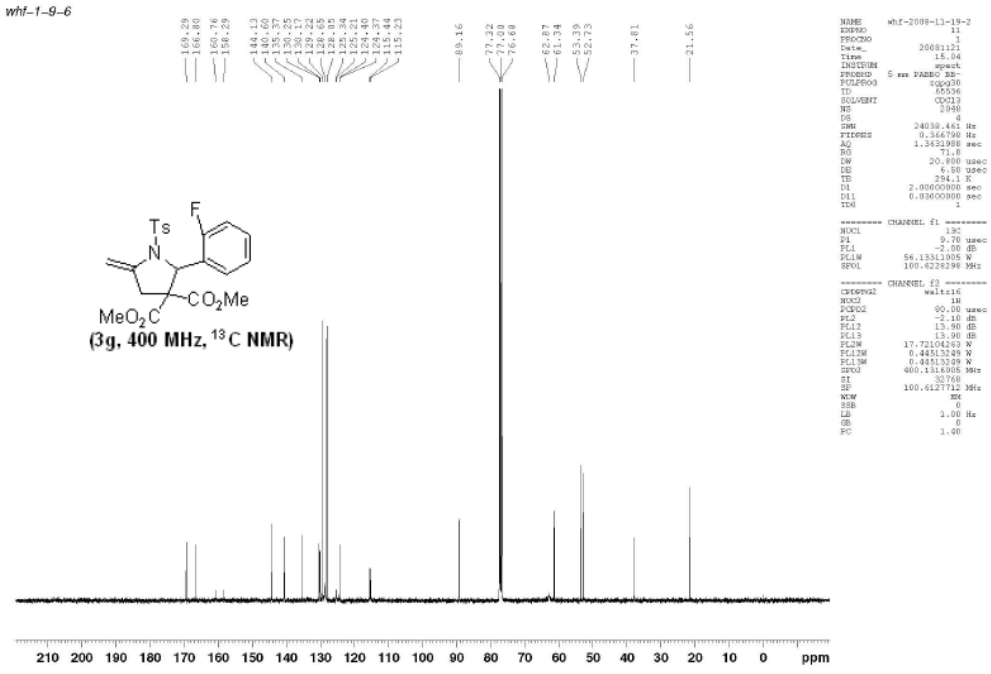


*4.8 Spectra for compound **3g***

^{1}H NMR:

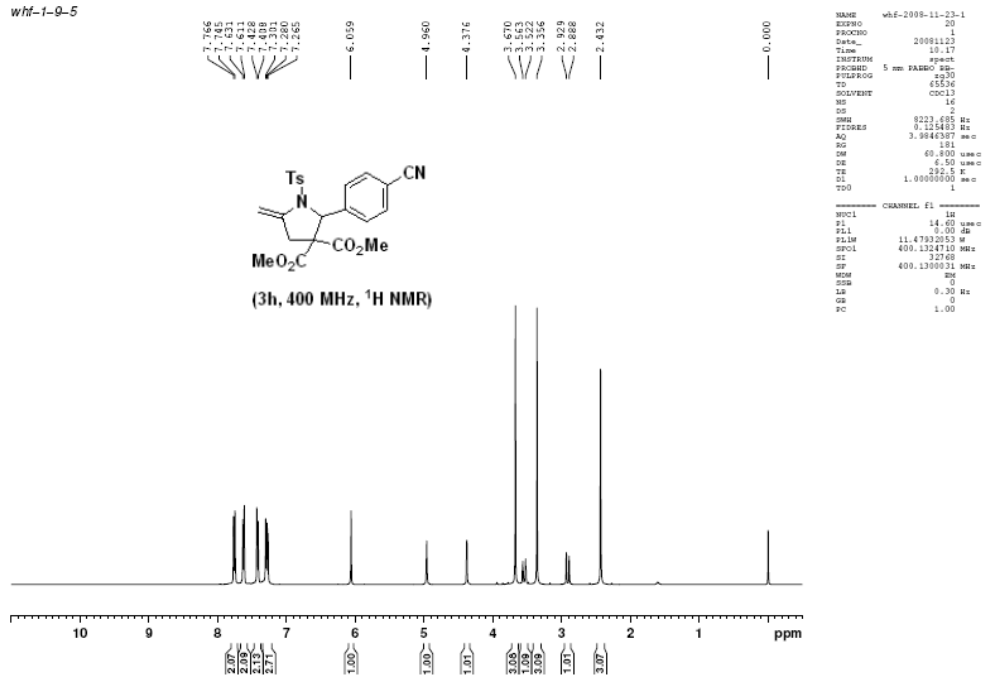


^{13}C NMR:

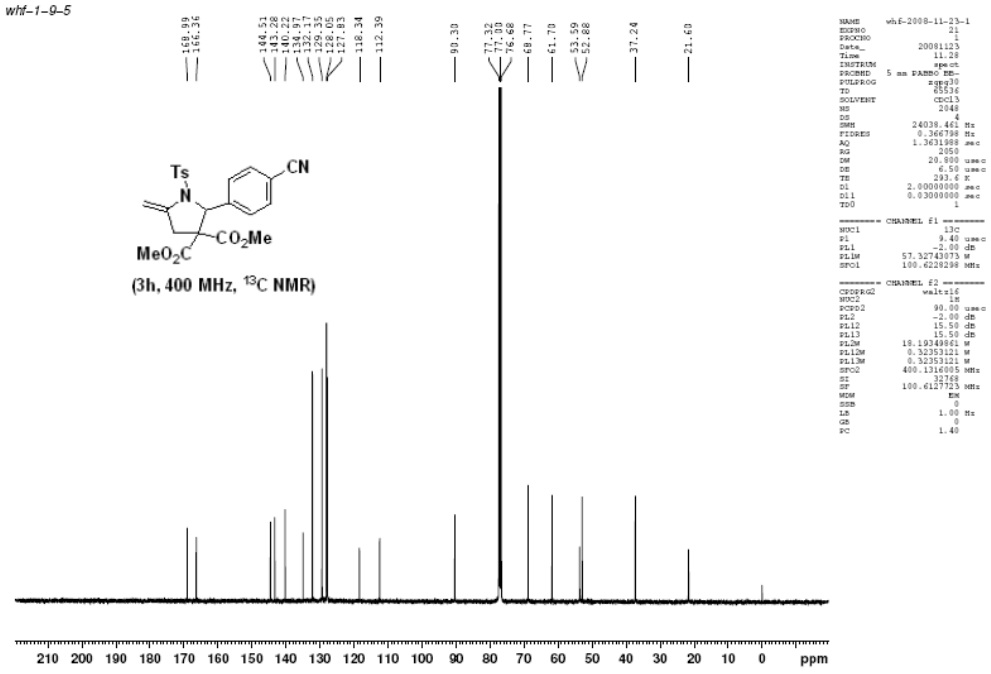


*4.9 Spectra for compound **3h***

^{1}H NMR:

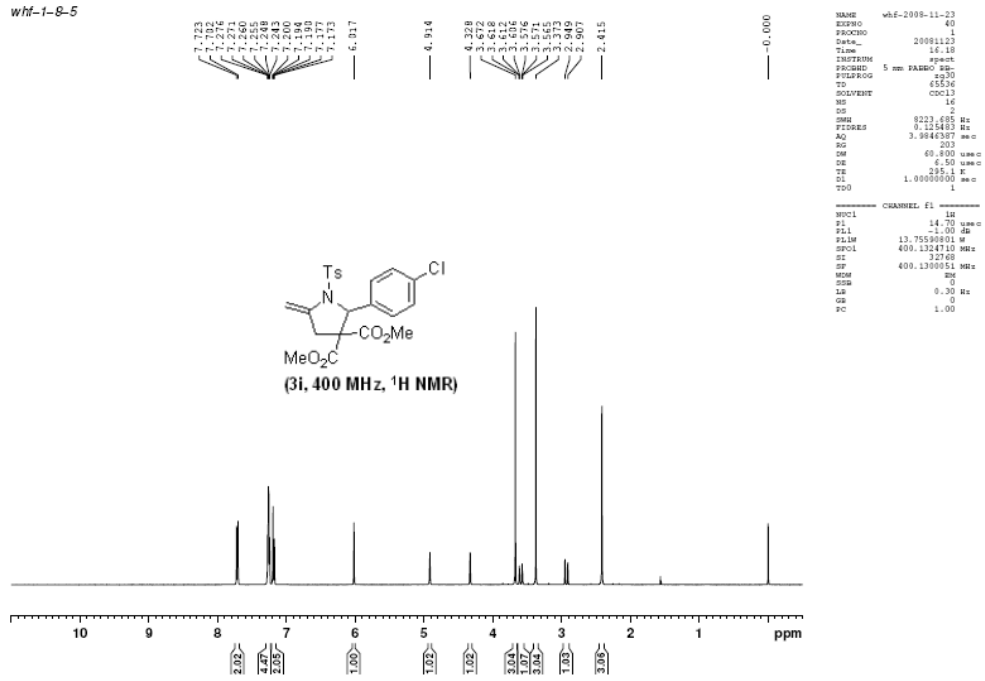


^{13}C NMR:

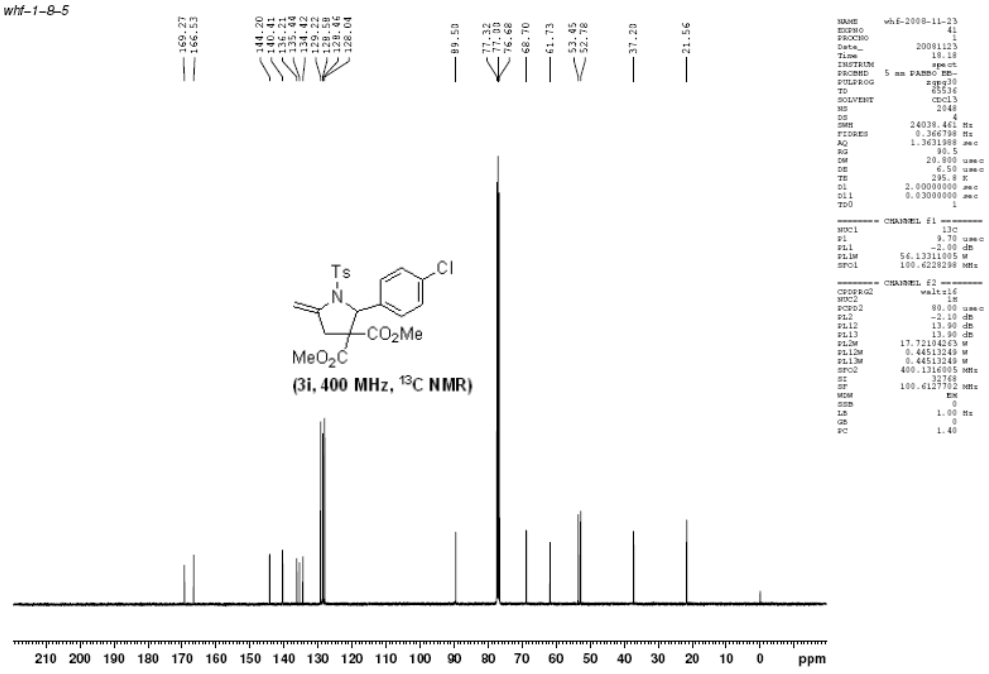


*4.10 Spectra for compound **3i***

^{1}H NMR:

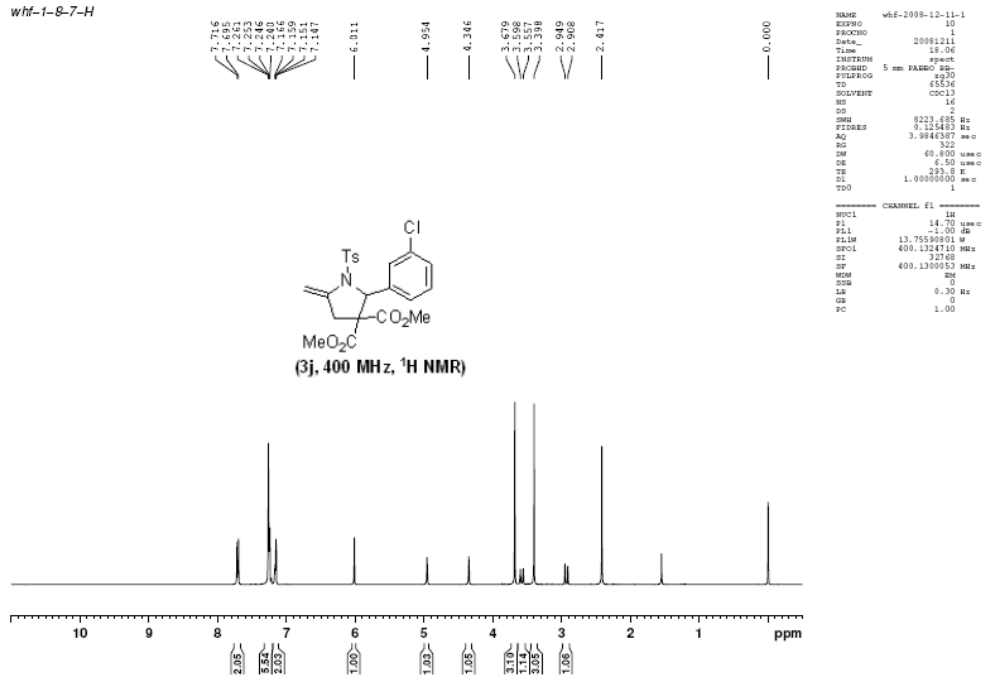


^{13}C NMR:

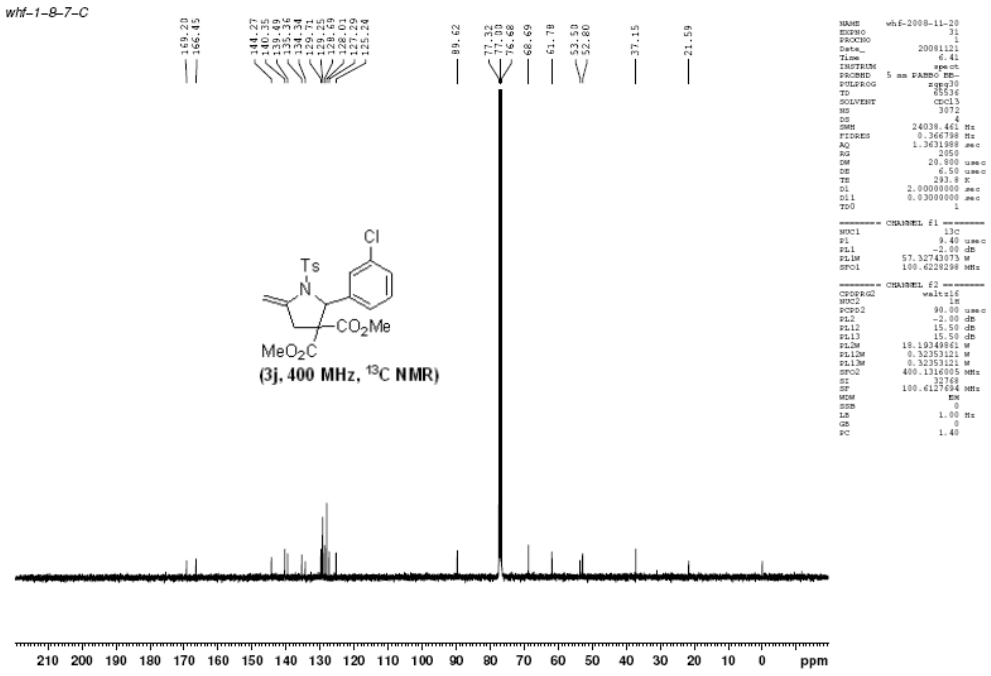


*4.11 Spectra for compound **3j***

^{1}H NMR:

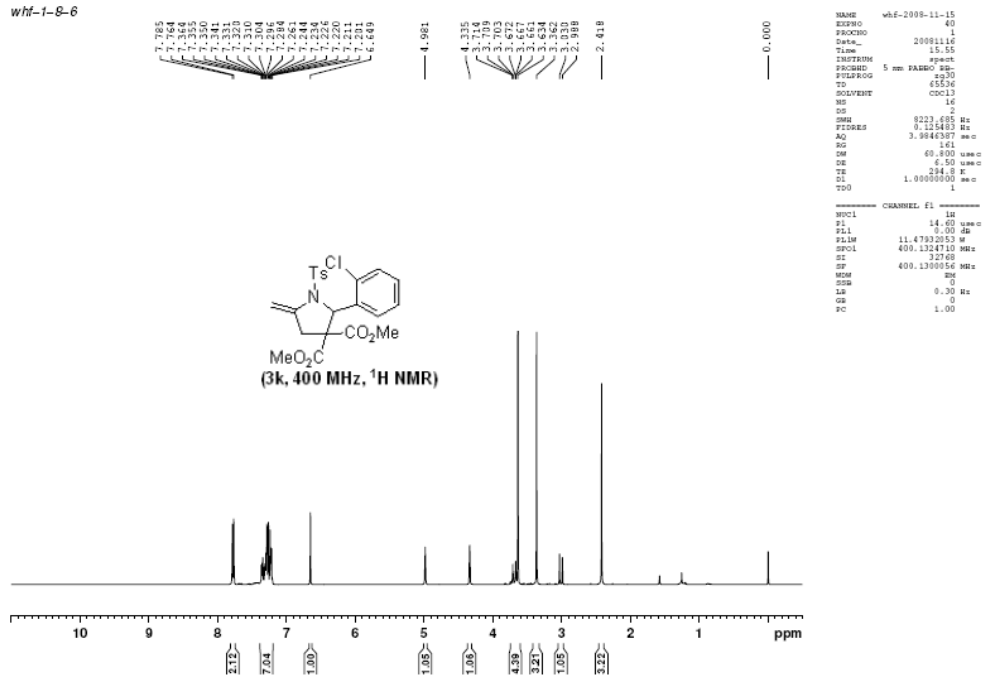


^{13}C NMR:

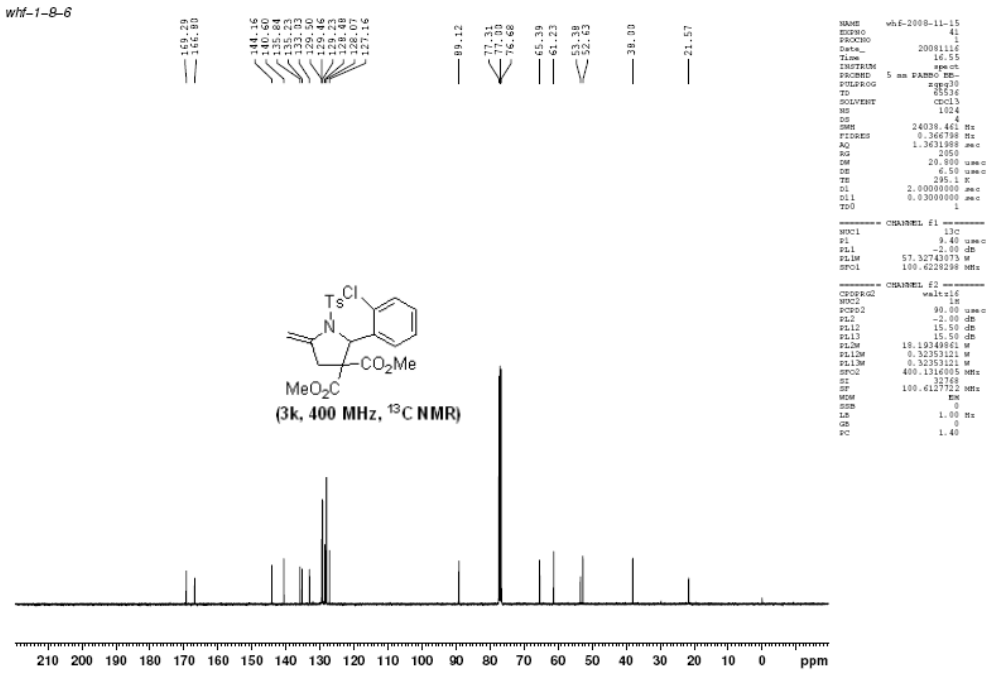


*4.12 Spectra for compound **3k***

^{1}H NMR:

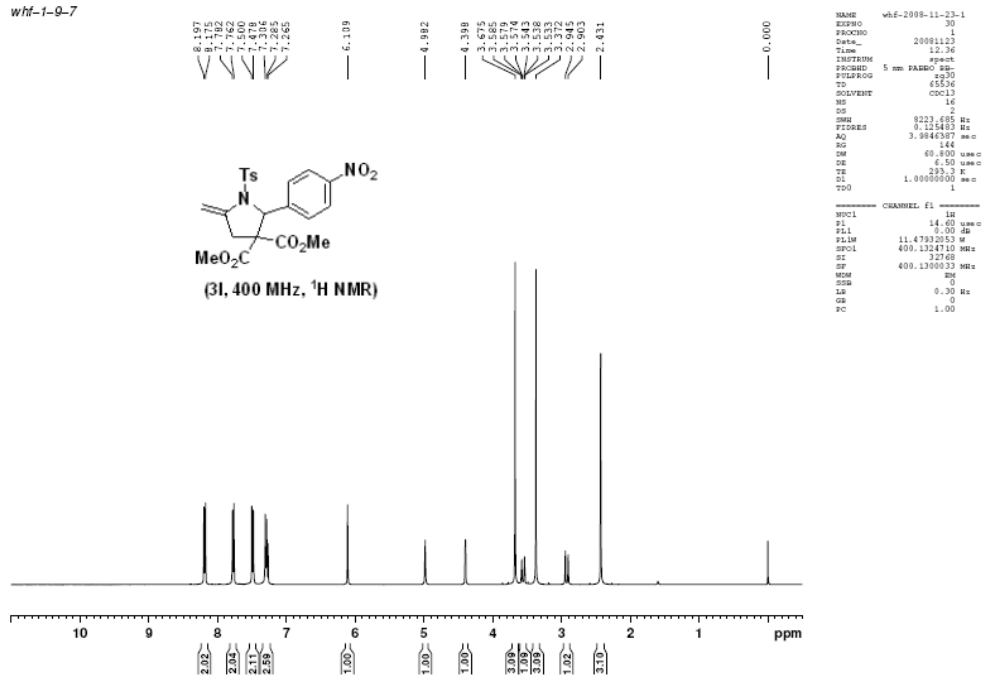


^{13}C NMR:

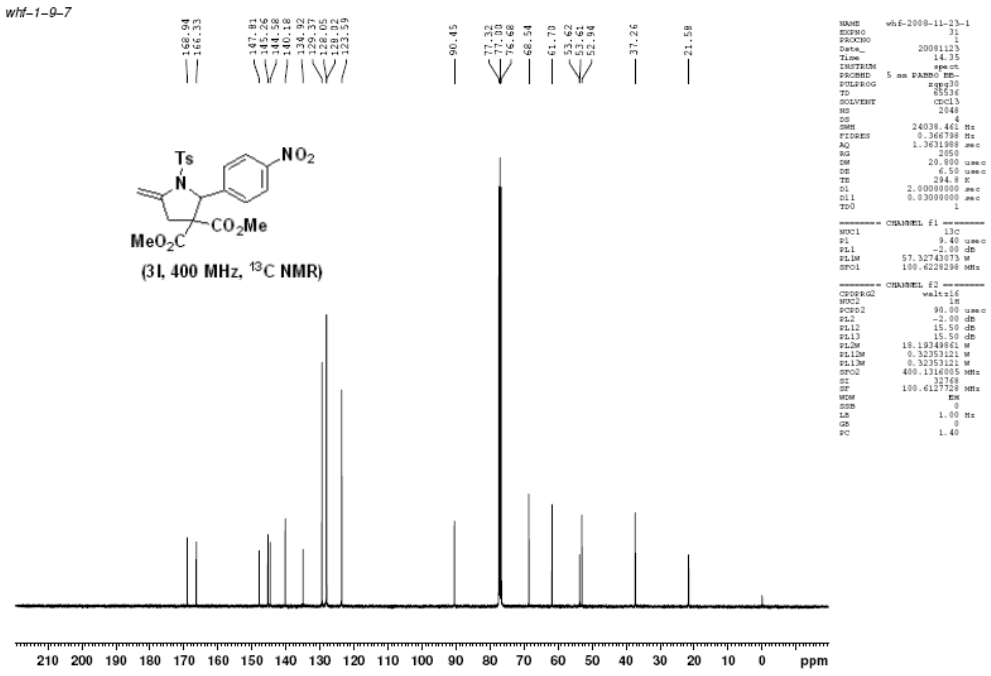


*4.13 Spectra for compound **3l***

^{1}H NMR:

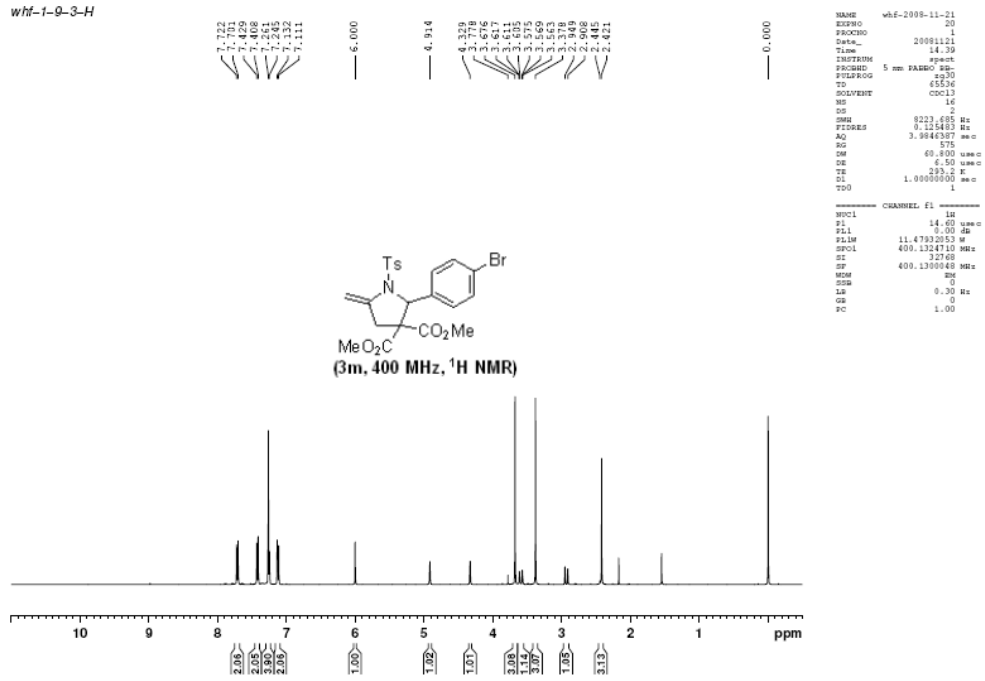


^{13}C NMR:

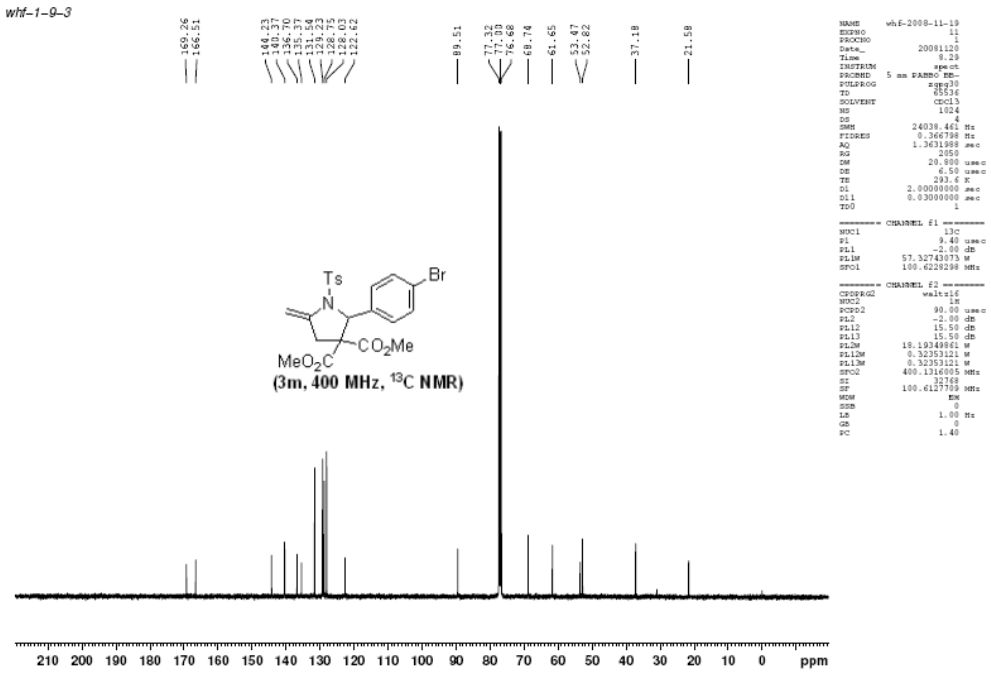


*4.14 Spectra for compound **3m***

^{1}H NMR:

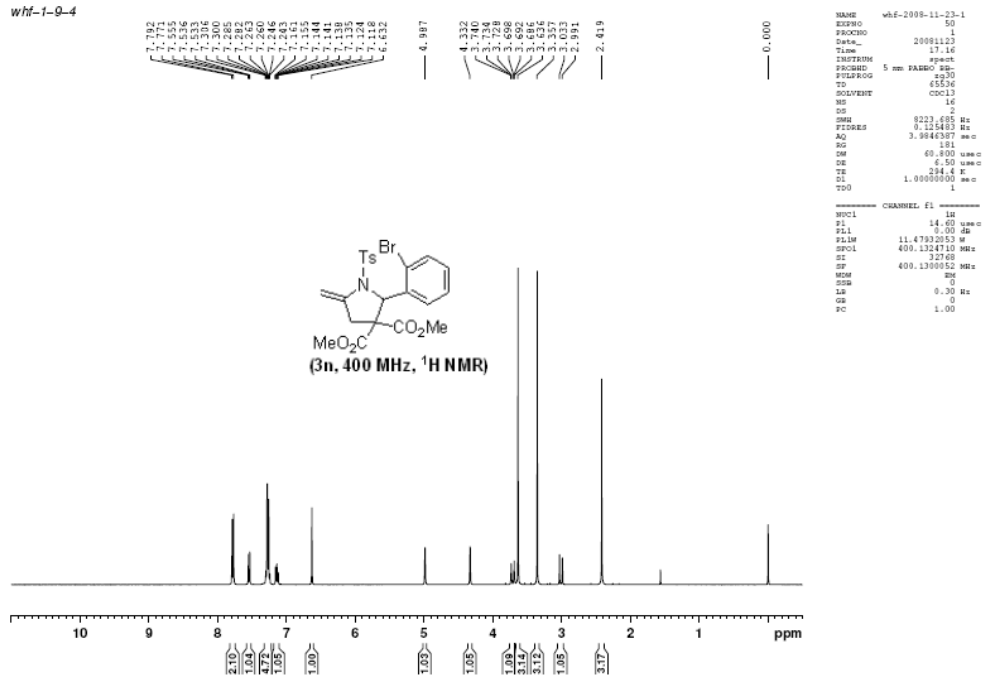


^{13}C NMR:

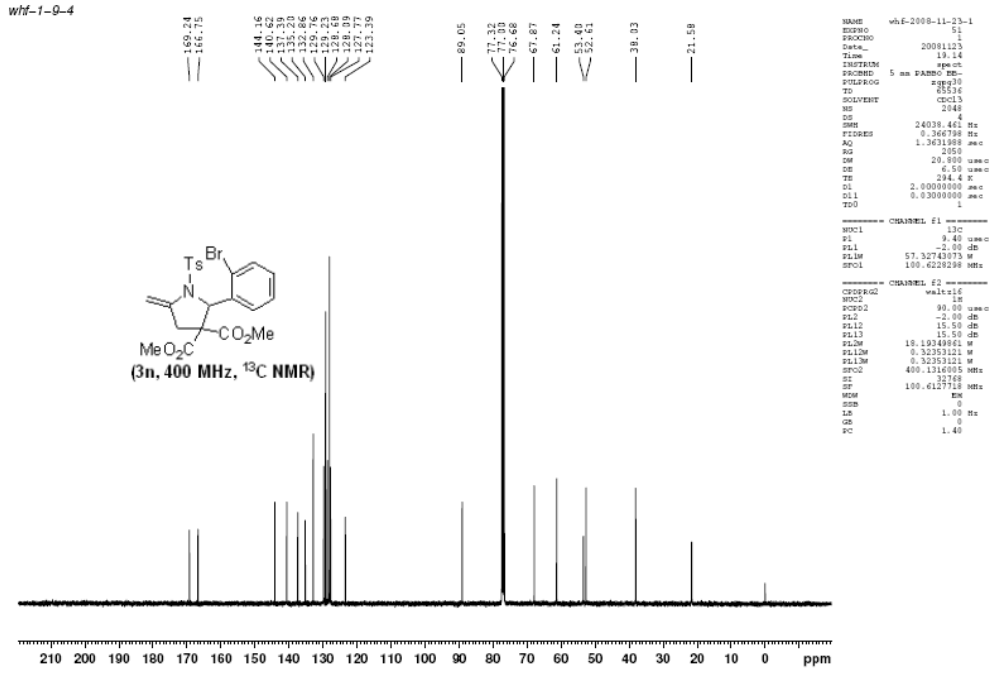


*4.15 Spectra for compound **3n***

^{1}H NMR:

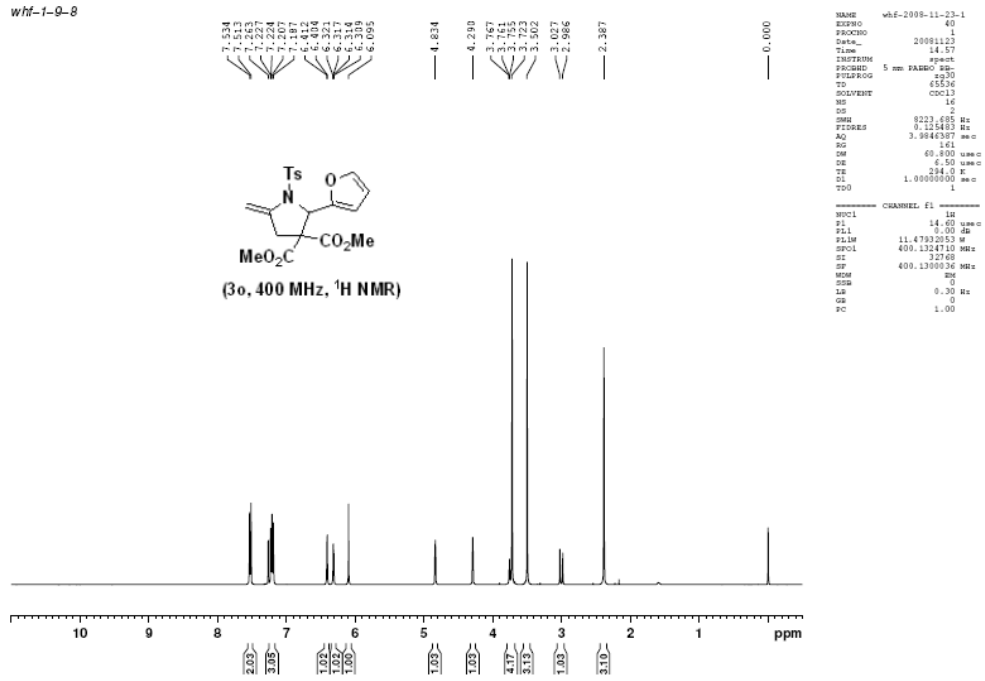


^{13}C NMR:

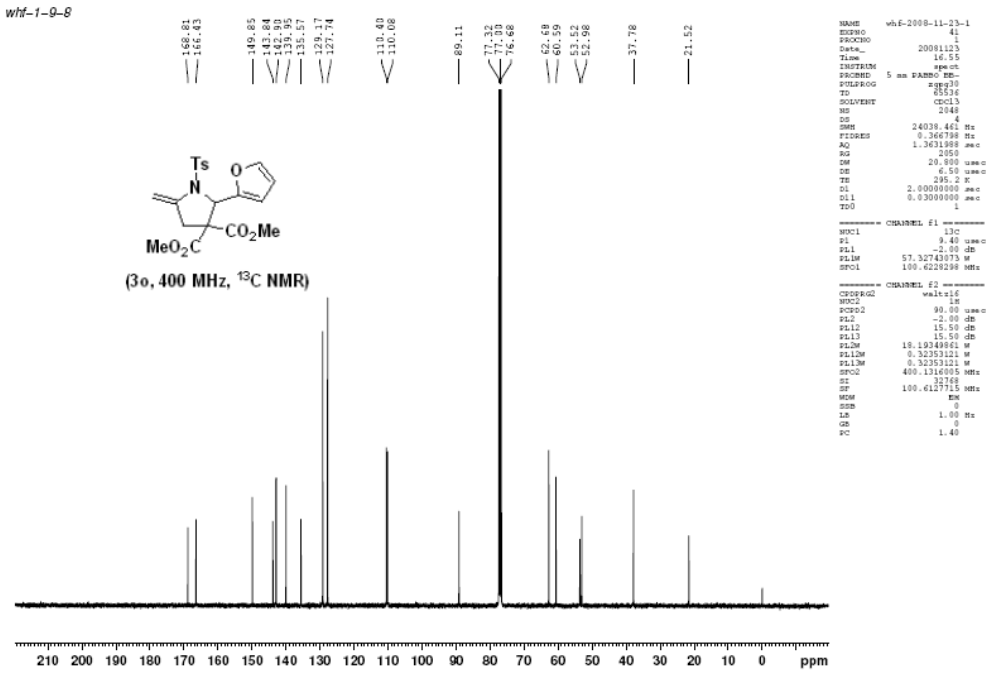


*4.16 Spectra for compound **3o***

^{1}H NMR:

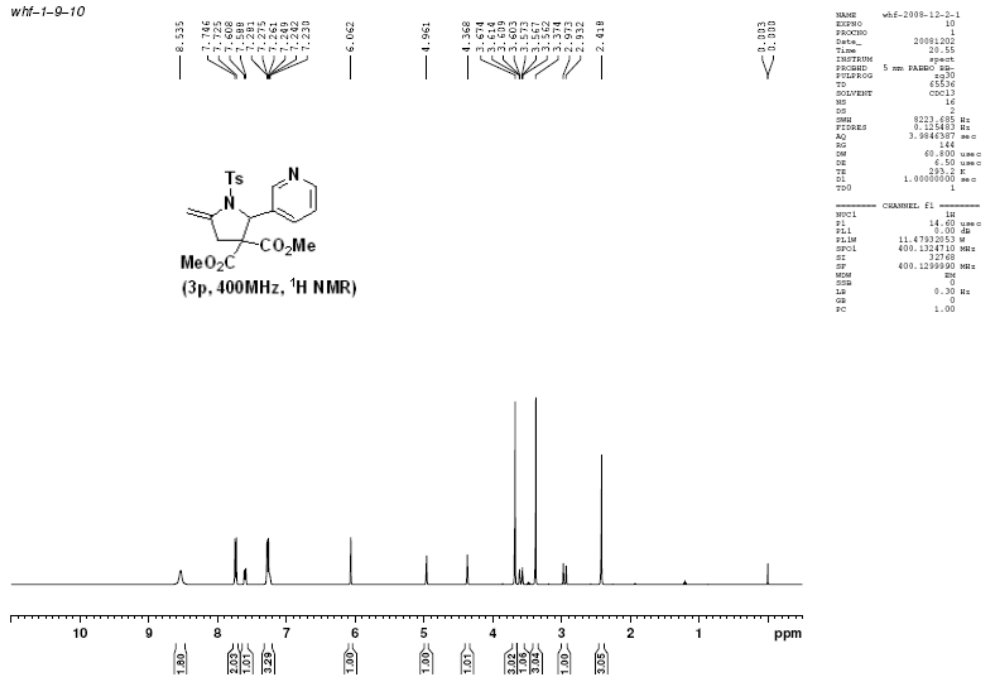


^{13}C NMR:

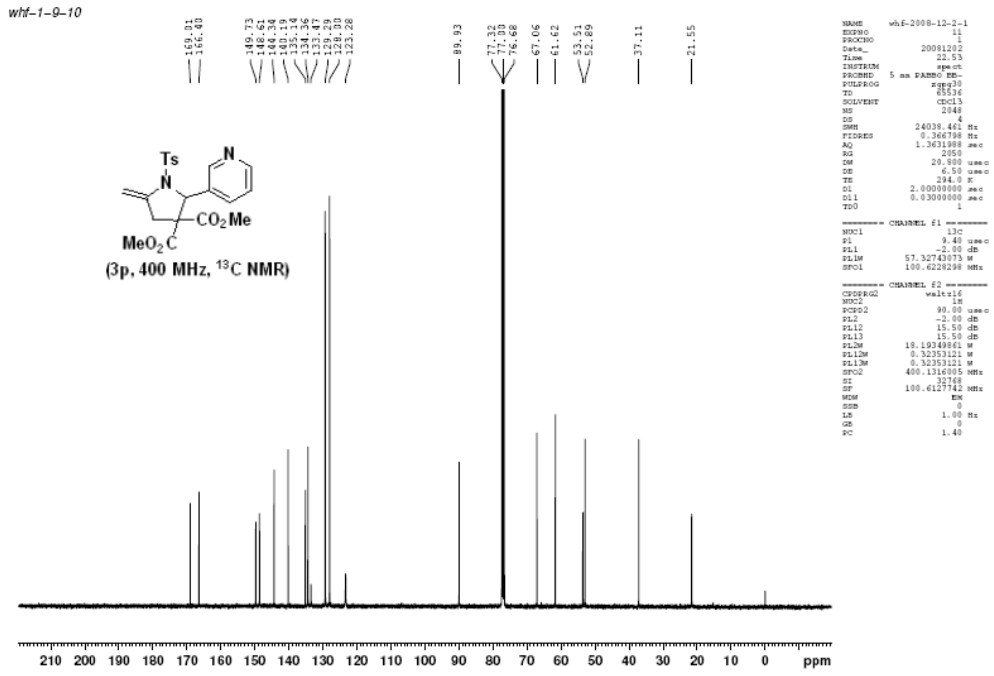


*4.17 Spectra for compound **3p***

^{1}H NMR:

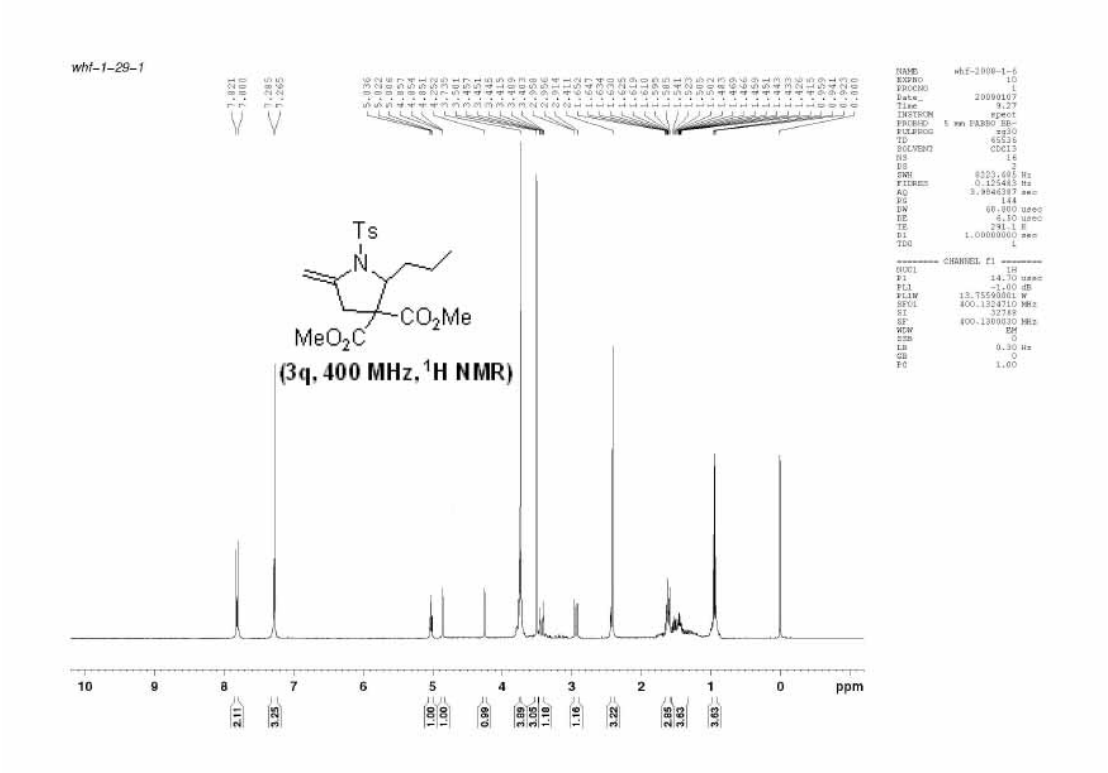


^{13}C NMR:

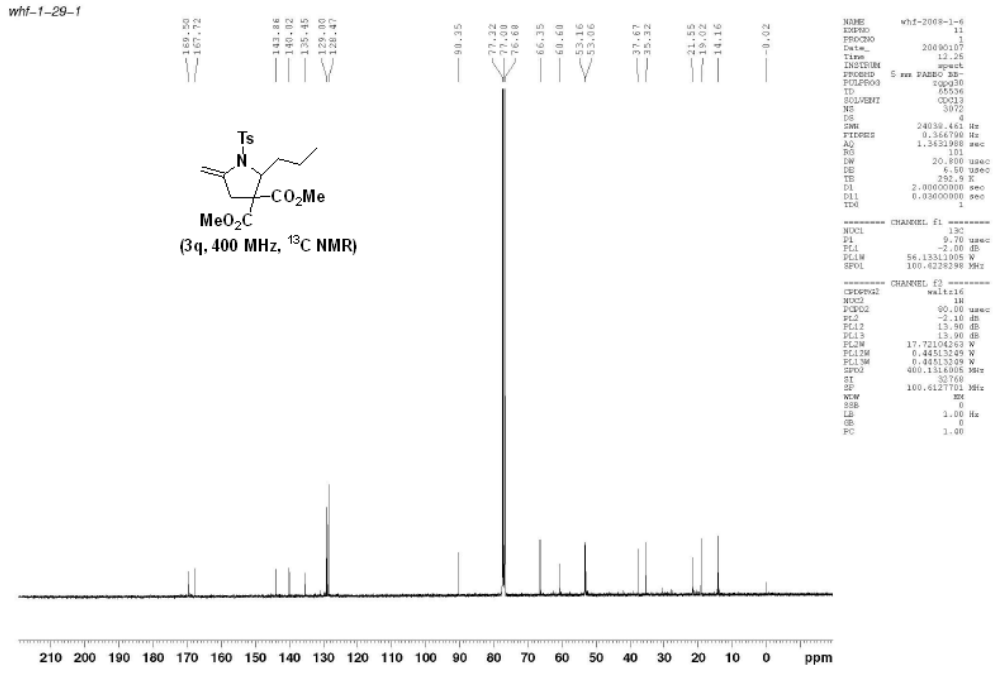


*4.18 Spectra for compound **3q***

^{1}H NMR:

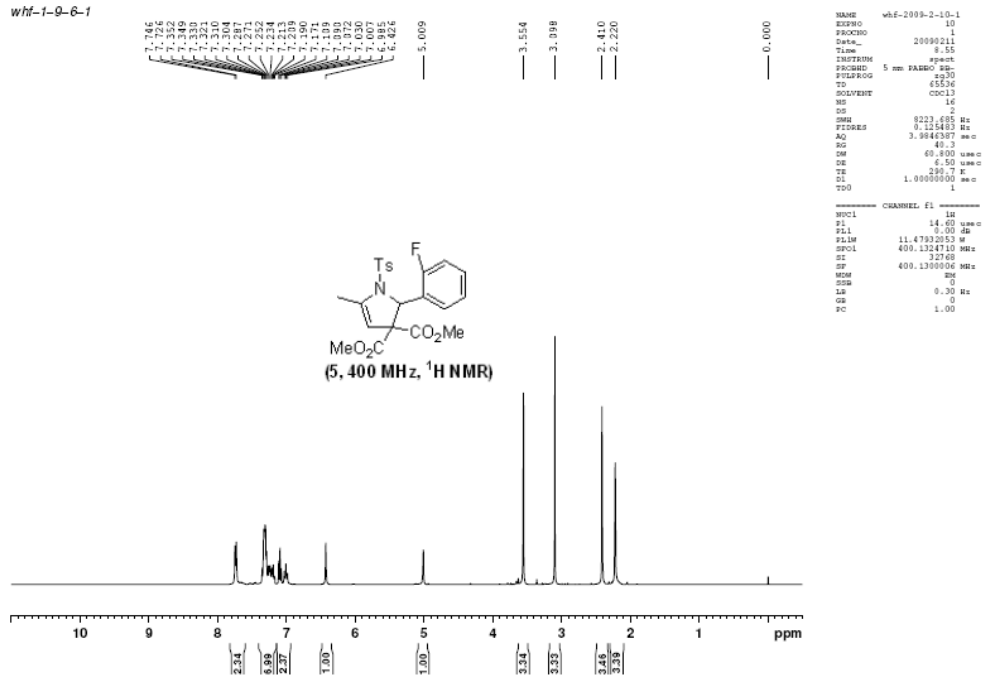


^{13}C NMR:



*4.19 Spectra for compound **5***

^{1}H NMR:



^{13}C NMR: