# Palladium Catalyzed, Multicomponent Synthesis of Indolizines via the Carbonylative Coupling of Bromopyridines, Imines and Alkynes

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## I. General Procedures

All manipulations were conducted in a glovebox under a nitrogen atmosphere. Unless otherwise noted, all reagents, including carbon monoxide (99.5%) were purchased from commercial sources and used without purification. Solvents were dried by using a solvent purifier system, then transferred and stored in a glovebox over 4 Å molecular sieves. Liquid reagents were stored over activated 4 Å molecular sieves inside a nitrogen glovebox. Deuterated benzene was stirred over calcium hydride, vacuum transferred, and degassed before being brought in the glovebox. $Bu_4NCl$ and imines that are solids at room temperature were dissolved in dichloromethane in a glovebox, dried with activated 4 Å molecular sieves overnight, then decanted and dried in vacuo. Imines were prepared using standard literature procedures and vacuum distilled.[1] $Pd(P^tBu_3)_2$ and $Pd_2dba_3$•$CHCl_3$ were prepared according to literature procedures and stored at -35 °C in the glovebox to avoid decomposition.[2]

Nuclear magnetic resonance (NMR) characterization was performed on 500 MHz spectrometers for proton and either 126 and 201 MHz for carbon. $^{1}$H and $^{13}$C NMR chemical shifts were referenced to residual solvent. Mass spectra was recorded on a high-resolution electrospray ionization quadrupole mass spectrometer.

## II. Supplementary Figure

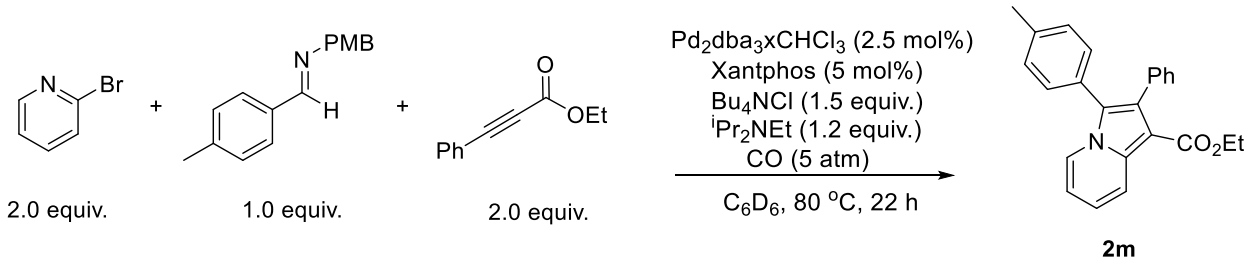



**Figure S1.** One step synthesis of indolizine 2m with alkyne in situ.

In a glovebox, a J-Young NMR tube was charged with 2-bromopyridine (16.0 mg, 0.100 mmol), p-tolyl(H)C=*N*(4-methoxybenzyl) (12.0 mg, 0.050 mmol), $^{i}Pr_2NEt$ (12.0 mg, 0.06 mmol), $Bu_4NCl$ (20.8 mg, 0.075 mmol), $Pd_2dba_3$•$CHCl_3$ (1.3 mg, 0.00125 mmol, Xantphos (1.5 mg, 0.0025 mmol), ethyl 3-phenylpropiolate (17.0 mg, 0.10 mmol), benzyl benzoate as internal standard, and $C_6D_6$ (for a total of 0.70 mL). $Bu_4NCl$ was dry transferred in the J-Young, and the liquid reagents and leftover solids were washed into the reaction vessel. The NMR tube was then sealed with a screw cap and taken out of the glovebox. The NMR tube was frozen in liquid nitrogen, evacuated, and a known quantity of CO was condensed into the tube, such that the pressure is 5 atm at room temperature. (This was accomplished by condensing 125 torr from a 67 mL CO filled vacuum line into the NMR tube with 2.25 mL headspace.) The reaction mixture was warmed to 80 °C for 22 h. $^1H$ NMR spectra was collected before and after the reaction, and integration relative to the internal standard shows the yield of **2m** is 82%.

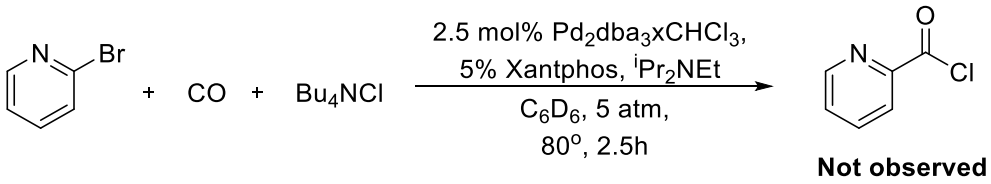
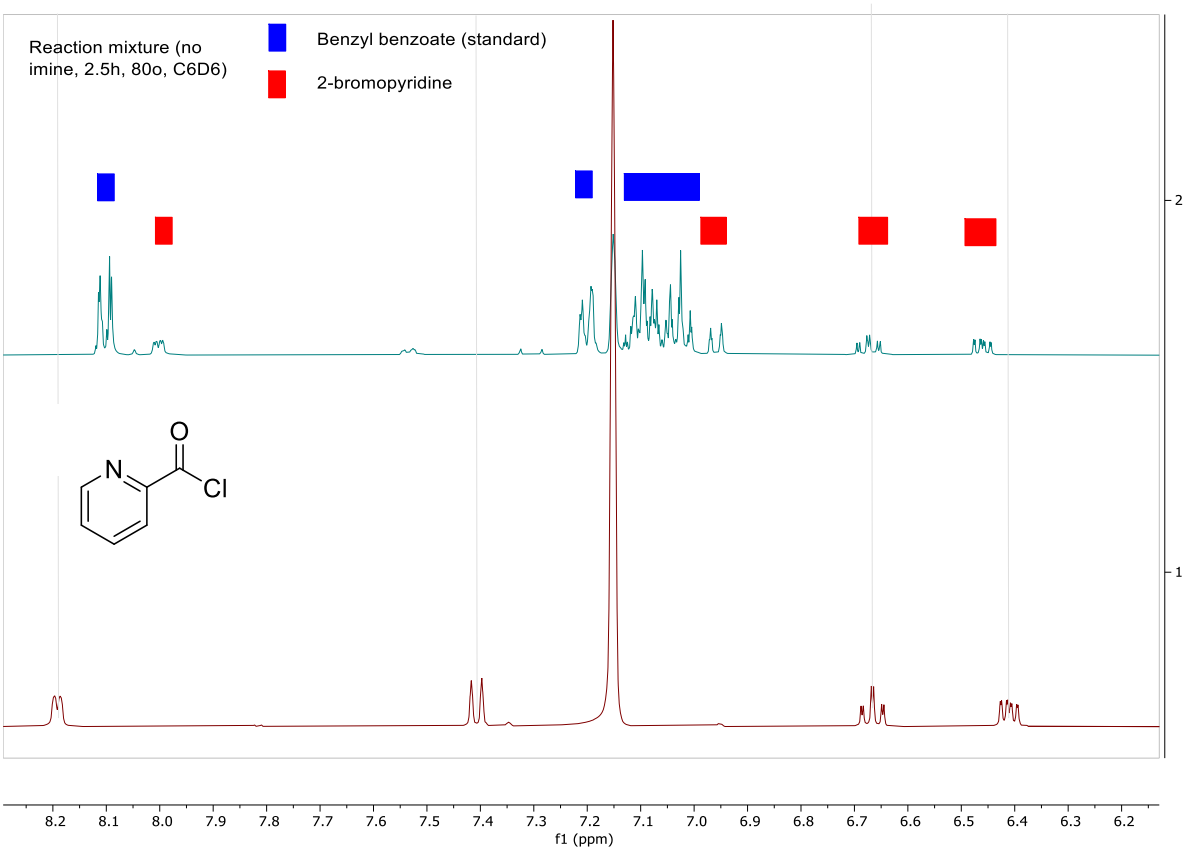



**Figure S2.** Catalysis in the absence of imine.

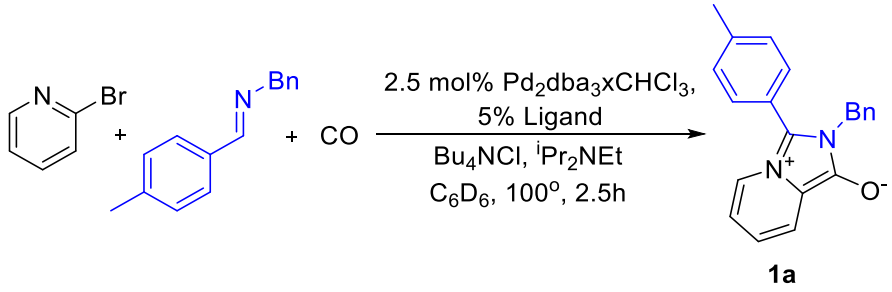
In a glovebox, a J-Young NMR tube was charged with 2-bromopyridine (6.3 mg, 0.040 mmol), $^{i}Pr_2NEt$ (6.2 mg, 0.048 mmol), $Bu_4NCl$ (17 mg, 0.060 mmol), $Pd_2dba_3$•$CHCl_3$ (1.0 mg, 0.0010 mmol) (obtained by taking 0.400 mL of $C_6D_6$ solution of 2.5 mM $Pd_2dba_3$•$CHCl_3$), Xantphos (1.1 mg, 0.0020 mmol) (obtained by taking 0.100 mL of a $C_6D_6$ solution of 20 mM Xantphos), benzyl benzoate as internal standard, and $C_6D_6$ (0.25 mL, for a total of 0.75 mL). $Bu_4NCl$ was dry transferred in the J-Young, and the liquid reagents and leftover solids were washed into the reaction vessel by portions of 250 μL, first using the stock solutions, then the dry solvent. The NMR tube was then sealed with a screw cap and taken out of the glovebox. The NMR tube was frozen in liquid nitrogen, evacuated, and a known quantity of CO was condensed into the tube, such that the pressure is 5 atm at room temperature. (This was accomplished by condensing 125 torr from a 67 mL CO filled vacuum line into the NMR tube with 2.25 mL headspace.) The reaction mixture was warmed to 80 °C for 2.5 h. $^1H$ NMR spectra shows no detectable amount of acid chloride is generated.




$^1$H NMR spectra ($C_6D_6$, aromatic region) of the reaction mixture in the absence of imine (top) and the pure 2-pyridyl acid chloride (bottom).

## III. Experimental Procedures

### A. Typical Procedure for Catalyst Development (Table 1)




**1a**

In a glovebox, a J-Young NMR tube was charged with 2-bromopyridine (9.5 mg, 0.060 mmol), *p*-tolyl(H)C=N(benzyl) (8.4 mg, 0.040 mmol), $^i$Pr$_2$NEt (6.2 mg, 0.048 mmol), Bu$_4$NCl (17 mg, 0.060 mmol), Pd$_2$dba$_3$•CHCl$_3$ (1.0 mg, 0.0010 mmol) (obtained by taking 0.400 mL of $C_6D_6$ solution of 2.5 mM Pd$_2$dba$_3$•CHCl$_3$), Xantphos (1.1 mg, 0.0020 mmol) (obtained by taking 0.100 mL of a $C_6D_6$ solution of 20 mM Xantphos), benzyl benzoate as internal standard, and $C_6D_6$ (0.25 mL, for a total of 0.75 mL). Bu$_4$NCl was dry transferred in the J-Young, and the liquid reagents and leftover solids were washed into the reaction vessel by portions of 250 μL, first using the stock solutions, then the dry solvent. The NMR tube was then

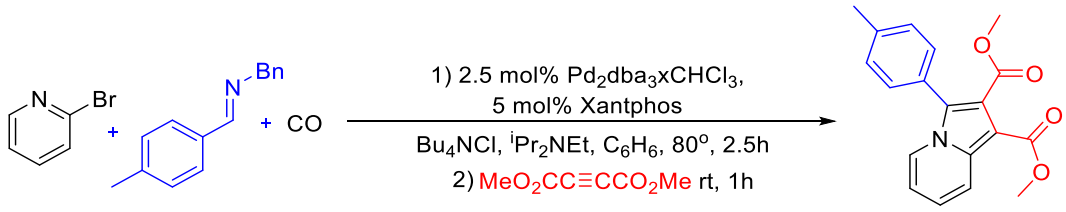
sealed with a screw cap and taken out of the glovebox. The NMR tube was frozen in liquid nitrogen, evacuated, and a known quantity of CO was condensed into the tube, such that the pressure is 5 atm at room temperature. (This was accomplished by condensing 125 torr from a 67 mL CO filled vacuum line into the NMR tube with 2.25 mL headspace.) The reaction mixture was warmed to 100 °C for 2.5 h. $^1$H NMR spectra was collected before and after the reaction, and integration relative to the internal standard shows the yield of **1a** is 94%. A similar procedure was followed with other ligands, except 0.0040 mmol of monodentate ligands was used. In order to prove the presence of the proposed mesoionic dipolar product **1a**, whose NMR is not known in $C_6D_6$, the reaction mixture was dried under vacuum after completion of the reaction, and NMR spectra were also taken with $CDCl_3$.

*In situ NMR data on **1a***: **$^1$H NMR** ($CDCl_3$, 500 MHz): δ 7.46 (dd, *J* = 9.0, 1.3 Hz, 1H), 7.31 (d, *J* = 7.3 Hz, 1H), 7.11-7.21 (m, 5H), 7.01-7.06 (m, 4H), 6.36 (t, *J* = 6.7 Hz, 1H), 6.00 (dd, *J* = 8.9, 6.4 Hz, 1H), 5.10 (s, 2H), 2.34 (s, 3H) ppm. **$^{13}$C NMR** ($CDCl_3$, 126 MHz): δ 151.1, 140.5, 137.1, 130.3, 129.3, 129.2, 128.5, 127.41, 127.38, 122.6, 121.2, 119.6, 116.7, 110.1, 109.0, 44.8, 21.4 ppm.

*Previously reported **1a:*** [3]

**$^1$H NMR** (400 MHz, $CDCl_3$) δ 7.51 (d, *J* = 8.9 Hz, 1H), 7.30 (d, *J* = 7.3 Hz, 1H), 7.21-7.11 (m, 5H), 7.01-7.07 (m, 4H), 6.35 (ddd, *J* = 7.4, 6.5, 1.3 Hz, 1H), 6.08 (ddd, *J* = 9.0, 6.4, 0.7 Hz, 1H), 5.11 (s, 2H), 2.34 (s, 3H) ppm. **$^{13}$C NMR** (101 MHz, $CDCl_3$) δ 151.1, 140.4, 137.1, 130.3, 129.5, 129.3, 128.5, 127.54, 127.47, 122.9, 121.4, 119.6, 116.7, 110.3, 109.2, 44.9, 21.5 ppm.

## B. Typical Synthesis of Indolizines (Tables 2 and 3)



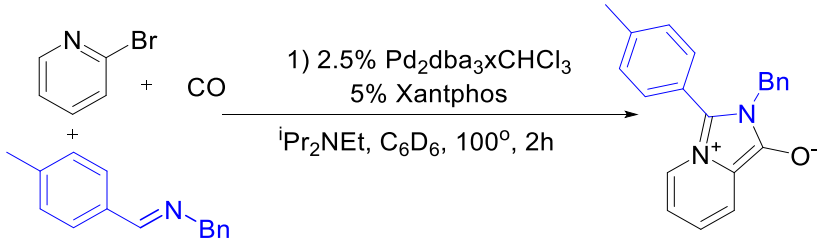

2-bromopyridine (79 mg, 0.50 mmol), p-tolyl(H)C=N(benzyl) (157 mg, 0.75 mmol), $NEt^iPr_2$ (77 mg, 0.60 mmol), $Bu_4NCl$ (208 mg, 0.75 mmol), $Pd_2dba_3$•$CHCl_3$ (13 mg, 0.0125 mmol) and Xantphos (14.5 mg, 0.025 mmol) were weighed in a glovebox. The solids were dry transferred into a 50 mL Teflon sealable, thick walled reaction tube, along with a stir bar. 10 mL benzene was used to wash the liquid reagents and leftover solids into the reaction vessel. The vessel was closed and brought out of the glovebox, frozen and its headspace evacuated. The tube was thawed and 5 atm of CO was then added (as measured on a pressure gauge connected to the CO source). The tube was then placed in a 80 °C oil bath for 2.5h. After completion of the reaction, the CO atmosphere was removed on a schlenk line, and the vessel taken into the glovebox. Dimethylacetylenedicarboxylate (DMAD; 85 mg, 0.60 mmol) was then added. The reaction mixture was left to stir at room temperature for 1 h. The solvent was then removed *in vacuo*, and the product purified by column chromatography (Silica gel, 25% ethyl acetate, 75% hexanes) afforded indolizine **2a** as a pale yellow solid (123 mg, 0.38 mmol, 75%).

A similar procedure was followed for the other products. In the case of **2i**, the reaction was performed in acetonitrile. For electron-poor imines or certain pyridine substitution patterns, the reaction temperature and time for generation of the dipole was varied (see product characterization for specific time/temperatures used). In the case of more electron-rich alkynes or sterically hindered imines, the cycloaddition was performed for a longer time and/or at elevated temperatures (see product characterization for details). For

**2h**, and **2m** and **2n**, the reaction mixture was dried prior to the addition of 2.5 mL of benzene for cycloaddition at 80°C for 48 h. For **2o**, the dipole mixture was concentrated to 2.5 ml for cycloaddition at 80 °C for 48 h, then heated to 100-150 °C for 72 h to complete reaction.

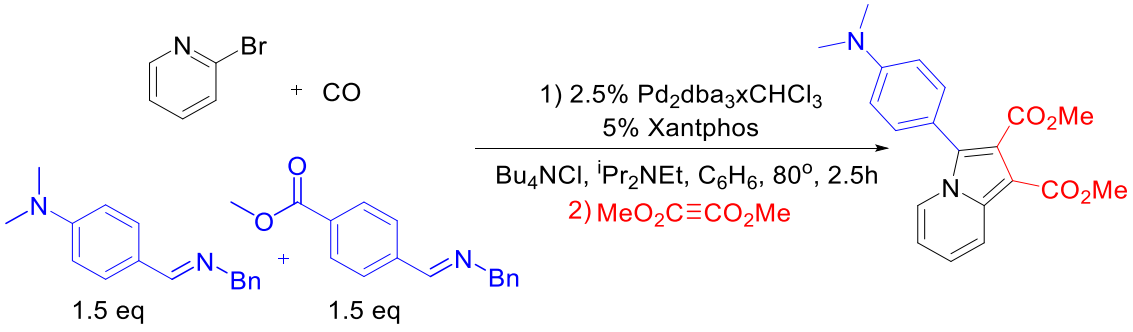
## IV. Mechanistic Experiments

### A. Reaction in the absence of chloride (Figure 3a)




In a glovebox, a J-Young NMR tube was charged with 2-bromopyridine (9.5 mg, 0.060 mmol), *p*-tolyl(H)C=N(benzyl) (8.4 mg, 0.040 mmol), $^{i}Pr_2NEt$ (6.2 mg, 0.048 mmol), $Pd_2dba_3$•$CHCl_3$ (1.0 mg, 0.0010 mmol) (obtained by taking 0.400 mL of $C_6D_6$ solution of 2.5 mM $Pd_2dba_3$•$CHCl_3$), Xantphos (1.1 mg, 0.0020 mmol) (obtained by taking 0.100 mL of a $C_6D_6$ solution of 20 mM Xantphos), benzyl benzoate as internal standard, and $C_6D_6$ (0.25 mL, for a total of 0.75 mL). The reagents were washed into the reaction vessel by portions of 250 µL, first using the stock solutions, then the dry solvent. The NMR tube was then sealed with a screw cap and taken out of the glovebox. The NMR tube was frozen in liquid nitrogen, evacuated, and a known quantity of CO was condensed into the tube, such that the pressure is 5 atm at room temperature. (This was accomplished by condensing 125 torr from a 67 mL CO filled vacuum line into the NMR tube with 2.25 mL headspace.) The reaction mixture was warmed to 100 °C for 2 h. $^{1}H$ NMR spectra was collected before and after the reaction, and integration relative to the internal standard shows the yield of **1a** is 22%. Upon extended reaction time (20h), the NMR yield reached 56%.

### B. Competition Experiment (Figure 3b)




2-bromopyridine (79 mg, 0.50 mmol), p-$Me_2NC_6H_4$(H)C=N(benzyl) (179 mg, 0.75 mmol), p-$MeO_2CC_6H_4$(H)C=N(benzyl) (190 mg, 0.75 mmol), $NEt^{i}Pr_2$ (77 mg, 0.60 mmol), $Bu_4NCl$ (208 mg, 0.75 mmol), $Pd_2dba_3$•$CHCl_3$ (13 mg, 0.0125 mmol) and Xantphos (14.5 mg, 0.025 mmol) were weighed in a glovebox. The solids were dry transferred into a 50 mL Teflon sealable, thick walled reaction tube, along with a stir bar. 10 mL benzene was used to wash the liquid reagents and leftover solids into the reaction vessel. The vessel was closed and brought out of the glovebox, frozen and its headspace evacuated. The

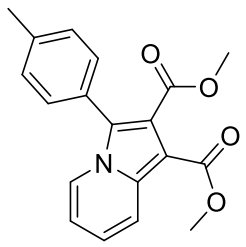
tube was thawed and 5 atm of CO was then added (as measured on a pressure gauge connected to the CO source). The tube was then placed in a 80 °C oil bath for 2.5h. After completion of the reaction, the CO atmosphere was removed on a schlenk line, and the vessel taken into the glovebox. Dimethylacetylenedicarboxylate (DMAD; 85 mg, 0.60 mmol) was then added. The reaction mixture was left to stir at room temperature for 1 h. $^1$H NMR analysis of the crude reaction mixture shows the formation of indolizine **2c**, and no evidence for the other indolizine product. Purification by column chromatography afforded unreacted (hydrolized) methyl 4-formylbenzoate and indolizine **2c** (139 mg, 0.40 mmol, 79%) as the only major products.

### C. Reaction at different pressures of CO (Figure 3c)

In a glovebox, two J-Young NMR tubes were charged with 2-bromopyridine (9.5 mg, 0.060 mmol), *p*-tolyl(H)C=N(benzyl) (8.4 mg, 0.040 mmol), $^i$Pr$_2$NEt (6.2 mg, 0.048 mmol), Bu$_4$NCl (17 mg, 0.060 mmol), Pd$_2$dba$_3$•CHCl$_3$ (1.0 mg, 0.0010 mmol) (obtained by taking 0.400 mL of $C_6D_6$ solution of 2.5 mM Pd$_2$dba$_3$•CHCl$_3$), Xantphos (1.1 mg, 0.0020 mmol) (obtained by taking 0.100 mL of a $C_6D_6$ solution of 20 mM Xantphos), benzyl benzoate as internal standard, and $C_6D_6$ (0.25 mL, for a total of 0.75 mL). Bu$_4$NCl was dry transferred in the J-Youngs, and the liquid reagents and leftover solids were washed into the reaction vessels by portions of 250 μL, first using the stock solutions, then the dry solvent. The NMR tubes were then sealed with a screw cap and taken out of the glovebox. The NMR tubes were frozen in liquid nitrogen, evacuated, and a known quantity of CO was condensed into the tubes, such that the pressure is 1 atm at room temperature in one, and 3 atm at room temperature in the other. (This was accomplished by respectively condensing 25 and 75 torr, respectively, from a 67 mL CO filled vacuum line into the NMR tubes with 2.25 mL headspace.) The reaction mixture was warmed to 80 °C for 1h h. $^1$H NMR spectra was collected before and after the reaction, and integration relative to the internal standard shows the yield of **1a** is 32% under one atm of CO and 84% under 3 atm of CO.

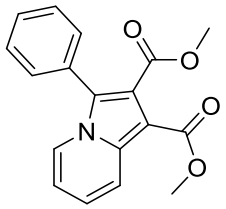
## V. Characterization Data on Indolizines

**Dimethyl 3-(p-tolyl)indolizine-1,2-dicarboxylate (2a)**



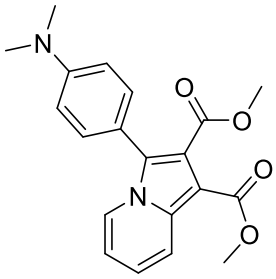

Pale yellow oil, 123 mg, 76%. **$^1$H NMR** (500 MHz, $CDCl_3$) δ 8.22 (dt, *J* = 9.1, 1.2 Hz, 1H), 8.04 (dt, *J* = 7.1, 1.1 Hz, 1H), 7.39 (d, *J* = 8.1 Hz, 2H), 7.31 (d, *J* = 7.9 Hz, 2H), 7.11 (ddd, *J* = 9.1, 6.6, 1.1 Hz, 1H), 6.71 (td, *J* = 6.9, 1.3 Hz, 1H), 3.90 (s, 3H), 3.81 (s, 3H), 2.43 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.1, 164.4, 139.2, 135.3, 130.0, 126.0, 125.3, 123.8, 123.6, 122.0, 120.5, 113.5, 102.0, 52.6, 51.4, 21.6 ppm. Spectral data is in accordance with the data reported in the literature [3]

**Dimethyl 3-phenylindolizine-1,2-dicarboxylate (2b)**



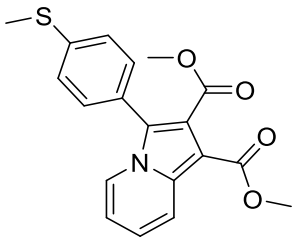
Pale yellow solid, 104 mg, 66%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.23 (dt, *J* = 9.1, 1.3 Hz, 1H), 8.05 (dt, *J* = 7.1, 1.1 Hz, 1H), 7.52 – 7.43 (m, 5H), 7.12 (ddd, *J* = 9.1, 6.6, 1.1 Hz, 1H), 6.72 (td, *J* = 6.9, 1.3 Hz, 1H), 3.91 (s, 3H), 3.80 (s, 3H).8.26 (dt, *J* = 9.1, 1.3 Hz, 1H), 8.07 (dt, *J* = 7.1, 1.1 Hz, 1H), 7.55-7.45 (m, 5H), 7.15 (ddd, *J* = 9.1, 6.6, 1.1 Hz, 1H), 6.74 (td, *J* = 6.9, 1.3 Hz, 1H), 3.93 (s, 3H), 3.83 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.0, 164.4, 135.4, 130.1, 129.24, 129.19, 129.0, 125.2, 123.71, 123.69, 122.2, 120.5, 113.6, 102.1, 52.6, 51.5 ppm. Spectral data is in accordance with the data reported in the literature [4]. Melting Point: 95.9-97.2 ℃.

**Dimethyl 3-(4-(dimethylamino)phenyl)indolizine-1,2-dicarboxylate (2c)**



Orange solid, 123 mg, 70%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.20 (dt, *J* = 9.1, 1.3 Hz, 1H), 8.05 (dt, *J* = 7.1, 1.2 Hz, 1H), 7.36 (d, *J* = 8.8 Hz, 2H), 7.08 (ddd, *J* = 9.1, 6.6, 1.1 Hz, 1H), 6.80 (d, *J* = 8.8 Hz, 2H), 6.68 (td, *J* = 6.9, 1.4 Hz, 1H), 3.89 (s, 3H), 3.82 (s, 3H), 3.03 (s, 6H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.4, 164.5, 150.7, 135.1, 131.0, 126.1, 124.0, 123.3, 121.5, 120.4, 115.9, 113.2, 112.4, 101.6, 52.6, 51.4, 40.4 ppm. **HRMS** (ESI+) for $C_{20}H_{20}N_2O_4Na^+$: calculated 375.1315, found 375.1315 (error m/z=0.2 ppm). Melting Point: 154.8-156.2 ℃.

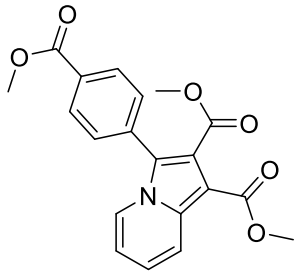
**Dimethyl 3-(4-(methylthio)phenyl)indolizine-1,2-dicarboxylate (2d)**



Yellow solid, 122 mg, 68%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.22 (dt, *J* = 9.2, 1.3 Hz, 1H), 8.02 (dt, *J* = 7.1, 1.2 Hz, 1H), 7.45 – 7.40 (d, *J* = 8.4 Hz, 2H), 7.38 – 7.33 (d, *J* = 8.4 Hz, 2H), 7.12 (ddd, *J* = 9.1, 6.6, 1.1 Hz,

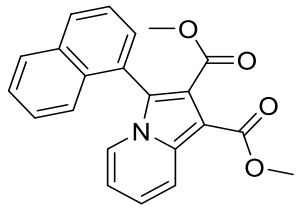
1H), 6.75 – 6.69 (ddd, *J* = 7.0, 6.7, 1.0 Hz, 1H), 3.90 (s, 3H), 3.82 (s, 3H), 2.54 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.0, 164.3, 140.3, 135.4, 130.4, 126.6, 125.2, 124.7, 123.7, 123.6, 122.1, 120.5, 113.6, 102.1, 52.7, 51.5, 15.4 ppm. **HRMS** (ESI+) for $C_{19}H_{17}NO_4SNa^+$: calculated 378.0770, found 378.0775 (error m/z=-1.1 ppm). Melting Point: 132.7-133.8 ℃.

**Dimethyl 3-(4-(methoxycarbonyl)phenyl)indolizine-1,2-dicarboxylate (2e)**



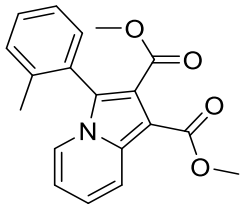
White solid, 106 mg, 58%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.26 (dt, *J* = 9.1, 1.3 Hz, 1H), 8.17 (d, *J* = 8.5 Hz, 2H), 8.08 (dt, *J* = 7.2, 1.2 Hz, 1H), 7.61 (d, *J* = 8.5 Hz, 2H), 7.16 (ddd, *J* = 9.2, 6.6, 1.0 Hz, 1H), 6.77 (td, *J* = 6.9, 1.3 Hz, 1H), 3.96 (s, 3H), 3.91 (s, 3H), 3.81 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 166.7, 166.6, 164.2, 135.8, 133.7, 130.6, 130.5, 129.8, 124.1, 123.9, 123.5, 122.9, 120.7, 114.1, 102.6, 52.7, 52.5, 51.6 ppm. **HRMS** (ESI+) for $C_{20}H_{17}NO_6Na^+$: calculated 390.0948, found 390.0954 (error m/z=-1.6 ppm). Melting Point: 142.0-143.8 ℃.

**Dimethyl 3-(naphthalen-1-yl)indolizine-1,2-dicarboxylate (2f)**



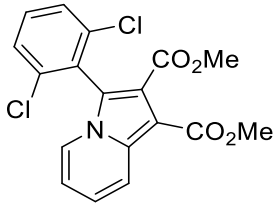
Yellow solid, 132 mg, 74%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.29 (dt, *J* = 9.2, 1.6 Hz, 1H), 8.12 (dt, *J* = 6.9, 0.7 Hz, 1H), 8.04 (s, 1H), 7.99 (d, *J* = 8.5 Hz, 1H), 7.95 – 7.88 (m, 2H), 7.62 – 7.55 (m, 3H), 7.16 (ddd, *J* = 9.2, 6.6, 1.1 Hz, 1H), 6.75 (td, *J* = 6.8, 1.3 Hz, 1H), 3.95 (s, 3H), 3.81 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.0, 164.4, 135.5, 133.5, 133.4, 129.8, 129.0, 128.4, 128.0, 127.13, 127.08, 126.9, 126.4, 125.1, 123.8, 123.7, 122.5, 120.6, 113.7, 102.2, 52.7, 51.5 ppm. **HRMS** (ESI+) for $C_{22}H_{17}NO_4Na^+$: calculated 382.1050, found 382.1038 (error m/z=3.2 ppm). Melting Point: 158.4-159.3 ℃.

**Dimethyl 3-(o-tolyl)indolizine-1,2-dicarboxylate (2g)**



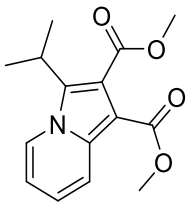
Light brown solid, 98 mg, 60%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.24 (dt, *J* = 9.0, 1.2 Hz, 1H), 7.44 (dt, *J* = 7.1, 1.2 Hz, 1H), 7.38-7.43 (m, 1H), 7.35 (d, *J* = 7.7 Hz, 1H), 7.28-7.33 (m, 2H), 7.12 (ddd, J = 9.2, 6.6, 1.1 Hz, 1H), 6.70 (td, *J* = 6.8, 1.3 Hz, 1H), 3.91 (s, 3H), 3.74 (s, 3H), 2.06 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 166.5, 164.5, 139.4, 135.1, 132.0, 130.5, 130.0, 128.3, 126.4, 125.5, 123.9, 123.4, 121.9, 120.5, 113.6, 101.7, 52.4, 51.4, 19.5 ppm. **HRMS** (ESI+) for $C_{19}H_{17}NO_4Na^+$: calculated 346.1050, found 346.1041 (error m/z=2.5 ppm). Melting Point: 68.0-69.0 ℃.

**Dimethyl 3-(2,6-dichlorophenyl)indolizine-1,2-dicarboxylate (2h)**



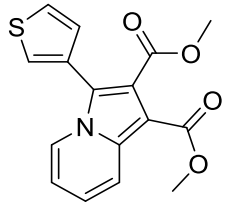
Light brown solid, 137 mg, 70%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.25 (dt, *J* = 9.2, 1.2 Hz, 1H), 7.50-7.47 (m, 2H), 7.43 – 7.37 (m, 2H), 7.16 (ddd, *J* = 9.2, 6.7, 1.1 Hz, 1H), 6.76 (td, *J* = 6.8, 1.3 Hz, 1H), 3.92 (s, 3H), 3.76 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 165.3, 164.4, 138.1, 135.8, 131.7, 128.4, 127.9, 123.8, 123.5, 122.1, 121.7, 120.7, 114.0, 102.8, 52.3, 51.5 ppm. **HRMS** (ESI+) for $C_{18}H_{13}Cl_2NO_4Na^+$: calculated 400.0114, found 400.0110 (error m/z=0.9 ppm).

**Dimethyl 3-isopropylindolizine-1,2-dicarboxylate (2i)**



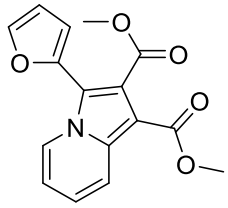
Brown oil, 68 mg, 53%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.19 (dt, *J* = 9.1, 1.3 Hz, 1H), 7.94 (d, *J* = 7.3 Hz, 1H), 7.07 (ddd, *J* = 9.2, 6.6, 1.1 Hz, 1H), 6.79 (td, *J* = 6.9, 1.4 Hz, 1H), 3.95 (s, 3H), 3.86 (s, 3H), 3.35 (hept, *J* = 7.0 Hz, 1H), 1.40 (d, *J* = 7.1 Hz, 6H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 168.4, 164.4, 134.9, 129.0, 123.3, 122.6, 120.7, 119.9, 113.3, 101.2, 52.7, 51.3, 25.9, 20.2 ppm. Spectral data is in accordance with the data reported in the literature[3]

**Dimethyl 3-(thiophen-3-yl)indolizine-1,2-dicarboxylate (2j)**



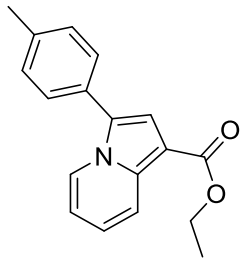
Yellow solid, 114 mg, 72%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.22 (dt, *J* = 9.2, 1.2 Hz, 1H), 8.10 (dt, *J* = 7.1, 1.1 Hz, 1H), 7.56 (dd, *J* = 3.0, 1.3 Hz, 1H), 7.49 (dd, *J* = 5.0, 3.0 Hz, 1H), 7.28 (dd, *J* = 5.0, 1.3 Hz, 1H), 7.13 (ddd, *J* = 9.2, 6.6, 1.1 Hz, 1H), 6.76 (td, *J* = 6.9, 1.3 Hz, 1H), 3.90 (s, 3H), 3.85 (s, 3H) pm. **$^{13}$C NMR** (201 MHz, $CDCl_3$) δ 167.0, 164.3, 135.4, 126.8, 126.4, 124.0, 123.7, 122.4, 120.46, 120.45, 113.7, 101.9, 52.7, 51.5 ppm. **HRMS** (ESI+) for $C_{16}H_{13}NO_4SNa^+$ : calculated 338.0457, found 338.0450 (error m/z=2.2 ppm). Melting Point: 93.0-94.2 ℃.

**Dimethyl 3-(furan-2-yl)indolizine-1,2-dicarboxylate (2k)**



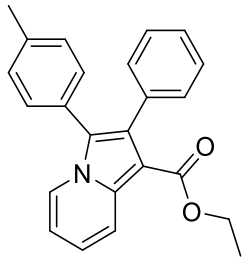
Brown solid, 66 mg, 44%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.46 (dt, *J* = 7.1, 1.1 Hz, 1H), 8.23 (dt, *J* = 9.1, 1.3 Hz, 1H), 7.58 (dd, *J* = 1.9, 0.8 Hz, 1H), 7.17 (ddd, *J* = 9.1, 6.6, 1.1 Hz, 1H), 6.84 (td, *J* = 6.9, 1.4 Hz, 1H), 6.68 (dd, *J* = 3.5, 0.8 Hz, 1H), 6.55 (dd, *J* = 3.4, 1.8 Hz, 1H), 3.93 (s, 4H), 3.90 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 166.8, 164.1, 143.6, 143,0, 135.7, 125.3, 124.2, 122.7, 120.4, 115.6, 114.1, 111.7, 110.7, 102.4, 52.9, 51.5 ppm. **HRMS** (ESI+) for $C_{16}H_{13}NO_5Na^+$: calculated 322.0686, found 322.0691 (error m/z=-1.6 ppm). Melting Point: 65.9-67.0 ℃.

**Ethyl 3-(p-tolyl)indolizine-1-carboxylate (2l)[5]**



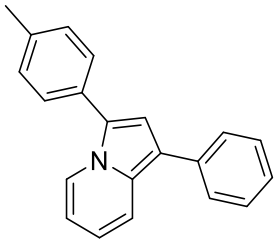
Yellow solid, 98 mg, 70%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.25 (d, *J* = 8.9 Hz, 2H), 7.42 (d, *J* = 8.1 Hz, 2H), 7.30 – 7.24 (m, 3H), 7.08 – 7.00 (m, 1H), 6.66 (td, *J* = 6.7, 1.5 Hz, 1H), 4.38 (q, *J* = 7.1 Hz, 2H), 2.41 (s, 3H), 1.41 (t, *J* = 7.1 Hz, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 165.2, 138.1, 136.4, 129.9, 128.7, 128.5, 126.6, 123.5, 122.2, 120.3, 115.9, 112.6, 104.3, 59.7, 21.5, 14.8 ppm. Spectral data is in accordance with the data reported in the literature[5]. Melting Point: 79.0-81.2 ℃.

**Ethyl 2-phenyl-3-(p-tolyl)indolizine-1-carboxylate (2m)**



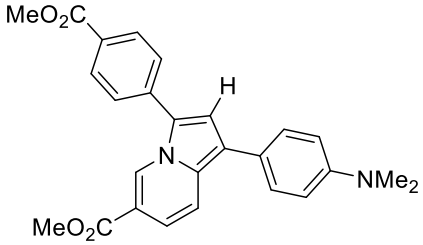

Brown solid, 134 mg, 75%. **$^1$H NMR** (500 MHz, $CDCl_3$) δ 7.81 (d, *J* = 7.2 Hz, 1H), 7.49 – 7.47 (m, 2H), 7.46 – 7.38 (m, 5H), 7.33 – 7.30 (m, 3H), 6.68 (ddd, *J* = 9.2, 6.4, 1.1 Hz, 1H), 6.48 – 6.45 (m, 1H), 4.04 (q, *J* = 7.1 Hz, 2H), 2.45 (s, 3H), 0.93 (t, *J* = 7.1 Hz, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 165.7, 138.4, 134.7, 130.6, 130.4, 130.0, 129.4, 127.9, 127.8, 127.2, 126.3, 122.8, 119.1, 118.5, 116.9, 115.6, 112.4, 60.1, 21.5, 13.7 ppm. **HRMS** (ESI+) for $C_{24}H_{21}NO_2Na^+$: calculated 378.1464, found 378.1465 (error m/z=-0.2 ppm). Melting Point: 86.9-89.0 ℃.

**1-phenyl-3-(p-tolyl)indolizine (2n)[4]**



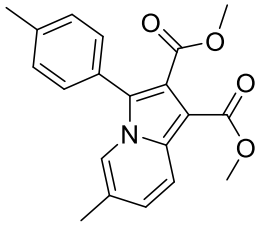

Bright yellow oil, 98 mg, 70%. **$^1$H NMR** (500 MHz, $CDCl_3$) δ 8.25 (dt, *J* = 7.1, 1.2 Hz, 1H), 7.77 (d, *J* = 9.2 Hz, 1H), 7.64 (d, *J* = 7.2 Hz, 2H), 7.51 (d, *J* = 8.0 Hz, 2H), 7.44 (t, *J* = 7.8 Hz, 2H), 7.31 (d, *J* = 7.8 Hz, 2H), 7.28 – 7.23 (m, 1H), 7.02 (s, 1H), 6.74 (ddd, *J* = 9.1, 6.4, 1.1 Hz, 1H), 6.50 (td, *J* = 6.8, 6.3, 1.3 Hz, 1H), 2.44 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 137.4, 136.5, 130.1, 129.8, 129.4, 128.9, 128.4, 127.7, 125.9, 125.5, 122.9, 118.6, 118.0, 115.2, 113.7, 111.1, 21.5 ppm. Spectral data is in accordance with the data reported in the literature [3].

**Methyl 1-(4-(dimethylamino)phenyl)-3-(4-(methoxycarbonyl)phenyl)indolizine-6-carboxylate (2o)**



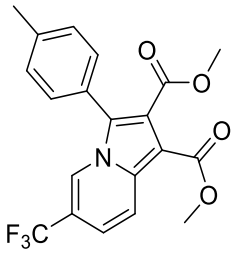

Yellow solid, 54 mg 25%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 9.06 (t. *J* = 1.3 Hz, 1H), 8.18 (d, *J* = 8.5 Hz, 2H), 7.73 – 7.67 (m, 3H), 7.49 (d, *J* = 8.8 Hz, 2H), 7.23 (dd, *J* = 9.5, 1.5 Hz, 1H), 7.15 (s, 1H), 6.86 (d, *J* = 8.8 Hz, 2H), 3.97 (s, 3H), 3.90 (s, 3H), 3.01 (s, 6H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 166.8, 166.3, 149.5, 136.0, 130.6, 130.6, 128.9, 128.6, 127.9, 127.6, 126.0, 123.3, 118.4, 117.7, 117.0, 117.0, 115.3, 113.2, 52.3, 52.2, 40.8 ppm. HRMS (ESI+) for $C_{26}H_{26}N_2O_4^+$: calculated 429.1814, found 429.1809 (error m/z = 1.5 ppm). Melting Point: 124.7-126.1 ℃.

**Dimethyl 6-methyl-3-(p-tolyl)indolizine-1,2-dicarboxylate (2p)**




Pale yellow solid, 81 mg, 48%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.12 (d, *J* = 9.2 Hz, 1H), 7.81-7.79 (m, 1H), 7.39 (d, *J* = 8.1 Hz, 2H), 7.31 (d, *J* = 7.9 Hz, 2H), 6.97 (dd, *J* = 9.2, 1.6 Hz, 1H), 3.89 (s, 3H), 3.80 (s, 3H), 2.43 (s, 3H), 2.22 (d, *J* = 1.1 Hz, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.2, 164.5, 139.1, 134.2, 130.0, 129.9, 126.9, 126.2, 125.0, 123.2, 121.7, 121.2, 119.8, 101.6, 52.5, 51.4, 21.6, 18.5 ppm. **HRMS** (ESI+) for $C_{20}H_{19}NO_4Na^+$: calculated 360.1206, found 360.1195 (error m/z=3.2 ppm). Melting Point: 118.2-119.5 ℃.

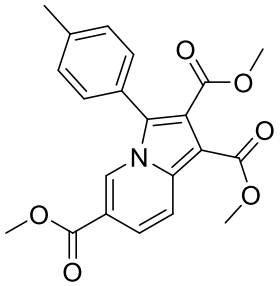
**Dimethyl 3-(p-tolyl)-6-(trifluoromethyl)indolizine-1,2-dicarboxylate (2q)**




Pale yellow solid, 147 mg, 74%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 8.37 – 8.29 (m, 2H), 7.39 (d, *J* = 8.3 Hz, 2H), 7.35 (d, *J* = 8.7 Hz, 2H), 7.21 (dd, *J* = 9.4, 1.7 Hz, 1H), 3.92 (s, 3H), 3.82 (s, 3H), 2.45 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 13C NMR (126 MHz, CDCl3) δ 166.3, 163.9, 140.0, 134.6, 130.3, 129.9, 126.9, 124.8, 123.52 (q, J = 271.2 Hz), 123.4, 122.7 (q, *J* = 5.9 Hz), 121.4, 118.8 (q, *J* = 2.5 Hz), 117.8 (q,

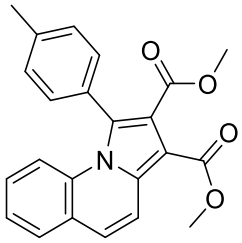
*J* = 34.2 Hz), 103.9, 52.7, 51.8, 21.6 ppm. **HRMS** (ESI+) for $C_{20}H_{16}F_3NO_4Na^+$: calculated 414.0924, found 414.0917 (error m/z=1.6 ppm). Melting Point: 154.9-156.8 ℃.

**Trimethyl 3-(p-tolyl)indolizine-1,2,6-tricarboxylate (2r)**



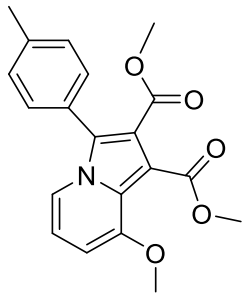
Yellow solid, 171 mg, 89%. **$^1$H NMR** (500 MHz, $CDCl_3$) δ 8.80 – 8.74 (m, 1H), 8.22 (dd, *J* = 9.5, 1.0 Hz, 1H), 7.61 (dd, *J* = 9.5, 1.5 Hz, 1H), 7.39 (d, *J* = 8.0 Hz, 2H), 7.34 (d, *J* = 7.8 Hz, 1H), 3.92 (s, 3H), 3.89 (s, 3H), 3.82 (s, 3H), 2.45 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 166.5, 165.4, 164.0, 139.8, 135.4, 130.2, 130.0, 128.3, 126.7, 125.1, 123.5, 122.5, 119.9, 117.5, 103.4, 52.7, 52.6, 51.7, 21.6 ppm. **HRMS** (ESI+) for $C_{21}H_{19}NO_6Na^+$: calculated 404.1105, found 404.1109 (error m/z=-1.1 ppm). Melting Point: 129.0-131.1 ℃.

**Dimethyl 1-(p-tolyl)pyrrolo[1,2-a]quinoline-2,3-dicarboxylate (2s)[4]**



Pale yellow solid, 141 mg, 73%. **$^1$H NMR** (500 MHz, $CDCl_3$) δ 8.20 (d, *J* = 9.5 Hz, 1H), 7.69 (dd, *J* = 8.1, 1.5 Hz, 1H), 7.41 – 7.27 (m, 7H), 7.15 (ddd, *J* = 8.7, 7.0, 1.6 Hz, 1H), 3.91 (s, 3H), 3.73 (s, 3H), 2.47 (s, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 166.8, 164.5, 139.3, 134.6, 134.1, 130.4, 129.8, 129.5, 129.4, 129.0, 127.8, 125.7, 125.2, 124.9, 122.9, 118.6, 117.9, 104.7, 52.4, 51.6, 21.7 ppm. Spectral data is in accordance with the data reported in the litterature [3]. Melting Point: 114.8-116.2 ℃.

**Dimethyl 8-methoxy-3-(p-tolyl)indolizine-1,2-dicarboxylate (2t)**



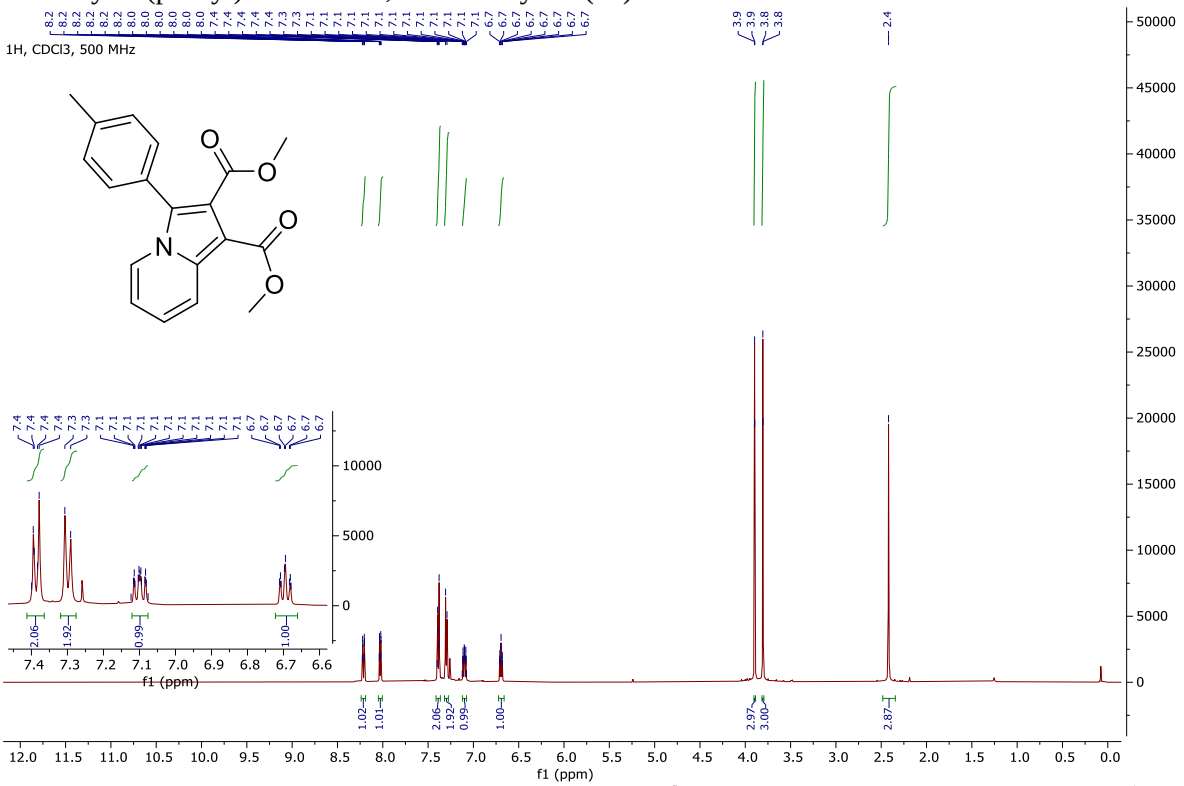
White solid, 57 mg, 60%. **$^{1}$H NMR** (500 MHz, $CDCl_3$) δ 7.33 (dd, *J* = 7.1, 2.0 Hz, 1H), 7.30 – 7.20 (m, 3H), 6.39 (td, *J* = 7.3, 2.0 Hz, 1H), 6.06 (dd, *J* = 7.4, 2.0 Hz, 1H), 3.91 (d, *J* = 2.1 Hz, 2H), 3.87 (d, *J* = 2.0 Hz, 3H), 3.66 (d, *J* = 2.1 Hz, 2H), 2.39 (d, *J* = 2.0 Hz, 3H) ppm. **$^{13}$C NMR** (126 MHz, $CDCl_3$) δ 167.5, 164.5, 151.8, 139.1, 130.8, 129.5, 128.6, 126.9, 124.5, 116.5, 115.5, 112.7, 107.4, 96.5, 56.0, 52.6, 51.8, 21.6 ppm. **HRMS** (ESI+) for $C_{20}H_{19}NO_5Na^+$: calculated 376.1155, found 376.1143 (error m/z=3.4 ppm). Melting Point: 148.7-150.1 ℃.

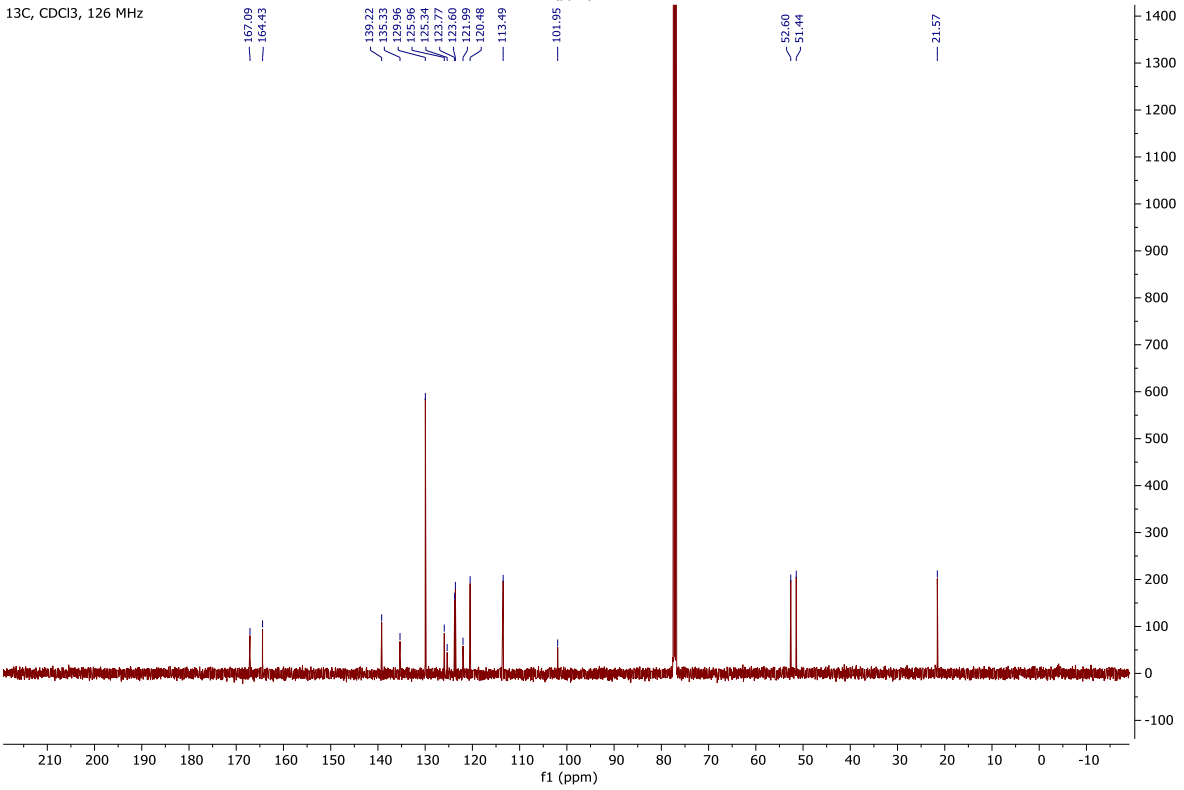
## VI. References


1. R. W. Layer *Chem. Rev.* 1963**, 63**, 489-510.
2. (a) J. S. Quesnel,L. V. Kayser, A. Fabrikant, B. A. Arndtsen *Chem. Eur. J.* 2015**, 21**, 9550-9555; (b) S. S. Zalesskiy, V. P. Ananikov *Organometallics* 2012**, 31**, 2302-2309.
3. H. Erguven, D. C. Leitch, E. N. Keyzer, B. A. Arndtsen *Angew. Chem. Int. Ed.* 2017**, 129**, 6174-6178.
4. C. R. D. S. Bertallo, T. R. Arroio, M. F. Z. L. Toledo, S. A. Sadler, R. Vessecchi, P. G. Steel,G. C. Clososki *Eur. J. Org. Chem.* 2019, 5205-5213.
5. S. Roy *Eur. J. Org. Chem.* 2019, 765-769.

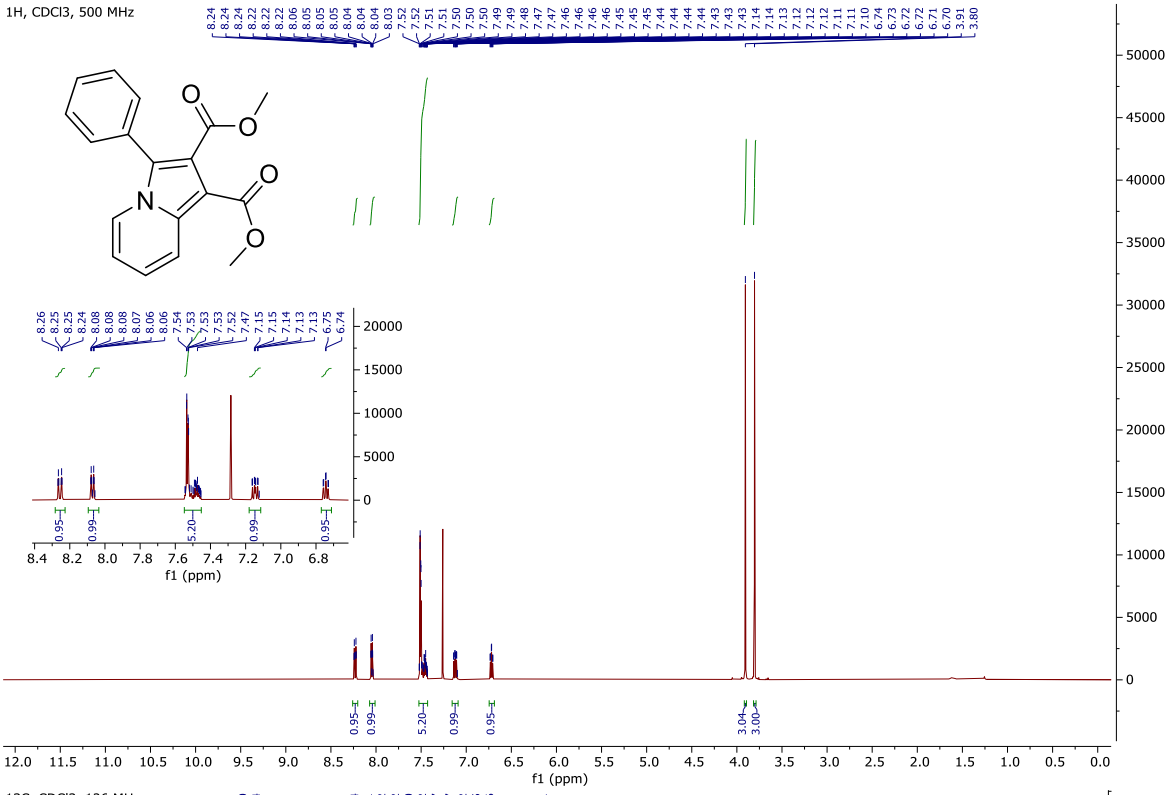
## VII. $^{1}H$ and $^{13}C$ NMR Spectra of Products

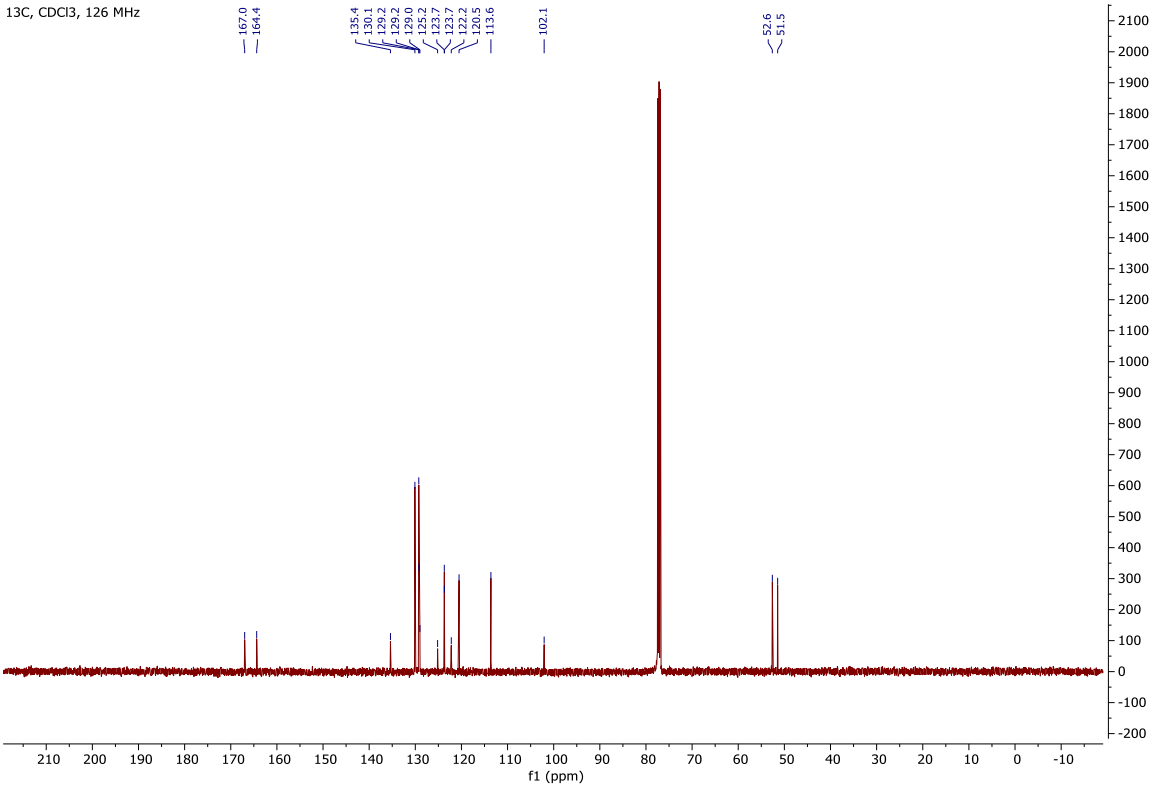
Dimethyl 3-(p-tolyl)indolizine-1,2-dicarboxylate (**2a**)



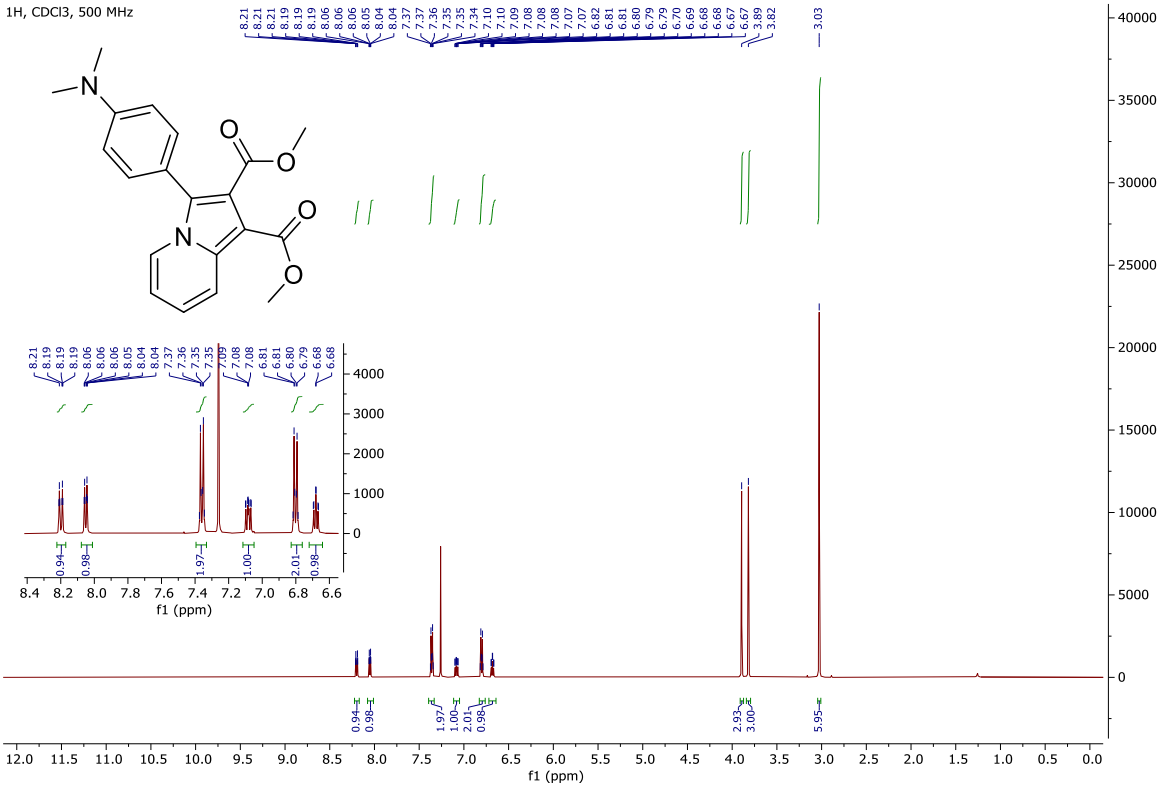



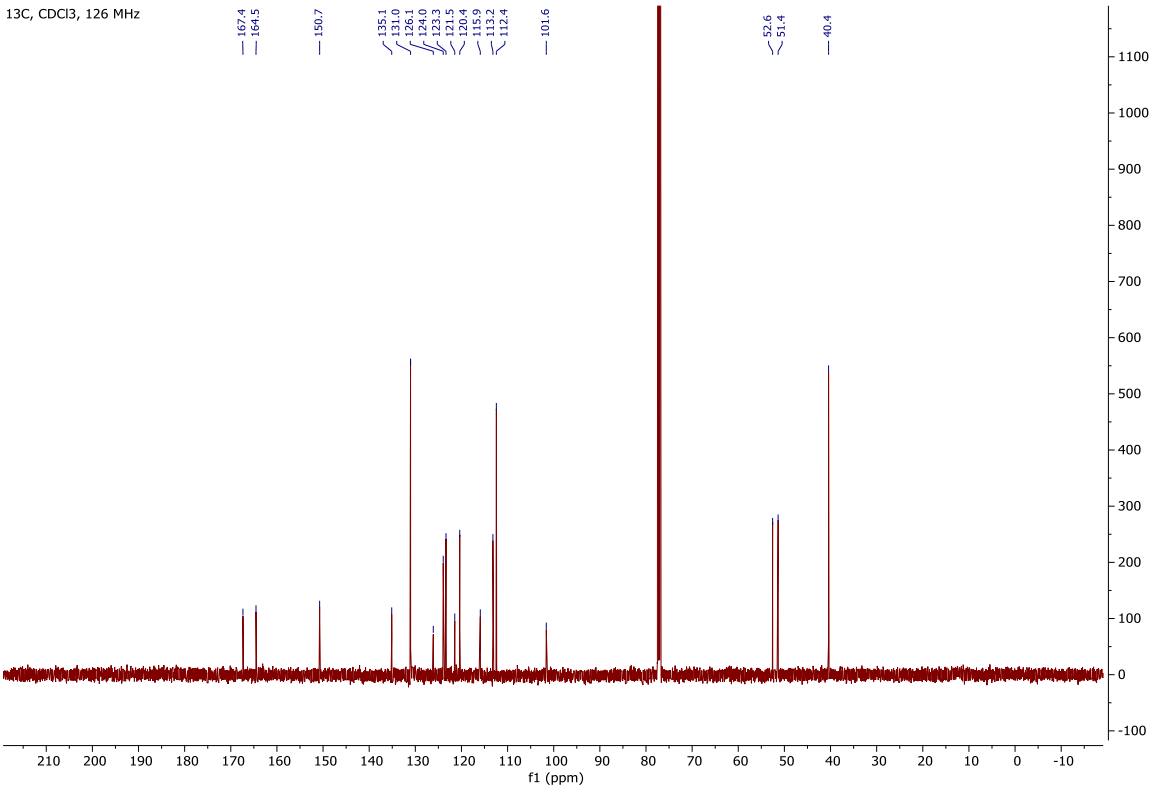
Dimethyl 3-phenylindolizine-1,2-dicarboxylate (**2b**)



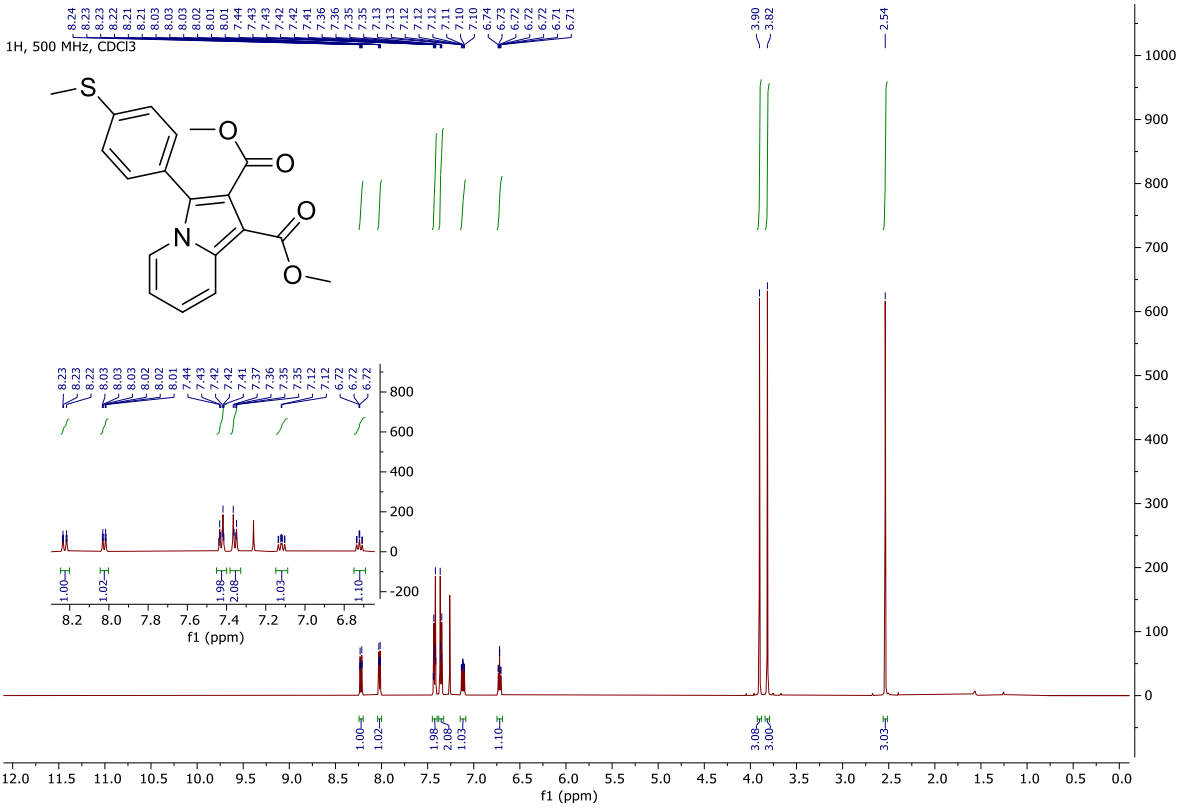



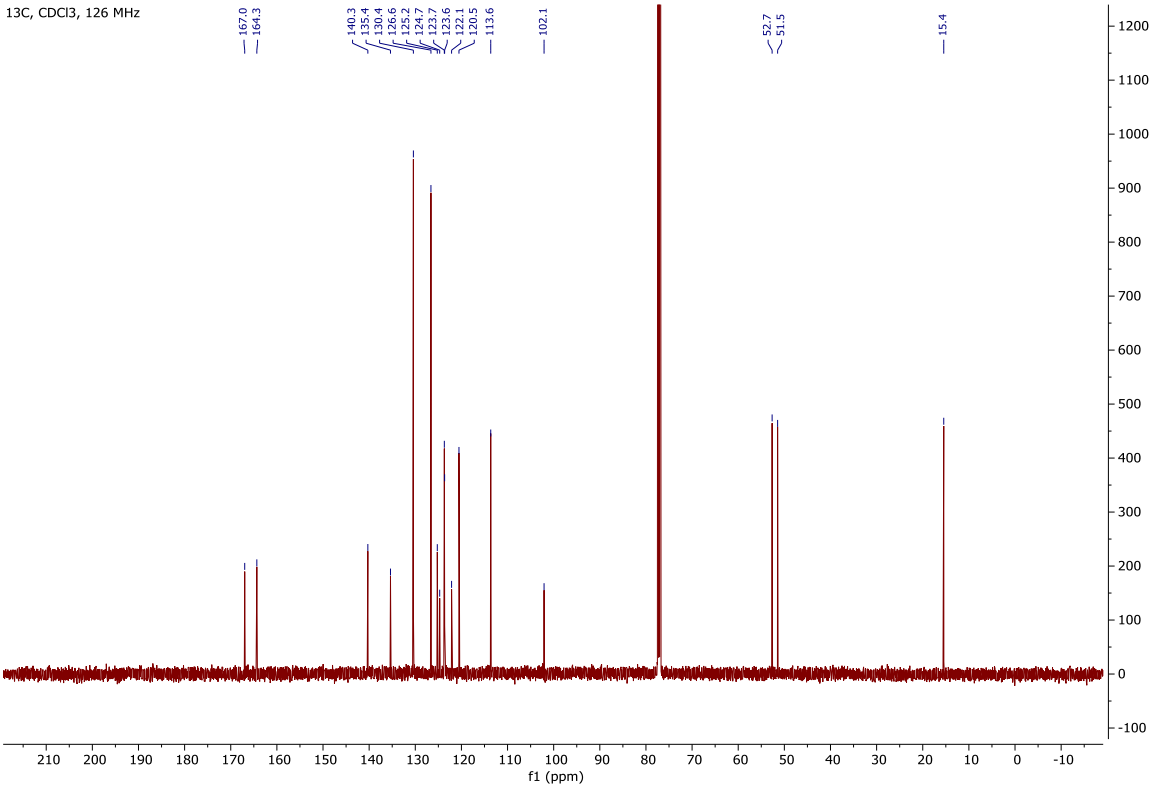
Dimethyl 3-(4-(dimethylamino)phenyl)indolizine-1,2-dicarboxylate (**2c**)



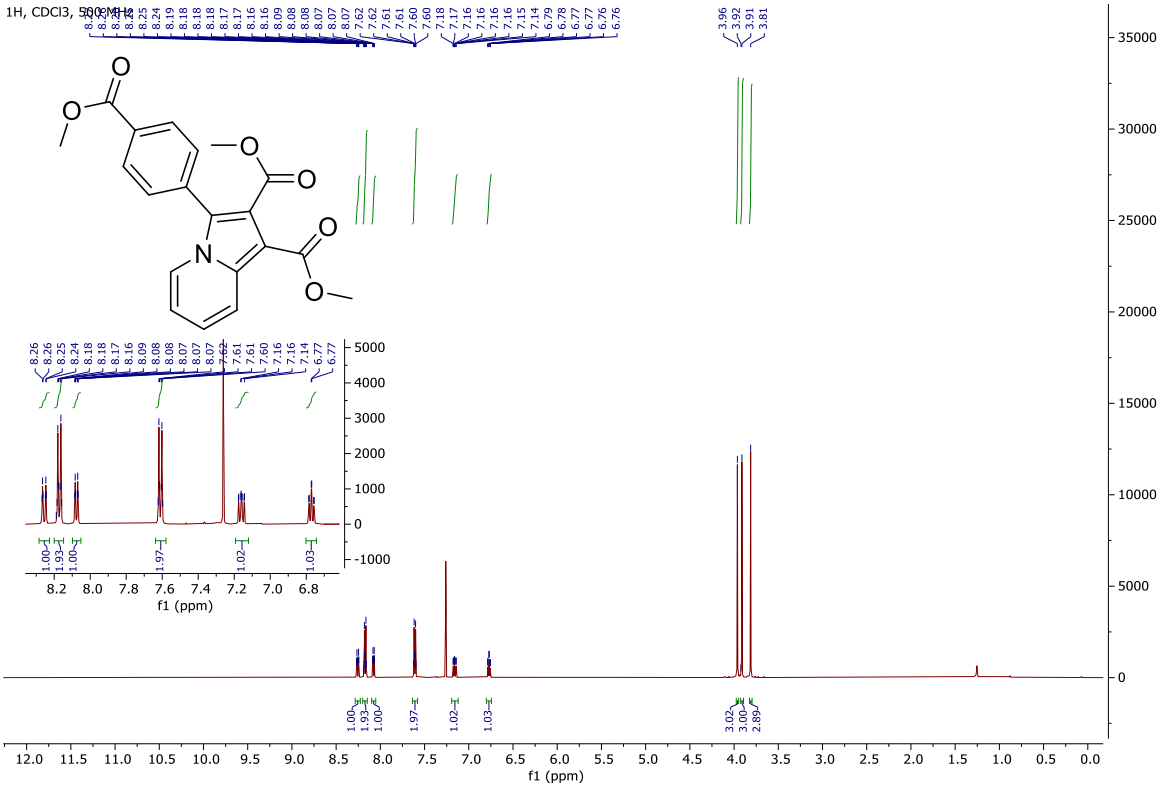



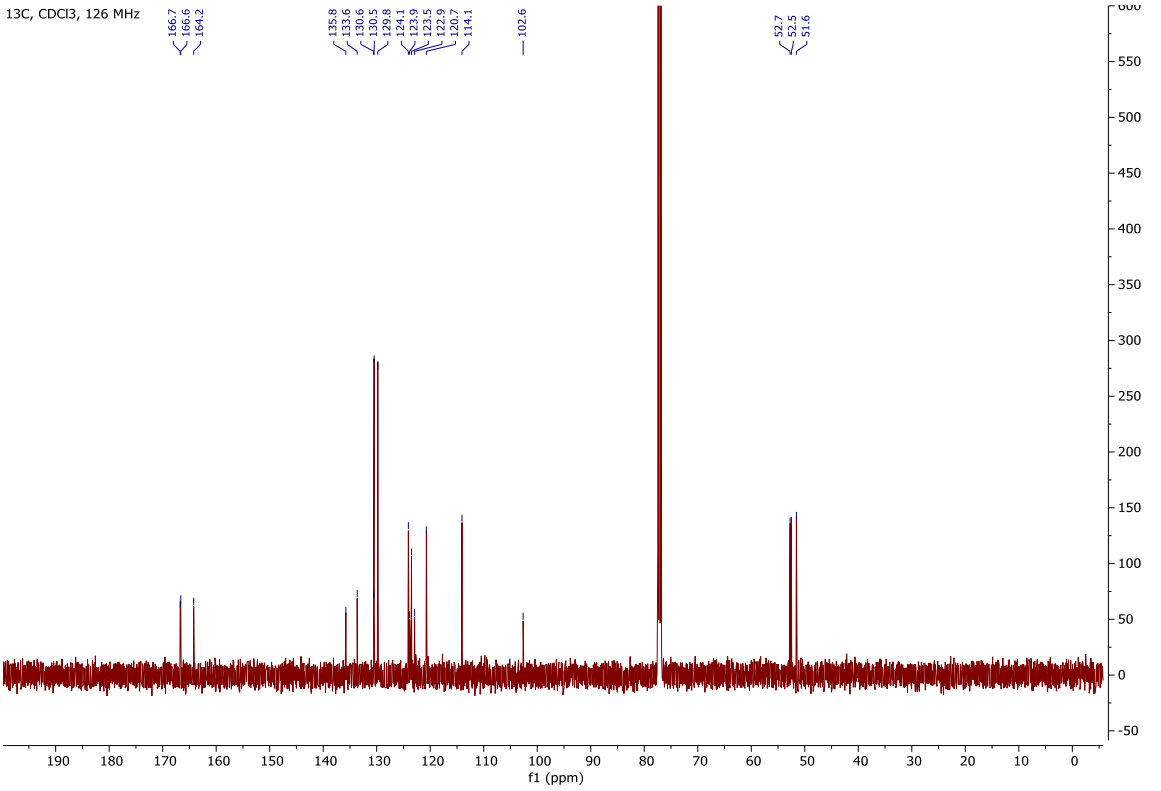
Dimethyl 3-(4-(methylthio)phenyl)indolizine-1,2-dicarboxylate (**2d**)



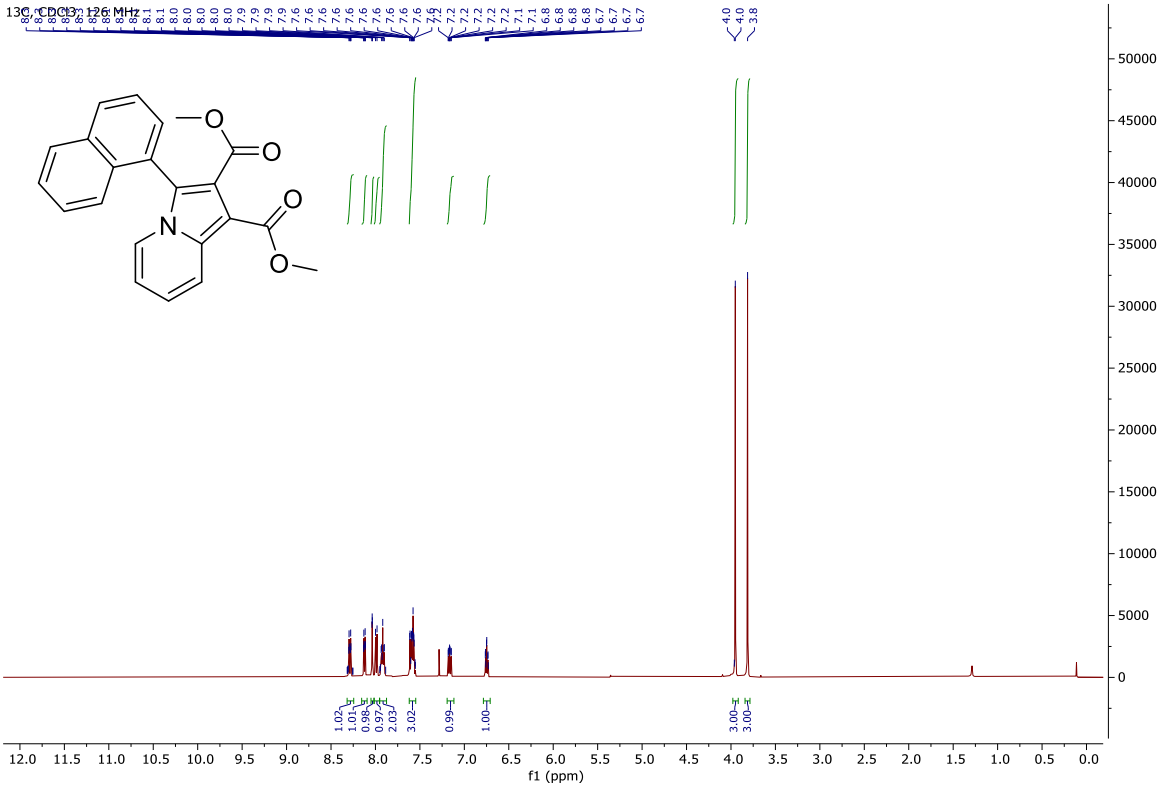



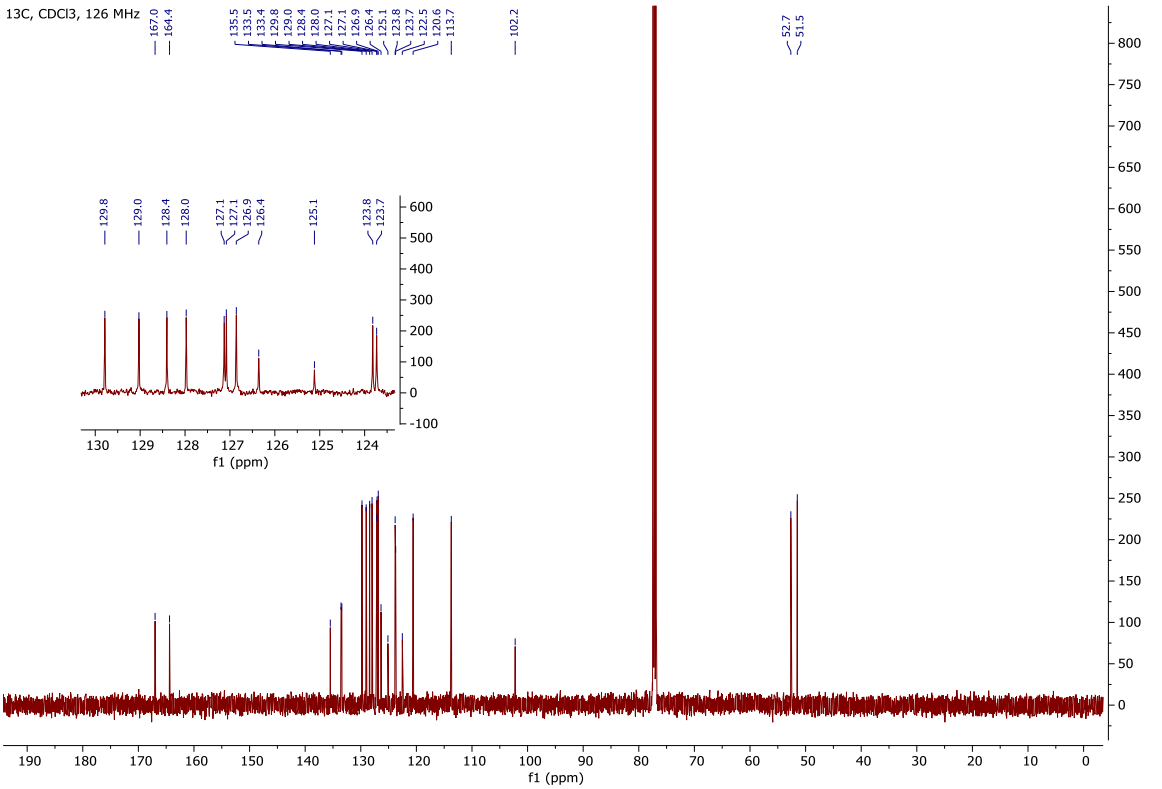
Dimethyl 3-(4-(methoxycarbonyl)phenyl)indolizine-1,2-dicarboxylate (**2e**)



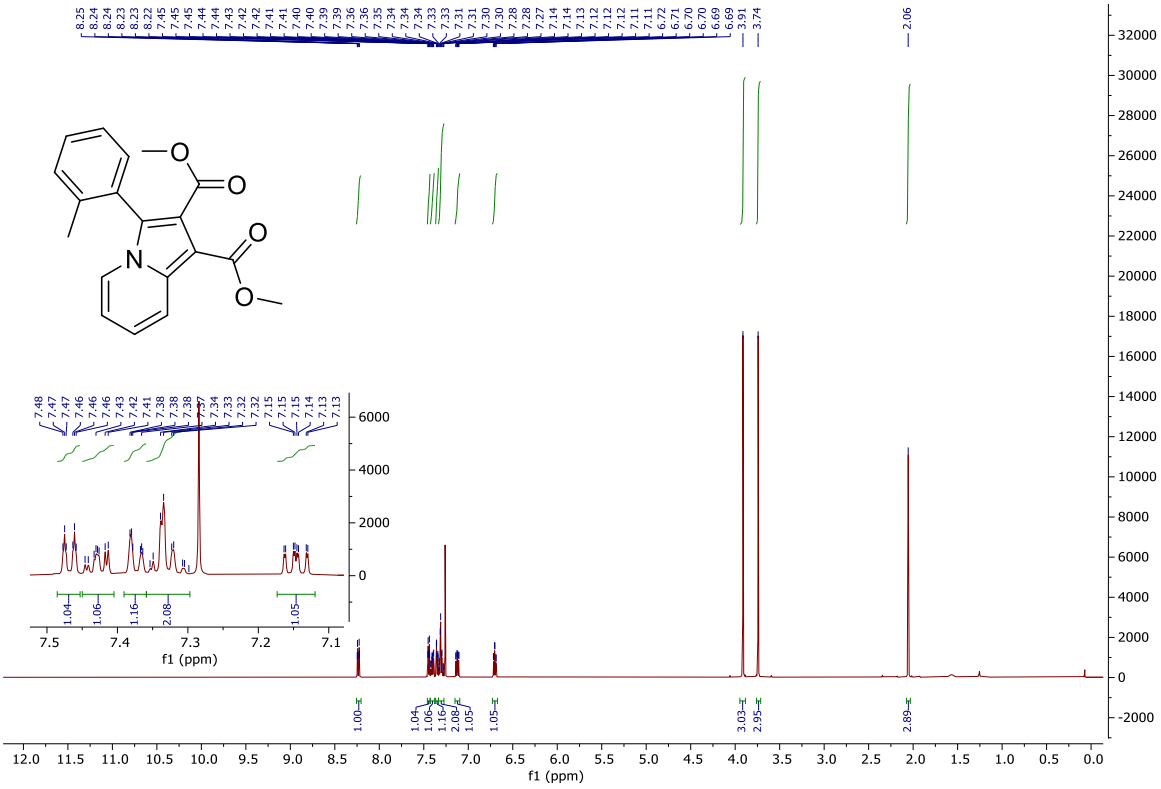



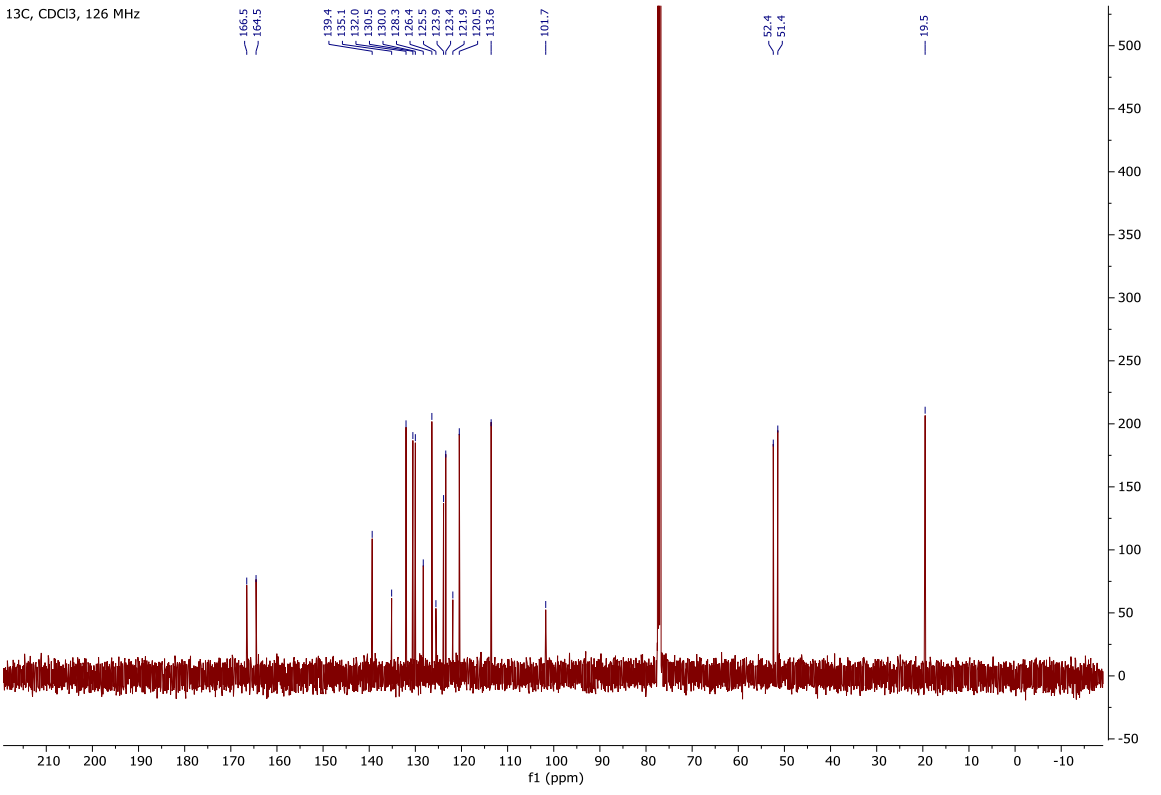
Dimethyl 3-(naphthalen-1-yl)indolizine-1,2-dicarboxylate (**2f**)



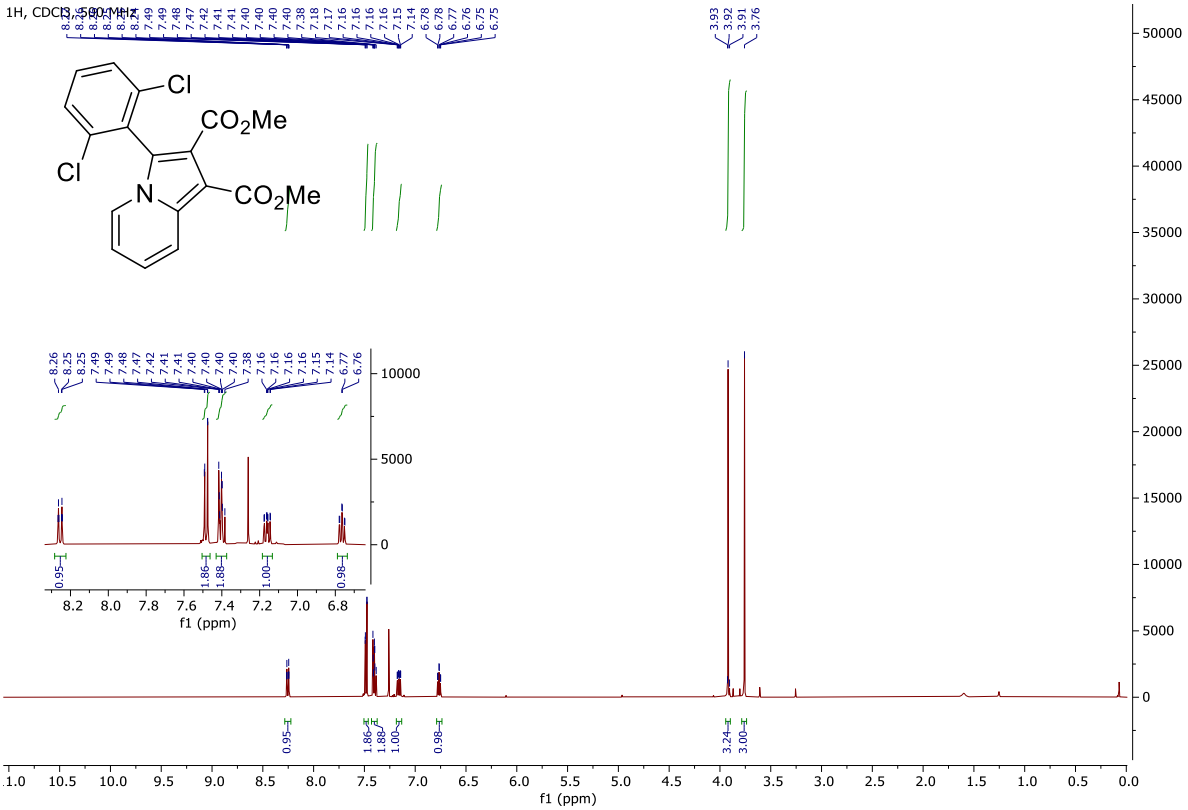



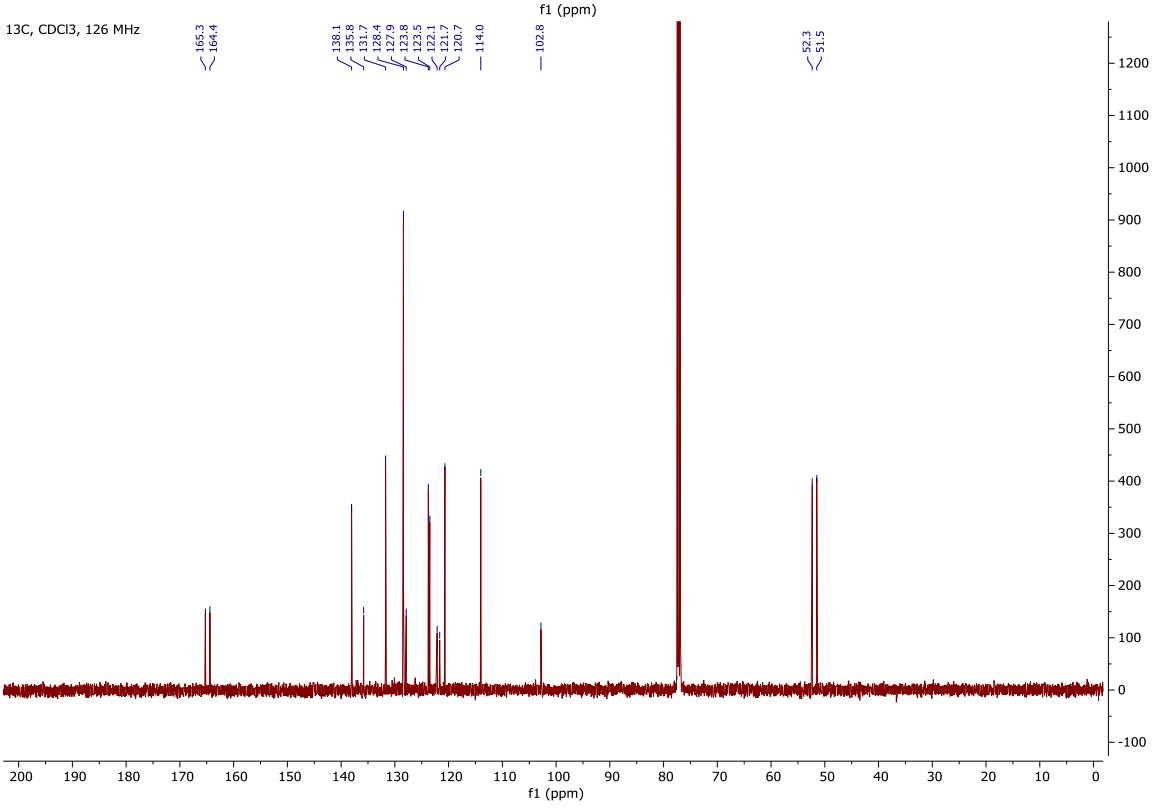
Dimethyl 3-(o-tolyl)indolizine-1,2-dicarboxylate (**2g**)



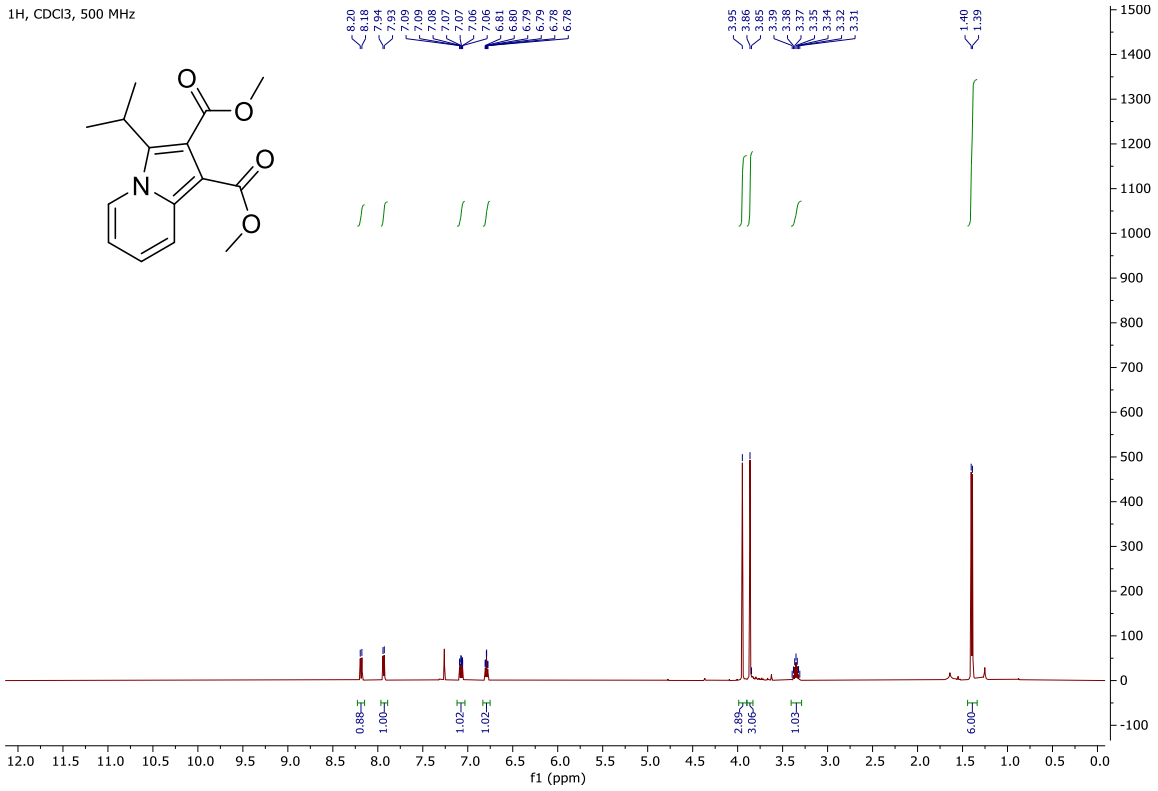



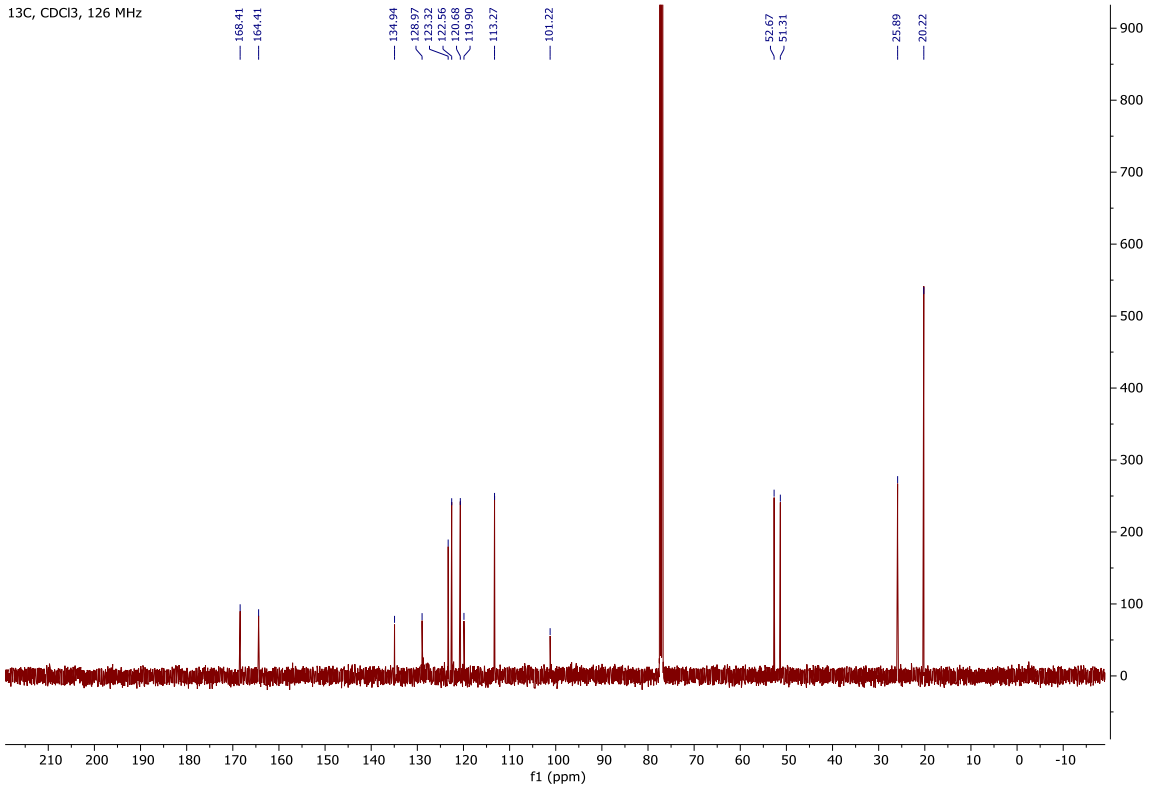
Dimethyl 3-(2,6-dichlorophenyl)indolizine-1,2-dicarboxylate (**2h**)



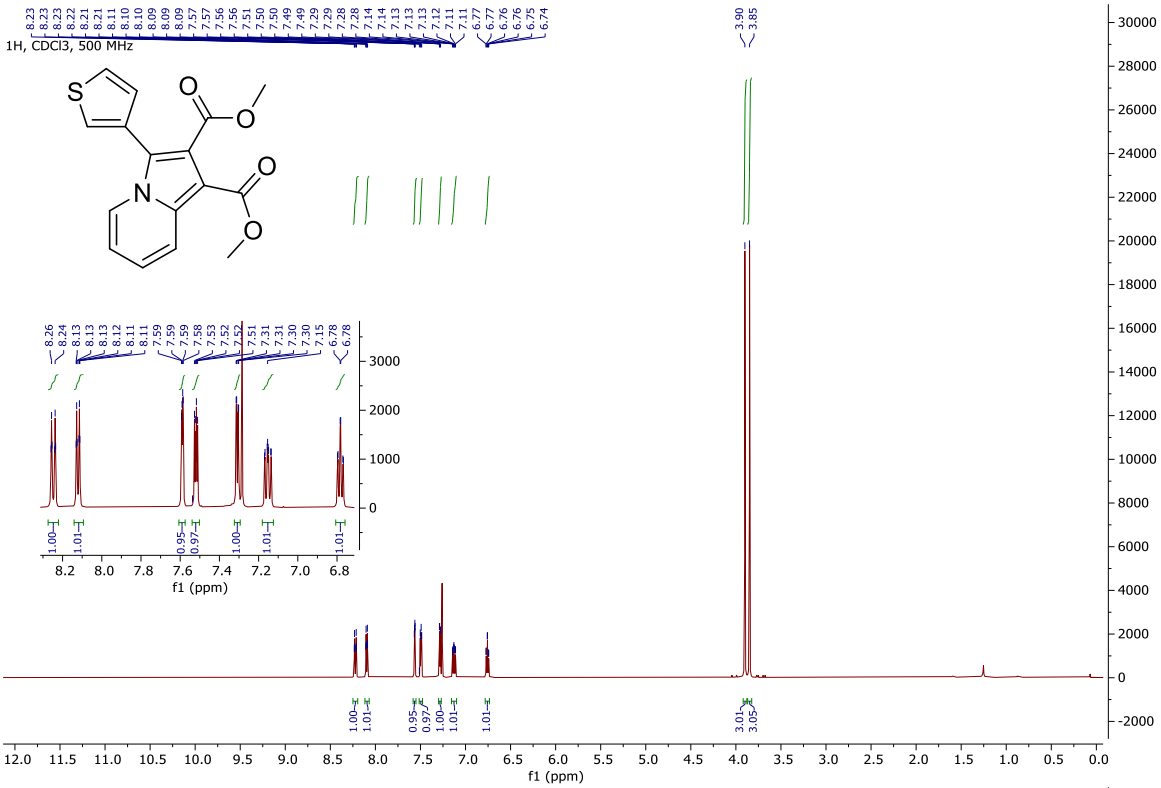



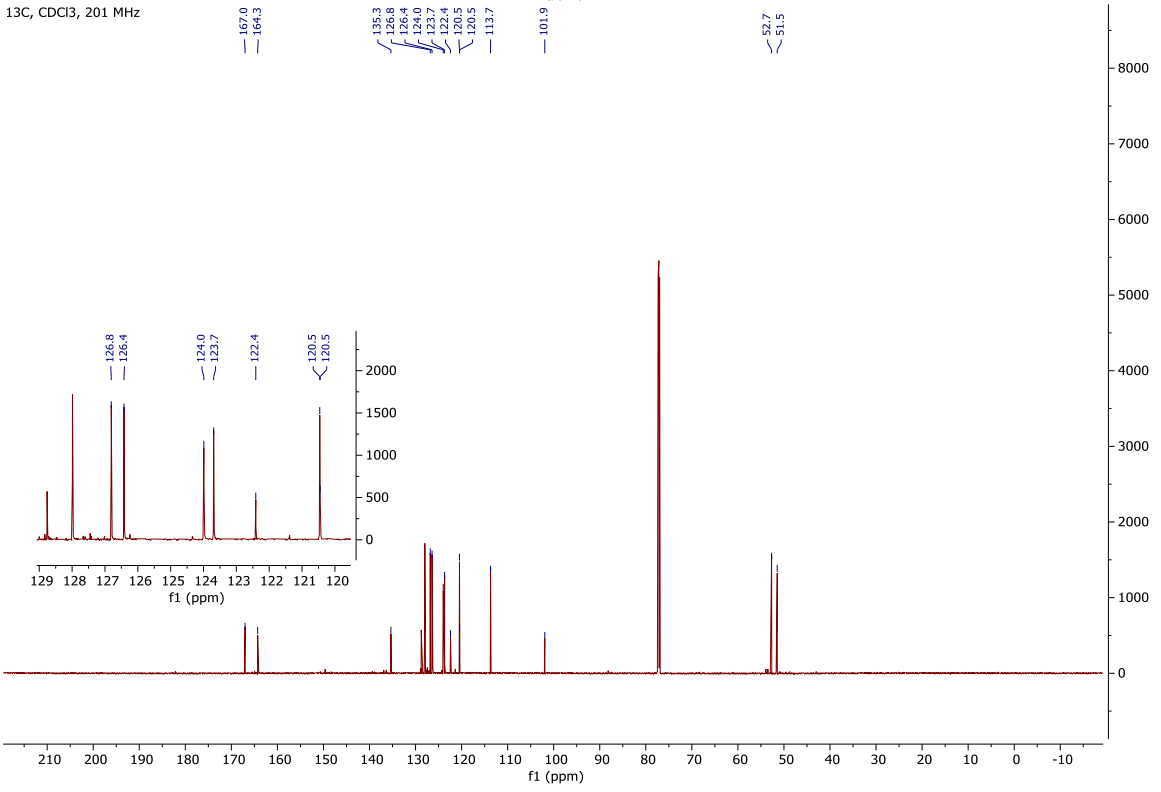
Dimethyl 3-isopropylindolizine-1,2-dicarboxylate (**2i**)



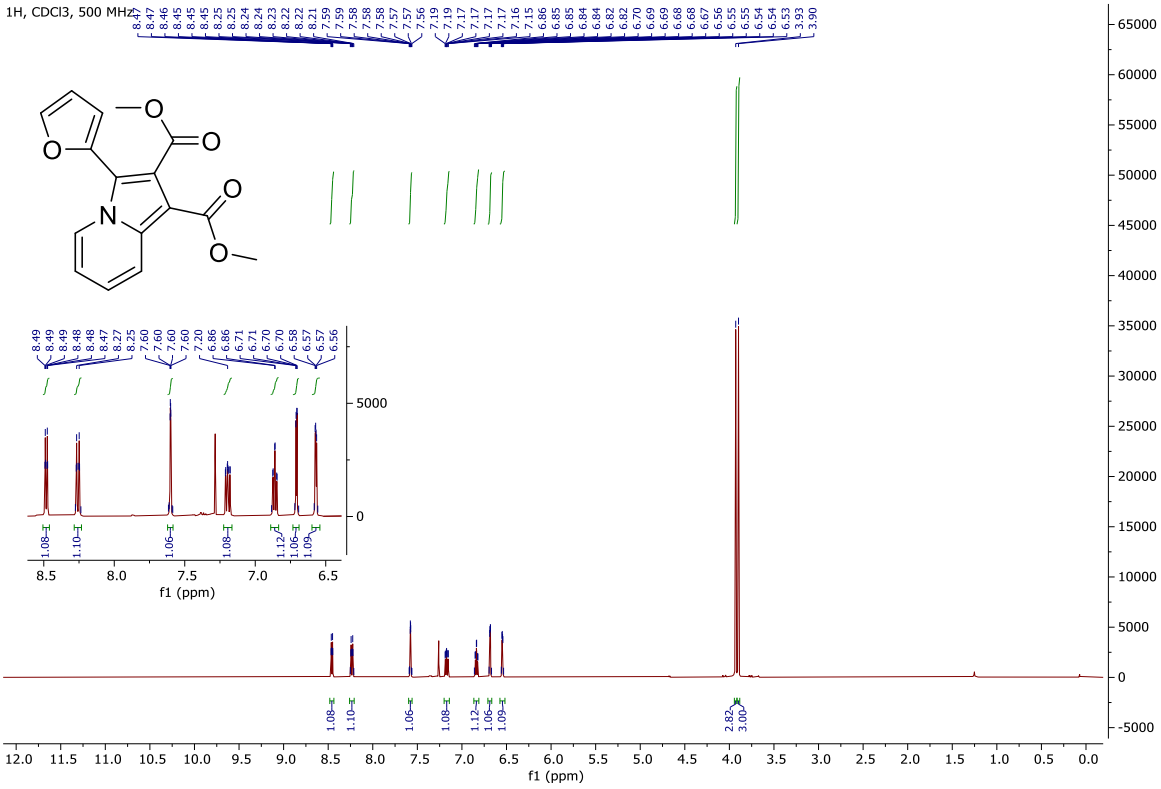



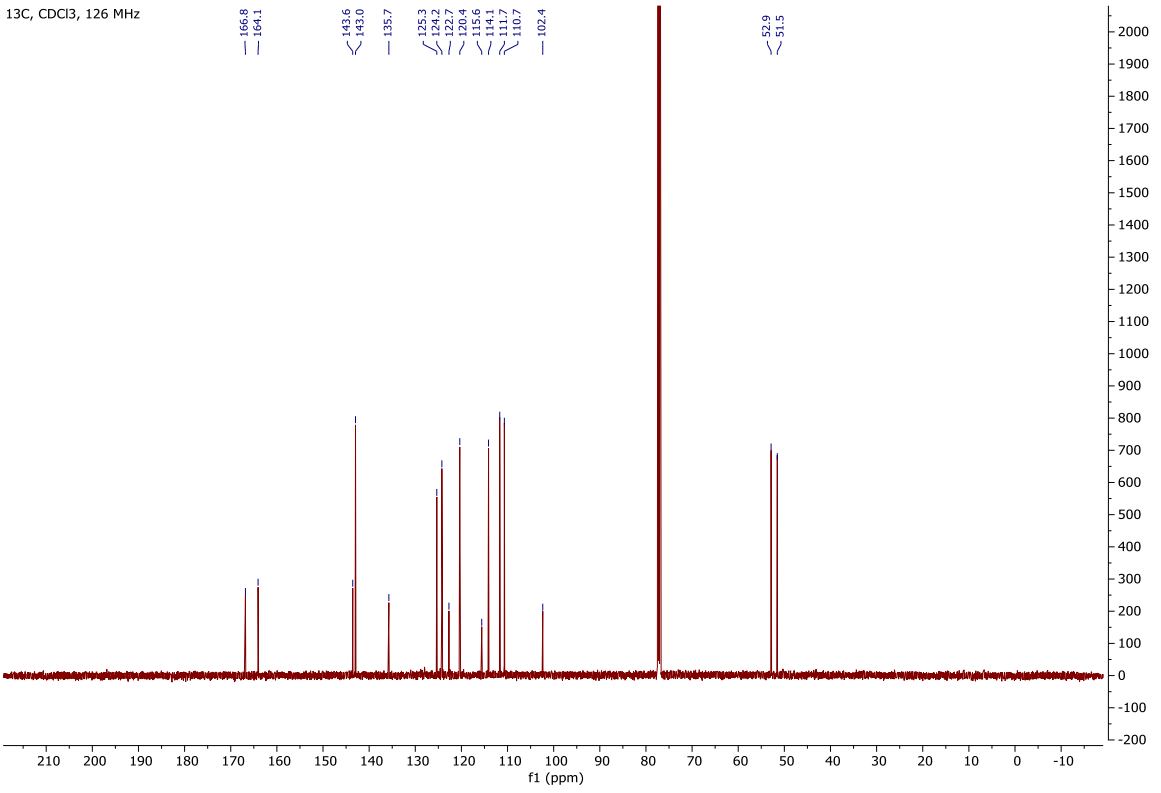
Dimethyl 3-(thiophen-3-yl)indolizine-1,2-dicarboxylate (**2j**)



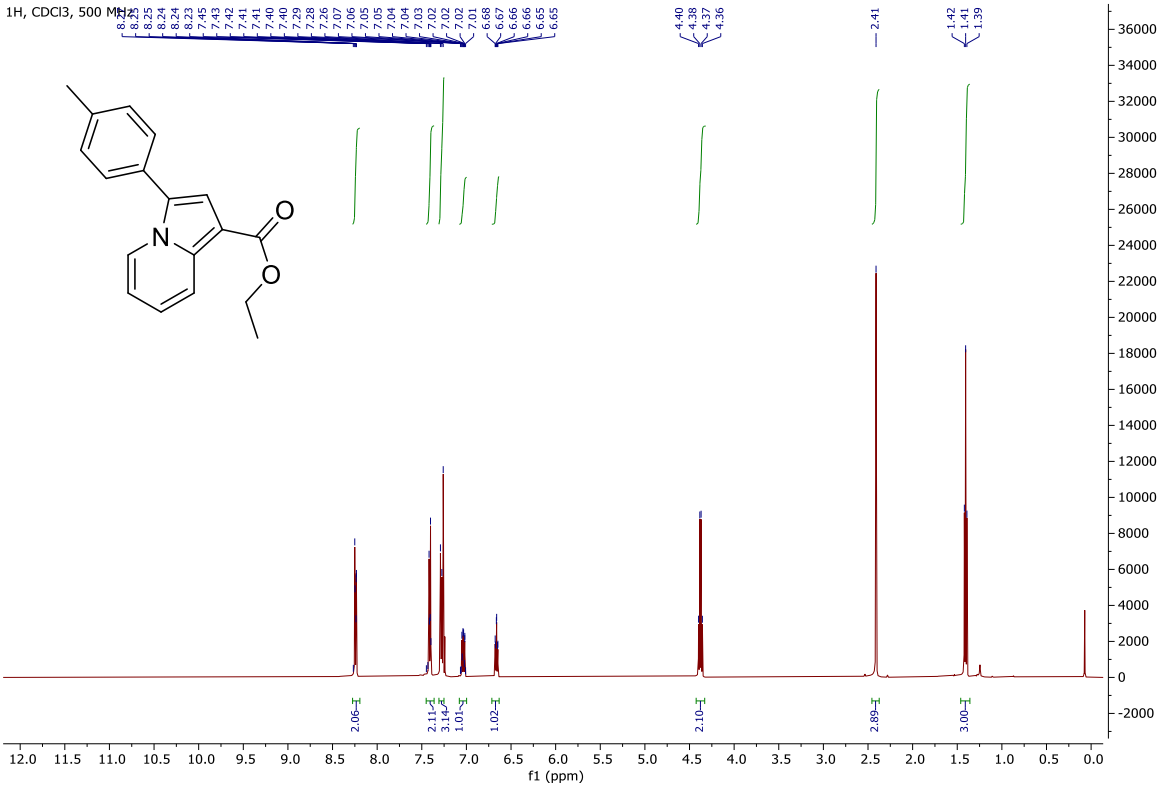



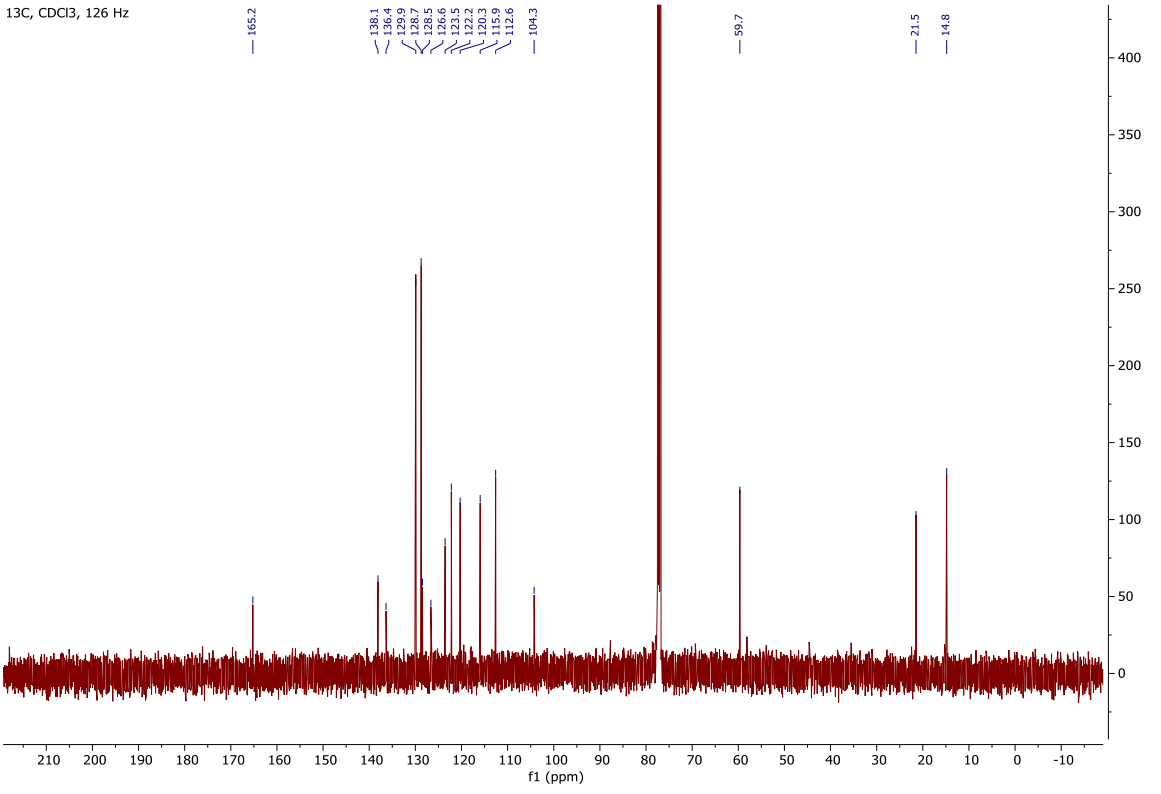
Dimethyl 3-(furan-2-yl)indolizine-1,2-dicarboxylate (**2k**)



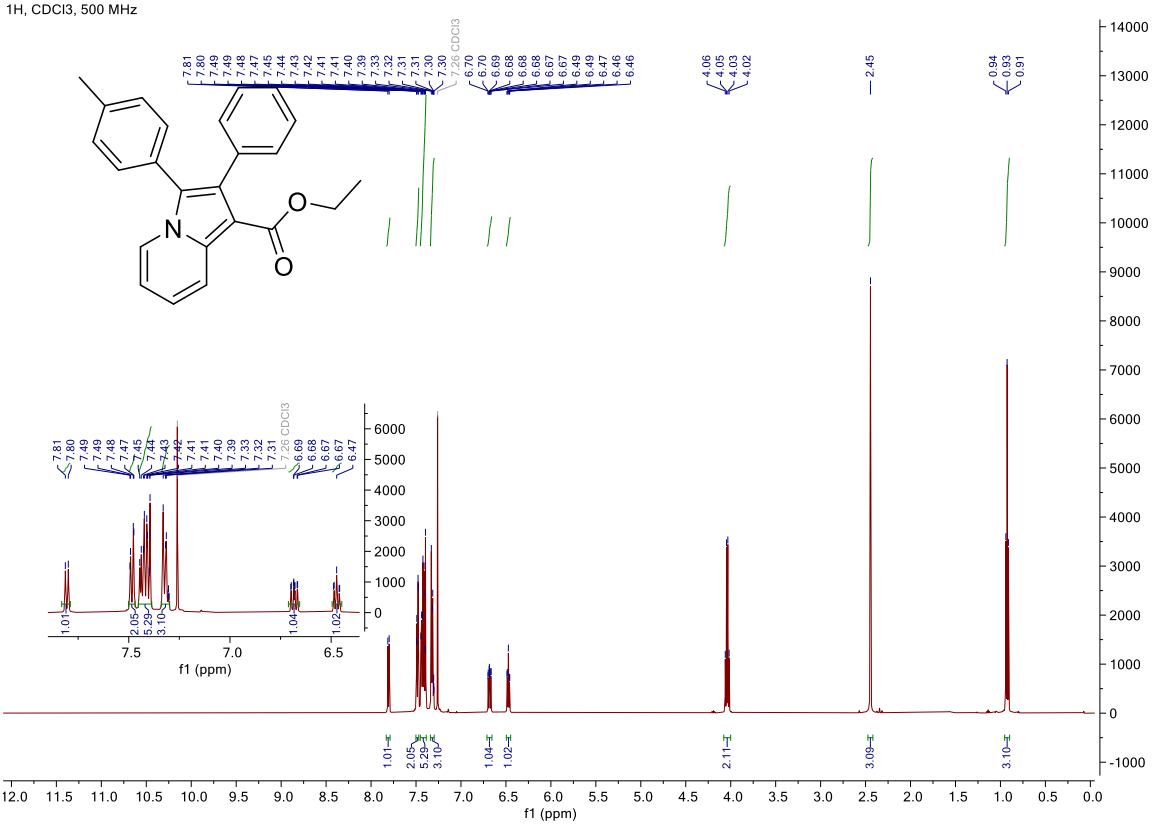



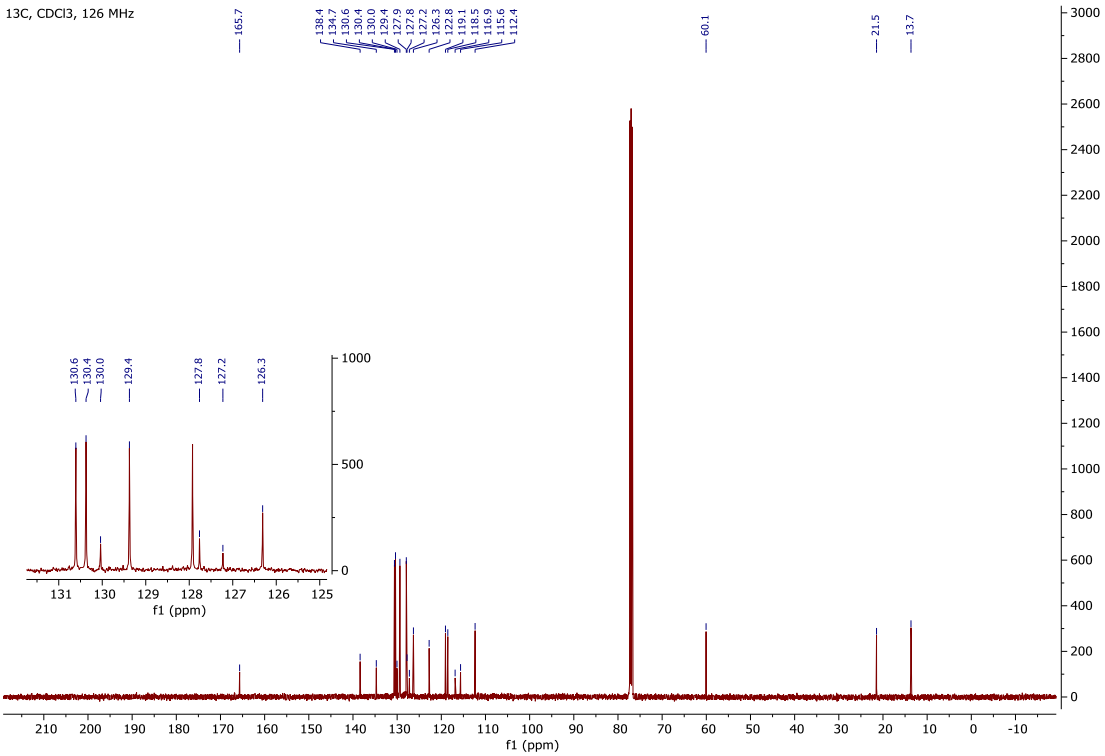
Ethyl 3-(p-tolyl)indolizine-1-carboxylate (**2l**)



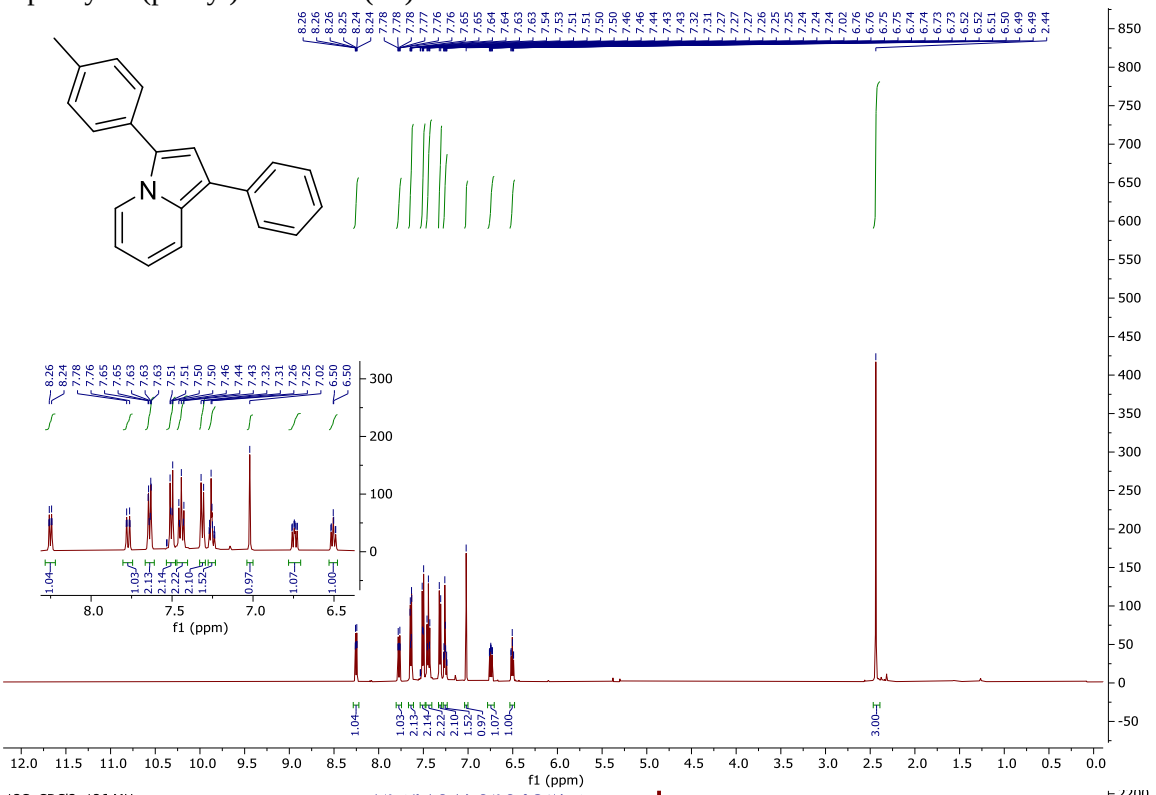



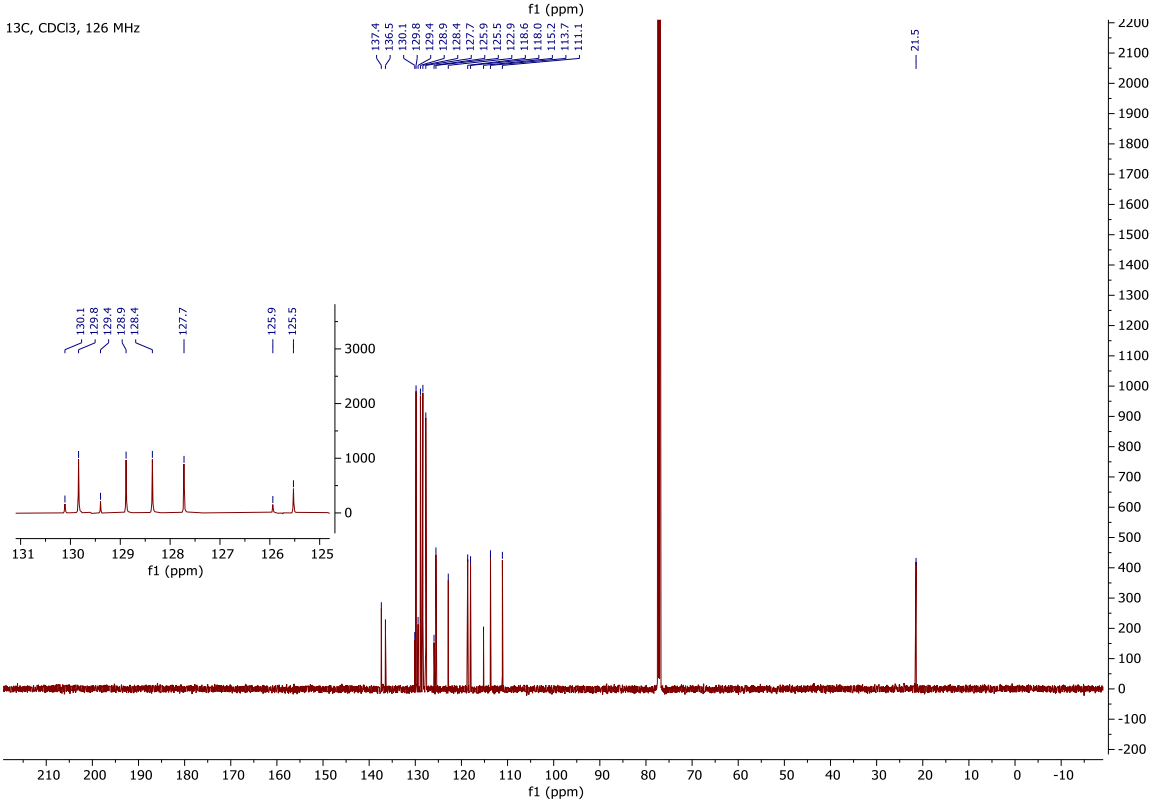
Ethyl 2-phenyl-3-(p-tolyl)indolizine-1-carboxylate (**2m**)



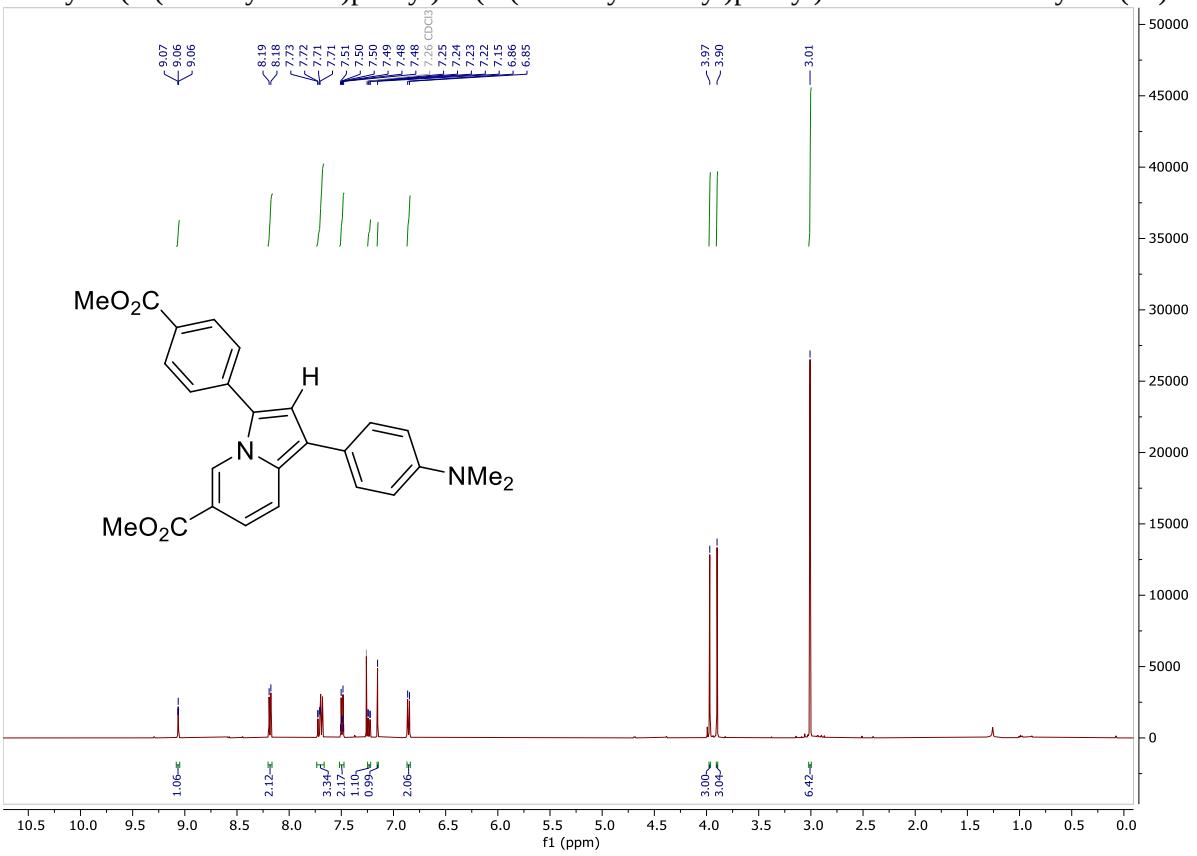



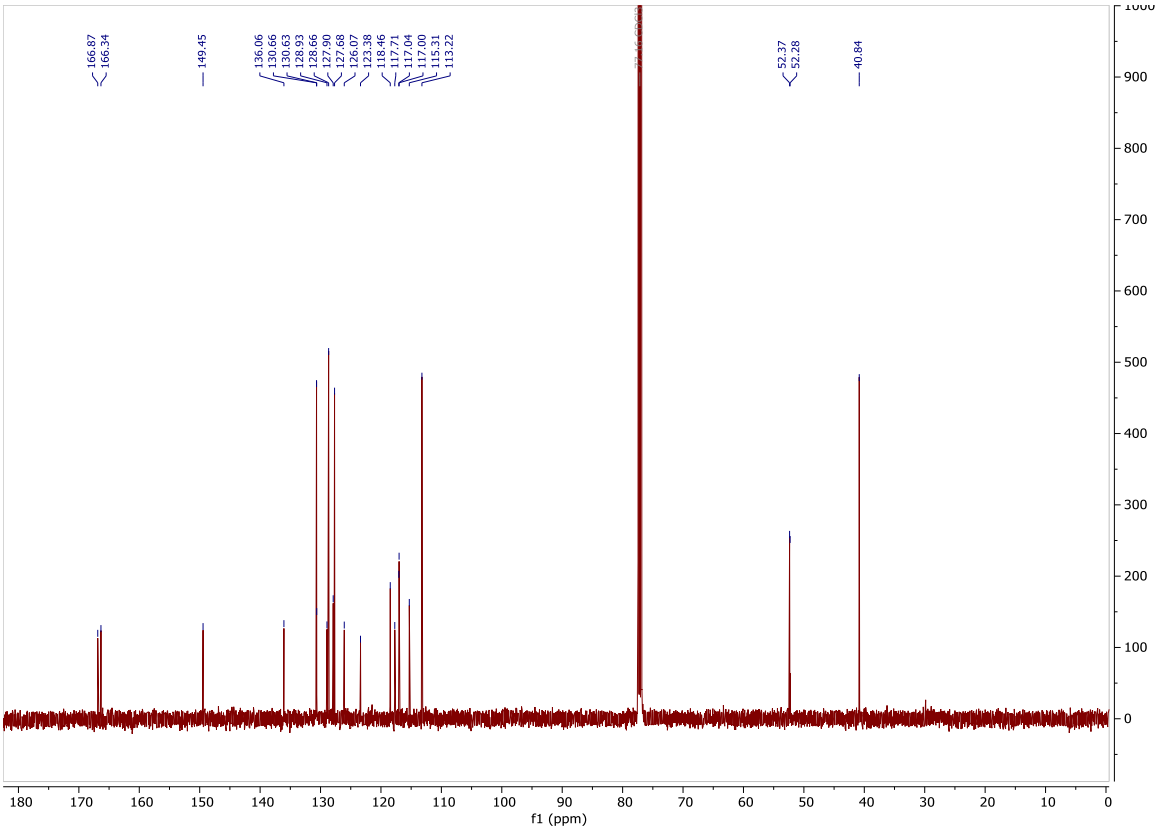
1-phenyl-3-(p-tolyl)indolizine (**2n**)



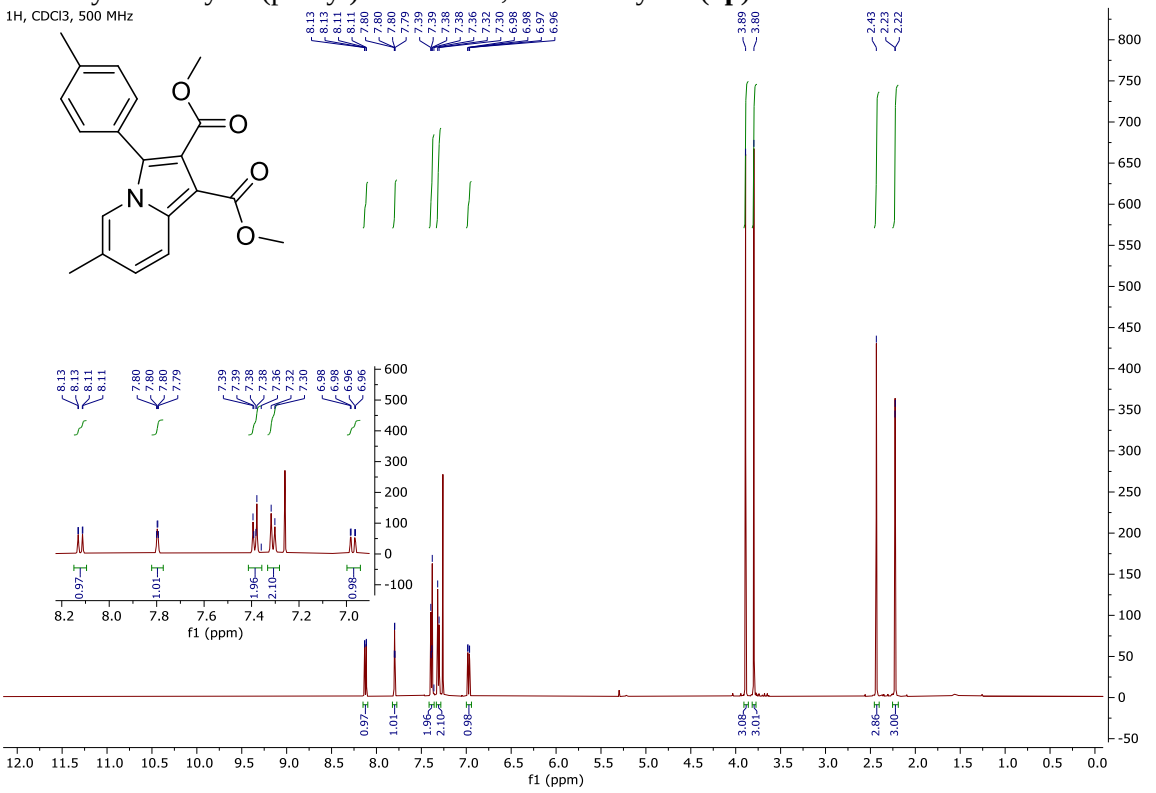



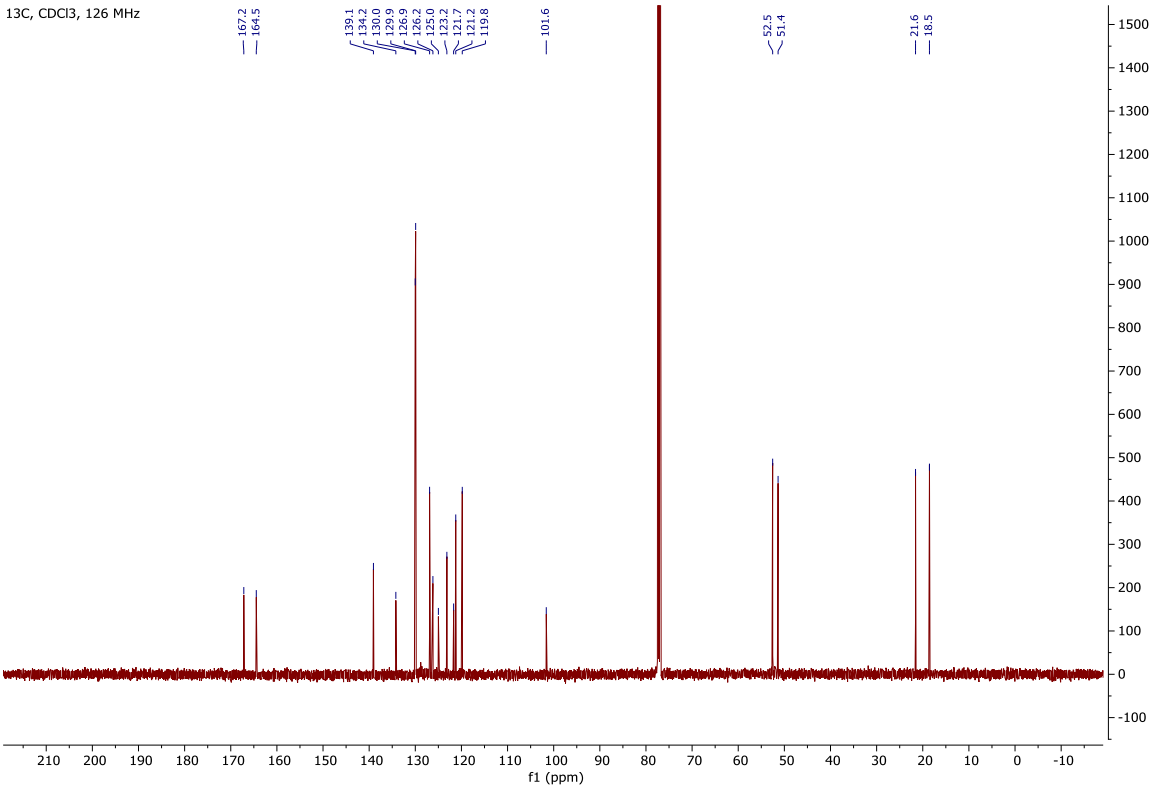
Methyl 1-(4-(dimethylamino)phenyl)-3-(4-(methoxycarbonyl)phenyl)indolizine-6-carboxylate (**2o**)



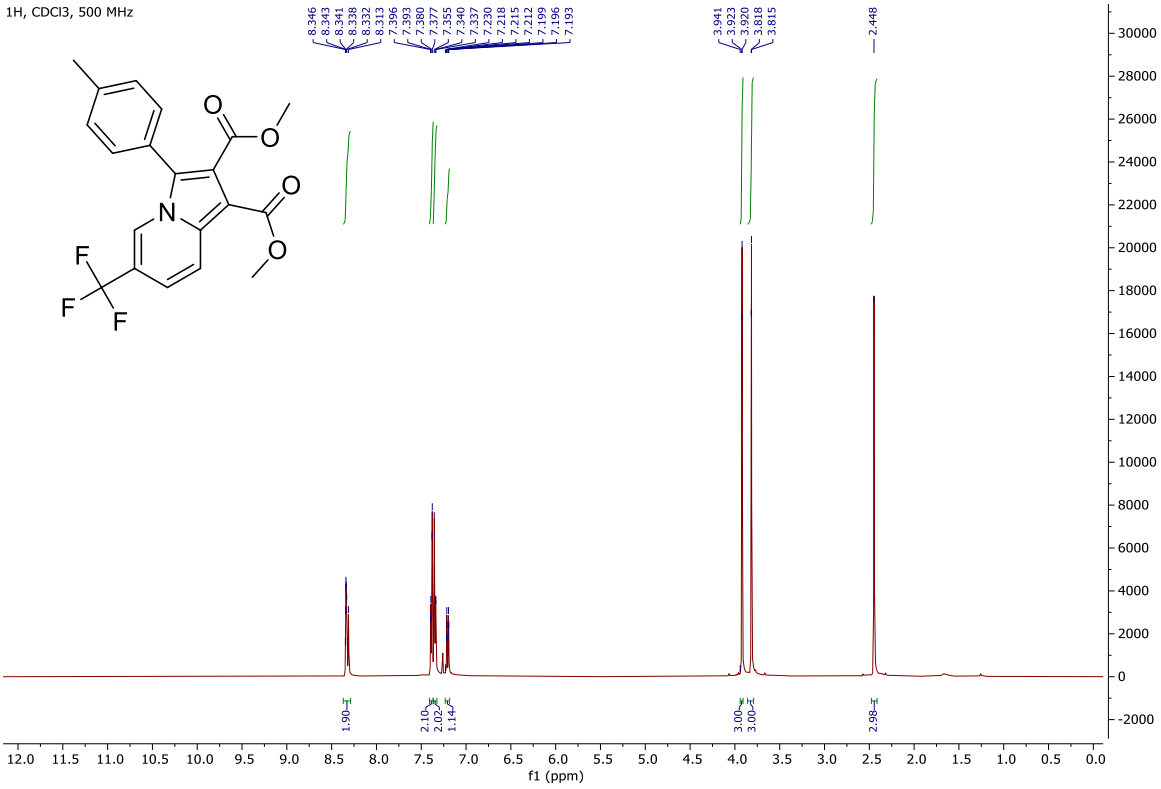



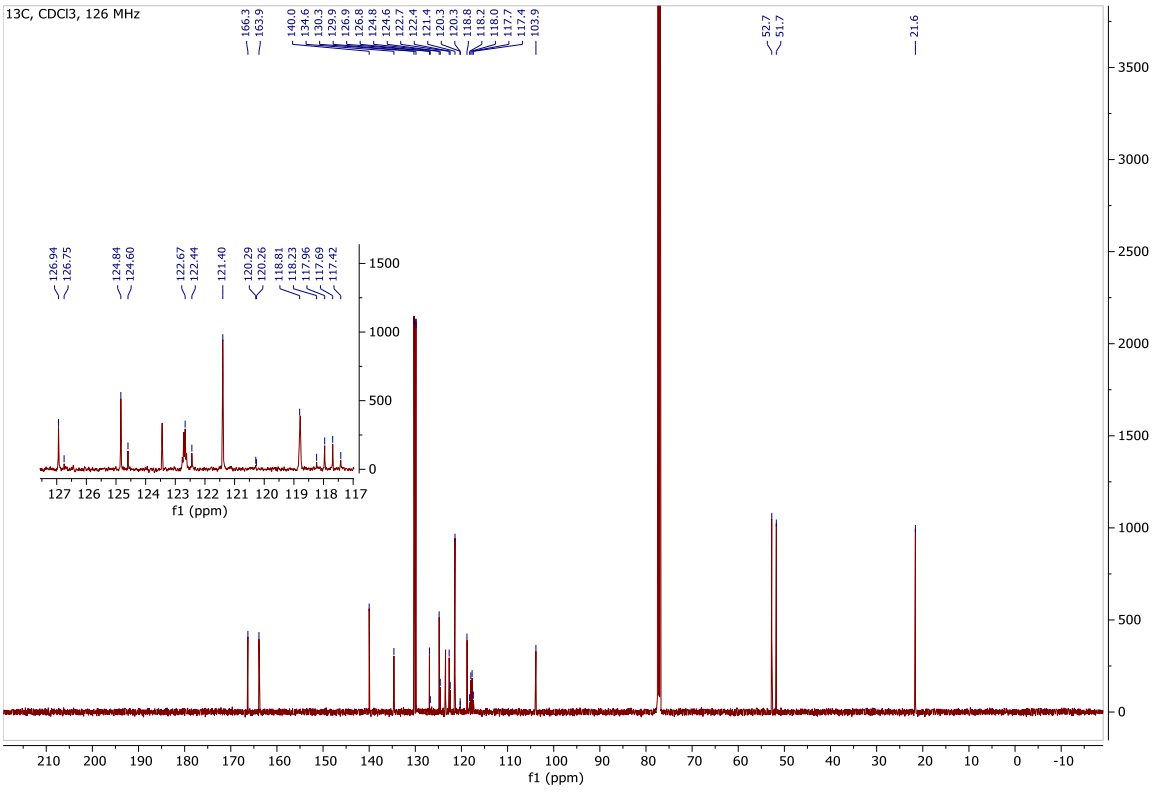
Dimethyl 6-methyl-3-(p-tolyl)indolizine-1,2-dicarboxylate (**2p**)



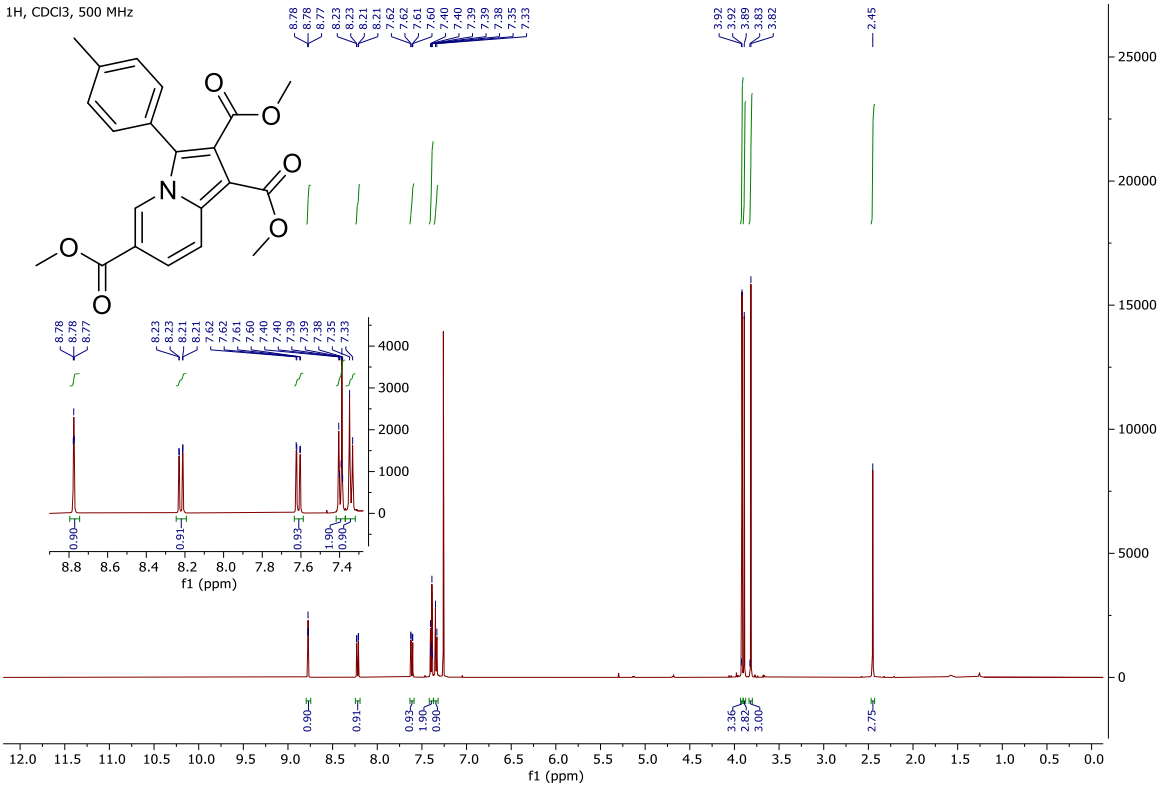



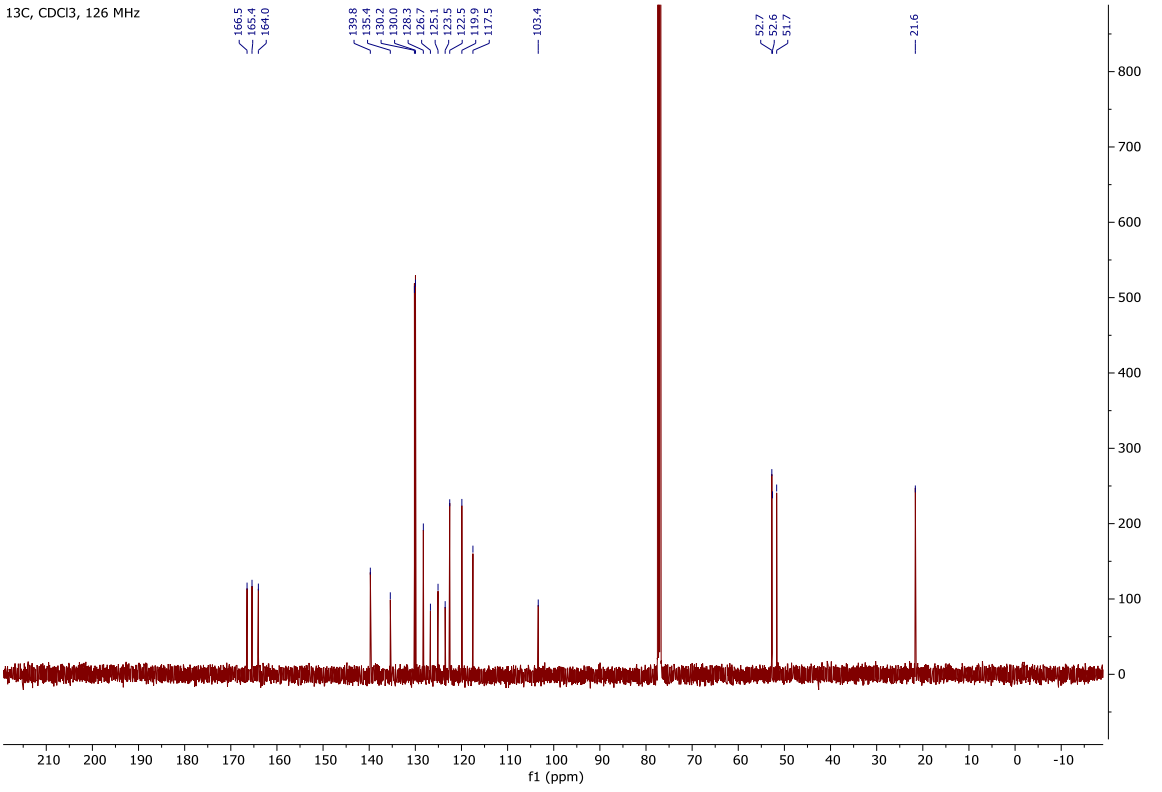
Dimethyl 3-(p-tolyl)-6-(trifluoromethyl)indolizine-1,2-dicarboxylate (**2q**)



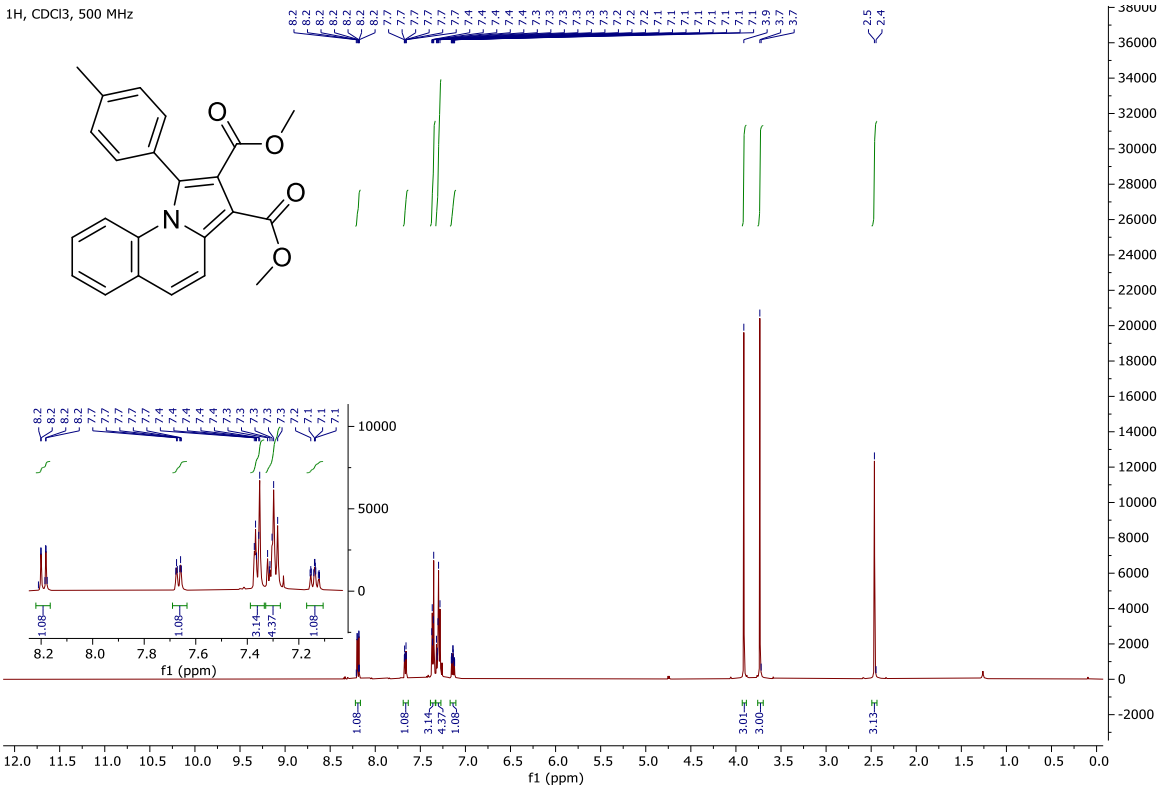



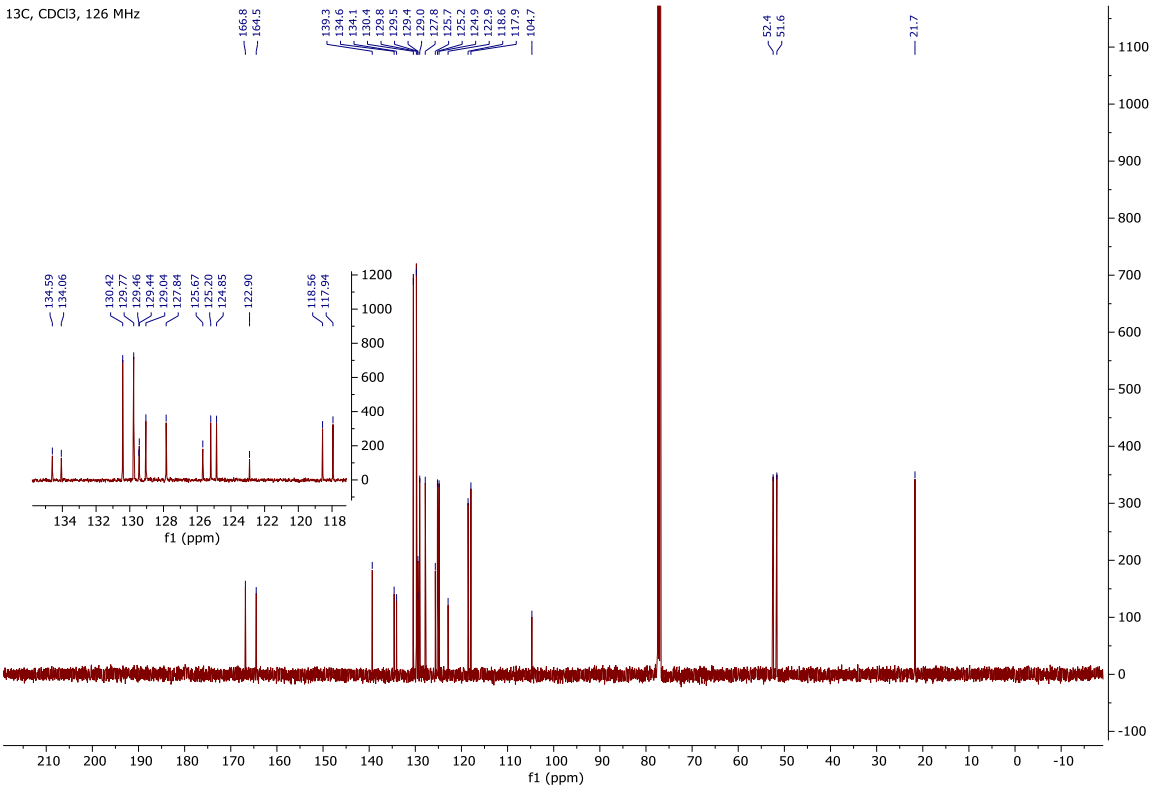
Trimethyl 3-(p-tolyl)indolizine-1,2,6-tricarboxylate (**2r**)



Dimethyl 1-(p-tolyl)pyrrolo[1,2-a]quinoline-2,3-dicarboxylate (**2s**)



Dimethyl 8-methoxy-3-(p-tolyl)indolizine-1,2-dicarboxylate (**2t**)