

Supporting information (SI)

Optimizing molecular structure and packing style of crystal by Intramolecular cyclization from picrylhydrazone to indazole

Jie Tang^a, Guangbin Cheng^a, Ying Zhao^a, Pengju Yang^a and Hongwei Yang^{*a}
School of Chemical Engineering, Nanjing University of Science and Technology
Nanjing 210094, P. R. China

Email: hyang@mail.njust.edu.cn

Table of Contents

1	Experimental Section	3
2	The crystallographic data.....	4
3	Theoretical study.....	7
4	Thermal Behaviors.....	9
5	Reference.....	10
6	¹H and ¹³C NMR Spectra of Compounds.....	11
7	Mass Spectra of Compounds.....	15

1 Experimental Section

General methods

^1H and ^{13}C NMR spectra were recorded on 500 MHz (Bruker AVANCE 500) nuclear magnetic resonance spectrometers operating at 500 and 125 MHz, respectively, by using either $\text{DMSO-}d_6$ or $\text{acetone-}d_6$ as the solvent and locking solvent unless otherwise stated. Chemical shifts in ^1H and ^{13}C NMR spectra are reported relative to DMSO. DSC was performed at a heating rate of $5\text{ }^\circ\text{C min}^{-1}$ in closed Al containers with a nitrogen flow of 30 mL min^{-1} on an STD-Q600 instrument. Infrared (IR) spectra were recorded on a Perkin-Elmer Spectrum BX FT-IR equipped with an ATR unit at $25\text{ }^\circ\text{C}$. Impact sensitivity, friction sensitivity and electrostatic discharge sensitivity of samples are measured by using the standard BAM methods.

X-ray crystallography

The data were collected with a Bruker three-circle platform diffractometer equipped with a SMART APEX II CCD detector. A Kryo-Flex low-temperature device was used to keep the crystals at a constant $173(2)\text{ K}$ during the data collection. The data collection and the initial unit cell refinement were performed by using APEX2 (v2010.3-0). Data reduction was performed by using SAINT (v7.68A) and XPREP (v2008/2). Corrections were applied for Lorentz, polarization, and absorption effects by using SADABS (v2008/1). The structure was solved and refined with the aid of the programs in the SHELXTL-plus (v2008/4) system of programs. The full-matrix least-squares refinement on F2 included atomic coordinates and anisotropic thermal parameters for all non-H atoms. The H atoms were included in a riding model. The structure was solved by direct methods with SHELXS-97 and expanded by using the Fourier technique. The nonhydrogen atoms were refined anisotropically. The hydrogen atoms were located and refined.

2 The crystallographic data

The crystal of **4 • HCl**, **5**, **6** and **7 • HCl** were performed on a Bruker Smart Apex II diffractometer with graphite-monochromated Mo K α radiation ($\lambda = 0.71073 \text{ \AA}$) at 173 K, respectively. Integration and scaling of intensity data were accomplished using the SAINT program². The structures were solved by intrinsic using SHELXT2014 and refinement was carried out by a full-matrix least-squares technique using SHELXT2014. The hydrogen atoms were refined isotropically, and the heavy atoms were refined anisotropically. N-H and O-H hydrogens were located from different electron density maps, and C-H hydrogens were placed in calculated positions and refined with a riding model. Data were corrected for the effects of absorption using SADABS4 Relevant crystal data and refinement results are summarized in Table S1

Table S1. Crystal data and structure refinement for **4 • HCl**, **5**, **6** and **7 • HCl**

Crystal	4 • HCl	5
CCDC number	1900215	1889333
Empirical formula	C ₉ H ₈ Cl N ₉ O ₆	C ₉ H ₆ N ₈ O ₄
Formula weight	373.69	290.22
Temperature	153(2) K	173(2) K
Crystal system	triclinic	monoclinic
Space group	<i>P</i> -1	P21/c
<i>a</i> [Å]	7.773(6) Å	7.5895(8) Å
<i>b</i> [Å]	9.309(8) Å	9.8629(10) Å
<i>c</i> [Å]	10.386(8) Å	14.7226(17) Å
α [°]	77.691(17) °	90 °
β [°]	78.764(17) °	95.149(4) °
γ [°]	87.961(18) °	90 °
Volume	720.2(10) Å ³	1097.6(2) Å ³
Z	2	4
ρ (g cm ⁻³)	1.723	1.756
F(000)	380.0	592.0
Crystal size (mm ³)	0.16 × 0.08 × 0.03	0.18 × 0.08 × 0.04

Theta range for data collection	4.09 ° to 52.844 °	6.792 ° to 50.818 °
Index ranges	-9≤h≤9, -9≤k≤11, -11≤l≤12	-9≤h≤9, -10≤k≤9, -17≤l≤17
Reflections collected	5635	5162
Independent reflections	2873	1989
Goodness-of-fit on F ²	1.025	1.057
Final R indices [I>2σ(I)]	R ₁ = 0.0601, wR ₂ = 0.1697	R ₁ = 0.0599, wR ₂ = 0.0994
R indices (all data)	R ₁ = 0.0799, wR ₂ = 0.1929	R ₁ = 0.1335, wR ₂ = 0.1241

Table S1. Continued

Crystal	6	7 • HCl
CCDC number	1900252	1900218
Empirical formula	C ₁₆ H ₁₅ N ₁₈ O ₁₅	C ₁₆ H ₂₃ ClN ₁₆ O ₁₅
Formula weight	699.46	714.95
Temperature	153.0 K	173(2) K
Crystal system	tetragonal	triclinic
Space group	<i>P4₁2₁2</i>	<i>P</i> -1
<i>a</i> [Å]	10.704(4) Å	7.0409(14) Å
<i>b</i> [Å]	10.704 Å	10.232(2) Å
<i>c</i> [Å]	23.932(9) Å	19.848(9) Å
<i>α</i> [°]	90 °	87.614(5) °
<i>β</i> [°]	90 °	85.009(5) °
<i>γ</i> [°]	90 °	82.298(5) °
Volume	2742(2) Å ³	1411.0(5) Å ³
<i>Z</i>	4	2
<i>ρ</i> (g cm ⁻³)	1.694	1.683
F(000)	1428.0	736.0

Crystal size (mm ³)	0.16 × 0.08 × 0.02	0.19 × 0.08 × 0.02
Theta range for data collection	5.382 ° to 52.62 °	2.06 ° to 52.744 °
Index ranges	-2 ≤ h ≤ 13, -13 ≤ k ≤ 10, -29 ≤ l ≤ 27	-8 ≤ h ≤ 8, -12 ≤ k ≤ 12, -24 ≤ l ≤ 24
Reflections collected	7104	11833
Independent reflections	2781	5683
Goodness-of-fit on F ²	1.009	0.979
Final R indices [I > 2σ(I)]	R ₁ = 0.0617, wR ₂ = 0.1200	R ₁ = 0.0823, wR ₂ = 0.2000
R indices (all data)	R ₁ = 0.1337, wR ₂ = 0.1592	R ₁ = 0.1482, wR ₂ = 0.2536

3 Theoretical study

Theoretical calculations were performed by using the Gaussian 09 (Revision D.01) suite of programs.^[1] The elementary geometric optimization and the frequency analysis were performed at the level of the Becke three parameter, Lee-Yan-Parr (B3LYP)[9] functional with the 6-311+G** basis set.^[2] All of the optimized structures were characterized to be local energy minima on the potential surface without any imaginary frequencies. Atomization energies were calculated by the CBS-4M.^[3] All the optimized structures were characterized to be true local energy minima on the potential-energy surface without imaginary frequencies.^[4]

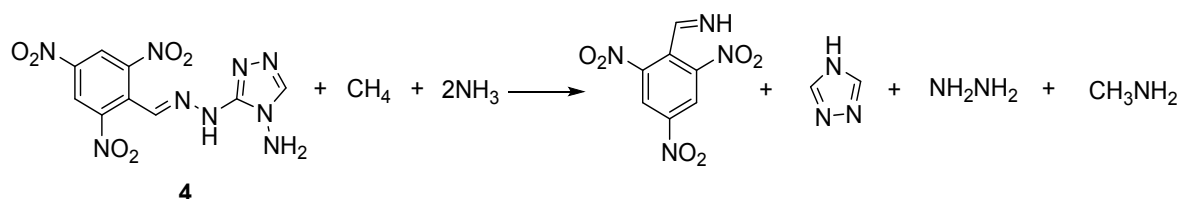
The predictions of heat of formation (*HOF*) adopt the hybrid DFT-B3LYP methods with 6-311+G** basis set via designed isodesmic reactions. The isodesmic reaction processes, i.e., the number of each kind of formal bond is conserved, are used with application of the bond separation reaction (BSR) rules. The molecule is broken down into a set of two heavy-atom molecules containing the same component bonds. The isodesmic reactions used to derive the HOF of the title compounds are in Scheme S1. The change of enthalpy for the reactions at 298 K can be expressed as

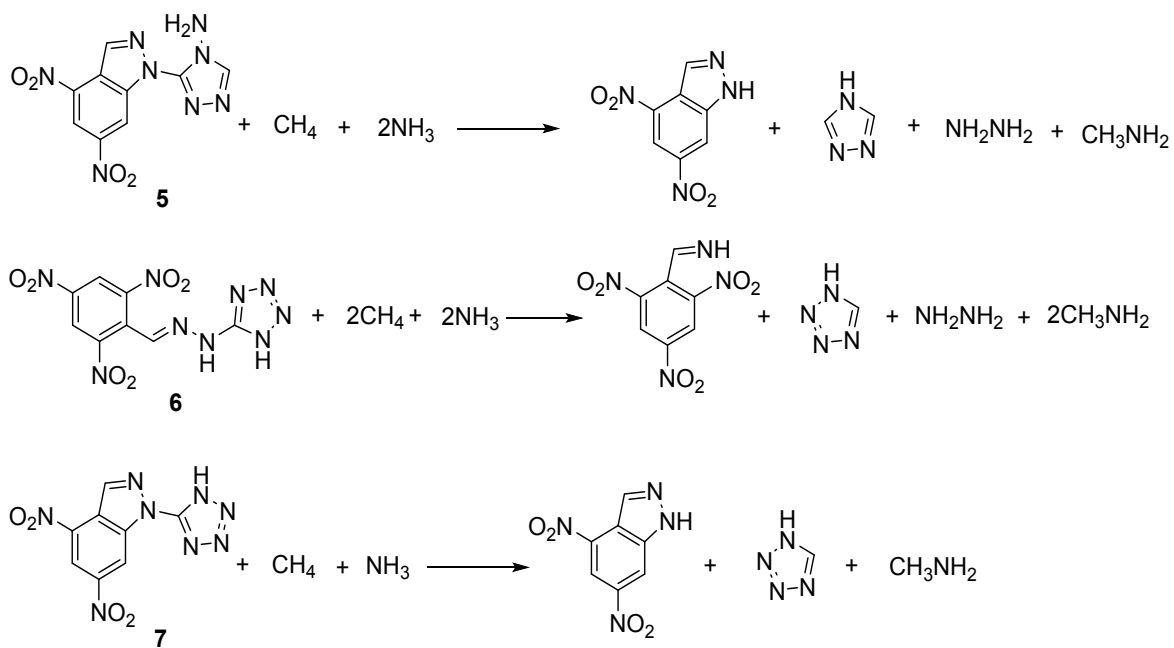
$$\Delta H_{298} = \sum \Delta_f H_P - \sum \Delta_f H_R \quad (1)$$

Where $\sum \Delta_f H_P$ and $\sum \Delta_f H_R$ are the *HOF* of reactants and products at 298 K, respectively, and ΔH_{298} can be calculated using the following expression:

$$\Delta H_{298} = \Delta E_{298} + \Delta(PV) = \Delta E_0 + \Delta ZPE + \Delta H_T + \Delta nRT \quad (2)$$

Where ΔE_0 is the change in total energy between the products and the reactants at 0 K; ΔZPE is the difference between the zero-point energies (*ZPE*) of the products and the reactants at 0 K; ΔH_T is thermal correction from 0 to 298 K. The $\Delta(PV)$ value in eq (2) is the *PV* work term. It equals $\Delta(nRT)$ for the reactions of ideal gas. For the isodesmic reaction, $\Delta n = 0$, so $\Delta(PV) = 0$. On the left side of Eq. (1), apart from target compound, all the others are called reference compounds. The HOF of reference compounds is available from the experiments:





Scheme S1. Isodesmic reactions of **4 • HCl**, **5**, **6** and **7 • HCl**

4 Thermal Behaviors

The thermal behavior of compounds **4** · HCl, **5**, **6** and **7** · HCl were investigated by differential scanning calorimetry (DSC) at a heating rate of 5 °C min⁻¹. As shown in Figure S1, the compound **7** dehydrated at 99 °C and decomposed at 316 °C.

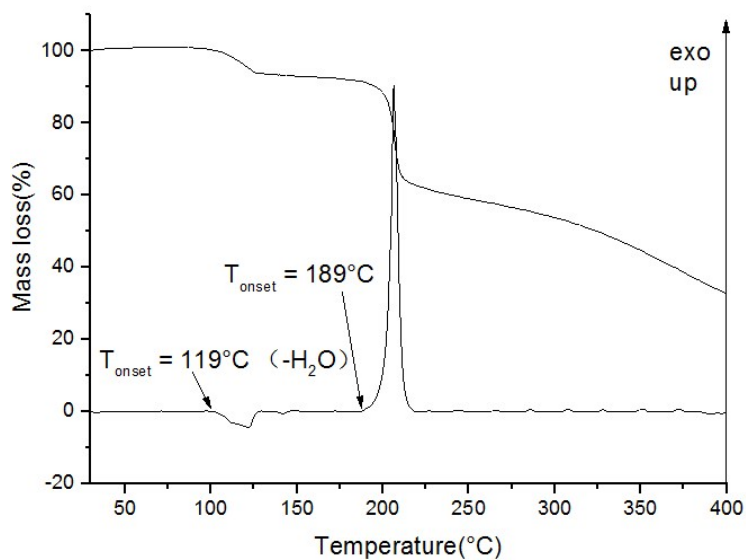


Figure S1. TG-DSC plot of **6**.

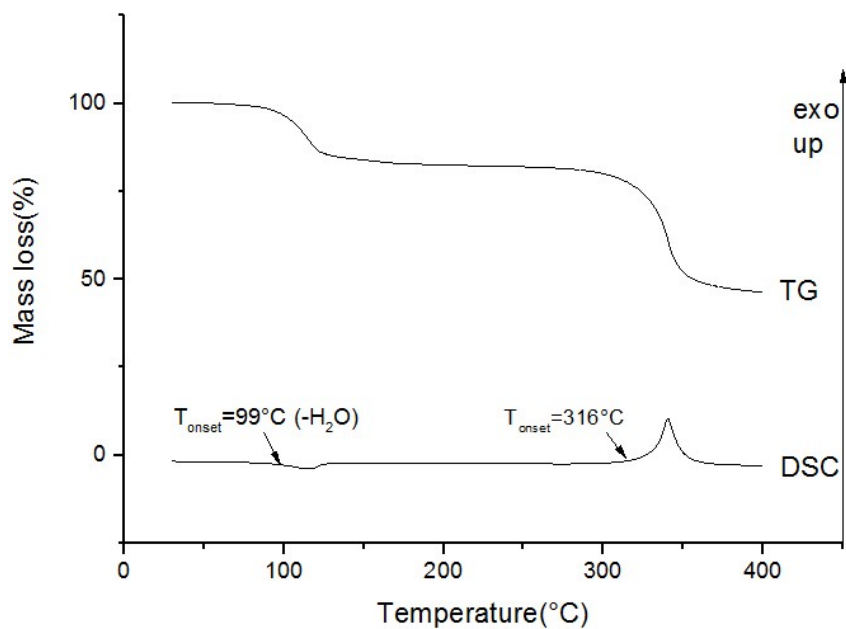


Figure S2. TG-DSC plot of **7**.

5 Reference

- [1] Frisch, M. J.; Trucks, G. W.; Schlegel, H. B.; Daniels, A. D.; Farkas, O.; Foresman, J. B.; Ortiz, J. V.; Cioslowski, J.; Fox, D. J. Gaussian 09, Revision D. 01, Gaussian, Inc. Wallingford CT, **2009**.
- [2] P. C. Hariharan, J. A. Pople, *Theor. Chim. Acta.* 1973, 28, 213-222.
- [3] J. W. Ochterski, G. A. Petersson, J. A. Montgomery, *J. Chem. Phys.* 1996, 104, 2598-2619.
- [4] H. D. B. Jenkins, D. Tudeal, L. Glasser, *Inorg. Chem.* 2002, 41, 2364-2367.

6 ^1H and ^{13}C NMR Spectra of Compounds

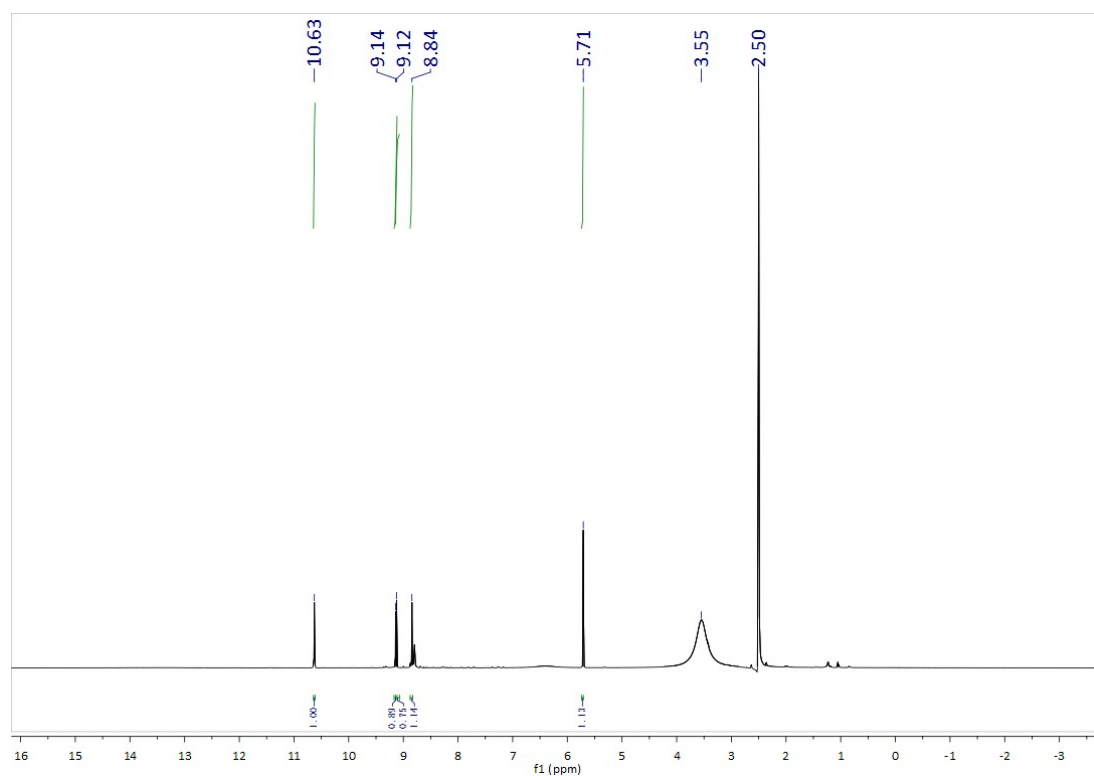


Figure S3 ^1H NMR spectra (500 MHz) of **4** in $[\text{D}_6]$ DMSO at 25 °C.

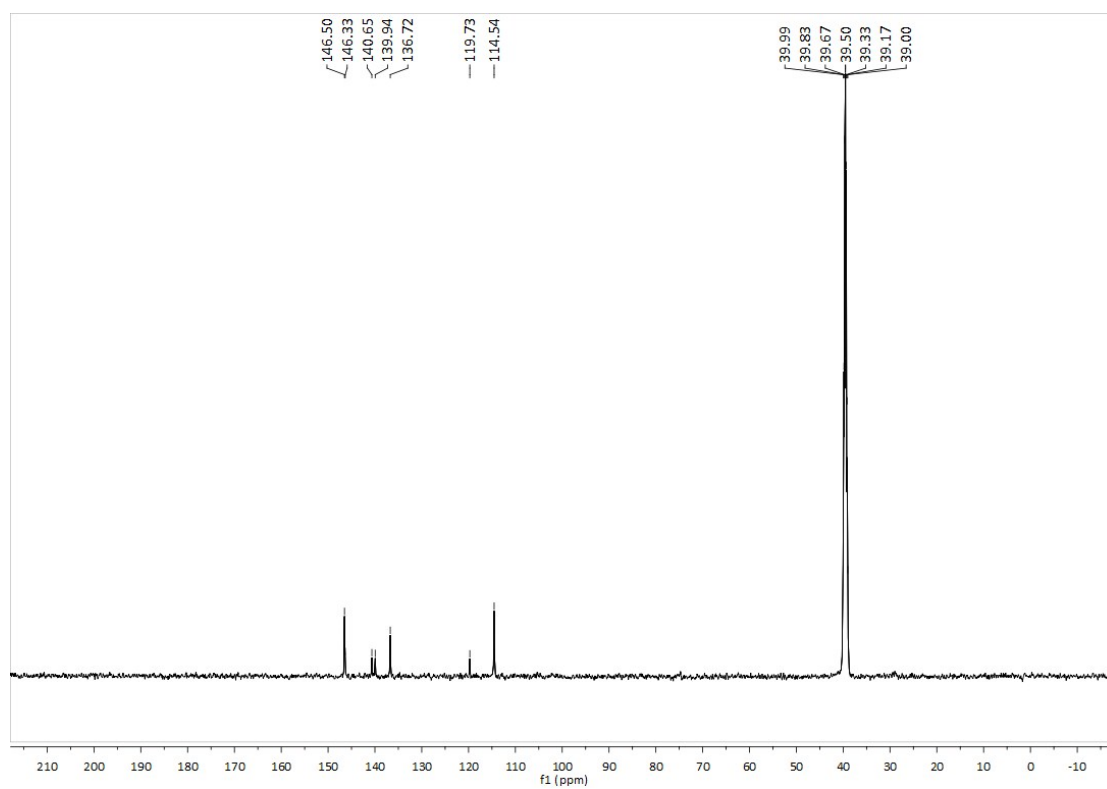


Figure S4 ^{13}C NMR spectra (125 MHz) of **4** in $[\text{D}_6]$ DMSO at 25 °C.

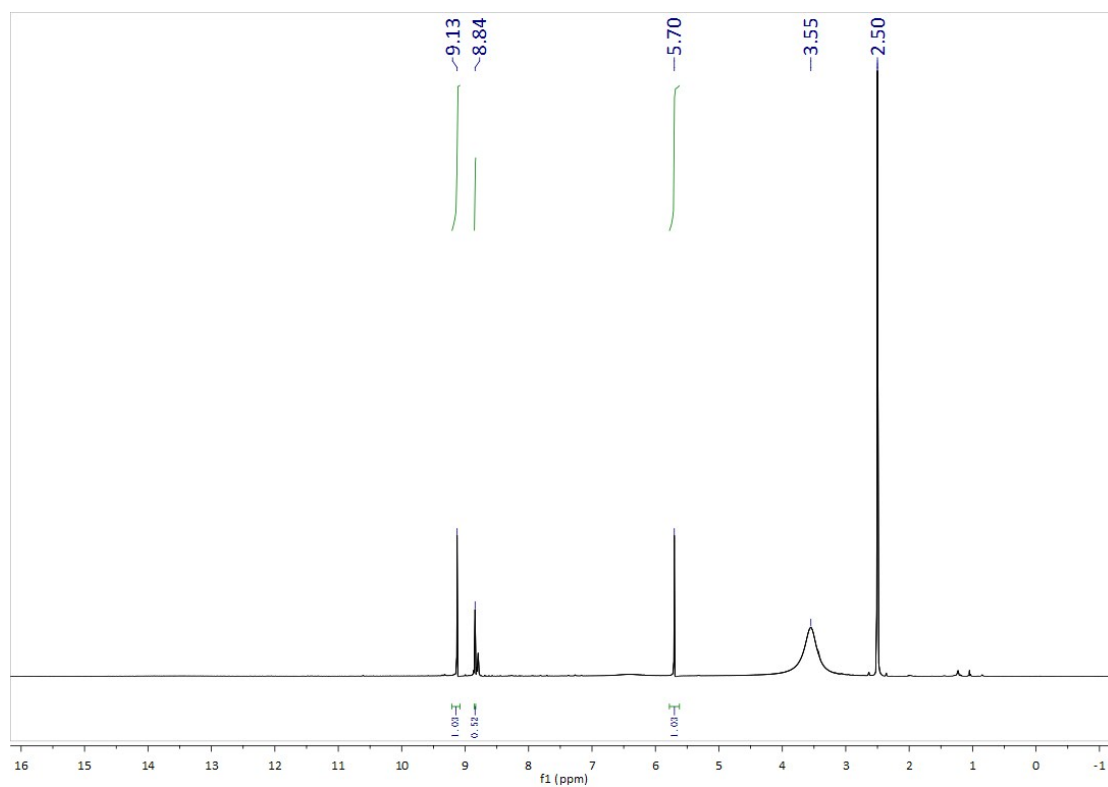


Figure S5 ^1H NMR spectra (500 MHz) of **5** in $[\text{D}_6]$ DMSO at 25 °C.

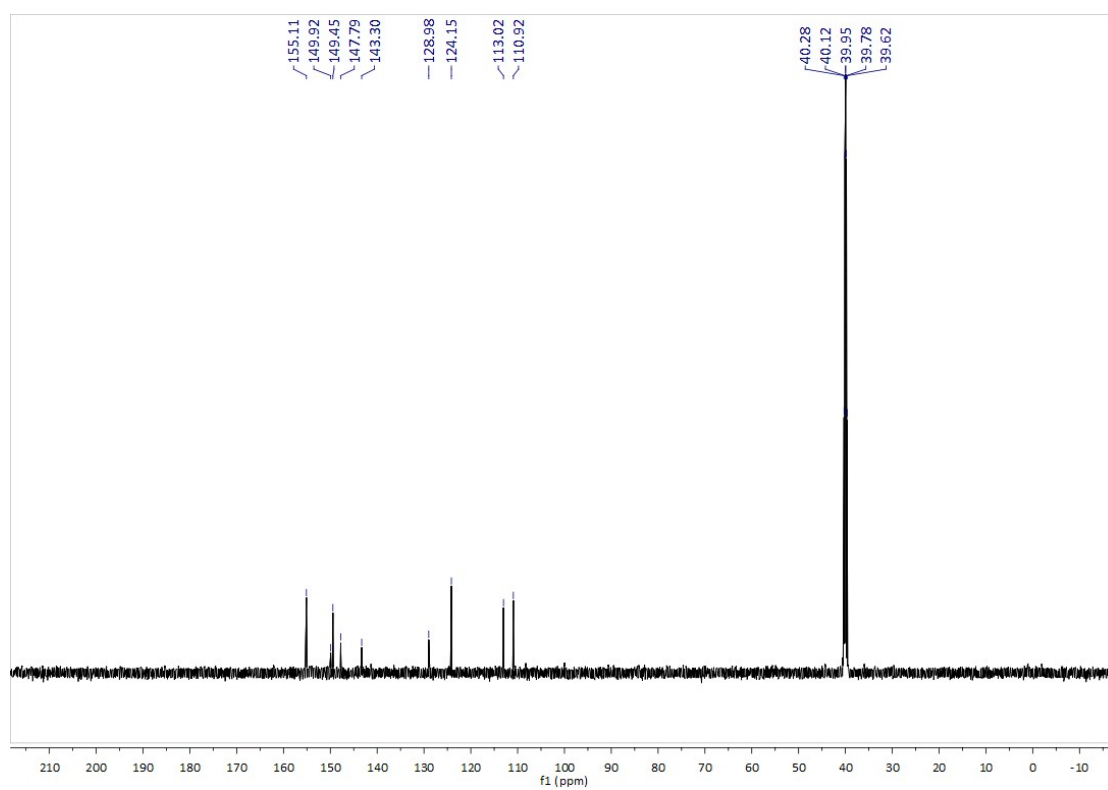


Figure S6 ^{13}C NMR spectra (125 MHz) of **5** in $[\text{D}_6]$ DMSO at 25 °C.

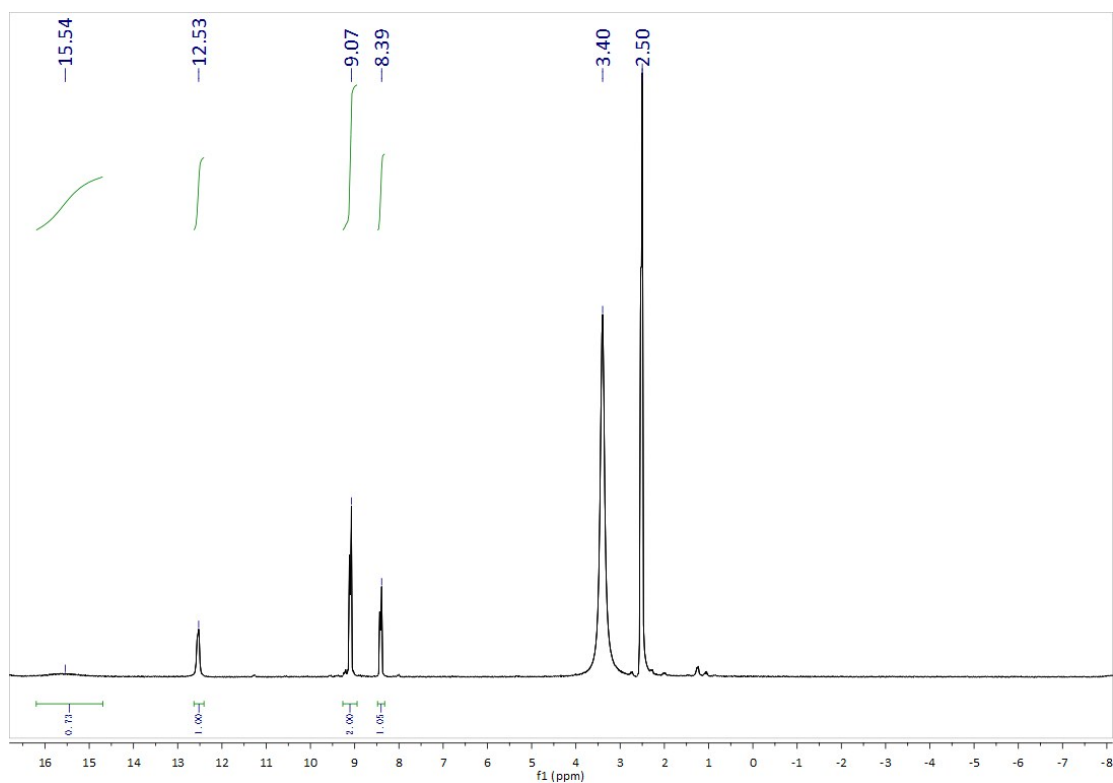


Figure S7 ^1H NMR spectra (500 MHz) of **6** in $[\text{D}_6]$ DMSO at 25 °C.

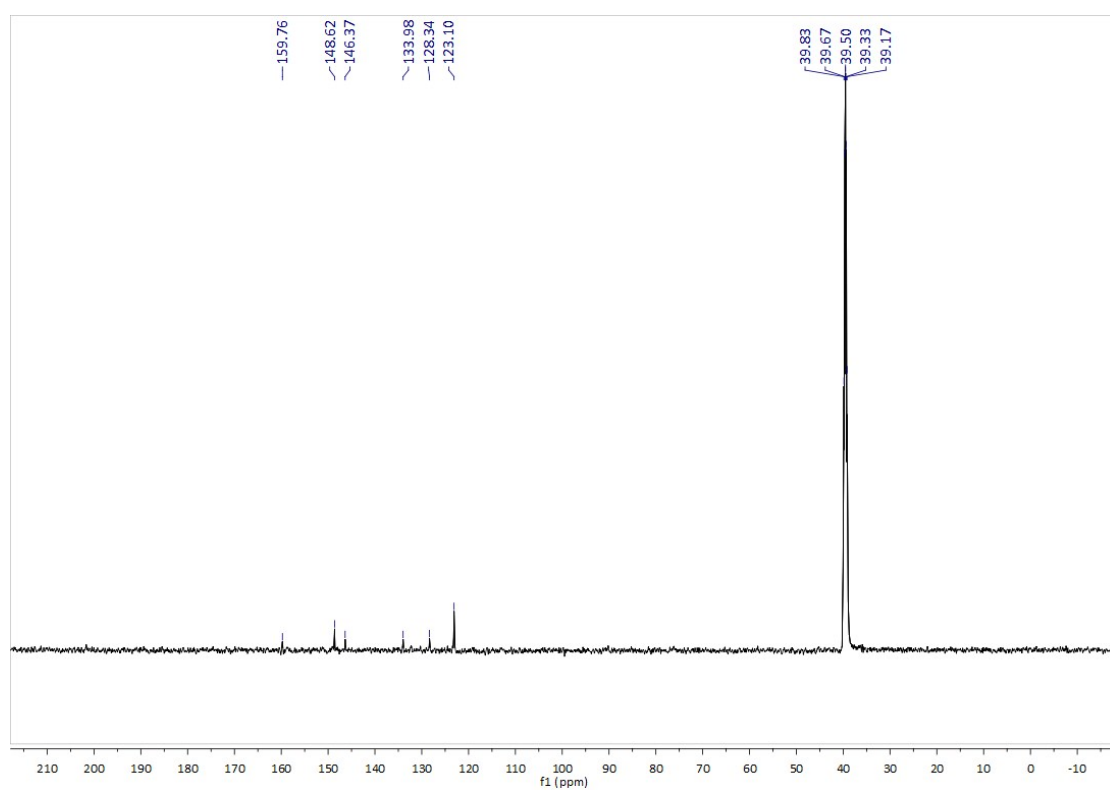


Figure S8 ^{13}C NMR spectra (125 MHz) of **6** in $[\text{D}_6]$ DMSO at 25 °C.

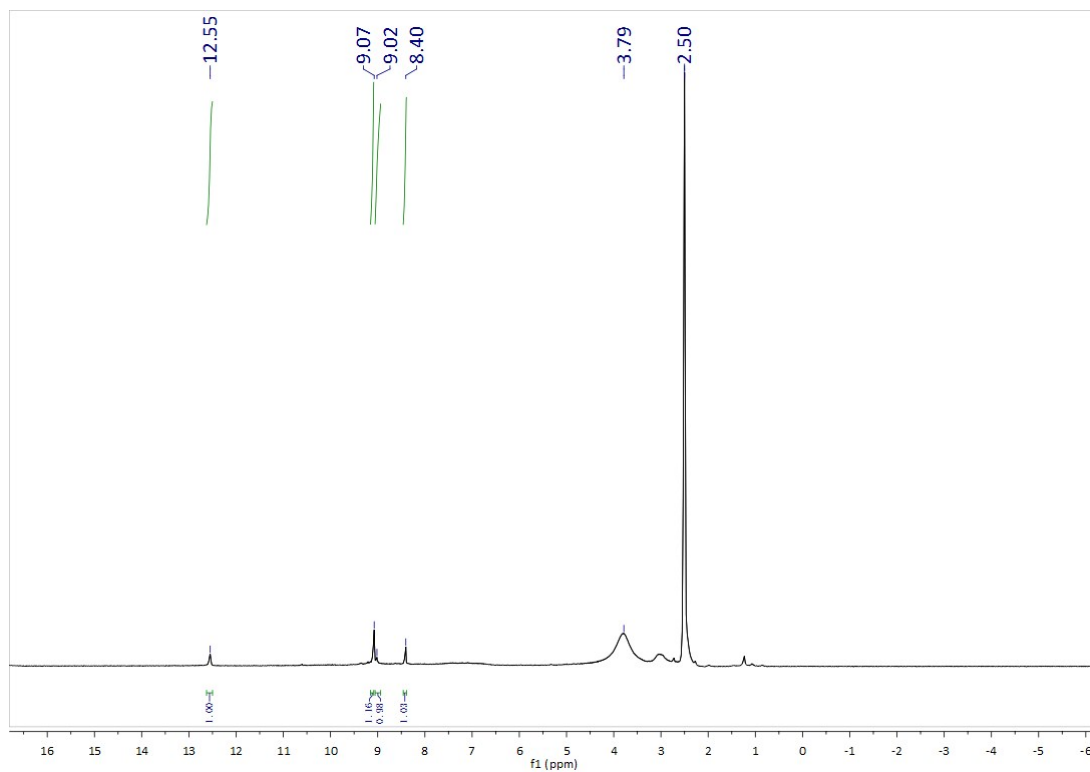


Figure S9 ^1H NMR spectra (500 MHz) of **7** in $[\text{D}_6]$ DMSO at 25 °C.

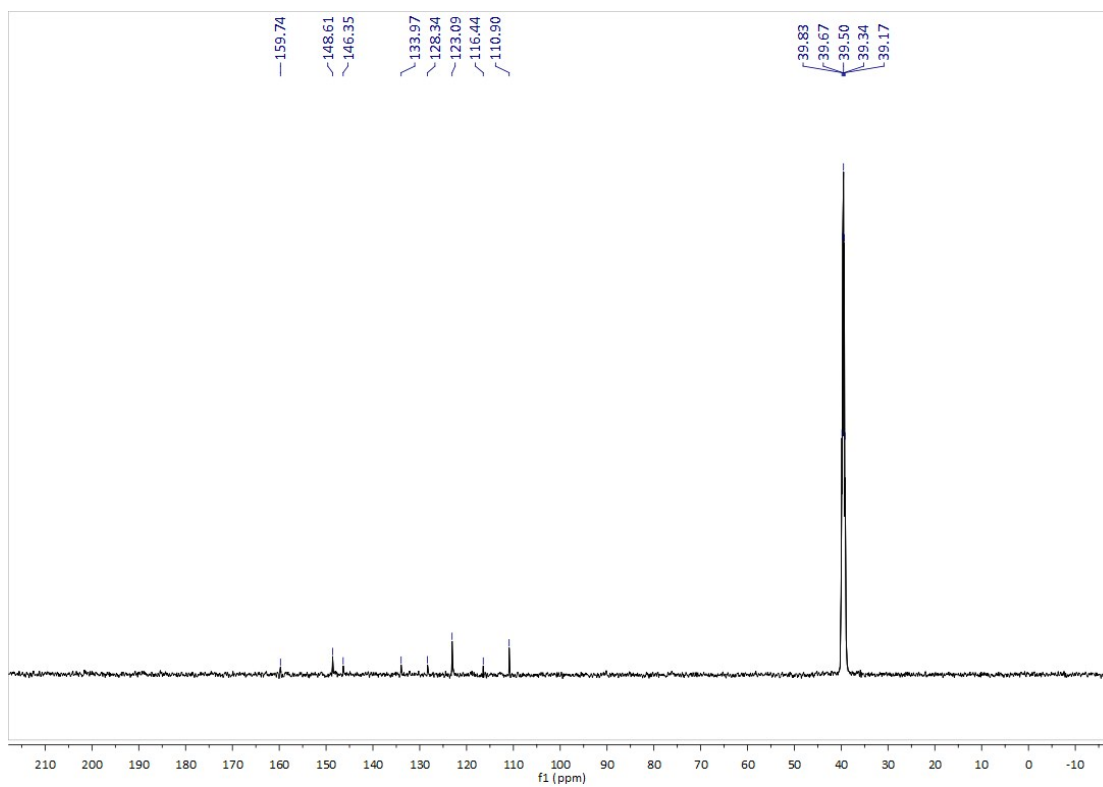


Figure S10 ^{13}C NMR spectra (125 MHz) of **7** in $[\text{D}_6]$ DMSO at 25 °C.

7 Mass Spectra of Compounds

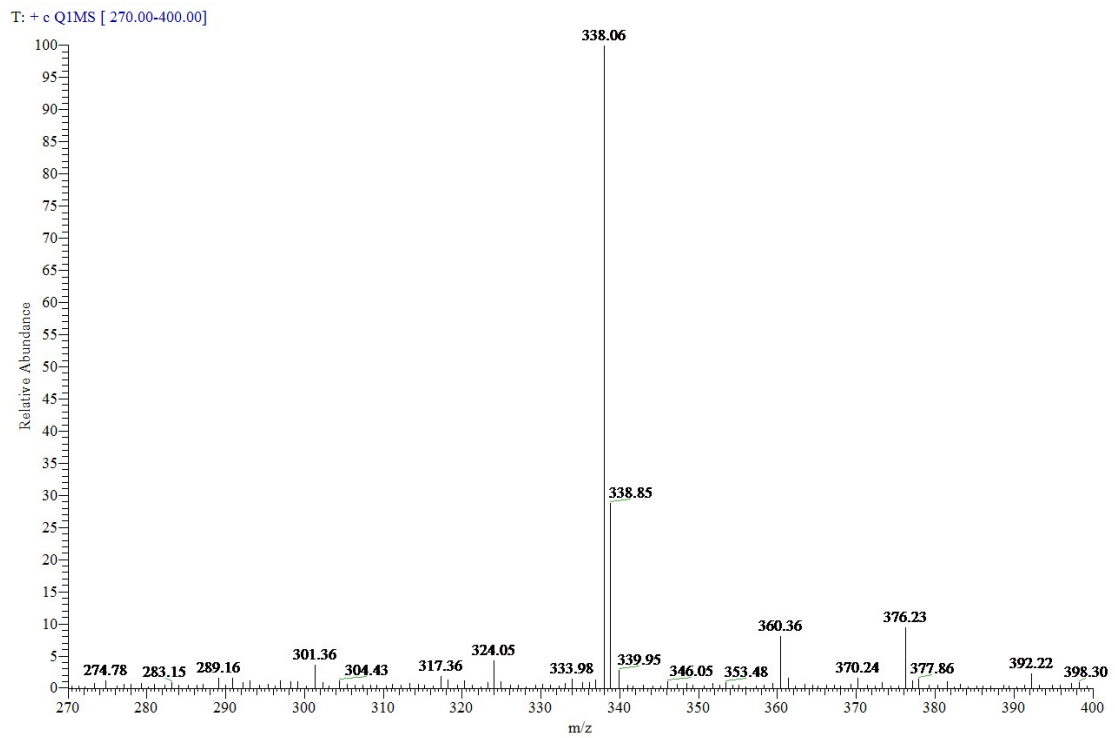


Figure S11. Mass spectra of compounds 4

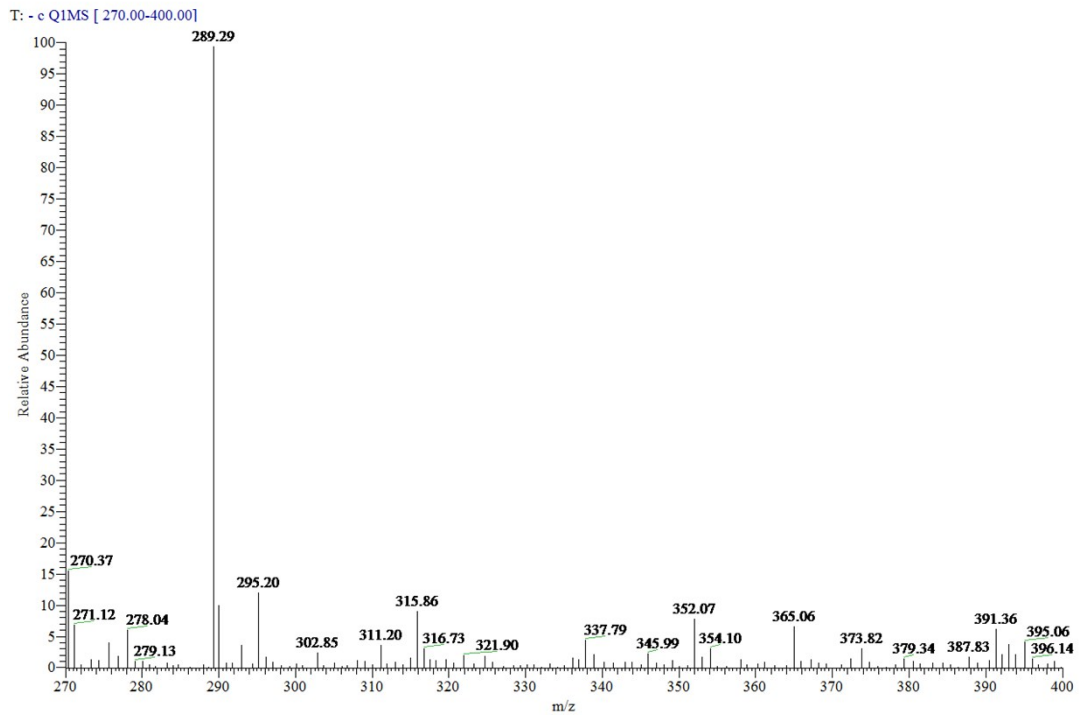


Figure S12. Mass spectra of compounds 5

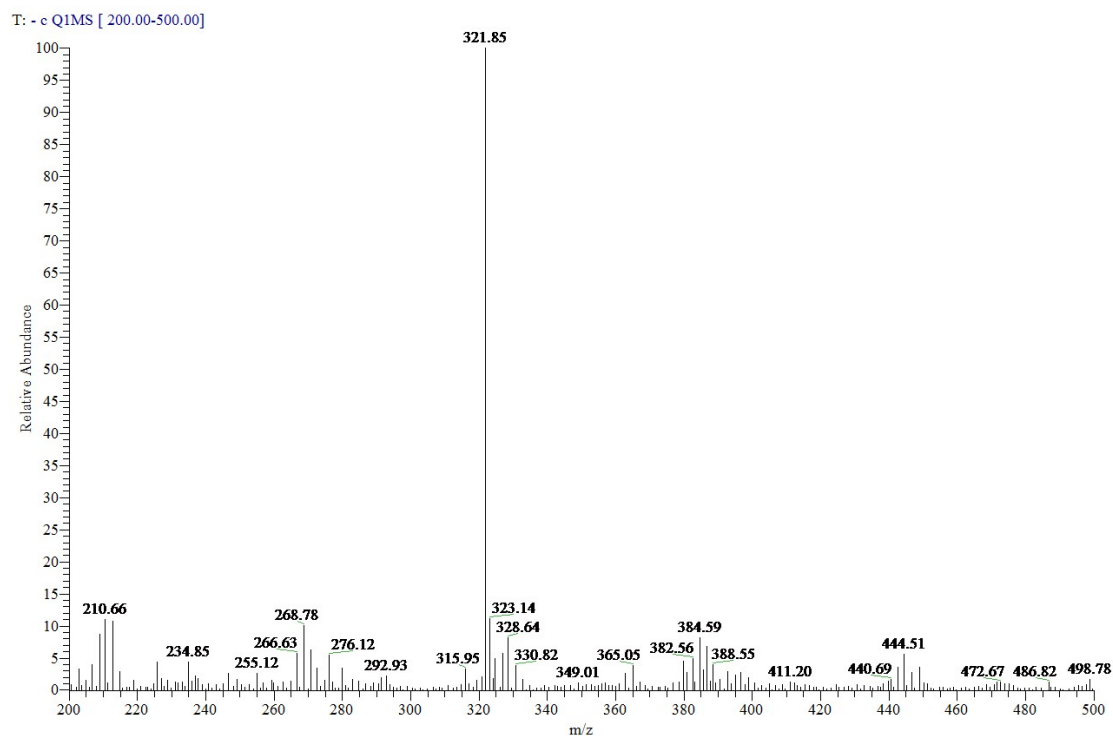


Figure S13. Mass spectra of compounds 6

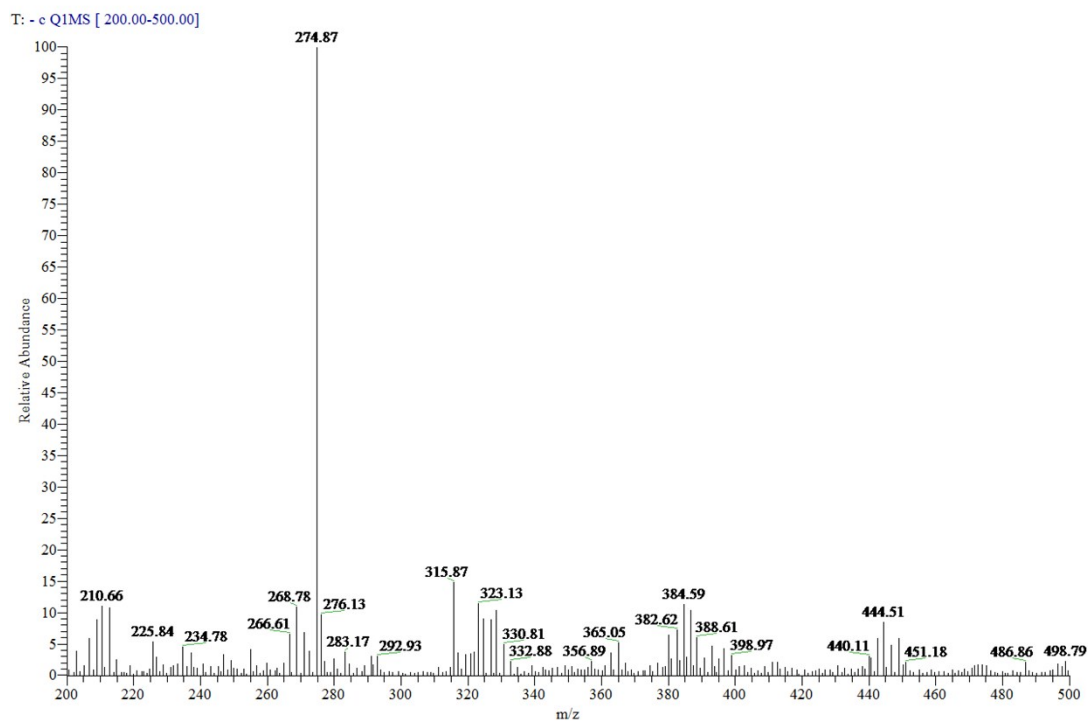


Figure S14. Mass spectra of compounds 7