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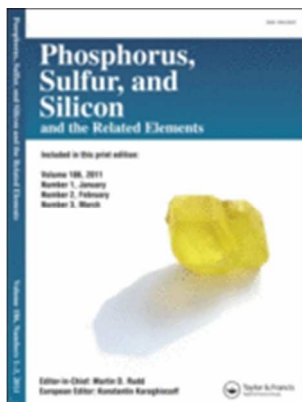
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**Synthesis, molecular structure exploration and in vitro cytotoxicity screening of five novel N, N'- disubstituted thiocarbamide derivatives**

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Keywords:	Thiocarbamide, X-ray crystallography, Cytotoxicity, Spectroscopic techniques, $\pi$ - $\pi$ stacking

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## Synthesis, molecular structure exploration and *in vitro* cytotoxicity screening of five novel N, N'- disubstituted thiocarbamide derivatives

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### ABSTRACT

The synthesis of five N,N'-substituted thiocarbamides, namely N-(naphthyl)-N'-(pentoxycarbonyl) thiocarbamide (**H<sub>2</sub>L1**), N-(2-Chloro-4-nitrophenyl)-N'-(pentoxycarbonyl) thiocarbamide (**H<sub>2</sub>L2**), N-(2-methoxy-4-nitrophenyl)-N'-(pentoxycarbonyl) thiocarbamide (**H<sub>2</sub>L3**), N-(3-nitrophenyl)-N'-(pentoxycarbonyl) thiocarbamide (**H<sub>2</sub>L4**) and N-(naphthyl)-N'-(2, 2, 2-trichloroethoxycarbonyl) thiocarbamide (**H<sub>2</sub>L5**) was performed by the reaction of pentoxycarbonyl chloroformate with naphthyl amine, 2-chloro-4-nitroaniline, 2-methoxy-4-nitroaniline, 3-nitroaniline, respectively, for the first four and by the reaction of 2, 2, 2-trichloroethoxycarbonyl chloroformate with naphthyl amine for the last compound. These compounds were fully characterized by using various spectroscopic (FT-IR, <sup>1</sup>H and <sup>13</sup>C NMR) and single crystal X-ray studies of **H<sub>2</sub>L1** and **H<sub>2</sub>L5**. In the crystal structure of both the compounds the (C=S) and (C=O) groups are trans to each other across the C–N bond. The crystal packing of **H<sub>2</sub>L1** shows that the molecules form centrosymmetric dimers connected by N2–H····S hydrogen bonds. In **H<sub>2</sub>L5** an offset face-to-face  $\pi$ – $\pi$  stacking is observed between two naphthalene rings of two molecules. *In vitro* cytotoxicity of synthesized compounds was evaluated using five human carcinoma cell lines 2008, C13\* (cervical carcinoma), A2780, A2780/CP and IGROV-1 (ovarian carcinoma). The IC<sub>50</sub> values of compounds **H<sub>2</sub>L2** – **H<sub>2</sub>L4** demonstrated them to be very promising anticancer agents.

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**Keywords:** Thiocarbamide; X-ray crystallography; Cytotoxicity; Spectroscopic techniques;  $\pi$ – $\pi$  stacking

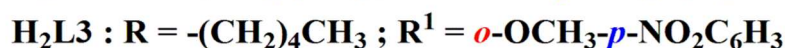
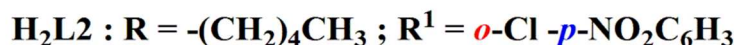
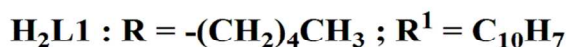
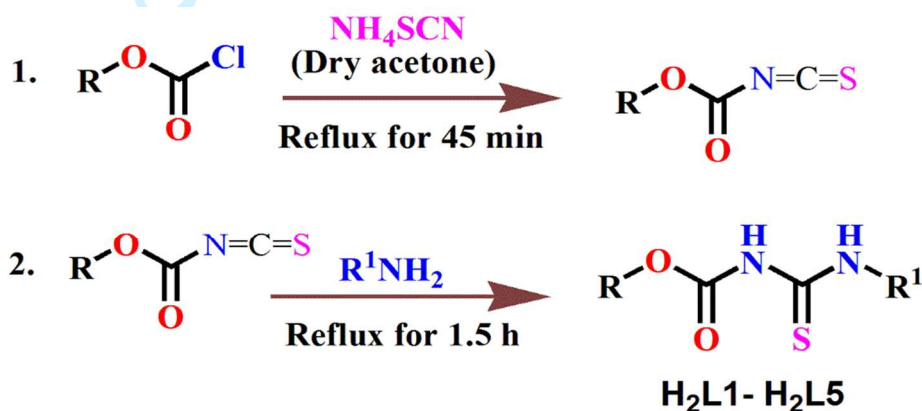
## Introduction

The structural studies of N,N'-disubstituted thiocarbamides have been the subject of extensive investigation on the ground of their potential medicinal, environmental<sup>1-3</sup> and analytical applications.<sup>4,5</sup> The vivid usage of these compounds may be credited to the presence of C=S and N-H groups in their structural motif. The presence of these groups facilitate the interaction of thiocarbamides with the variety of metal ions through coordinate bonds and also with many anions via the formation of intermolecular hydrogen bonds.<sup>6-11</sup> In addition, the presence of intramolecular hydrogen bond (C=O·····H-N) causes monodentate coordination through thione sulfur forming trigonal planar copper (I) complexes which act as catalysts in many organic synthesis.<sup>12-15</sup> The anticancer properties of substituted thiocarbamides have not been explored much though some of them have displayed excellent cytotoxic behavior against various human cancer cell lines.<sup>16-19</sup> It has been reported that structural changes in these molecules, their modes of bonding to the DNA have considerable impact on their anticancer properties.<sup>20-22</sup> Some additional therapeutic values of substituted thiocarbamides can be reflected by their use as antimicrobial, antiviral, antimalarial, antitubercular, antiallergic, antithyroid, rodenticidal, herbicidal agents.<sup>23-27</sup> These compounds have also been proven valuable in liquid-liquid extraction of precious metals (Pt, Pd, Au Ag.), as anion and cation sensors<sup>28, 29</sup>, liquid crystal materials<sup>30,31</sup>, non-linear optical materials<sup>32,33</sup>, as catalyst in oxidation reaction of alcohols.<sup>34,35</sup> In view of the above facts and as part of our continuing work, we present here the "Synthesis, molecular structure exploration and *in vitro* cytotoxicity screening of five novel N, N'-disubstituted thiocarbamide derivatives".<sup>12-14</sup>

## Results and discussion

### Synthesis and Characterization

The synthesis of compounds **H<sub>2</sub>L1–H<sub>2</sub>L5** was achieved by the reaction of n-pentoxycarbonyl/2, 2, 2-trichloroethocarbonyl isothiocyanate and suitable substituted primary amines. All the compounds were obtained in good yield. The slow evaporation at room temperature of acetone solution of compounds **H<sub>2</sub>L1** and **H<sub>2</sub>L5** (Scheme 1) afforded single crystals suitable for X-ray diffraction.



**Scheme 1.** Synthesis of compounds **H<sub>2</sub>L1 – H<sub>2</sub>L5**

### FT-IR Spectra

The FT-IR spectra of the compounds displayed two N–H stretching vibrational bands in 3418–3443 and 3160–3180 cm<sup>-1</sup> regions, respectively. The high energy strong band (3418–3443 cm<sup>-1</sup>) may be assigned to free N–H and the latter weak band (3160–3180 cm<sup>-1</sup>) to the intramolecularly hydrogen bonded N1–H (N1–H⋯O=C).<sup>12–14</sup> The bands appearing at ~1670, ~1440 and ~778 cm<sup>-1</sup> region may be assigned to ν(C=O), ν(C–N) and ν(C=S) vibrations, respectively. The appearance of ν(C=O) at a lower wave number region in comparison to free ν(C=O) vibrations (1710 cm<sup>-1</sup>) may be attributed to the formation of intramolecular hydrogen bond between carbonyl oxygen and –N1H.<sup>36</sup>

## NMR Spectra

The  $^1\text{H}$  NMR spectra of the compounds exhibited two singlets at 8.58–8.65 ppm and 11.63 – 11.35 ppm corresponding to N1H and N2H protons, respectively. The presence of intramolecular hydrogen bonding interaction between N1H and carbonyl oxygen is responsible for its high chemical shift value.<sup>6, 37</sup> In all the compounds the signals for aliphatic protons appeared between 1.01–4.19 ppm and those for aromatic protons between 7.52–8.21 ppm, respectively, in their usual regions. The  $^{13}\text{C}$  NMR spectra of compounds exhibits signals due to all the carbon present in them. The resonances at 178.6–179.5 and 151.2–153.1 ppm correspond to thiocarbonyl and carbonyl carbons, respectively.<sup>12–14</sup> Due to steric and electronic factors carbon in C=S is more exposed than C=O hence resonates downfield at ~179 ppm.<sup>38</sup>

## Crystal structure description

The important crystallographic data refinement parameters, selected bond lengths, bond angles and hydrogen bonds for the compounds **H<sub>2</sub>L1** and **H<sub>2</sub>L5** are gathered in **Tables 1, 2** and **S 1 (Supplemental Materials)**, respectively. The crystal structure, unit cell diagram and packing pattern of **H<sub>2</sub>L1** and **H<sub>2</sub>L5** are depicted in **Figures 1(a), 1(b), S1**, and **2(a), 2(b), S2**, respectively. The molecular structures of the compounds show them to be almost coplanar. The C=O and C=S bonds lengths are of typical double bond nature whereas all the C–N bonds indicate a partial double bond character.<sup>12–13</sup> The shortening of C–N bonds confirm the presence of resonance in this part of molecule (**Table 2**).<sup>12–15</sup> All the bond distances and angles for these compounds exhibit conventional nature and show no significant differences from those reported earlier.<sup>39</sup> The strong intramolecular hydrogen bond between N1–H·····O=C is responsible for trans orientation of the carbonyl and thiocarbonyl moieties across the C–N bond. An additional intermolecular hydrogen bond viz, N2–H·····S=C in **H<sub>2</sub>L1** joins two molecules together to be a dimer. Beside strong intramolecular hydrogen bond an offset face-face  $\pi$ – $\pi$  stacking interaction is also observed in **H<sub>2</sub>L5** between naphthalene rings. Weak intermolecular interactions C–H·····O, C–S·····H, C–H·····N and C $\pi$ –C $\pi$  stabilize the crystal packing and lead to an infinite chain length along the a-axis (**Figure 2b** and **S 2**).<sup>40</sup>

[Insert Figure 1]

[Insert Figure 2]

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3 [Insert Table 1]  
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5 [Insert Table 2]  
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### 12 ***In vitro* cytotoxicity screening**

13 The inhibition of cancer cell proliferation by compounds **H<sub>2</sub>L1– H<sub>2</sub>L5** has been examined by  
14 using the methods describe in experimental section. Naphthyl amine and three other aromatic  
15 amines having one or two electron withdrawing groups have been chosen purposely as to see  
16 their effect on cytotoxic property of the compounds since it has been observed that electron  
17 withdrawing groups attached to the aromatic ring of the compounds enhance their cytotoxicity  
18 considerably.<sup>17–19</sup> The results in the form of IC<sub>50</sub> values (the concentration which produces 50%  
19 growth inhibition of cell lines) are shown in **Table S 1 (Supplemental Materials)**. The  
20 comparative cytotoxicity of the compounds is depicted in **Figure S 3**. The results indicated that  
21 the compounds **H<sub>2</sub>L2–H<sub>2</sub>L4** were more potent inhibitors than **H<sub>2</sub>L1** (IC<sub>50</sub> ~100 μM) and **H<sub>2</sub>L5**  
22 (IC<sub>50</sub> ~75 μM) against all the cell lines tested. The best result was obtained for 2008 cell line.  
23 The significant inhibitory activity for compounds **H<sub>2</sub>L2–H<sub>2</sub>L4** can be related to the presence of  
24 electronegative group as substituents on the aromatic ring attached to N1.<sup>19</sup> The best result is  
25 obtained for **H<sub>2</sub>L2** having two electronegative groups attached to the aromatic ring. These  
26 compounds exhibited more improved results than the compounds reported in our previous  
27 papers.<sup>12, 13</sup> The most promising compound **H<sub>2</sub>L2** is worthy of further investigation.  
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### 40 **Experimental Procedure**

#### 41 **Chemicals, Instruments and Methods**

42 n-pentyl chloroformate and 2, 2, 2-trichloroethyl chloroformate, primary amine derivatives and  
43 ammonium thiocyanate were purchased from Merck (Germany). Analytical grade acetone,  
44 acetonitrile, and dichloromethane were purchased from Rankem. The acetone was dried and  
45 freshly distilled prior to use. Melting points was measured on a X-4 digital melting-point  
46 apparatus and were uncorrected. Elemental analyses were performed on a CE-440 Exeter  
47 Analytical CHN analyzer. The infrared spectra of the title compounds as KBr pellets (4000–400  
48 cm<sup>-1</sup>) were recorded on a Varian 3100 FT-IR Excalibur series spectrophotometer.<sup>1</sup>H and <sup>13</sup>C  
49 NMR spectra were obtained on a JEOL FT-NMR AL 300 and 500 MHz spectrometer in CDCl<sub>3</sub>  
50 and DMSO-d<sub>6</sub>, 25°C with chemical shifts relative to SiMe<sub>4</sub>. The splitting of proton resonances  
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3 in the reported  $^1\text{H}$  NMR spectra were remarked as s = singlet, d = doublet, t = triplet, dd =  
4 doublet of doublets, dt = doublet triplet and m = multiplet; coupling constants are reported in Hz.  
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### 11 **Crystal structure determination**

12 Data collection was performed using CrysAlisPRO on an Oxford Diffraction Xcaliber Ruby  
13 Gemini CCD diffractometer using graphite- monochromatic CuK $\alpha$  ( $k=1.54178 \text{ \AA}$ ) at 123 K. The  
14 structures were solved by direct methods and refined by full-matrix least-square on  $F^2$  using  
15 SHELXL-97.<sup>41</sup> The non-hydrogen atoms were refined with anisotropic thermal parameters. All  
16 hydrogen atoms were geometrically fixed and allowed to refine using the riding model. The  
17 refinement converged to a final  $R1 = 0.0399$ ,  $wR2 = 0.0996$  for **H<sub>2</sub>L1** and  $R1 = 0.0524$ ,  $wR2 =$   
18  $0.0987$  for **H<sub>2</sub>L5**. Drawings were made using ORTEP-III<sup>42</sup> and MERCURY.<sup>43</sup>  
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### 26 **Synthesis of compounds**

27 All the compounds were prepared by in two stages as shown in **Scheme 1**.<sup>40</sup> An acetone solution  
28 of n-pentyl chloroformate (1.44 mmol, 30 mL) for **H<sub>2</sub>L1–H<sub>2</sub>L4** /2, 2, 2-trichloroethyl  
29 chloroformate (1.37 mmol, 30 mL) for **H<sub>2</sub>L5** was mixed to the ammonium thiocyanate (10  
30 mmol, 0.76 g) solution in acetone (30 mL) and the resulting mixture was refluxed for 45 min at  
31 75°C. After cooling to room temperature, a solution of suitable aromatic primary amine (10  
32 mmol) in acetone (15 mL) was added slowly with stirring and the mixture was refluxed for 90  
33 minute to complete the reaction. The precipitated ammonium chloride was filtered off and the  
34 pale yellow solution was evaporated in vacuum to dryness to get a crude product. Slow  
35 evaporation of acetone solution of the ligands **H<sub>2</sub>L1** and **H<sub>2</sub>L5** at 20–25°C yielded bright yellow  
36 single crystals suitable for X-ray diffraction.  
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### 44 **N-(naphthyl)-N'-(pentoxycarbonyl) thiocarbamide (H<sub>2</sub>L1)**

45 Yellow solid; m.p 100-101°C; (Naphthylamine, 1.432g, 10 mmol) Yield: 80%; FT-IR (KBr,  $\text{cm}^{-1}$ )  
46 3418, 3162  $\nu(\text{N-H})$ , 3050  $\nu(\text{aromatic C-H})$ ; 2955,  $\nu(\text{aliphatic C-H})$ ; 1715,  $\nu(\text{ester -COOR})$ ;  
47 1598,  $\nu(\text{C=O})$ ; 1537,  $\nu(\text{aromatic, C=C})$ ; 1531, [Thioamide band I,  $\nu(\text{C-N}) + \nu(\text{N-H})$ ]; 1379,  
48 [Thioamide band II,  $\nu(\text{C-N}) + \nu(\text{C=S})$ ].  $^1\text{H}$  NMR(300 MHz,  $\text{CDCl}_3$ ,  $\delta$ , ppm): 11.63 (s, 1H,  
49 -CSNH), 8.59 (s, 1H, -CONH), 7.97 (m, 1H,  $\text{C}_{10}\text{H}_7$ ), 7.87 (m, 2H,  $\text{C}_{10}\text{H}_7$ ), 7.69 (m, 1H,  $\text{C}_{10}\text{H}_7$ ),  
50 7.55 (m, 3H,  $\text{C}_{10}\text{H}_7$ ), 4.20 (t, 2H,  $J = 6.5 \text{ Hz}$ , - $\text{OCH}_2$ ), 2.49 (m, 2H, -( $\text{CH}_2$ )-), 1.67 (m, 4H,  
51  $2x(-\text{CH}_2)$ ), 0.93 (t, 3H, - $\text{CH}_3$ ,  $J = 5.7 \text{ Hz}$ , - $\text{CH}_3$ ).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ,  $\delta$ , ppm): 179.5  
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(C=S), 153.1(C=O), 134.1, 133.4, 128.7, 127.8, 125.1, 121.6 (Ar-C), 67.1 (-OCH<sub>2</sub>), 28.3–22.1 – (CH<sub>2</sub>)<sub>3</sub>–; 13.8 (-CH<sub>3</sub>). Elemental analyses for C<sub>17</sub>H<sub>20</sub>N<sub>2</sub>O<sub>2</sub>S (316.31) (%) Calcd: C, 64.55; H, 6.37; N, 8.85. Found: C, 64.43; H, 6.30; N, 8.79.

### **N-(2-Chloro-4-nitrophenyl)-N'-(pentoxycarbonyl) thiocarbamide (H<sub>2</sub>L2)**

Yellow solid; m.p 85-86°C; (2-Chloro-4-nitroaniline, 1.731g, 10 mmol) Yield: 76%; FT-IR (KBr, cm<sup>-1</sup>): 3494, 3176 ν(N-H), 3128 ν(aromatic C-H); 2958, ν(aliphatic C-H); 1733, ν(ester -COOR); 1588, ν(C=O); 1518, ν(aromatic, C=C); 1501, [Thioamide band I, ν(C-N) + ν(N-H)]; 1342, [Thioamide band II, ν(C-N) + ν(C=S)]. <sup>1</sup>H NMR (500 MHz, DMSO-d<sub>6</sub>, δ, ppm): 10.74 (s, 1H, CSNH), 9.01 (s, 1H, CONH), 8.04 (d, 1H, J = 3.1 Hz, -C<sub>6</sub>H<sub>3</sub>), 7.88 (dd, 1H, J = 8.5, 3.1 Hz, -C<sub>6</sub>H<sub>3</sub>), 6.78(d, 1H, J = 9.0 Hz, -C<sub>6</sub>H<sub>3</sub>), 4.12 (t, 2H, J = 7.0 Hz, -OCH<sub>2</sub>), 2.46 (m, 2H, -(CH<sub>2</sub>)<sub>3</sub>-), 1.50 (m, 4H, 2x(-CH<sub>2</sub>)), 0.79 (t, 3H, J = 4.1 Hz, -CH<sub>3</sub>). <sup>13</sup>C NMR (125 MHz, DMSO-d<sub>6</sub>, δ, ppm): 181.7 (C=S), 153.7 (C=O), 136.5, 133.4, 126.7, 126.1, 125.1, 124.9 (Ar-C), 66.2 (-OCH<sub>2</sub>), 28.1–22.1 -(CH<sub>2</sub>)<sub>3</sub>-; 14.2 (-CH<sub>3</sub>). Elemental analyses for C<sub>13</sub>H<sub>16</sub>N<sub>3</sub>O<sub>4</sub>SCl (345.80) (%) Calcd: C, 45.15; H, 4.66; N, 12.15. Found: C, 44.73; H, 4.63; N, 12.11.

### **N-(2-methoxy-4-nitrophenyl)-N'-(pentoxycarbonyl) thiocarbamide (H<sub>2</sub>L3)**

Dark yellow solid m.p 90-91°C; (2-Methoxy-4-nitroaniline, 1.682g, 10 mmol) Yield: 88%; FT-IR (KBr, cm<sup>-1</sup>): 3407, 3179 ν(N-H), 3031 ν(aromatic C-H); 2958, ν(aliphatic C-H); 1731, ν(ester -COOR); 1598, ν(C=O); 1537, ν(aromatic, C=C); 1417, [Thioamide band I, ν(C-N) + ν(N-H)]; 1367, [Thioamide band II, ν(C-N) + ν(C=S)]. <sup>1</sup>H NMR (500 MHz, DMSO-d<sub>6</sub>, δ, ppm): 12.31 (s, 1H, -CSNH), 11.53 (s, 1H, -CONH), 9.03 (d, 1H, J = 9.5 Hz, -C<sub>6</sub>H<sub>3</sub>), 7.90 (dd, 1H, J = 9.5, 3.0 Hz, -C<sub>6</sub>H<sub>3</sub>), 7.83 (d, 1H, J = 2.5 Hz, -C<sub>6</sub>H<sub>3</sub>), 4.15 (s, 3H, -OCH<sub>3</sub>), 4.13 (t, 2H, J = 6.5 Hz, -OCH<sub>2</sub>), 2.49 (m, 2H, -(CH<sub>2</sub>)<sub>3</sub>-), 1.60 (m, 4H, 2x(-CH<sub>2</sub>)), 0.85 (t, 3H, J = 7.0 Hz, -CH<sub>3</sub>). <sup>13</sup>C NMR (125 MHz, DMSO-d<sub>6</sub>, δ, ppm): 178.2 (C=S), 150.6(C=O), 134.1, 133.4, 128.7, 127.8, 125.1, 122.6(Ar-C), 57.2 (OCH<sub>3</sub>), 66.8 (-OCH<sub>2</sub>), 28.0-22.1 -(CH<sub>2</sub>)<sub>3</sub>-; 14.26 (-CH<sub>3</sub>). Elemental analyses for C<sub>14</sub>H<sub>19</sub>N<sub>3</sub>O<sub>5</sub>S (341.38) (%) Calcd: C, 49.26; H, 5.61; N, 12.31. Found: C, 49.23; H, 5.58; N, 12.29.

### **N-(3-nitrophenyl)-N'-(pentoxycarbonyl) thiocarbamide (H<sub>2</sub>L4)**

Dark yellow solid; m.p 78-79°C; (3-nitroaniline, 1.381g, 10 mmol) Yield: 78%; FT-IR (KBr, cm<sup>-1</sup>): 3430, 3326 ν(N-H), 3098 ν(aromatic C-H); 2923, ν(aliphatic C-H); 1736, ν(ester -COOR); 1627, ν(C=O); 1580, ν(aromatic, C=C); 1526, [Thioamide band I, ν(C-N) + ν(N-H)];

1338, [Thioamide band II,  $\nu(\text{C-N}) + \nu(\text{C=S})$ ].  $^1\text{H}$  NMR (500 MHz,  $\text{DMSO-d}_6$ ,  $\delta$ , ppm): 11.46 (s, 1H,  $-\text{CSNH}$ ), 8.34 (s, 1H,  $-\text{CONH}$ ), 7.58 (d, 1H,  $J = 6.1$  Hz,  $-\text{C}_6\text{H}_4$ ), 7.57 (dd, 1H,  $J = 6.1, 2.5$  Hz,  $-\text{C}_6\text{H}_4$ ), 7.49 (dt, 1H,  $J = 6.1, 2.5, 2.0$  Hz,  $-\text{C}_6\text{H}_4$ ), 6.95 (d, 1H,  $J = 2.5$  Hz,  $-\text{C}_6\text{H}_4$ ), 4.19 (t, 2H,  $J = 7.0$  Hz,  $-\text{OCH}_2$ ), 2.17 (m, 2H,  $-(\text{CH}_2)-$ ), 1.66 (m, 2H,  $2x(-\text{CH}_2)$ ), 0.92 (t, 3H,  $J = 5.0$  Hz,  $-\text{CH}_3$ ).  $^{13}\text{C}$  NMR (125 MHz,  $\text{DMSO-d}_6$ ,  $\delta$ , ppm): 181.7 (C=S), 166.9 (C=O), 149.3, 147.4, 142.8, 136.4, 129.9, 120.6 (Ar-C), 67.2 ( $-\text{OCH}_2$ ), 28.6–22.2 ( $-(\text{CH}_2)_3-$ ); 13.9 ( $-\text{CH}_3$ ). Elemental analyses for  $\text{C}_{13}\text{H}_{17}\text{N}_3\text{O}_4\text{S}$  (311.35) (%) Calcd: C, 50.15; H, 5.50; N, 13.50. Found: C, 50.11; H, 5.47; N, 13.47.

### **N-(naphthyl)-N'-(2, 2, 2-trichloroethoxycarbonyl) thiocarbamide (H<sub>2</sub>L5)**

Yellow solid; m.p 80-81°C; (Naphthylamine, 1.432g, 10 mmol) Yield: 85%; FT-IR (KBr,  $\text{cm}^{-1}$ ): 3443, 3235,  $\nu(\text{N-H})$ , 3010  $\nu(\text{aromatic C-H})$ ; 2961,  $\nu(\text{aliphatic C-H})$ ; 1732,  $\nu(\text{ester } -\text{COOR})$ ; 1505,  $\nu(\text{C=O})$ ; 1597,  $\nu(\text{aromatic, C=C})$ ; 1519, [Thioamide band I,  $\nu(\text{C-N}) + \nu(\text{N-H})$ ]; 1383, [Thioamide band II,  $\nu(\text{C-N}) + \nu(\text{C=S})$ ].  $^1\text{H}$  NMR (300 MHz,  $\text{CDCl}_3$ ,  $\delta$ , ppm): 11.34 (s, 1H,  $-\text{CSNH}$ ), 8.61 (s, 1H,  $-\text{CONH}$ ), 7.92 (m, 1H,  $\text{C}_{10}\text{H}_7$ ), 7.90 (m, 2H,  $\text{C}_{10}\text{H}_7$ ), 7.86 (m, 1H,  $\text{C}_{10}\text{H}_7$ ), 7.56 (m, 3H,  $\text{C}_{10}\text{H}_7$ ), 4.88 (s, 2H,  $-\text{OCH}_2$ ).  $^{13}\text{C}$  NMR (75 MHz,  $\text{CDCl}_3$ ,  $\delta$ , ppm): 178.6 (C=S), 151.2 (C=O), 134.1, 133.4, 128.7, 127.8, 125.1, 121.6 (Ar-C), 77.4 ( $-\text{OCH}_2$ ), 75.1 ( $-\text{CCl}_3$ ). Elemental analyses for  $\text{C}_{14}\text{H}_{11}\text{N}_2\text{O}_2\text{SCl}_3$  (377.57) (%) Calcd: C, 44.54; H, 2.94; N, 7.42. Found: C, 44.42; H, 2.90; N, 7.40.

### **Biological assays**

#### **Cell lines**

Two human cervical cancer cell lines (2008 and C13\*) and three ovarian cancer cell lines (IGROV-1, A2780 and A2780/CP) were used. Among these, C13\* and A2780/CP are cisplatin (ccDDP)-resistant cells.<sup>44, 45</sup> Cells were grown as monolayers in RPMI 1640 medium containing 10% heat-inactivated fetal bovine serum and 50  $\mu\text{g/ml}$  gentamycin sulfate. All cell media and serum were purchased from Lonza (Verviers, Belgium). Cultures were equilibrated with humidified 5%  $\text{CO}_2$  in air at 38 °C. All studies were performed in Mycoplasma negative cells, as routinely determined with the MycoAlert Mycoplasma detection kit (Lonza, Walkersville, MD, USA).

#### **Cytotoxicity screening**

*In vitro* cytotoxicity of compounds used in the present study was determined by MTT assay.<sup>46</sup> The cells were seeded into 96-well plates and cultured overnight. Various concentrations of the test compounds dissolved in DMSO solvents were then added and incubated for 72 h. After

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2  
3 incubation, the medium was removed and added fresh culture medium 100 $\mu$ l containing 0.5 mg  
4 mL-1MTT (3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide; Sigma) and then  
5 incubated at 38 $^{\circ}$ C for 4 h. The medium was removed and 100  $\mu$ L DMSO solvent was added to  
6 dissolve the dark blue crystals. After incubation for 30 min at room temperature, to ensure that  
7 all crystals were dissolved, absorbance was measured using an ELISA plate reader at 570 nm  
8 with reference wavelength of 650 nm.  
9

### 13 **Conclusion**

14  
15 In our present work, five N, N'-disubstituted thiocarbamide derivatives were prepared using the  
16 mentioned method in this paper and all of them were characterized by various spectroscopic and  
17 single crystal X-ray diffraction techniques. The crystal structure of **H<sub>2</sub>L1** and **H<sub>2</sub>L5** revealed the  
18 planar confirmation of thiocarbamide unit which may be due to the formation of intramolecular  
19 hydrogen bond N1–H $\cdots$ O=C. An intermolecular hydrogen bond N2–H $\cdots$ S=C links two  
20 thiocarbamide molecules as a dimer in case of **H<sub>2</sub>L1**. An offset face-to-face  $\pi$ – $\pi$  stacking is  
21 present in **H<sub>2</sub>L5**. *In vitro* cytotoxicity study of the synthesized compounds against five human  
22 cancer cell lines indicated significant inhibitory activity for compounds **H<sub>2</sub>L2–H<sub>2</sub>L4** in which  
23 **H<sub>2</sub>L2** is most promising.  
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### 30 **Acknowledgements**

31  
32 The author, SKP is grateful to Banaras Hindu University, Varanasi, India for the financial  
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35 to Prof. R. J. Butcher, Department of Chemistry, Howard University, 525 College Street NW,  
36 Washington, DC 20059, USA for the X-ray studies.  
37  
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40

### 41 **Supplementary Information**

42  
43 X-ray crystallographic hydrogen bonding Table **S 1** of compounds (**H<sub>2</sub>L1**) and (**H<sub>2</sub>L5**),  
44 Cytotoxicity Table **S 2** of compounds (**H<sub>2</sub>L1–H<sub>2</sub>L5**) and Figures (**S 1**, **S 2** and **S 3**) have been  
45 provided in Supporting Information.  
46  
47

48  
49 CCDC **999080** and **999081** contain the supplementary crystallographic data for compounds  
50 (**H<sub>2</sub>L1**) and (**H<sub>2</sub>L5**). These data can be obtained free of charge from The Cambridge  
51 Crystallographic Data Centre via [www.ccdc.cam.ac.uk/data\\_request/cif](http://www.ccdc.cam.ac.uk/data_request/cif), by e-mailing  
52 [deposit@ccdc.cam.ac.uk](mailto:deposit@ccdc.cam.ac.uk) or by contacting the Cambridge Crystallographic Data.  
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## References:

- [1] Saeed, A.; Flörke Ulrich & F. Erben Mauricio. *J. Sulfur Chem.* **2014**, 35, 318–355.
- [2] Ashraf, A. Aly.; Essam, K. Ahmed.; Khaled, M.J. *Sulfur Chem.* **2007**, 28, 73–93.
- [3] Estevez-Hernandez, O.; Otazo-Sanchez, E. *Spectrochim. Acta Part A* **2005**, 62, 964–971.
- [4] Otazo-Sanchez, E.; Ortiz-del-Toro, P. *Spectrochim. Acta Part A* **2002**, 58, 2281–2290.
- [5] Estevez-Hernandez, O.; Duque J & Reguera, E. *J. Sulfur Chem.* **2011**, 32, 213–222.
- [6] Zhang, Q.; Zhao, B.; Song, Y.; Hua, Chengwen.; Gou, Xiao.; Chen, B.; Zhao, Junlong. *Heteroatom Chem.* **2015**, 26, 5.
- [7] Halim, A. N. A.; Ngaini, Zainab. *Phosphorus Sulfur Silicon Relat. Elem.* **2017**, 192, 1012–1017.
- [8] Yuan, Y. F.; Wang, JiTao.; Gimeno, M. C.; Laguna, A.; Jones, P. G. *Inorg. Chim. Acta.* **2001**, 324, 309–317.
- [9] Xian, L.; Wei, T.; Zhang, Y. M. *J. Coord. Chem.* **2004**, 57, 453–457.
- [10] Duque, J.; Hernández, O. E.; Reguera, E.; Ellena, J.; Corrêa, R. S. *J. Coord. Chem.* **2009**, 62, 2804–2813.
- [11] Li, D.; Che, D. J.; Li, Z. F.; Zhu, Y.; Zou, D. P. *New J.Chem.* **2002**, 26, 1629–1633.
- [12] Singh, D. P.; Pratap, S.; Shukla, M. *Inorg.Chim. Acta* 2014, 423, 386–396.
- [13] Singh, D. P.; Pratap, S.; Pandey, S. K.; Butcher, R. J.; Marverti, G. *J. Coord. Chem.* 2015, 68, 261–276.
- [14] Khanam, S.; Pandey, S. K.; Rai, S. K.; Verma, D.; Jasinski, J. P.; Pratap, S.; Tewari, A. K. *ChemistrySelect* **2017**, 2, 6370 – 6374.
- [15] Wang, Dan.; Wu, Su-Yun.; Li, Hai-Pu.; Yang, Y.; Roesky, H. W. *Eur. J. Inorg. Chem.* **2017**, 1406–1413.
- [16] Santini, C.; Pellei, M.; Gandin, V.; Porchia, M.; Tisato, F. C.; Marzano, C. *Chem. Rev.* **2014**, 114, 815–862.
- [17] Eatock, M. M.; Schatzlein, A.; Kaye, S. B. *Cancer Treat. Rev.* **2000**, 26, 191.
- [18] Marverti, G.; Ligabue, A.; Lombardi, P.; Ferrari, S.; Monti, M. G.; Frassinetti, C.; Costi, M. *P. Int. J. Oncol.* **2013**, 43, 1269–1280.
- [19] Li, H.Q.; Yan, Tao.; Yang, Ying. *Bioorg. Med. Chem.* **2010**, 18, 305–313.

- 1  
2  
3 [20] Zhang, Y.M.; Wei, T.B.; Xian, L.; Gao, L. M. *Phosphorus Sulfur Silicon Relat. Elem.* **2004**,  
4 179, 2007-2013.  
5  
6 [21] Rashid, S. S.; Hussain, N.; Ali, R.; Jones, M. *Eur. J. Med. Chem.* **2010**, 45, 4990-4996.  
7  
8 [22] Solomon, V. R.; Haq, W.; Smilkstein, M.; Srivastava, K.; Puri, S.K.; Katti, S.B. *Eur. J.*  
9 *Med. Chem.* **2010**, 45, 4990-4996.  
10  
11 [23] Li, Q.J.; Yang, C. L.; *J. Chem. Crystallogr.* **2008**, 38, 927-930.  
12  
13 [24] Selvakumaran, N.; Pratheepkumar, A.; Ng, S.W.; Karvembu. R. *Inorg.Chim. Acta* **2013**,  
14 404, 82-87.  
15  
16 [25] Maurya, M. R.; Uprety, Bhawna. *Eur. J. Med. Chem.* **2015**, 98, 54-60.  
17  
18 [26] Venkatachalam, T. K.; Mao, C.; Uckun, F. M. *Bioorg. Med. Chem.* **2004**, 12, 4275-4284.  
19  
20 [27] Saeed, S.; Rashid, N.; Jones, P.G.; Ali, M.; Hussain, R. *Eur. J. Med. Chem.* **2010**,45, 1323-  
21 1331.  
22  
23 [28] Hernandez, O.E.; Duque, J.; Reguera, E. *J. Sulfur Chem.* **2011**, 32, 213-222.  
24  
25 [29] Luckay, R. C.; Mebrahtu, F.; Esterhuysen, C.; Koch, K. R. *Inorg. Chem. Commun.* **2010**,  
26 13, 468-470.  
27  
28 [30] Seshadri, T.; Haupt, H. J. *J. Mater. Chem.* **1998**, 8, 1345-1350.  
29  
30 [31] Seshadri, T.; Haupt, H. J.; Florke, U.; Herald, G. *Liq. Cryst.* **2007**, 34, 33-47.  
31  
32 [32] Venkataramanan, V.; Srinivasan, M. R.; Bhat H. L. *J. Raman Spectrosc.* **1994**, 25, 805-811.  
33  
34 [33] Venkataramanan, V.; Bhat, H.L.; Srinivasan, M. R.; Ayyub, P.; Multan, M.S. *J. Raman*  
35 *Spectrosc.* **1997**, 28, 779-784.  
36  
37 [34] Gunasekaran, N.; Ramesh, P.; Ronnuswami, M. N. G.; Karvembu, R. *Dalton Trans.* **2011**,  
38 40, 12519-12526.  
39  
40 [35] Gunasekaran, N.; Jerome, P.; Ng, S.W.; Tiekink, E. R. T.; Karvembu, R. *J. Mol. Catl.*  
41 **2012**,353, 156-162.  
42  
43 [36] Saeed, A.; Erben, M.F.; Bolte, M. *Spectrochim. Acta* **2013**, 102, 408-413.  
44  
45 [37] Qiao, Lei; Zhang, Yu; Hu, Wei; Guo, J.; Cao, W.; Ding, Z.; Guo, Z.; Fan, A.; Song, J.;  
46 Huang, Jie. *J. Mol. Struct.* **2017**, 1141, 309-321.  
47  
48 [38] Silverstein, R. M.; Webster, F. X.; Kiemle, D. J. *Spectrometric Identification*  
49 *of Organic Compounds*, Wiley: New York, **Seventh Edition**. ISBN0-471-39362-2.  
50  
51 [39] Weiqun, Zhou. Kuishenga, Leng. Yonga.; Zhang.; Lude, Lu. *J. Mol. Struct.* **2003**, 657, 215-  
52 223.  
53  
54 [40] Wang, Guangliang.; Cheng, Ming. *J. Chem. Crystallogr.* **2009**, 39, 612-614.  
55  
56  
57  
58  
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60

1  
2  
3  
4 [41] Farrugia, Louis. WinGX and ORTEP for Windows: an update. *J. Appl. Cryst.* **2012**, 45,  
5 849-854.

6 [42] Burnett, M. N.; Johnson, C. K. Oak ridge thermal ellipsoid plot program for crystal structure  
7 illustrations. **1996**, Report ORNL-6895, Oak Ridge National Laboratory, Oak Ridge, TN.

8 [43] Macrae, C.F.; Bruno, I.J.; Chisholm, J. A.; Edgington, P. R.; McCabe, P.; Pidcock, E.;  
9 Rodriguez-Monge, L.; Taylor, R. *J. Appl. Cryst.* **2008**, 41, 466.

10 [44] Korch, C.; Spillman, M. A.; Jackson, T. A.; Jacobsen, B. M.; Murphy, S. K.; Lessey, B. A.;  
11 Jordan, V. C.; Bradford, A. P. *Gynecol. Oncol.* **2012**, 127, 241-248.

12 [45] Andrews, P. A.; Jones, J. A. *Cancer Commun.* 1991, 3, 93-102.

13 [46] Mosmann, T. *J. Immunol. Methods* **1983**, 65, 55-63.  
14  
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**Table 1:** Summary of crystal data and structure refinement of **H<sub>2</sub>L1** and **H<sub>2</sub>L5**

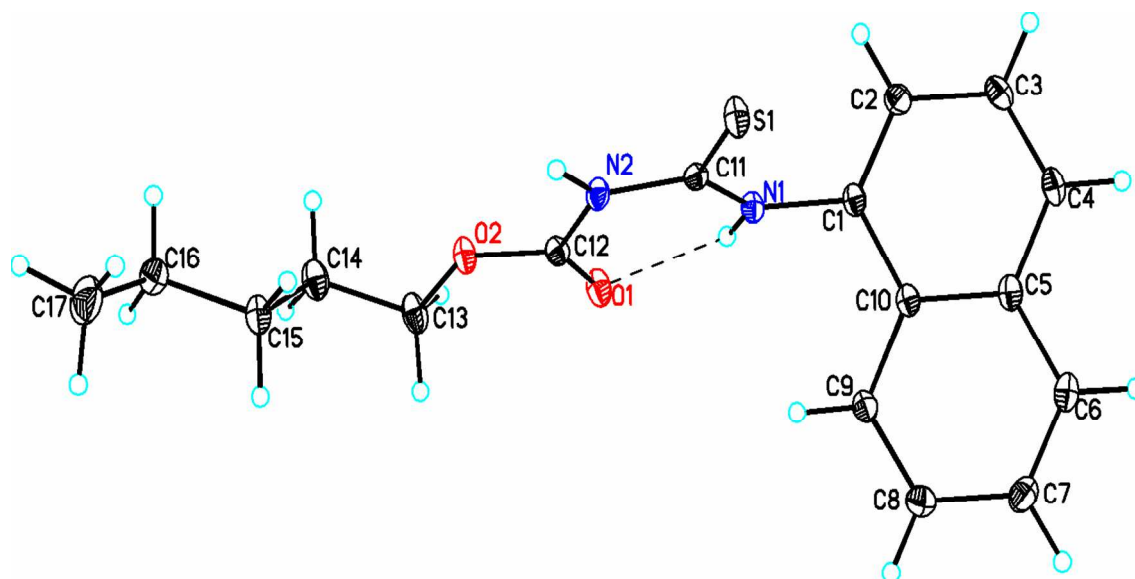
<b>Compounds</b>	<b>H<sub>2</sub>L1</b>	<b>H<sub>2</sub>L5</b>
Empirical Formula	C <sub>17</sub> H <sub>20</sub> N <sub>2</sub> O <sub>2</sub> S	C <sub>14</sub> H <sub>11</sub> Cl <sub>3</sub> N <sub>2</sub> O <sub>2</sub> S
Formula Weight	316.41	377.66
Crystal System / Space Group	Triclinic / P-1	Triclinic / P-1
a / Å	7.139(5)	8.115(5)
b / Å	10.751(5)	8.899(5)
c / Å	12.442(5)	12.238(5)
α / °	109.738(5)	75.345(5)
β / °	99.872(5)	87.734(5)
γ / °	106.335(5)	64.477(5)
V / Å <sup>3</sup>	824.2(8)	769.1(7)
Z	2	2
D <sub>calc</sub> (g/cm <sup>3</sup> )	1.275	1.631
μ (mm <sup>-1</sup> )	1.812	0.738
Crystal size (mm)		0.5481 x 0.2877 x 0.1066
Color / Shape	Bright yellow single crystal	Bright yellow single crystal
Temp (K)	120(2)	120(2)
Theta range for collection	3.950 to 76.019°	2.790 to 41.226°
Reflections collected	5337	20621
Independent reflections	3279 [R(int) = 0.0200]	9968 [R(int) = 0.0257]
Data/restraints/parameters	3279 / 7 / 231	9968 / 0 / 199
Goodness of fit on F <sup>2</sup>	1.067	1.040
Final R indices [I > 2σ(I)]	R1 = 0.0375, wR2 = 0.0984	R1 = 0.0376, wR2 = 0.0884
R indices (all data)	R1 = 0.0399, wR2 = 0.0996	R1 = 0.0524, wR2 = 0.0987
Largest difference peak/hole	0.497 and -0.244 e. Å <sup>-3</sup>	1.283 and -0.592 e. Å <sup>-3</sup>



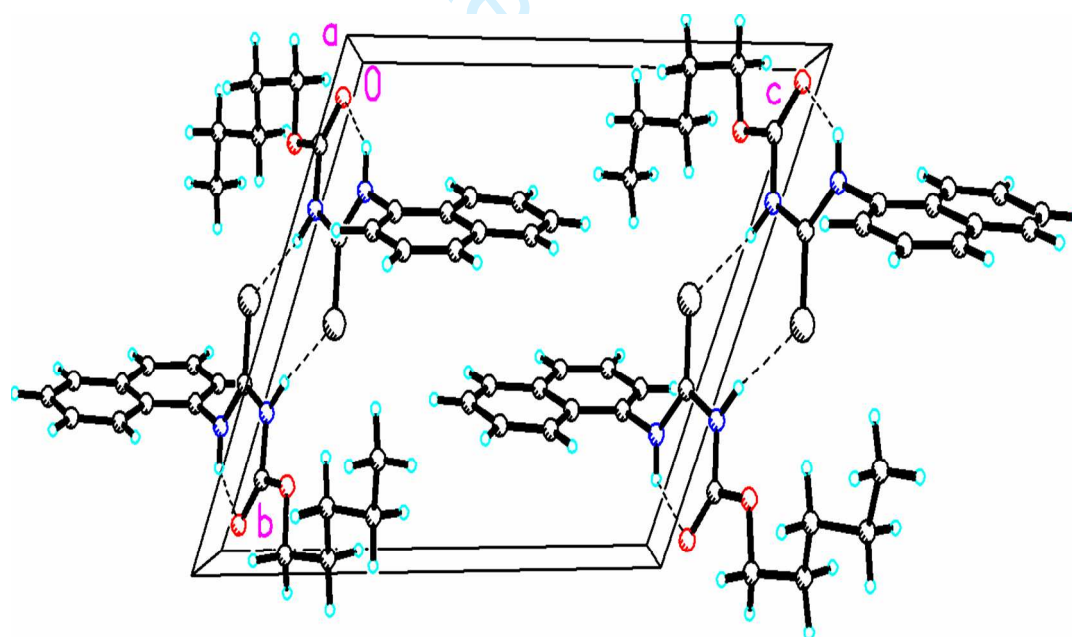
**Table 2:** Selected bond lengths (Å), and bond angles (°) for **H<sub>2</sub>L1** and **H<sub>2</sub>L5**

Compound H <sub>2</sub> L1		Compound H <sub>2</sub> L5	
Bond lengths (Å)		Bond lengths (Å)	
C(11)–S(1)	1.674(16)	C(1)–N(1)	1.429(12)
C(11)–N(1)	1.331(18)	N(1)–C(11)	1.335(11)
C(1)–N(1)	1.431(18)	C(11)–S(1)	1.667(12)
O(1)–C(12)	1.327(18)	N(2)–C(12)	1.364(13)
O(2)–C(13)	1.455(16)	O(1)–C(12)	1.213(11)
N(2)–C(11)	1.381(18)	O(2)–C(12)	1.347(11)
N(2)–C(12)	1.378(18)	O(2)–C(13)	1.424(12)
C(16)–C(17)	1.491(4)	C(13)–C(14)	1.769(11)
C(15)–C(16)	1.520(3)	C(14)–Cl(1)	1.764(11)
C(15)–C(16)	1.520(3)	C(14)–Cl(2)	1.771(11)
C(13)–C(14)	1.502(6)	C(14)–Cl(3)	1.769(11)
Bond angles (°)		Bond angles (°)	
C(12)–O(2)–C(13)	116.50(3)	C(11)–N(1)–C(1)	124.25(8)
C(11)–N(1)–C(1)	123.60(10)	C(12)–O(2)–C(13)	117.13(7)
C(12)–N(2)–C(11)	127.52(12)	C(12)–N(2)–C(11)	127.38(7)
C(2)–C(1)–C(10)	121.79(12)	C(2)–C(1)–N(1)	120.13(8)
C(2)–C(1)–N(1)	119.97(13)	C(10)–C(1)–N(1)	118.14(9)
C(10)–C(1)–N(1)	118.24(12)	N(1)–C(11)–N(2)	116.10(8)
N(1)–C(11)–N(2)	116.90(12)	N(1)–C(11)–S(1)	125.55(7)
N(1)–C(11)–S(1)	124.48(11)	N(2)–C(11)–S(1)	118.35(6)
N(2)–C(11)–S(1)	118.61(10)	O(1)–C(12)–O(2)	124.84(8)
O(1)–C(12)–O(2)	125.94(12)	O(1)–C(12)–N(2)	126.88(8)
O(1)–C(12)–N(2)	125.60(13)	O(2)–C(12)–N(2)	108.26(7)
O(2)–C(12)–N(2)	108.46(11)	O(2)–C(13)–C(14)	110.00(8)
O(2)–C(13)–C(14)	107.40(8)	C(13)–C(14)–Cl(1)	111.32(6)
C(13)–C(14)–C(15)	115.70(5)	C(13)–C(14)–Cl(2)	106.93(6)
C(14)–C(15)–C(16)	111.66(19)	C(13)–C(14)–Cl(3)	110.27(7)

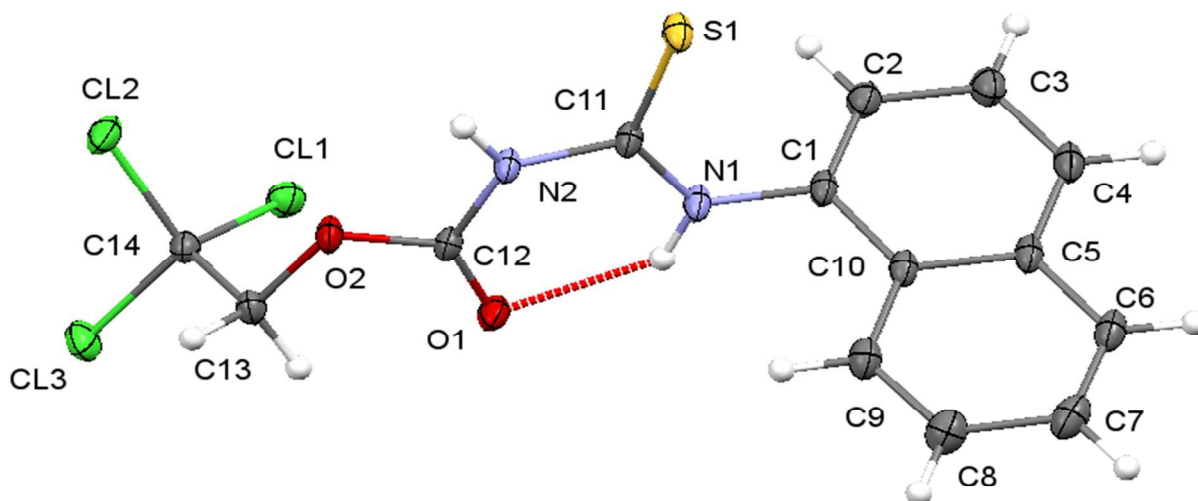




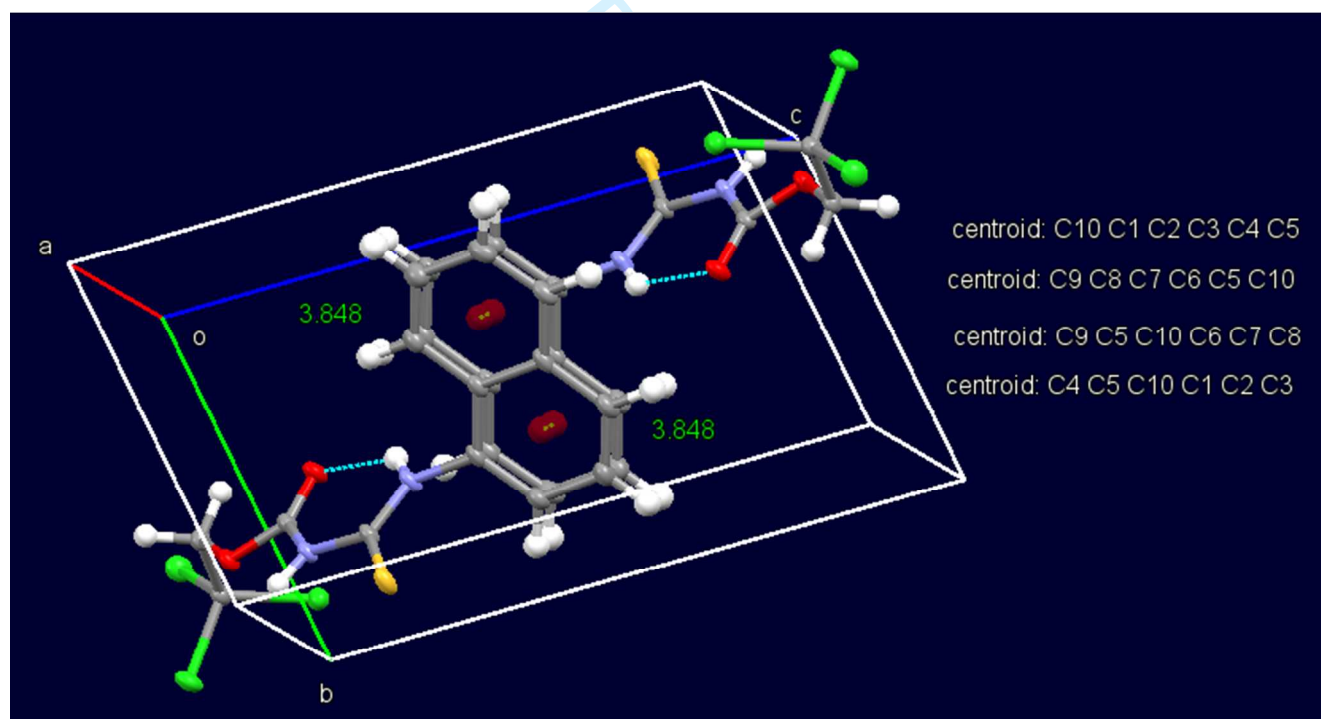
**Figure 1(a):** Molecular structure of H<sub>2</sub>L1. The intramolecular hydrogen bonds as shown by dashed lines.



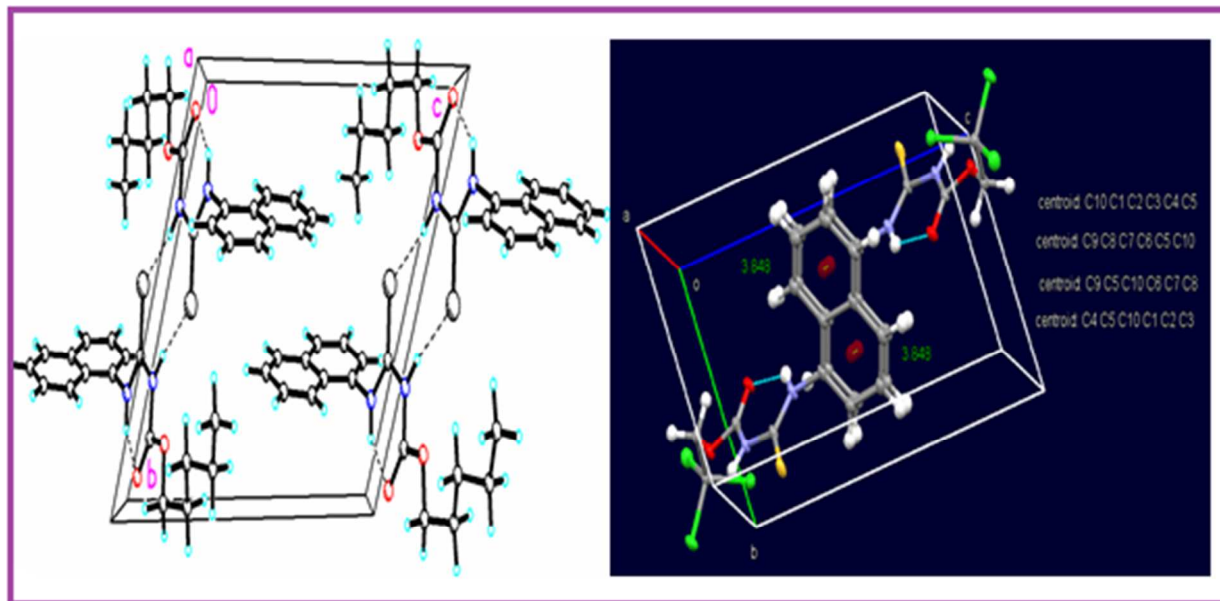
**Figure 1(b):** Unit cell diagram of H<sub>2</sub>L1.



**Figure 2(a):** Molecular structure of  $\text{H}_2\text{L5}$ . The intramolecular hydrogen bonds as shown by dashed lines.



**Figure 2(b):** Unit cell diagram viewed down the b axis for  $\text{H}_2\text{L5}$ . Intermolecular face-to-face  $\pi$ - $\pi$  stacking interaction is also observed in the compound.



Review Only

**Synthesis, molecular structure exploration and in vitro cytotoxicity screening of five novel N, N'- disubstituted thiocarbamide derivatives**

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**Supplemental Materials**

**Table S 1:** Important hydrogen bonding interactions of **H<sub>2</sub>L1** and **H<sub>2</sub>L5** [Å and °].

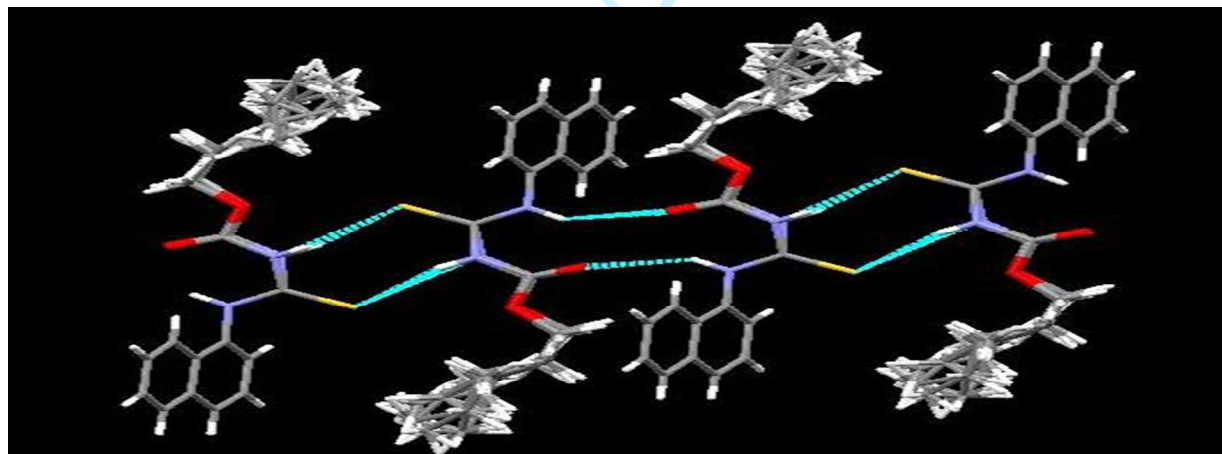
<b>D–H···A</b>	<b>D–H</b>	<b>H···A</b>	<b>D···A</b>	<b>&lt; (DHA)</b>
<b>H<sub>2</sub>L1</b>				
N(1)–H(1N)···O(1)	0.83(2)	2.05(19)	2.701(2)	134.6(17)
N(1)–H(1N)···O(1)#1	0.83(2)	2.48(2)	3.160(2)	139.9(16)
N(2)–H(2N)···S(1)#2	0.89(2)	2.45(2)	3.327(16)	166.8(16)
<b>H<sub>2</sub>L5</b>				
N(1)–H(1A)···O(1)	0.88	2.00	2.6995(13)	135.7
N(2)–H(2B)···S(1)#1	0.88	2.53	3.3811(14)	162.5

Symmetry transformations used to generate equivalent atoms:

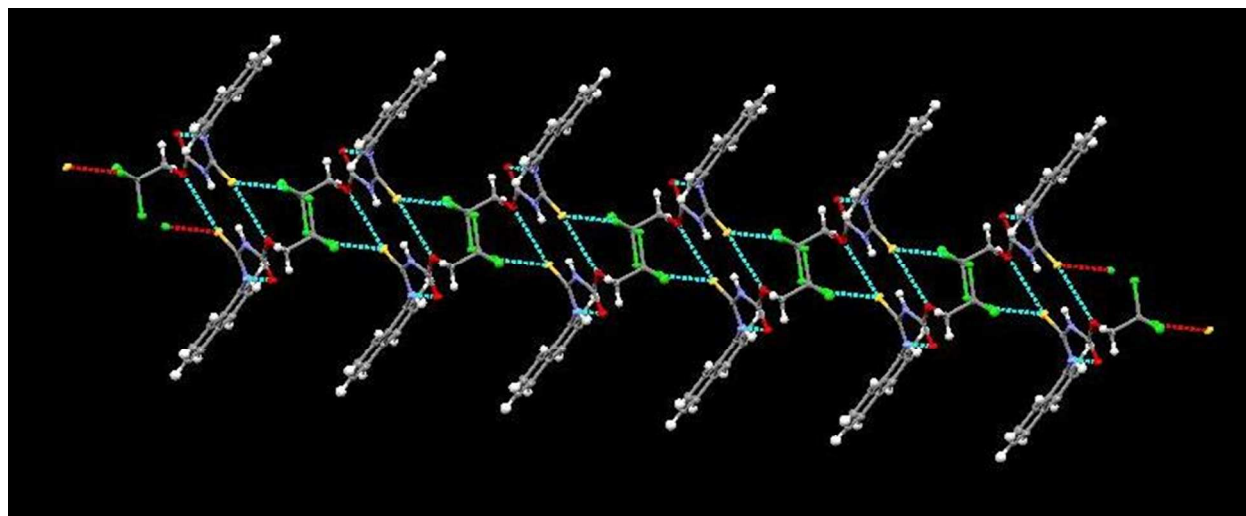
**H<sub>2</sub>L1** .#1 -x+2, -y+1, -z+1 #2 -x+2, -y+2, -z+1 **H<sub>2</sub>L5**. #1 -x+1, -y, -z+2

**Table S 2:** IC<sub>50</sub> Values (μM) for the compounds **H<sub>2</sub>L1** – **H<sub>2</sub>L5** against two human cervical Cell lines (**2008** and **C13\***) and three human ovarian carcinoma cell lines (**A2780**, **A2780/CP** and **IGROV-1**).

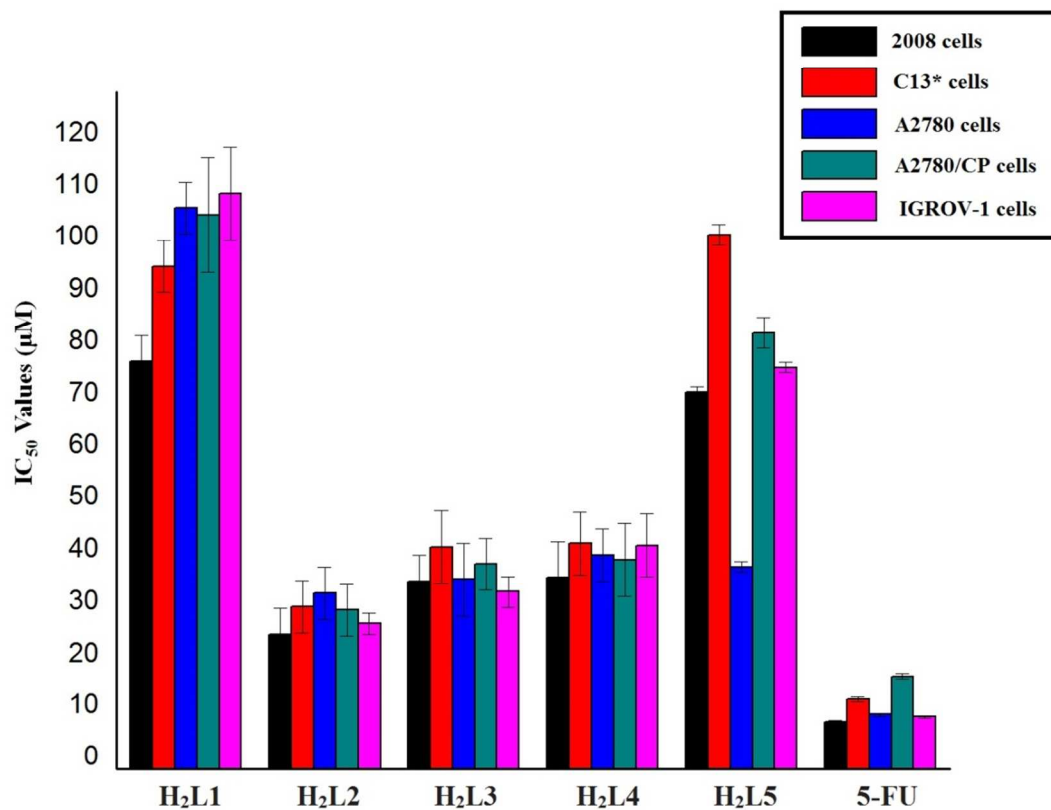
Compounds	2008 cells	C13*cells	A2780 cells	A2780/CP cells	IGROV-1 cells
<b>H<sub>2</sub>L1</b>	73.4±5	91.7±5	102.8±5	101.5±11	105.6±9
<b>H<sub>2</sub>L2</b>	21.0±5	26.3±6	28.9±5	25.6±5	23.0±2
<b>H<sub>2</sub>L3</b>	31.2±5	37.2±7	32.5±7	34.4±5	29.1±3
<b>H<sub>2</sub>L4</b>	31.8±7	38.4±6	36.2±5	35.2±3	38.0±6
<b>H<sub>2</sub>L5</b>	67.5±1	97.7±2	73.9±1	78.9±4	72.2±1
<b>5-FU</b>	4.1±0.3	8.5±0.5	5.5±0.3	12.8±0.5	5.1±0.2



**Figure S 1:** Four molecules linked with H-bonds indicated by dashed lines. Weak intermolecular interactions (C–O···H–N and C–S···H–N) lead to an infinite chain length along the a-axis.



**Figure S 2:** The packing diagram of  $\text{H}_2\text{L5}$ . Weak intermolecular interactions ( $\text{C}-\text{O}\cdots\text{H}$ ,  $\text{C}-\text{S}\cdots\text{H}$ , and  $\text{C}-\text{Cl}\cdots\text{H}$ ) lead to an infinite chain length along the a-axis.



**Figure S 3:** Comparative cytotoxicity of compounds H<sub>2</sub>L1 – H<sub>2</sub>L5