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Novel isatin–triazole based thiosemicarbazones as potential anticancer agents: synthesis, DFT and molecular docking studies†

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Thiosemicarbazones of isatin have been found to exhibit versatile bioactivities. In this study, two distinct types of isatin–triazole hybrids **3a** and **3b** were accessed *via* copper-catalyzed azide–alkyne cycloaddition reaction (CuAAC), together with their mono and bis-thiosemicarbazone derivatives **4a–h** and **5a–h**. In addition to the characterization by physical, spectral and analytical data, a DFT study was carried out to obtain the optimized geometries of all thiosemicarbazones. The global reactivity values showed that among the synthesized derivatives, **4c**, **4g** and **5c** having nitro substituents are the most soft compounds, with compound **5c** having the highest electronegativity and electrophilicity index values among the synthesized series, thus possessing strong binding ability with biomolecules. Molecular docking studies were performed to explore the inhibitory ability of the selected compounds against the active sites of the anticancer protein of phosphoinositide 3-kinase (PI3K). Among the synthesized derivatives, 4-nitro substituted bithiosemicarbazone **5c** showed the highest binding energy of $-10.3 \text{ kcal mol}^{-1}$. These findings demonstrated that compound **5c** could be used as a favored anticancer scaffold *via* the mechanism of inhibition against the PI3K signaling pathways.

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1. Introduction

Heterocyclic scaffolds are important synthetic precursors for a wide range of biologically active compounds.¹ They play an important role as a core moiety in a diverse range of natural products, including hemoglobin, biomolecules, RNA, DNA, proteins, vitamins, and biologically active compounds.² Isatin (1*H* indole-2,3-dione) has attracted the interest of researchers in both synthetic and medicinal chemistry due to its chemical reactivity and broad range of applications, which include antimicrobial,^{3,4} anti-cancer,^{5,6} anti-HIV,⁷ anticonvulsant,⁸ anti-oxidant,^{9,10} anti-inflammatory,^{3,11} antitubercular,^{12–14} and anti-diabetic^{11,15,16} properties. Sutent (SU11248), also known as Sunitinib, is a drug derived from 5-fluoro isatin that is used for targeted therapy in gastrointestinal stromal tumors, advanced renal cancer, and pancreatic neuroendocrine carcinoma.^{17,18} Fig. 1 shows some biologically active compounds containing isatin scaffold that have been recently reported for their anti-cancer potential.^{19–21}

Triazoles, specifically 1,2,3-triazole and 1,2,4-triazole, stand out as highly significant nitrogen-containing heterocycles. The incorporation of triazole can enhance solubility and facilitate binding to biomolecular targets through a range of non-covalent interactions.²² Triazoles exhibit a broad spectrum of biological activities, encompassing antimicrobial,²³ antiviral,²⁴ analgesic,²⁵ anti-inflammatory,²⁶ antileishmanial,^{26,27} and anti-cancer^{28,29} activities. The development of resistance to drugs used to treat different diseases is a serious problem which needs to be addressed.³⁰ Hence, extensive efforts have been made for the synthesis of safe, more effective, selective and multi-targeted drugs by utilizing pharmacophore hybridization approach.^{31,32} Several *N*-1,2,3-triazole–isatin hybrids have been reported for their potential as tumour anti-proliferative,^{33,34} antitubercular,^{13,35} and antimicrobial³⁶ agents. Furthermore, thiosemicarbazones (TSCs) being a type of Schiff bases (typically synthesized by condensation of thiosemicarbazides with a suitable aldehyde or ketone)³⁷ have also captured the interest of the chemical and biological communities owing to their potent metal chelating ability and diverse pharmacological effects.^{38,39} TSCs have displayed a broad clinical antitumor spectrum, with efficacy against leukemia, pancreatic cancer, breast cancer, non-small cell lung cancer, cervical cancer, prostate cancer, and bladder cancer.^{38,40–48}

The strategy of linking two pharmacophores together in order to improve the biological and pharmacological potency of the resulting molecules is now widely used in pharmaceutical

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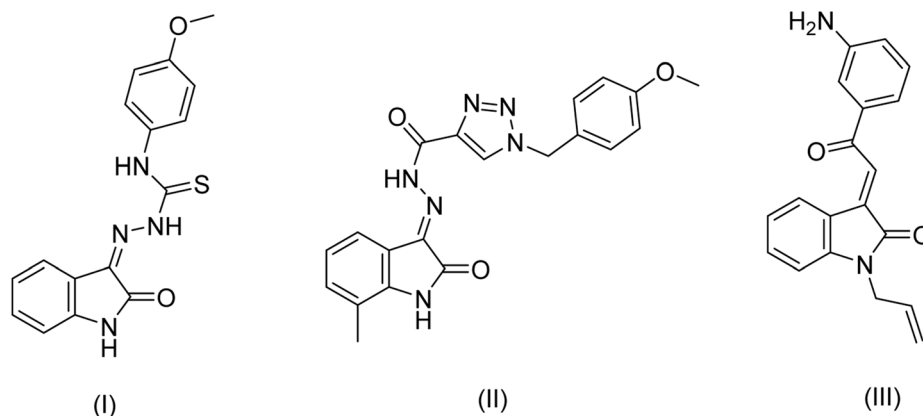


Fig. 1 Some biologically active isatin derivatives as anticancer agents.^{19–21}

and medicinal chemistry.⁴⁹ When compared to individual moieties, this pharmacophore hybridization approach holds promise for overcoming drug-resistance and increasing potency. Motivated by these considerations and our desire to find more potent anticancer agents to combat drug resistance, we present a facile synthetic protocol for synthesizing novel mono and bis-thiosemicarbazone derivatives of isatin–triazole hybrids through the well known Cu(I)-catalyzed alkyne–azide cycloaddition (CuAAC) reaction. In the present study, the DFT studies of all the synthesized compounds have been explored in order to forecast the structure–reactivity relationship of the synthesized compounds. The most reactive compounds among the series, having the least band gap energy have been selected for the molecular docking studies and explored their probable binding interactions with phosphoinositide 3-kinases (PI3K) which is one of the key therapeutic targets for cancer treatment. The results of this study clearly indicate the potential of the synthesized compounds as anticancer agents, thus providing important guidelines for *in vitro* and *in vivo* studies of the synthesized compounds and for the design and development of efficient anticancer agents. It is also worth mentioning here that a considerable number of clinically approved anticancer drugs either in current use or undergoing trials are derived from isatin, 1,2,3-triazoles and thiosemicarbazones.^{50–54}

2. Results and discussion

2.1 Synthesis

The synthesis of two distinct types of desired isatin–triazole hybrid intermediates **3a** and **3b** was initiated from the terminal alkynes **1b** and **2a** (Scheme 1), both of which were prepared *via* *N*-propargylation of commercially available isatin and 4-hydroxybenzaldehyde respectively with the propargyl bromide in the presence of K_2CO_3 in DMF.⁵⁵ The targeted alkynes, 1-(prop-2-ynyl)indoline-2,3-dione **1b** and 4-(prop-2-ynoxy)benzaldehyde **2a** were obtained after recrystallization from ethanol as brown and orange color precipitates in appreciable yield of 92% and 84%, respectively (Scheme 1). Similarly, the azide precursors **1a** and **2b** were synthesized in good yields of 92% and 78% from intermediates 1-(2-chloroethyl)isatin and 4-

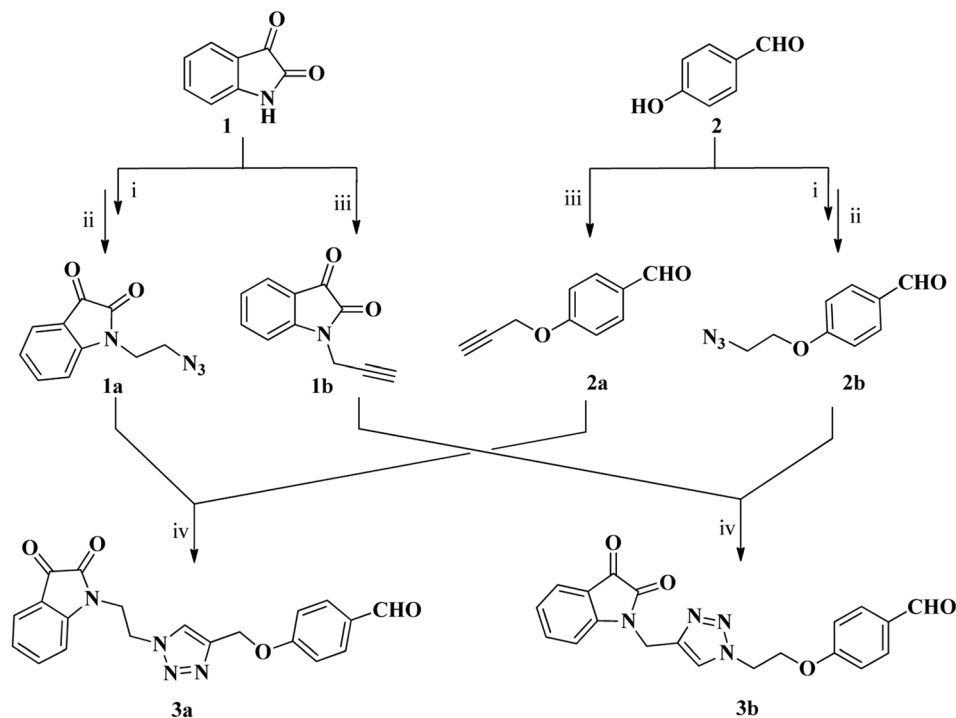
(2-chloroethoxy)benzaldehyde respectively,⁵⁶ by their reaction with sodium azide. Finally, the conditions of “Click” chemistry *i.e.* Cu(I) catalyzed 1,3-dipolar cycloaddition reaction (CuAAC)⁵⁵ was employed to synthesize isatin–triazole hybrid intermediates **3a** and **3b**. The reaction between the respective alkynes **1b** and **2a** and the azide precursors **1a** and **2b** in the presence of copper sulphate as a catalyst and sodium ascorbate as a reducing agent for copper sulphate provided the desired isatin–triazole hybrid intermediates **3a** and **3b** in 89% and 85% yield, respectively (Scheme 1).

In the next step, series of mono and bis-thiosemicarbazones **4a–h** and **5a–h** (Scheme 2) were synthesized from isatin–triazole hybrid intermediates **3a** and **3b** by using suitable *N*⁴-substituted thiosemicarbazides in different stoichiometric ratios. The synthesis of mono-thiosemicarbazone derivatives **4a–h** was achieved by stirring **3a** and respective *N*⁴-substituted thiosemicarbazide (1.1 eq.) for 4–8 h in ethanol solvent at room temperature. Similarly, bis-thiosemicarbazones of isatin–triazole hybrids **5a–h** were obtained by reacting **3a** and **3b** with 2.1 equivalents of suitable *N*⁴-substituted thiosemicarbazide under reflux conditions (Scheme 2).

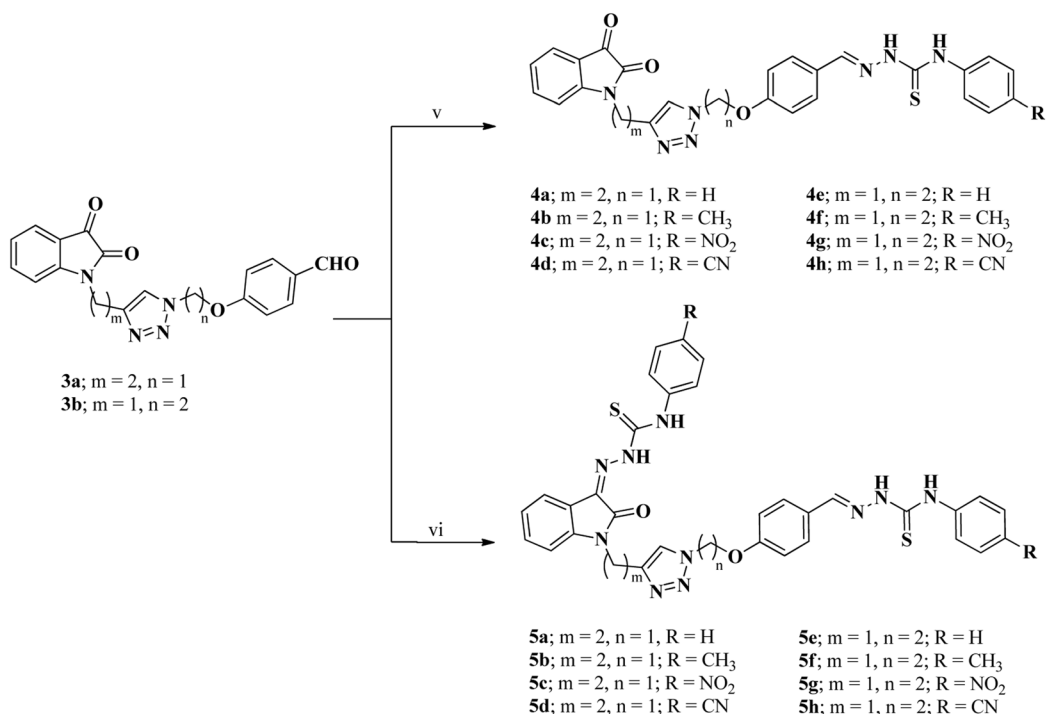
2.2 Characterization

The formation of isatin–triazole hybrid intermediates **3a** & **3b** and mono and bis-thiosemicarbazones **4a–h** & **5a–h** was confirmed by their FT-IR, ¹H & ¹³C NMR and LC-MS data. In the FT-IR spectrum, the absence of the absorption peaks for azide and alkyne functional groups and the presence of three absorption bands at (1732 cm⁻¹, 1692 cm⁻¹ and 1598 cm⁻¹) and (1728 cm⁻¹, 1673 cm⁻¹ and 1600 cm⁻¹) corresponding to the three carbonyls of the lactam, aldehyde and ketone functional groups clearly indicate the successful formation of intermediates **3a** & **3b**, respectively. Moreover, the presence of absorption bands for ether, methylene and aromatic rings in their respective regions also establishes the desired structures.

In the ¹H NMR spectrum, the only singlet present in the aromatic region at 8.25 ppm and 7.85 ppm, respectively corresponds to the single proton of triazole ring of **3a** & **3b**. The presence of two triplets in ¹H NMR of **3a** at 4.30 ppm (³J = 6 Hz) and 4.84 ppm (³J = 6 Hz) for two methylene protons attached to



Scheme 1 Synthesis of isatin–triazole hybrids **3a** and **3b**; reagents and conditions: (i) dibromoethane (2.1 eq.), DMF, K_2CO_3 (ii) NaN_3 (1.2 eq.), DMF (iii) propargyl bromide, DMF, K_2CO_3 (iv) $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$, sodium ascorbate, EtOH : H_2O (9 : 1), rt.



Scheme 2 Synthesis of mono and bis-thiosemicarbazones (**4a–h** and **5a–h**) of isatin–triazole hybrids (**3a** and **3b**); reagents and conditions: (v) N^4 -substituted thiosemicarbazides (1.1 eq.), EtOH, rt; (vi) N^4 -substituted thiosemicarbazides (2.1 eq.), EtOH, CH_3COOH (cat.), reflux.

isatin and triazole, respectively and a singlet present downfield at 5.25 ppm for oxymethylene present next to triazole further support its formation. Similarly, two triplets for two methylene

protons attached to triazole and phenoxy ring respectively appeared at 4.45 ppm and 4.80 ppm and a singlet for the methylene that links isatin and triazole appeared downfield at

5.05 ppm supports the formation of **3b**. Finally, the presence of singlet at 9.91 ppm and 9.88 ppm, respectively for one proton integration corresponding to aldehyde proton of **3a** & **3b**, respectively confirms their formation. The ^{13}C NMR spectrum showed two characteristic signals one at 124.4 ppm and 124.0 ppm respectively and a relatively less intense signal at 142.9 ppm and 141.9 ppm respectively due to C-5 and C-4 of triazole ring further confirms the formation of 1,4-disubstituted triazole ring in **3a** & **3b**. Moreover, three signals at (40.3 ppm, 47.4 ppm, 61.6 ppm) and (35.3 ppm, 49.7 ppm, 66.3 ppm), respectively due to two carbons of ethyl linker and one carbon of $-\text{OCH}_2$ group also indicated the formation of desired products. The presence of carbonyl carbons of aldehyde and ketone at 182.9–190.6 ppm provided the final evidence for the formation of intermediates **3a** & **3b**. Finally, the peak at m/z 412 $[\text{M} + 36]^-$ for $\text{C}_{20}\text{H}_{16}\text{O}_4\text{N}_4$ in the LCMS spectrum also support the proposed structures of **3a** & **3b**.

Similarly, the presence of two signals for NH protons at 11.68 ppm and 9.98 ppm and a singlet at 8.25 ppm for the azomethine proton in ^1H NMR spectrum of representative mono-thiosemicarbazone **4f** clearly suggests the selective and successful condensation of thiosemicarbazide at aldehydic position. Moreover, a singlet at 2.30 ppm for methyl protons further confirms the formation of **4f**. In contrast to the ^1H NMR spectrum of **4f**, the bis-thiosemicarbazone **5e** shows four signals for NH protons at 12.76 ppm, 11.73 ppm, 10.89 ppm and 10.05 ppm and a singlet of azomethine proton at 8.27 ppm. In the ^{13}C NMR spectrum, an upfield signal of **4f** appeared at 142.9 ppm and two signals of **5e** observed at 143.8 ppm and 142.9 ppm corresponding to imine moieties of thiosemicarbazones strongly support the formation of mono- and bis-thiosemicarbazones **4f** and **5e** respectively. The absence of signal for aldehydic carbonyl and both aldehyde and ketone carbonyls observed in the respective starting materials and the appearance of signal for thiocarbonyl at 176.2 ppm and two signals at 176.8 and 176.1 ppm for **4f** and **5e** respectively also support the formation of desired thiosemicarbazones. The final evidence for the formation of mono- and bis-thiosemicarbazones was obtained from their LCMS data. The observation of peaks at 539 m/z and 673 m/z respectively corresponding to $[\text{M}]^-$ clearly confirms the formation of **4f** and **5e**. All the other compounds of the series are characterized in a similar manner (see Experimental section for more details).

2.3 Computational study

2.3.1 DFT studies. Obtaining the structural parameters from the optimized geometry of the synthesized molecules that lead to the information of molecular interactions is considered as preliminary step before molecular docking analyses.²² In this context, the Density Functional Theory (DFT) calculations, specifically the 6-311G (d,p) basis set at the B3LYP level were carried out.^{57–59}

The highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) are two popular quantum chemical parameters.⁶⁰ The energies of these molecular orbitals, also known as frontier molecular orbitals (FMOs),

are important parameters for predicting the reactivity of a chemical species.⁶¹ These parameters are critical in molecular reactivity, because HOMO (highest energy orbital with electrons) can act as an electron donor, while LUMO orbital serves as an electron acceptor because it has a lower energy than the other orbitals and can accept electrons.^{62,63} The energies of the HOMO and LUMO orbital values are shown in Table 1. Higher E_{HOMO} value of compound **3b** indicated the greater tendency for electron donation to a suitable acceptor molecule with a low energy and empty molecular orbital.⁶⁴ Negative E_{HOMO} and E_{LUMO} values, on the other hand, indicated the stability of the compounds under investigation.^{65,66} Quantum mechanical calculations⁶⁷ (Table 2) have been used to investigate the properties of donors and acceptors in molecules. The LUMO–HOMO energy differences were measured, demonstrating that the energy gap represents the chemical behavior of a molecule.⁶⁸ The $E_{\text{LUMO-HOMO}}$ energy gap separation was used to assess the kinetic stability of the compounds.⁶⁹ Frontier molecular orbital energies along with the energy gap between HOMO and LUMO of compounds (**3a–b**, **4a–h** and **5a–h**) is given in Table 1.

FMOs are studied in order to investigate the bioactivity and catalytic behavior of the compounds.^{17,70} According to FMO theory, both HOMO and LUMO are important factors in understanding electronic transitions, molecular reactivities, and intermolecular interactions, and thus provide insight into bioactivity.^{71–73} Furthermore, the presence of FMOs on the same side of the molecule significantly reduces biological activity.⁷⁴ The distribution patterns of FMOs (HOMOs and LUMOs) of synthesized triazole hybrids at ground states are shown in Fig. 2. The green color represents a low electron density while the red represents the high electron density.⁷⁵ The addition of substituents to benzene ring has little effect on the pi-electron cloud of HOMO and LUMO. Interestingly, the energy gap ($E_{\text{LUMO-HOMO}}$) values of the synthesized derivatives of hybrid **3b**

Table 1 FMO energy of isatin triazole hybrids (**3a** and **3b**) and their thiosemicarbazones (**4a–h** and **5a–h**)

S. No.	Compound (R)	E_{LUMO} (eV)	E_{HOMO} (eV)	ΔE (eV)
1	3a	0.73	−1.57	2.31
2	3b	0.95	−1.22	2.18
3	4a (H)	0.76	−4.91	5.68
4	4b (CH ₃)	0.78	−4.87	5.66
5	4c (NO ₂)	−0.36	−0.51	0.14
6	4d (CN)	0.52	−5.21	5.74
7	4e (H)	0.72	−3.05	3.78
8	4f (CH ₃)	0.82	−3.04	3.86
9	4g (NO ₂)	−0.24	−0.33	0.09
10	4h (CN)	0.09	−3.12	3.21
11	5a (H)	0.84	−5.01	5.85
12	5b (CH ₃)	0.48	−4.80	5.28
13	5c (NO ₂)	−1.76	−3.58	1.82
14	5d (CN)	0.68	−5.65	6.34
15	5e (H)	0.71	−3.11	3.82
16	5f (CH ₃)	0.84	−3.18	4.02
17	5g (NO ₂)	−0.03	−3.64	3.61
18	5h (CN)	0.05	−3.28	3.34

Table 2 Reactivity indices of isatin triazole hybrids (**3a** and **3b**) and their mono and bis-thiosemicarbazones (**4a–h** and **5a–h**)

S. No.	Compound	EA ^a	IP ^b	χ^c	η^d	S ^e	μ^f	ω^g
1	3a	-0.73	1.57	0.42	1.15	0.43	-0.42	-0.07
2	3b	-0.95	1.22	0.13	1.09	0.45	-0.13	0.07
3	4a	-0.76	4.91	2.07	2.84	0.17	-2.07	0.75
4	4b	-0.78	4.87	2.04	2.83	0.17	-2.04	0.73
5	4c	0.36	0.51	0.43	0.08	6.25	-0.43	1.15
6	4d	-0.52	5.21	2.34	2.87	0.17	-2.34	0.95
7	4e	-0.72	3.05	1.16	1.89	0.26	-1.16	0.35
8	4f	-0.82	3.04	1.11	1.93	0.25	-1.11	0.31
9	4g	0.24	0.33	0.28	0.04	12.5	-0.28	0.98
10	4h	-0.09	3.12	1.51	1.61	0.31	-1.51	0.70
11	5a	-0.84	5.01	2.08	2.92	0.17	-2.08	0.74
12	5b	-0.48	4.80	2.15	2.64	0.18	-2.15	0.87
13	5c	1.76	3.58	2.67	0.91	0.54	-2.67	3.91
14	5d	-0.68	5.65	2.48	3.17	0.15	-2.48	0.97
15	5e	-0.71	3.12	1.20	1.91	0.26	-1.20	0.37
16	5f	-0.84	3.18	1.17	2.01	0.24	-1.17	0.34
17	5g	0.03	3.64	1.83	1.80	0.27	-1.83	0.93
18	5h	-0.05	3.28	1.61	1.67	0.29	-1.61	0.77

^a Electron affinity. ^b Ionization Energy. ^c Electronegativity. ^d Chemical hardness. ^e Chemical softness. ^f Chemical potential. ^g Electrophilicity.

differ only slightly, with all derivatives falling within the range of 0.09–4.02 eV while those for hybrid **3a** derivatives lies in the range of 0.14–6.34 eV. Results showed that incorporating nitro substituents on the phenyl ring lowers the energy separation gap ($E_{\text{LUMO-HOMO}}$). In fact, nitro compounds **4c**, **4g** and **5c** (0.14, 0.09, 1.82 eV, respectively) are found to be the lowest among all the synthesized derivatives (see Table 1). The lower $E_{\text{LUMO-HOMO}}$ corresponds to the greater the biological potential,¹⁷ by increasing the chemical reactivity and catalytic activity of these synthesized hybrids. Recent studies indicated that molecules with an FMO energy gap of less than 2.5 eV are more likely to bind to specific protein targets.⁷⁶ Herein, compounds **3b**, **4c**, **4g** and **5c** displayed the FMO energy gap of less than 2.2 eV as

shown in Fig. 2, hence expected to show the best binding interactions with the biological targets.

Beside the evaluation of quantum chemical parameters⁷⁷ *i.e.* frontier molecular orbitals and separation energies ΔE_{gap} ; global reactivity descriptors⁷⁸ such as ionization potentials ($\text{IP} = -E_{\text{HOMO}}$), electron affinity ($\text{EA} = -E_{\text{LUMO}}$), electronegativities [$\chi = (\text{IP} + \text{EA})/2$], chemical potentials ($\mu = -\chi$), chemical hardness [$\eta = (\text{IP} - \text{EA})/2$], chemical softness ($S = 1/2\eta$), global electrophilicity or electrophilicity index ($\omega = \mu^2/2\eta$) have also been calculated.^{79–82} Chemical descriptors are used to analyze drug properties and interactions with biological targets.^{83–85} Results showed that chemically harder and more stable molecules have a larger LUMO–HOMO energy gap than softer and less stable molecules.⁶² It was also observed that chemically reactive molecules showed greater chemical potential.⁸⁶ The lower LUMO value corresponds to the higher electron acceptance ability,⁸⁷ and the compound **5c** showed the highest electron affinity value among the series (Table 2). Similarly, the higher HOMO value corresponds to the higher electron donor ability,⁸⁸ and the compound **4g** displayed the least value of ionization potential, thus indicating the highest electron donor ability of the compound among the synthesized derivatives (Table 2).

Electronegativity refers to a ligand's ability to bind to a protein, which is important for successful binding.⁸⁹ A direct relationship was observed between electronegativity values (χ) values and tendency to accept electrons *i.e.* electron affinity (Table 2). Results showed that compound **5c** (bisthiosemicarbazone having two nitro substituents) (Table 2) displayed the highest electronegativity value, thus making it more susceptible to accept electrons, through the electron withdrawing effect, hence showing its higher catalytic ability and binding affinity with the target protein.^{90–92}

The electrophilicity index (ω) indicates the compound's ability to interact with electron-rich sites of biological targets and measures the tendency to accept electrons from the environment.⁹³ The most stable compound is the one with a low

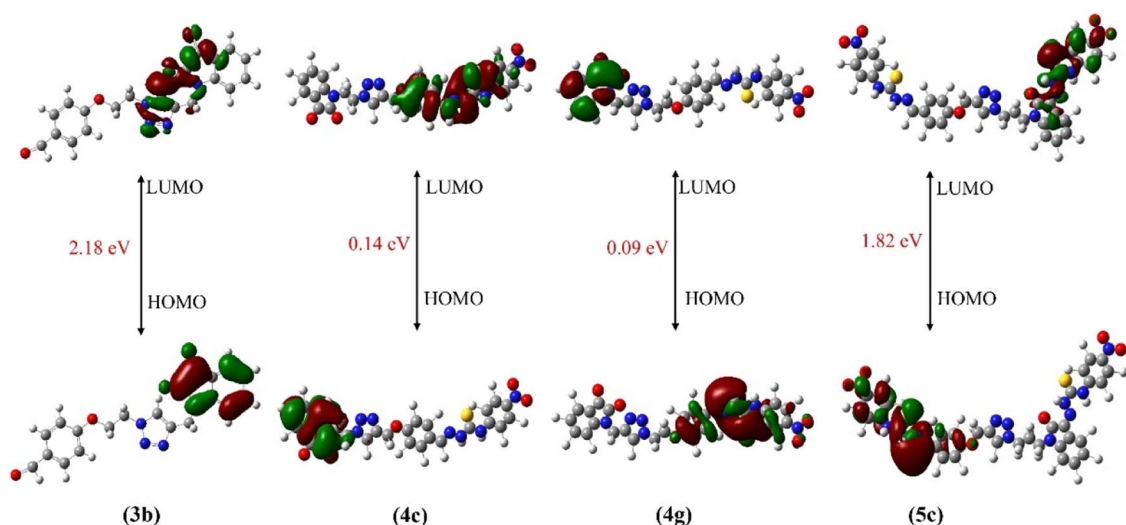


Fig. 2 HOMO and LUMO of **3b**, **4c**, **4g** and **5c**.

electrophilicity value *i.e.* **3a** among the studied substrates (Table 2). As we moved from electron donating to electron withdrawing substituents in the substrate, the electrophilicity index value increased. Compound **5c** having the *p*-nitro substituent displayed the highest electrophilicity index value and is found to be the most reactive among the series (Table 2), thus showed greater potential to bind with the biological target. Compounds with a higher electrophilicity index value are more reactive and less stable, whereas compounds with a lower electrophilicity index value are more stable and less reactive.⁹⁴ Furthermore, lower chemical potential (μ) value makes a substituent more electrophilic (electron-seeking), and in this case, the value for the compound **5c** having the *p*-nitro substituent is the lowest *i.e.* -2.67 eV among the series (Table 2).

Hardness refers to a resistance of compound to electron donation or acceptance and plays an important role in water solubility.⁸⁹ Overall range of global hardness (η) was found to be 0.04 – 0.17 eV while the hardest character was shown by the compound **5d** within the series (Table 2). Softness, the inverse of hardness, refers to a compound's ability to donate or accept electrons, as well as their reactivity with biological targets.⁹⁵ Considering the soft nature of the synthesized compounds, the compound **4g** having nitro substituent showed the highest value of chemical softness (S) (Table 2). Compound **4g** being the most reactive compound among the series (Table 2), appeared as a favorable candidate for efficient applications in different synthetic routes and further theoretical calculations, possibly due to the extended conjugation and electron withdrawing nature of nitro group. Moreover, the lowest hardness (η) and the highest softness (S) value of compound **4g** (Table 2) indicate that it is less likely to undergo rapid structural changes during binding, which is crucial for stable protein interactions. Concludingly, the DFT studies provided comprehensive analysis of theoretical structure stability and mechanistic explanations of chemical properties of the synthesized compounds for their ability to interact with biological targets.

2.3.2 Molecular docking studies. Molecular docking provides a theoretical direction for visual representation of the binding characteristics of the ligand molecule to the protein under study, as well as guidelines for further exploration and validation of experimental data.^{96,97} It is a convenient predictive tool in drug discovery which assess in computer-aided drug designing.⁹⁸ The molecular docking study was carried out using the AutoDock Vina software package,⁹⁹ for the selected compounds **3b**, **4c**, **4g** and **5c** having ΔE_{gap} less than 2.2 eV as indicated by the DFT results based on the optimised structures of the synthesized thiosemicarbazones of isatin-triazole hybrids.

PASS online (prediction of activity of spectra for substances)¹⁰⁰ predicted the profound anticancer potential of synthesized thiosemicarbazones of isatin triazole hybrids. Phosphoinositide 3-kinase PI3K protein was chosen for this study because of its well-known roles in regulating cell growth and survival, particularly in cancer.^{89,101} The selected active site of the PI3K inhibitor of PDB ID (4TV3)^{102,103} was downloaded from RCSB¹⁰⁴ protein data bank. The structure of desired PI3K protein was prepared for docking using AutoDock Tools.^{105,106}

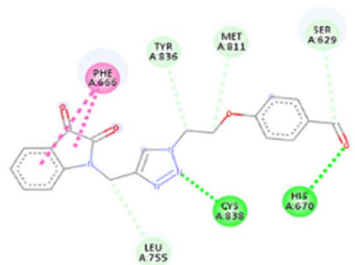
The primary goal of the molecular docking studies was to evaluate the binding potential of the synthesized compounds as well as molecular interaction with various amino acid residues of the membrane protein PI3K. The Autodock Vina 1.5.7 (ref. 99) was used to obtain docking simulations and the visualization of protein-ligand complex was performed using the Discovery Studio.¹⁰⁷ The most stable anchoring conformations having the lowest binding energy values, as well as interacting residues were visualized through three-dimensional and two-dimensional models, as depicted in Fig. 3, which were created using the Discovery Studio Visualizer.¹⁰⁸ It has been demonstrated that receptors have active sites that are capable to behave both as hydrogen bond donor and acceptor as well.⁷⁵

The 2D representation in Fig. 3 helps to clearly visualize the types of interactions including hydrophobic interactions, hydrogen bonding, donor atoms, acceptor atoms, and π - π stacking interactions between the studied compounds and the cancer protein's active sites. Table 3 shows the binding energy of enzymes on the ligand, hydrostatic interactions, and hydrogen bonding in the selective host-guest systems. Results displayed the following decreasing order of binding affinity score for the studied compounds **5c** > **4g** > **4c** > **3b** (Table 3).

Among the selected compounds, the compound **5c** having two nitro substituents displayed the highest binding energy score of -10.3 kcal mol⁻¹. The amino His 670(A), Met 811(A), Ile 633(A), Leu 632(A), Cys 838(A) formed hydrogen bonding with the nitrogen of $-NH$ of thiosemicarbazones and oxygen of nitro substituents in compound **5c** (Fig. 3). Moreover, carbon-hydrogen bond formation was observed with Gly 837(A) and the amino acids Glu 172(A), Glu 821(A) showed π -sulphur and π -anion interactions with the ligand and the amino acid Phe 666(A) formed π -alkyl and π - π stacking interactions with the benzene ring. Similarly, the compound **4g** which is 4-nitro substituted mono-thiosemicarbazone derivative of isatin triazole hybrid **3b** displayed the second best binding score of -8.9 kcal mol⁻¹, alongwith several binding interactions such as hydrogen bonding of carbonyl oxygen of isatin, nitrogen of 1,2,3-triazole and $-NH$ of thiosemicarbazone moiety with the Lys 548(A), Asn 575(A), Tyr 361(A) residues respectively (Table 3). Furthermore, carbon hydrogen bond, π -alkyl and salt bridge interactions with the active site residues of PI3K protein were also depicted in 2D model (Fig. 3) of compound **4g**.

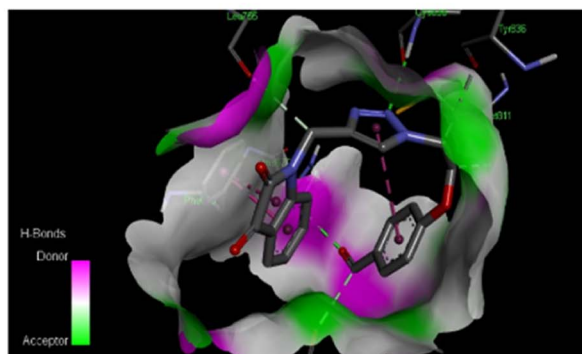
The docking scores suggested that isatin-triazole hybrid **3b** posses lesser binding affinity with target protein, as compared to its 4-nitro substituted mono-thiosemicarbone derivative **4g**. While the 4-nitro substituted bis-thiosemicarbone derivative **5c** displayed even superior binding affinity with the target protein. These results reveal the importance of substitution on benzene ring and presence of thiosemicarbazone scaffold on the isatin-triazole hybrid for enhanced binding interaction of the drug molecules which is also supported by the literature.^{22,109} Molecular docking results are in good agreement with the findings of DFT analyses and these computational explanations suggested that the synthesized thiosemicarbazones of isatin-triazole hybrids may act against PI3K as anti-cancer agents.

3b

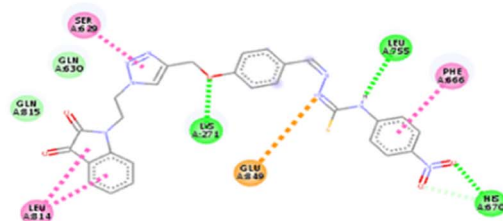


Interactions

- Conventional Hydrogen Bond
- Carbon Hydrogen Bond
- Pi-Pi Stacked

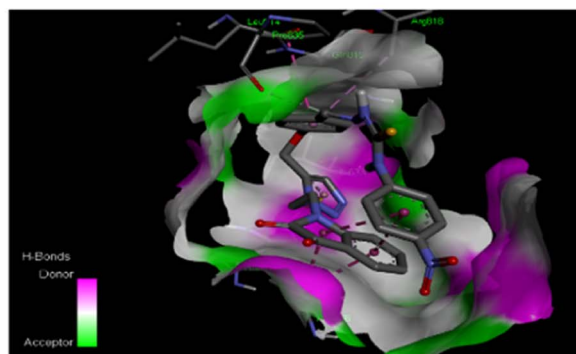


4c

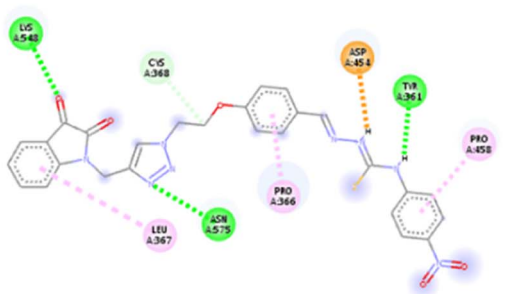


Interactions

- van der Waals
- Attractive Charge
- Conventional Hydrogen Bond
- Carbon Hydrogen Bond
- Pi-Pi Stacked
- Amide-Pi Stacked
- Pi-Alkyl

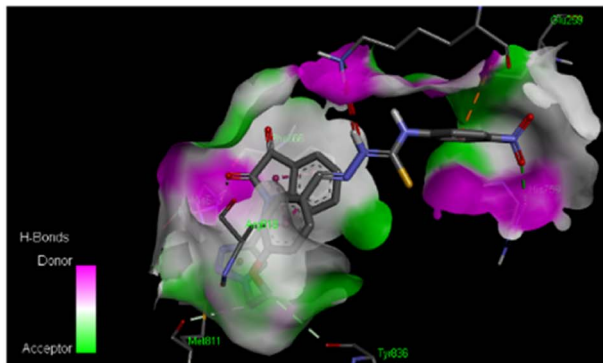


4g

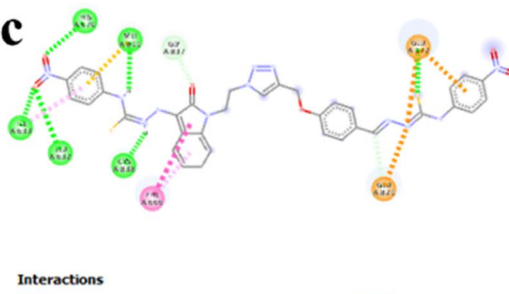


Interactions

- Salt Bridge
- Conventional Hydrogen Bond
- Carbon Hydrogen Bond
- Pi-Alkyl



5c



Interactions

- Attractive Charge
- Conventional Hydrogen Bond
- Carbon Hydrogen Bond
- Pi-Sulfur
- Pi-Pi Stacked
- Pi-Alkyl
- Pi-Anion

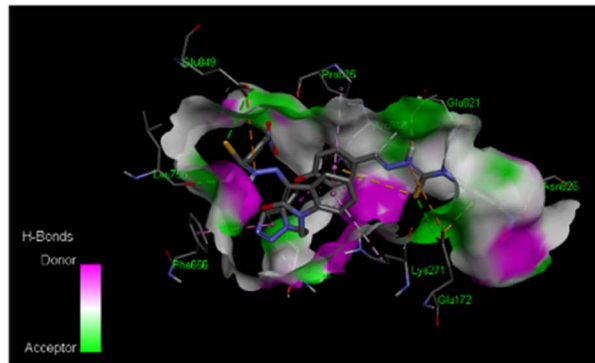


Fig. 3 Diagrammatic representation of molecular interactions of the ligand molecules (3b, 4c, 4g and 5c) with various amino acid residues in the binding pocket of the protein PI3K.

Table 3 The interaction analysis of the PI3K protein on the basis of molecular docking studies with the mono and bis-thiosemicarbazones of isatin-triazole hybrids

S. No.	Drug name (ligand)	Binding energy (kcal mol ⁻¹)	Hydrogen bond interaction	Hydrostatic interaction with amino acids
1	3b	-8.3	Cys 838(A), His 670(A), Ser 629(A), Met 811(A), Tyr 836(A)	Leu 755(A), Phe 666(A)
2	4c	-8.6	Gln 630 (A), Gln 815 (A), Lys 271 (A), Leu 755 (A), His 670 (A)	Phe 666(A), Leu 814(A), Glu 849 (A), Ser 629 (A)
3	4g	-8.9	Lys 548(A), Asn 575(A), Tyr 361(A)	Leu 367(A), Cys 368(A), Pro 366(A), Asp 454(A), Pro 458(A)
4	5c	-10.3	His 670(A), Met 811(A), Ile 633(A), Leu 632(A), Cys 838(A)	Phe 666(A), Gly 837(A), Glu 172(A), Glu 821(A)

3. Conclusions

A series of mono- and bis-thiosemicarbazones have been synthesized starting from two novel isatin-triazole hybrid intermediates, in turn obtained through the Cu(I)-sodium ascorbate catalysed click reaction, in excellent yield. All the synthesized compounds are characterized by their spectral (FT-IR, ¹H & ¹³C NMR, LCMS) and analytical data. The DFT studies carried out on these compounds showed that the compound **5c** (4-nitro-substituted bis-thiosemicarbazone) exhibited the highest electron affinity, electronegativity and electrophilicity index values among the series, hence exhibiting the greater potential to bind with the target protein. The outcome of DFT studies was further validated by molecular docking analysis against the active sites of the phosphoinositide 3-kinases (PI3Ks), indicating the potential of compound **5c** (block the active site of targeted enzyme with the lowest binding score of -10.3 kcal mol⁻¹) to be studied as an anticancer agent.

4. Experimental

4.1 Chemicals and materials

The used chemicals and materials were supplied as ESI.†

4.2 Computational details

The molecular structure of all the synthesized compounds were optimized using Gaussian 09 Package.¹¹⁰ The optimized structures were used to calculate the electronic properties of the synthesized compounds. The frontier molecular orbitals HOMO and LUMO alongwith other descriptors were calculated using Gauss View to understand the effect of substituents on the reactivity of compounds. For molecular docking studies the Autodock Vina 1.5.7 (ref. 99) was used for docking simulations, and the Discovery Studio¹⁰⁷ was used for visualization.

4.3 Synthesis of 4-((1-(2-(2,3-dioxindolin-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)-methoxy)benzaldehyde (3a)

For the synthesis of **3a**, the reported conditions⁵⁵ of the click reaction were employed. In a stirred solution of the 1-(2-azidoethyl)isatin **1a** (0.10 g, 0.46 mmol) and 4-(prop-2-ynoxy)benzaldehyde **2a** (0.07 g, 0.46 mmol) in 10 mL ethanol:water (9:1), addition of copper sulphate (0.00625 g, 0.025 mmol) was followed by sodium ascorbate (0.013 g, 0.066 mmol) addition at room temperature. Upon the completion of the reaction, as indicated by the TLC (*n*-hexane: EtOAc, 1:1), ice-cold water was added to the reaction mixture and the precipitates formed were filtered out and dried. Recrystallization from ethanol was performed to obtain the purified product.

Appearance: bright orange solid; yield: 89%; melting point: 157–160 °C; *R*_f: 0.53 (*n*-hexane: EtOAc, 1:1); FT-IR $\bar{\nu}$ (cm⁻¹): 3129, 3049 (C_{sp}²-H stretch), 2928, 2873 (C_{sp}³-H stretch), 2823, 2724 (C_{sp}²-H stretch, aldehyde), 1731 (C=O stretch, ketone), 1692 (C=O stretch, aldehyde), 1598 (C=O stretch, lactam), 1509 (C=C stretch, aromatic ring), 1471 (C_{sp}³-H bend, methylene), 1258 (C_{sp}²-O stretch, ether), 1217 (C-N stretch, lactam), 1160 (C_{sp}³-O stretch, ether), 810 (C-H bend, 1,4-disubstitution),

754 (C–H bend, 1,2-disubstitution); ^1H NMR (300 MHz, CDCl_3) δ (ppm): 9.91 (s, 1H, –CHO), 8.25 (s, 1H, triazole-H), 7.88 (d, $^3J = 8.7$ Hz, 2H, Ar–H), 7.52 (d, $^3J = 7.3$ Hz, 1H, Ar–H), 7.43 (t, $^3J = 7.5$ Hz, 1H, Ar–H), 7.10–7.04 (t, 1H, $^3J = 7.3$ Hz, Ar–H), 7.06–7.03 (d, 2H, $^3J = 8.7$ Hz, Ar–H), 6.84 (d, $^3J = 7.9$ Hz, 1H, Ar–H), 5.25 (s, 2H, –OCH₂), 4.84 (t, $^3J = 6$ Hz, 2H, –CH₂-triazole), 4.30 (t, $^3J = 6$ Hz, 2H, –CH₂-isatin); ^{13}C NMR (75 MHz, CDCl_3) δ (ppm): 190.3 (C=O aldehyde), 182.9 (C=O ketone), 163.3, 158.1 (C=O lactum), 150.6, 142.9 (C-5 triazole), 138.1, 131.6, 130.4, 125.0, 124.4 (C-4 triazole), 123.4, 117.6, 115.1, 109.9, 61.6 (–CH₂ phenoxy), 47.4 (–CH₂ triazole), 40.3 (–CH₂ isatin); LC-MS m/z 412 [$\text{M} + 36$]; anal. calcd for $\text{C}_{20}\text{H}_{16}\text{N}_4\text{O}_4$: C, 63.83; H, 4.29; N, 14.89; O, 17.00; found: C, 63.98; H, 4.15; N, 14.93.

4.4 Synthesis of 4-(2-(4-((2,3-dioxindolin-1-yl)methyl)-1H-1,2,3-triazol-1-yl)-ethoxy)-benzaldehyde (3b)

For the synthesis of **3b**, reported reaction conditions for click reaction were utilized. Copper sulphate (0.04 g, 0.16 mmol) and sodium ascorbate (0.08 g, 0.23 mmol) were added in succession, to the stirred solution of previously synthesized 1-(prop-2-ynyl) indoline-2,3-dione **1b** (0.20 g, 1.08 mmol) and 4-(2-azidoethoxy)benzaldehyde **2b** (0.21 g, 1.08 mmol) in 10 mL ethanol: water (9 : 1) at room temperature. Progress of reaction was monitored by TLC (*n*-hexane: EtOAc, 1 : 1). After the reaction completion, ice cold water (15 mL) was added to the reaction mixture and the precipitates formed were filtered off, dried and recrystallized from ethanol to obtain the pure product.

Appearance: orange solid; yield: 85%; melting point: 168–170 °C; R_f : 0.52 (*n*-hexane: EtOAc, 1 : 1); FT-IR $\bar{\nu}$ (cm^{-1}): 3141, 3031 (C_{sp^2} -H stretch), 2970, 2942 (C_{sp^3} -H stretch), 2847, 2759 (C_{sp^2} -H stretch, aldehyde), 1728 (C=O stretch, ketone), 1673 (C=O stretch, aldehyde), 1600 (C=O stretch, lactam), 1508 (C=C stretch, aromatic), 1469 (C_{sp^3} -H bend, methylene), 1244 (C_{sp^2} -O stretch, ether), 1213 (C–N stretch, lactam), 1159 (C_{sp^3} -O stretch, ether), 831 (C–H bend, 1,4-disubstitution), 755 (C–H bend, 1,2-disubstitution); ^1H NMR (300 MHz, CDCl_3) δ (ppm): 9.88 (s, 1H, –CHO), 7.85 (s, 1H, triazole-H), 7.81 (d, $^3J = 7.5$ Hz, 2H, Ar–H), 7.57 (m, 2H, Ar–H), 7.31 (d, $^3J = 8.1$ Hz, 2H, Ar–H), 7.11 (t, $^3J = 7.5$ Hz, 1H, Ar–H), 6.95 (d, $^3J = 8.7$ Hz, 2H, Ar–H), 5.03 (s, 2H, –CH₂-isatin), 4.80 (t, $^3J = 4.2$ Hz, 2H, –CH₂-triazole), 4.45 (t, $^3J = 4.2$ Hz, 2H, –OCH₂); ^{13}C NMR (75 MHz, CDCl_3) δ (ppm): 190.6 (C=O aldehyde), 183.0 (C=O ketone), 162.4, 157.9 (C=O lactum), 150.1, 141.9 (C-5 triazole), 138.6, 132.0, 130.7, 125.3, 124.2 (C-4 triazole), 124.0, 117.5, 114.7, 111.4, 66.3 (–CH₂ phenoxy), 49.7 (–CH₂ triazole), 35.3 (–CH₂ isatin); LC-MS m/z 412 [$\text{M} + 36$]; anal. calcd for $\text{C}_{20}\text{H}_{16}\text{N}_4\text{O}_4$: C, 63.83; H, 4.29; N, 14.89; O, 17.00; found: C, 63.92; H, 4.41; N, 14.74.

4.5 General procedure for the synthesis of isatin–triazole derived mono-thiosemicarbazones (4a–h)

For the synthesis of mono-thiosemicarbazones **4a–h** of two different types of isatin–triazole hybrids **3a** and **3b**, same procedure was followed. To the stirred ethanolic solution of isatin–triazole hybrid (0.1 g, 0.27 mmol), suitable *N*¹-substituted thiosemicarbazide **3c** (1.1 eq., 0.30 mmol) was added under vigorous stirring. The reaction was carried out at room

temperature for 6 hours and progress of reaction was monitored after regular intervals by TLC (*n*-hexane: ethyl acetate 7 : 3). The precipitates formed upon completion, were filtered, washed, dried and recrystallized when required to obtain the pure product.

By following the above procedure, a series of mono-thiosemicarbazone derivatives **4a–h** having different thiosemicarbazide moieties were synthesized.

4.5.1 1-((4-((1-(2-(2,3-Dioxindolin-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy) phenyl)methylene)-4-phenylthiosemicarbazide (4a). Appearance: orange-yellow solid; yield: 75%; melting point: 215–218 °C; R_f : 0.52 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1737 (C=O stretch, ketone), 1600 (C=O stretch, lactam), 1525 (C=N stretch, imine), 1508 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1274 (C_{sp^2} -O stretch, ether), 1201 (C–N stretch, lactam), 1165 (C_{sp^3} -O stretch, ether), 833 (C–H bend, 1,4-disubstitution), 755 (C–H bend, 1,2-disubstitution); ^1H NMR (300 MHz, DMSO-*d*₆) δ (ppm): 11.82 (s, 1H, –NH), 9.98 (s, 1H, –NH), 8.38 (s, 1H, –CH=N), 7.36 (s, 1H, –CH triazole), 8.37–6.89 (m, 13H, Ar–H), 5.13 (s, 2H, –CH₂ isatin), 4.71 (t, 2H, $^3J = 6$ Hz, –OCH₂), 4.14 (t, 2H, $^3J = 6$ Hz, –CH₂ triazole); ^{13}C NMR (75 MHz, DMSO-*d*₆) δ (ppm): 183.4, 161.8 (C=S), 160.2, 158.6, 150.6, 149.6, 142.9 (C=N azomethine), 139.7, 138.6, 129.6, 129.4, 127.3, 125.9, 124.9, 124.1, 123.7, 117.8, 115.5, 110.7, 61.6, 47.4, 35.4; LC-MS m/z 525 [M^-]; anal. calcd for $\text{C}_{27}\text{H}_{23}\text{N}_7\text{O}_3\text{S}$: C, 61.70; H, 4.41; N, 18.66; found: C, 61.63; H, 4.29; N, 18.77.

4.5.2 1-((4-((1-(2-(2,3-Dioxindolin-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy) phenyl)methylene)-4-*p*-tolylthiosemicarbazide (4b). Appearance: yellow solid; yield: 79%; melting point: 196–198 °C; R_f : 0.46 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1731 (C=O stretch, ketone), 1612 (C=O stretch, lactam), 1541 (C=N stretch, imine), 1506 (C=C stretch, aromatic ring), 1469 (C_{sp^3} -H bend, methylene), 1271 (C_{sp^2} -O stretch, ether), 1214 (C–N stretch, lactam), 1170 (C_{sp^3} -O stretch, ether), 815 (C–H bend, 1,4-disubstitution), 756 (C–H bend, 1,2-disubstitution); ^1H NMR (300 MHz, DMSO-*d*₆) δ (ppm): 11.68 (s, 1H, –NH), 9.98 (s, 1H, –NH), 8.25 (s, 1H, –CH=N), 8.07 (s, 1H, –CH triazole), 7.81–6.89 (m, 12H, Ar–H), 4.97 (s, 2H, –CH₂ isatin), 4.74 (t, 2H, $^3J = 6$ Hz, –OCH₂), 4.42 (t, 2H, $^3J = 6$ Hz, –CH₂ triazole), 2.31 (s, 3H, –CH₃); ^{13}C NMR (75 MHz, DMSO-*d*₆) δ (ppm): 183.5, 176.2 (C=S), 159.7, 158.2, 150.6, 142.9 (C=N azomethine), 141.9, 138.5, 137.0, 134.8, 129.7, 129.3, 128.9, 127.5, 126.3, 124.9, 124.7, 123.8, 118.0, 115.4, 115.1, 111.6, 66.6, 49.5, 35.4, 21.0 (CH₃); LC-MS m/z 539 [M^-]; anal. calcd for $\text{C}_{20}\text{H}_{16}\text{N}_4\text{O}_4$: C, 63.83; H, 4.29; N, 14.89; found: C, 63.88; H, 4.17; N, 14.96.

4.5.3 1-((4-((1-(2-(2,3-Dioxindolin-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy) phenyl)methylene)-4-(4-nitrophenyl)thiosemicarbazide (4c). Appearance: yellow solid; yield: 76%; melting point: 220–221 °C; R_f : 0.43 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1732 (C=O stretch, ketone), 1683 (C=O stretch, lactam), 1600 (C=N stretch, imine), 1543 (N–O stretch, asymmetric, nitro), 1506 (C=C stretch, aromatic ring),

1465 (C_{sp^3} -H bend, methylene), 1328 (N-O stretch, symmetric, nitro), 1249 (C_{sp^2} -O stretch, ether), 1203 (C-N stretch, lactam), 1166 (C_{sp^3} -O stretch, ether), 831 (C-H bend, 1,4-disubstitution), 758 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.03 (s, 1H, -NH), 9.98 (s, 1H, -NH), 8.42–6.87 (m, 15H, CH=N, -CH triazole, Ar-H), 5.15 (s, 2H, -CH₂ isatin), 4.68 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.14 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.4, 161.7 (C=S), 160.2, 158.6, 150.6, 149.6, 142.9 (C=N azomethine), 139.6, 138.6, 129.6, 129.4, 127.4, 125.9, 124.9, 124.1, 123.7, 117.8, 115.5, 110.6, 61.6, 47.4, 35.4; LC-MS m/z 570 [M^-]; anal. calcd for C₂₇H₂₂N₈O₅S: C, 56.84; H, 3.89; N, 19.64; found: C, 56.78; H, 3.69; N, 19.47.

4.5.4 4-(4-Cyanophenyl)-1-((4-((1-(2-(2,3-dioxindolin-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy)phenyl)methylene)thiosemicarbazide (4d). Appearance: bright yellow solid; yield: 82%; melting point: 236–238 °C; R_f : 0.41 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm⁻¹): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 2250 (C≡N stretch, cyano) 1735 (C=O stretch, ketone), 1606 (C=O stretch, lactam), 1537 (C=N stretch, imine), 1510 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1249 (C_{sp^2} -O stretch, ether), 1195 (C-N stretch, lactam), 1169 (C_{sp^3} -O stretch, ether), 837 (C-H bend, 1,4-disubstitution), 752 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 11.68 (s, 1H, -NH), 9.99 (s, 1H, -NH), 8.29–6.89 (m, 14H, -CH=N, -CH triazole Ar-H), 4.97 (s, 2H, -CH₂ isatin), 4.74 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.42 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.5, 176.2 (C=S), 159.7, 158.2, 150.6, 142.9 (C=N azomethine), 141.9, 138.5, 137.0, 134.8, 129.7, 129.3, 128.9, 127.5, 126.3, 124.9, 124.7, 123.8, 118.0 (C≡N), 115.4, 115.1, 111.6, 66.6, 49.5, 35.4; LC-MS m/z 550 [M^-]; anal. calcd for C₂₈H₂₂N₈O₃S: C, 61.08; H, 4.03; N, 20.35; found: C, 60.97; H, 3.89; N, 20.18.

4.5.5 1-((4-(2-(4-((2,3-Dioxindolin-1-yl)methyl)-1H-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-phenylthiosemicarbazide (4e). Appearance: yellow solid; yield: 83%; melting point: 202–204 °C; R_f : 0.52 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm⁻¹): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1737 (C=O stretch, ketone), 1600 (C=O stretch, lactam), 1525 (C=N stretch, imine), 1508 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1274 (C_{sp^2} -O stretch, ether), 1201 (C-N stretch, lactam), 1165 (C_{sp^3} -O stretch, ether), 833 (C-H bend, 1,4-disubstitution), 755 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 11.82 (s, 1H, -NH), 9.98 (s, 1H, -NH), 8.38 (s, 1H, -CH=N), 7.36 (s, 1H, -CH triazole), 8.37–6.89 (m, 13H, Ar-H), 5.13 (s, 2H, -CH₂ isatin), 4.71 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.14 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.4, 161.8 (C=S), 160.2, 158.6, 150.6, 149.6, 142.9 (C=N azomethine), 139.7, 138.6, 129.6, 129.4, 127.3, 125.9, 124.9, 124.1, 123.7, 117.8, 115.5, 110.7, 61.6, 47.4, 35.4; LC-MS m/z 525 [M^-]; anal. calcd for C₂₇H₂₃N₇O₃S: C, 61.70; H, 4.41; N, 18.66; found: C, 61.56; H, 4.32; N, 18.43.

4.5.6 1-((4-(2-(4-((2,3-Dioxindolin-1-yl)methyl)-1H-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-*p*-tolylthiosemicarbazide (4f). Appearance: yellow solid; yield: 85%;

melting point: 207–209 °C; R_f : 0.46 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm⁻¹): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1731 (C=O stretch, ketone), 1612 (C=O stretch, lactam), 1541 (C=N stretch, imine), 1506 (C=C stretch, aromatic ring), 1469 (C_{sp^3} -H bend, methylene), 1271 (C_{sp^2} -O stretch, ether), 1214 (C-N stretch, lactam), 1170 (C_{sp^3} -O stretch, ether), 815 (C-H bend, 1,4-disubstitution), 756 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 11.68 (s, 1H, -NH), 9.98 (s, 1H, -NH), 8.25 (s, 1H, -CH=N), 8.07 (s, 1H, -CH triazole), 7.81–6.89 (m, 12H, Ar-H), 4.97 (s, 2H, -CH₂ isatin), 4.74 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.42 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole), 2.31 (s, 3H, -CH₃); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.5, 176.2 (C=S), 159.7, 158.2, 150.6, 142.9 (C=N azomethine), 141.9, 138.5, 137.0, 134.8, 129.7, 129.3, 128.9, 127.5, 126.3, 124.9, 124.7, 123.8, 118.0, 115.4, 115.1, 111.6, 66.6, 49.5, 35.4, 21.0 (CH₃); LC-MS m/z 539 [M^-]; anal. calcd for C₂₈H₂₅N₇O₃S: C, 62.32; H, 4.67; N, 18.17; found: C, 62.13; H, 4.51; N, 18.01.

4.5.7 1-((4-(2-(4-((2,3-Dioxindolin-1-yl)methyl)-1H-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-(4-nitrophenyl)thiosemicarbazide (4g). Appearance: bright yellow solid; yield: 79%; melting point: 221–223 °C; R_f : 0.43 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm⁻¹): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1732 (C=O stretch, ketone), 1683 (C=O stretch, lactam), 1579 (C=N stretch, imine), 1556 (N-O stretch, asymmetric, nitro), 1508 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1354 (N-O stretch, symmetric, nitro), 1244 (C_{sp^2} -O stretch, ether), 1219 (C-N stretch, lactam), 1165 (C_{sp^3} -O stretch, ether), 831 (C-H bend, 1,4-disubstitution), 758 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.03 (s, 1H, -NH), 9.98 (s, 1H, -NH), 8.42–6.87 (m, 14H, CH=N, -CH triazole, Ar-H), 5.15 (s, 2H, -CH₂ isatin), 4.68 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.14 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.4, 161.7 (C=S), 160.2, 158.6, 150.6, 149.6, 142.9 (C=N azomethine), 139.6, 138.6, 129.6, 129.4, 127.4, 125.9, 124.9, 124.1, 123.7, 117.8, 115.5, 110.6, 61.6, 47.4, 35.4; LC-MS m/z 570 [M^-]; anal. calcd for C₂₇H₂₂N₈O₅S: C, 56.84; H, 3.89; N, 19.64; found: C, 56.65; H, 3.71; N, 19.66.

4.5.8 1-((4-(2-(4-((2,3-Dioxindolin-1-yl)methyl)-1H-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-(4-cyanophenyl)thiosemicarbazide (4h). Appearance: yellow solid; yield: 87%; melting point: 226–228 °C; R_f : 0.41 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm⁻¹): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 2250 (C≡N stretch, cyano) 1737 (C=O stretch, ketone), 1600 (C=O stretch, lactam), 1525 (C=N stretch, imine), 1508 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1274 (C_{sp^2} -O stretch, ether), 1201 (C-N stretch, lactam), 1165 (C_{sp^3} -O stretch, ether), 833 (C-H bend, 1,4-disubstitution), 755 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 11.68 (s, 1H, -NH), 9.99 (s, 1H, -NH), 8.29–6.89 (m, 14H, -CH=N, -CH triazole Ar-H), 4.97 (s, 2H, -CH₂ isatin), 4.74 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.42 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.5, 176.2 (C=S), 159.7, 158.2, 150.6, 142.9 (C=N azomethine), 141.9, 138.5, 137.0, 134.8, 129.7, 129.3, 128.9, 127.5, 126.3, 124.9, 124.7, 123.8, 118.0 (C≡N), 115.4, 115.1, 111.6,

66.6, 49.5, 35.4; LC-MS m/z 550 [M^-]; anal. calcd for $C_{28}H_{22}N_8O_3S$: C, 61.08; H, 4.03; N, 20.35; found: C, 60.86; H, 3.93; N, 20.54.

4.6 General procedure for the synthesis of isatin-triazole derived bis-thiosemicarbazones (5a-h)

To the stirred solution of isatin-triazole hybrids **3a** & **3b** (0.1 g, 0.27 mmol) respectively in ethanol, suitable N^1 -substituted thiosemicarbazide **3c** (2.1 eq., 0.56 mmol) was added under vigorous stirring. The reaction was carried out for 6 hours heating under reflux and progress of reaction was monitored after regular intervals by TLC (*n*-hexane: EtOAc, 7 : 3). The precipitates formed upon completion, were filtered, washed, dried and recrystallized when required to give the pure product. By following this procedure, a series of bis-thiosemicarbazone derivatives **5a-h** of isatin-triazole hybrids **3a** & **3b** having different thiosemicarbazide moieties were synthesized.

4.6.1 1-((4-((1-(2-(Indolin-3(4-phenylthiosemicarbazone)-2-one-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy)phenyl)methylene)-4-phenylthiosemicarbazide (5a). Appearance: orange yellow solid; yield: 79%; melting point: 202–204 °C; R_f : 0.52 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1600 (C=O stretch, lactam), 1544, 1525 (C=N stretch, imine), 1487 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1249 (C_{sp^2} -O stretch, ether), 1192 (C–N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 827 (C–H bend, 1,4-disubstitution), 746 (C–H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.56 (s, 1H, –NH), 11.73 (s, 1H, –NH), 10.88 (s, 1H, –NH), 10.05 (s, 1H, –NH), 8.29 (s, 1H, –CH=N), 8.11 (s, 1H, –CH triazole), 7.86–6.98 (m, 16H, Ar–H), 5.13 (s, 2H, –OCH₂), 4.73 (t, 2H, $^3J = 6$ Hz, –CH₂-triazole), 4.25 (t, 2H, $^3J = 6$ Hz, –CH₂-isatin); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 183.3, 176.8 (C=S), 176.1 (C=S), 161.3, 160.1, 150.6, 143.2 (C=N imine), 142.9 (C=N azomethine), 139.5, 138.9, 131.7, 129.7, 128.9, 128.5, 127.3, 126.6, 126.3, 124.9, 123.7, 123.4, 121.6, 119.6, 117.8, 115.3, 110.7, 110.1, 61.5, 49.5, 35.1; LC-MS m/z 674 [M^-]; anal. calcd for $C_{34}H_{30}N_{10}O_2S_2$: C, 60.52; H, 4.48; N, 20.76; found: C, 60.41; H, 4.25; N, 20.81.

4.6.2 1-((4-((1-(2-(Indolin-3(*p*-tolylthiosemicarbazone)-2-one-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy)phenyl)methylene)-*p*-tolylthiosemicarbazide (5b). Appearance: yellow solid; yield: 82%; melting point: 207–209 °C; R_f : 0.54 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1610 (C=O stretch, lactam), 1540, 1516 (C=N stretch, imine), 1487 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1249 (C_{sp^2} -O stretch, ether), 1197 (C–N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 813 (C–H bend, 1,4-disubstitution), 746 (C–H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.53 (s, 1H, –NH), 11.68 (s, 1H, –NH), 10.88 (s, 1H, –NH), 9.98 (s, 1H, –NH), 8.29 (s, 1H, –CH=N), 8.10 (s, 1H, –CH triazole), 7.86–6.98 (m, 16H, Ar–H), 5.13 (s, 2H, –OCH₂), 4.73 (t, 2H, $^3J = 6$ Hz, –CH₂-triazole), 4.25 (t, 2H, $^3J = 6$ Hz, –CH₂-isatin), 2.32 (s, 6H, –CH₃); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.7 (C=S), 176.1 (C=S), 161.2, 160.0, 143.0 (C=N imine), 142.8 (C=N azomethine),

137.0, 136.3, 135.9, 134.8, 131.6, 131.2, 129.7, 129.3, 128.9, 127.3, 126.2, 126.1, 125.7, 123.4, 121.6, 119.6, 115.3, 110.1, 61.6, 47.4, 21.6, 21.1 (CH₃), 21.1 (CH₃); LC-MS m/z 702 [M^-]; anal. calcd for $C_{36}H_{34}N_{10}O_2S_2$: C, 61.52; H, 4.88; N, 19.93; found: C, 61.37; H, 4.96; N, 20.16.

4.6.3 1-((4-((1-(2-(Indolin-3(4-phenylthiosemicarbazone)-2-one-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy)phenyl)methylene)-4-nitrophenylthiosemi-carbazide (5c). Appearance: bright yellow solid; yield: 76%; melting point: 232–234 °C; R_f : 0.60 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1600 (C=O stretch, lactam), 1544, 1525 (C=N stretch, imine), 1556 (N–O stretch, asymmetric, nitro), 1508 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1354 (N–O stretch, symmetric, nitro), 1249 (C_{sp^2} -O stretch, ether), 1192 (C–N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 827 (C–H bend, 1,4-disubstitution), 746 (C–H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.71 (s, 1H, –NH), 11.73 (s, 1H, –NH), 10.90 (s, 1H, –NH), 10.05 (s, 1H, –NH), 8.27 (s, 1H, –CH=N), 8.25 (s, 1H, –CH triazole), 8.08–6.91 (m, 16H, Ar–H), 5.07 (s, 2H, –CH₂ isatin), 4.75 (t, 2H, $^3J = 6$ Hz, –OCH₂), 4.43 (t, 2H, $^3J = 6$ Hz, –CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.5 (C=S), 175.4 (C=S), 172.5, 160.9, 160.0, 144.1, 143.9 (C=N imine), 143.2 (C=N azomethine), 141.9, 133.1, 132.7, 131.9, 129.9, 127.2, 125.6, 125.4, 124.9, 123.5, 121.8, 119.6, 119.5, 119.2, 115.2, 108.2, 107.1, 66.6, 49.5, 35.1; LC-MS m/z 764 [M^-]; anal. calcd for $C_{34}H_{28}N_{12}O_6S_2$: C, 53.40; H, 3.69; N, 21.98; found: C, 53.32; H, 3.57; N, 22.11.

4.6.4 1-((4-((1-(2-(Indolin-3(4-cyanophenylthiosemicarbazone)-2-one-1-yl)ethyl)-1H-1,2,3-triazol-4-yl)methoxy)phenyl)methylene)-4-(4-cyanophenyl)thiosemicarbazide (5d). Appearance: yellow solid; yield: 69%; melting point: 221–223 °C; R_f : 0.63 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 2223 (C≡N stretch, cyano), 1604 (C=O stretch, lactam), 1585, 1537 (C=N stretch, imine), 1508 (C=C stretch, aromatic ring), 1465 (C_{sp^3} -H bend, methylene), 1249 (C_{sp^2} -O stretch, ether), 1192 (C–N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 829 (C–H bend, 1,4-disubstitution), 750 (C–H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.71 (s, 1H, –NH), 12.01 (s, 1H, –NH), 11.06 (s, 1H, –NH), 10.26 (s, 1H, –NH), 8.32 (s, 1H, –CH=N), 8.30 (s, 1H, –CH triazole), 8.14–6.99 (m, 16H, Ar–H), 5.14 (s, 2H, –OCH₂), 4.73 (t, 2H, $^3J = 6$ Hz, –CH₂-triazole), 4.24 (t, 2H, $^3J = 6$ Hz, –CH₂-isatin); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.5 (C=S), 175.4 (C=S), 172.5, 160.9, 160.0, 144.1, 143.9 (C=N imine), 143.2 (C=N azomethine), 141.9, 133.1, 132.7, 131.9, 129.9, 127.2, 125.6, 125.4, 124.9, 123.5, 121.8, 119.6 (C≡N), 119.5 (C≡N), 119.2, 115.2, 108.2, 107.1, 66.7, 49.5, 35.1; LC-MS m/z 724 [M^-]; anal. calcd for $C_{36}H_{28}N_{12}O_2S_2$: C, 59.65; H, 3.89; N, 23.19; found: C, 59.49; H, 3.99; N, 23.32.

4.6.5 1-((4-((1-(2-(Indolin-3(4-phenylthiosemicarbazone)-2-one-1-yl)methyl)-1H-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-phenylthiosemicarbazide (5e). Appearance: bright yellow solid; yield: 81%; melting point: 232–234 °C; R_f : 0.51 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N–H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1608

(C=O stretch, lactam), 1544, 1525 (C=N stretch, imine), 1492 (C=C stretch, aromatic ring), 1465 (C_{sp^3} -H bend, methylene), 1244 (C_{sp^2} -O stretch, ether), 1192 (C-N stretch, lactam), 1141 (C_{sp^2} -O stretch, ether), 827 (C-H bend, 1,4-disubstitution), 740 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.71 (s, 1H, -NH), 11.73 (s, 1H, -NH), 10.89 (s, 1H, -NH), 10.05 (s, 1H, -NH), 8.27 (s, 1H, -CH=N), 8.09 (s, 1H, -CH triazole), 7.83–6.91 (m, 18H, Ar-H), 5.07 (s, 2H, -CH₂ isatin), 4.75 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.43 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.8 (C=S), 176.1 (C=S), 160.9, 159.8, 143.1 (C=N imine), 142.9 (C=N azomethine), 141.9, 139.5, 138.8, 131.6, 131.5, 129.7, 128.9, 128.4, 127.5, 126.6, 126.3, 126.1, 125.7, 124.8, 123.5, 121.6, 119.8, 115.2, 110.9, 66.6, 49.5, 35.1; LC-MS m/z 674 [M^-]; anal. calcd for $C_{34}H_{30}N_{10}O_2S_2$: C, 60.52; H, 4.48; N, 20.76; found: C, 60.61; H, 4.29; N, 20.87.

4.6.6 1-((4-(2-(4-((Indolin-3(*p*-tolylthiosemicarbazone)-2-one-1-yl)methyl)-1*H*-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-*p*-tolylthiosemicarbazide (5f). Appearance: yellow solid; yield: 83%; melting point: 236–238 °C; R_f : 0.54 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1612 (C=O stretch, lactam), 1544, 1539 (C=N stretch, imine), 1487 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1271 (C_{sp^2} -O stretch, ether), 1193 (C-N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 813 (C-H bend, 1,4-disubstitution), 750 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.68 (s, 1H, -NH), 11.68 (s, 1H, -NH), 10.83 (s, 1H, -NH), 9.98 (s, 1H, -NH), 8.27 (s, 1H, -CH=N), 8.25 (s, 1H, -CH triazole), 8.07–6.89 (m, 16H, Ar-H), 5.07 (s, 2H, $^3J = 6$ Hz, -CH₂ isatin), 4.75 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.43 (t, 2H, -CH₂ triazole), 2.32 (s, 6H, -CH₃); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.2 (C=S), 176.1 (C=S), 160.9, 159.8, 158.2, 150.6, 142.9 (C=N imine), 141.9 (C=N azomethine), 138.5, 137.0, 136.3, 135.9, 134.8, 131.6, 129.7, 129.3, 128.9, 127.5, 126.3, 126.1, 124.9, 124.7, 123.8, 123.5, 118.0, 115.2, 111.6, 66.7, 49.5, 35.1, 21.6 (CH₃), 21.0 (CH₃); LC-MS m/z 702 [M^-]; anal. calcd for $C_{36}H_{34}N_{10}O_2S_2$: C, 61.52; H, 4.88; N, 19.93; found: C, 61.35; H, 4.74; N, 19.89.

4.6.7 1-((4-(2-(4-((Indolin-3(4-nitrophenylthiosemicarbazone)-2-one-1-yl) methyl)-1*H*-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-nitrophenyl thiosemicarbazide (5g). Appearance: yellow; yield: 75%; melting point: 252–254 °C; R_f : 0.59 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 1612 (C=O stretch, lactam), 1544, 1539 (C=N stretch, imine), 1556 (N-O stretch, asymmetric, nitro), 1508 (C=C stretch, aromatic ring), 1467 (C_{sp^3} -H bend, methylene), 1354 (N-O stretch, symmetric, nitro), 1271 (C_{sp^2} -O stretch, ether), 1193 (C-N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 813 (C-H bend, 1,4-disubstitution), 750 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.90 (s, 1H, -NH), 12.09 (s, 1H, -NH), 11.18 (s, 1H, -NH), 10.37 (s, 1H, -NH), 8.31–6.89 (m, 18H, -CH=N, -CH triazole, Ar-H), 5.07 (s, 2H, -CH₂ isatin), 4.97 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.76 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.5 (C=S), 175.4 (C=S), 172.5, 160.9, 160.0, 144.1, 143.9 (C=N imine), 143.2 (C=N azomethine), 141.9, 133.1, 132.7, 131.9,

129.9, 127.2, 125.6, 125.4, 124.9, 123.5, 121.8, 119.6, 119.5, 119.2, 115.2, 108.2, 107.1, 66.7, 49.5, 35.1; LC-MS m/z 764 [M^-]; anal. calcd for $C_{34}H_{28}N_{12}O_6S_2$: C, 53.40; H, 3.69; N, 21.98; found: C, 53.53; H, 3.78; N, 21.69.

4.6.8 1-((4-(2-(4-((Indolin-3(4-cyanophenylthiosemicarbazone)-2-one-1-yl) methyl)-1*H*-1,2,3-triazol-1-yl)ethoxy)phenyl)methylene)-4-cyanophenyl thiosemicarbazide (5h). Appearance: bright yellow solid; yield: 79%; melting point: 258–260 °C; R_f : 0.62 (*n*-hexane: EtOAc, 4 : 6); FT-IR $\bar{\nu}$ (cm^{-1}): 3300 (N-H stretch), 3129, 3049 (C_{sp^2} -H stretch), 2928, 2873 (C_{sp^3} -H stretch), 2223 (C≡N stretch, cyano), 1604 (C=O stretch, lactam), 1585, 1537 (C=N stretch, imine), 1508 (C=C stretch, aromatic ring), 1465 (C_{sp^3} -H bend, methylene), 1249 (C_{sp^2} -O stretch, ether), 1192 (C-N stretch, lactam), 1151 (C_{sp^3} -O stretch, ether), 829 (C-H bend, 1,4-disubstitution), 750 (C-H bend, 1,2-disubstitution); 1H NMR (300 MHz, DMSO- d_6) δ (ppm): 12.86 (s, 1H, -NH), 12.01 (s, 1H, -NH), 11.08 (s, 1H, -NH), 10.26 (s, 1H, -NH), 8.27 (s, 1H, -CH=N), 8.25 (s, 1H, -CH triazole), 8.12–6.93 (m, 16H, Ar-H), 5.07 (s, 2H, -CH₂ isatin), 4.77 (t, 2H, $^3J = 6$ Hz, -OCH₂), 4.44 (t, 2H, $^3J = 6$ Hz, -CH₂ triazole); ^{13}C NMR (75 MHz, DMSO- d_6) δ (ppm): 176.5 (C=S), 175.4 (C=S), 172.5, 160.9, 160.0, 144.1, 143.9 (C=N imine), 143.2 (C=N azomethine), 141.9, 133.1, 132.7, 131.9, 129.9, 127.2, 125.6, 125.4, 124.9, 123.5, 121.8, 119.6 (C≡N), 119.5 (C≡N), 119.2, 115.2, 108.2, 107.0, 66.6, 49.5, 35.1; LC-MS m/z 724 [M^-]; anal. calcd for $C_{36}H_{28}N_{12}O_2S_2$: C, 59.65; H, 3.89; N, 23.19; found: C, 59.48; H, 3.75; N, 23.33.

Conflicts of interest

There are no conflicts to declare.

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