Synthesis and Antitumor Evaluation of Novel Cyclic Arylsulfonylureas: ADME-T and Pharmacophore Prediction

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Abstract—— Novel derivatives of 5-(substituted)benzylidene-3-(4-substituted)phenylsulfonylimidazolidine-2,4-diones (**3a-r**), 1-(4-substituted)phenylsulfonyl-3-(4-substituted)phenylpyrimidine-2,4,6-(1H,3H,5H)-triones (**6a-l**), and 3-(4-substituted)phenyl-1-(4-substituted)phenylsulfonylquinazoline-2,4(1H,3H)-diones (**8a-l**) have been synthesized and tested for their antitumor activity against 60 tumor cell lines taken from 9 different organs. The tested compounds have showed good inhibitory effect at the ovarian cancer (IGROV1) cell line. A significant inhibition for (RXF393) renal cancer cells was observed with series **3** compounds, while in the other two series **6** and **8**, there was a significant inhibition of ovarian cancer cells (OVCAR-8) and melanoma cells (SK-MEL-2). Interestingly; beside the strong inhibition of compound **3q** to IGROV1 and RXF393 cells, a great inhibition (199.62 %) for (M14) Melanoma cells was observed at the tested concentration (10 μM). ADME-T and pharmacophore prediction methodology were used to study the antitumor activity of the most active compounds and to identify the structural features required for antitumor activity. © 2011 Elsevier Science. All rights reserved.

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1. Introduction

Cancer is continuing to be a major health problem in developing as well as developed countries [1,2]. Surpassing heart diseases, it is taking the position number one killer due to various worldwide factors.

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Although major advances have been made in the chemotherapeutic management of some patients, the continued commitment to the laborious task of discovering new anticancer agents remains critically important. Among the wide range of compounds tested as potential anticancer agents, derivatives comprising the sulfonamide, diarylsulfonylurea and thiourea functionalities have attracted reasonable attention [3-8], especially after the discovery of sulofenur [9] (LY186641) A and its structure analogs [8] **B** and (LY295501) **C** (Figure 1). Sulofenur is an antineoplastic sulfonylurea that has been clinically evaluated in lung, breast, colon, ovarian, pancreatic, and gastric cancer [9]. It is generally assumed that the strong cytotoxicity and, as a consequence, the antitumor properties of the diarylsulfonylurea is due to the uncoupling of mitochondria [4,5], however, other mechanisms, such as inhibition of the mitochondrial isozyme V of carbonic anhydrase (CAs) have also been hypothesized, since hydrolysis of the cytotoxic agent leading to the formation of unsubstituted sulfonamides as the principal products has been reported both in vivo and in vitro [10]. It is well known that aromatic/heterocyclic sulfonamides (formed after such a hydrolytic process) act as very potent inhibitors of CAs [11,12], and that these enzymes are involved in a multitude of crucial physiologic processes [13]. However, clinical trials of sulofenur have yielded unsatisfactory results because of its high protein binding and limited dosing caused by the appearance of anemia, and methemoglobinemia, a side effect that is likely caused by its aniline-related metabolites [14]. In contrast; LY295501 (C) is principally metabolized by hydroxylation with negligible formation of aniline metabolites at relevant doses in experimental animals and demonstrated impressive activity against a broad spectrum of human tumor xenografts [15].

Trying to overcome the serious side effects of Sulofenur, several imidazolidinone derivatives containing diarylsulfonylurea pharmacophore, have been synthesized and screened for antitumor activity against various human solid tumors. Among these compounds are; 1-(4-clorophenylsulfonyl)-4-phenylimidazolidin-2-one (**D**) and DW2143 (**E**) which have shown higher cytotoxic activity than that of Sulofenur, in addition, there was no production of methemoglobinemia or hypoglycemia upon

administration of these agents, which indicates a different metabolic fate from that of Sulofenur (Figure 1) [16-26]. On the other hand, over the past few years, much interest has been given to the chemotherapeutic activity of hydantoins [27-31]. Quinazolinediones [32,33] and pyrimidinetriones [34,35] as potential anticancer agents.

In view of the previous rationale and in continuation of an ongoing program aiming at finding new structure leads with potential chemotherapeutic activities, new series of 5-(substituted) benzylidene-3-(4-substituted)phenylsulfonylimidazolidine-2,4-diones (3a-r), 1-(4-substituted) phenylsulfonyl-3-(4substituted)phenylpyrimidine-2,4,6-(1H,3H,5H)-triones (6a-l),and 3-(4-substituted)phenyl-1-(4substituted)phenylsulfonylquinazoline-2,4(1H,3H)-diones (8a-l) have been synthesized and screened for cytotoxic activity (Figure 1). These series comprise the derived N^{1} , N^{3} -disubstituted sulfonvlurea pharmacophores that are structurally related to sulofenur **A** and its cyclic form **D** (Figure 1). The thrust of efforts in the derivatization of such type of compounds focused mainly on the aryl moiety of the sulfonamide portion of the diarylsulfonylureas. In the present study, such arylsulfonylurea moiety was incorporated basically as a part of the cyclic structures of hydantoin because of the reported potential anticancer activity of this ring system hoping to induce some biological synergism. In addition, ring replacement of the hydantoin with pyrimidinetrione and quinazolinedione functionality was considered as an interesting structure variation in order to study the influence of such modification on the anticipated antitumor activity. The substitution pattern at the aryl part of the diarylsulfonylurea pharmacophores was selected so as to confer different electronic environment that would affect the lipophilicity, and hence the activity of the target molecules. The objective of forming these hybrids is an attempt to reach an active antitumor agent with potentiated activity and selectivity toward cancerous cells. Moreover ADME-T and pharmacophore prediction methodology were used to identify the structural features required for the antitumor properties of these new series.

2. Results and discussion

2.1. Chemistry

2.1.1. Synthesis of compounds 3a-r (Scheme 1, Table 1).

Scheme 1 outlines the synthetic pathway used to obtain compounds (3a-r). The starting material 5-(substituted)benzylideneimidazolidine-2,4-diones (2a-f) were prepared by allowing hydantoin 1 to condense with the corresponding aromatic aldehydes in glacial acetic acid and in the presence of fused sodium acetate as a condensing agent [36]. Upon mixing of 2 with the appropriate arylsulfonyl chloride and K_2CO_3 in acetone:water (1:1);5-(substituted)benzylidene-3-(4-substituted) phenylsulfonylimidazolidine-2,4-diones (3a-r) were obtained in relatively good yield. Although geometrical isomerism (E/Z isomers) was possible because of the restricted rotation about the exocyclic C=C bond of the arylidene hydantoins, all the derivatives prepared in this study were obtained exclusively in the Z-form as confirmed by the analytical data. In all the IR spectra of the prepared arylidenehydantoins (2a-f), and their subsequent arylsulfonyl derivatives (3a-r), the stretching of the C=C bond appeared in a higher frequency region (1660–1675 cm⁻¹) compared to those expected for the E-form (1630–1640 cm⁻¹) [37]. Furthermore; the H¹-NMR spectra of the prepared arylidene hydantoins have showed that the most diagnostic olefinic proton, H6 (-CH=) was deshielded more (δ = 6.4–7.0 ppm) as expected in the Z-form, relative to the slightly shielded proton of the E-form (δ = 6.2–6.3 ppm). This deshielding of the olefinic proton is caused by the anisotropic effect exerted by the nearby C4 carbonyl group in the Z-isomer [37].

2.1.2. Synthesis of compounds 6a-l (Scheme 2, Table 2).

1-(4-substituted)phenylureas (**4a-d**); which were prepared according to Hofmann [38,39] procedure by reacting the aromatic amine with potassium cyanate in water and in the presence of excess acetic acid; were treated with diethyl malonate in the presence of sodium ethoxide/absolute ethanol to afford 1-(4-substituted)phenylpyrimidine-2,4,6-(1H,3H,5H)-triones (**5a-d**) [40]. As previously mentioned under the

preparation of compounds **3a-r**; compounds **6a-l** were prepared by addition of the appropriate arylsulfonyl chloride to a stirred solution of **5a-d** and K₂CO₃ in acetone: water (1:1).

2.1.3. Synthesis of compounds 8a-l (Scheme 3, Table 3).

3-(4-substituted)phenylquinazoline-2,4(1H,3H)-diones (**7a-d**) were prepared by fusing anthranilic acid with 1-(4-substituted)phenylureas (**4a-d**) [41]. The synthesis of 3-(4-substituted)phenyl-1-(4-substituted)phenylquinazoline-2,4(1H,3H)-diones (**8a-l**) was performed via the reaction of 3-(4-substituted)phenylquinazoline-2,4(1H,3H)-diones (**7a-d**) with sodium *tert*-butoxide in *tert*-butanol to induce salt formation, then the separated salt was refluxed with an equivalent amount of the appropriate arylsulfonyl chloride in *tert*-butanol to yield the target products **8a-l**.

2.2. Biological activity

2.2.1. *In vitro* antitumor evaluation

The Thirteen compounds indicated in (Figures 2 and 3; Tables 4 and 5) were selected by National Cancer Institute, Bethesda, Maryland, USA on the basis of degree of the structure variation and computer modeling techniques for evaluation of their antineoplastic activity. The selected compounds were subjected to *in vitro* anticancer assay against tumor cells in a full panel of 60-cell lines taken from 9 different organs (lung, colon, breast, ovary, blood, kidney, skin, prostate and brain). The compounds were tested at a single dose concentration of 10 μ M, and the percentages of growth inhibitions over the sixty tested cell lines were determined. The percentages of growth inhibitions over the most sensitive 5-cell lines are shown in figure 2 and table 4.

2.2.2. Structural activity relationship

By investigating the variation in selectivity of the tested compounds over the full panel of cell lines, it was revealed that nearly all of the compounds belonging to the three series (compounds 3, 6 & 8) show significant inhibition for the ovarian cancer cell line (IGROV1). The percentages of inhibition for (IGROV1) ovarian cancer reached 100% in a number of the tested derivatives (Figure 2, Table 4).

However; a distinguish in selectivity was observed between the first series (compounds 3), and the second and third series (compounds 6 and 8). In series 3, a significant inhibition for (RXF393) renal cancer cells (76.2 - 96.5 %) was observed, while in both of the other two series 6 and 8, there was a significant inhibition for another type of ovarian cancer cells (OVCAR-8; 33.2 – 58.9 %) and melanoma cells (SK-MEL-2; 61.0 – 79.3 %). The agreement between the three series in the inhibition of (IGROV1) ovarian cancer cells could be correlated to a similar inhibitory mechanism related to the common structural feature in the three series (the diarylsulfonyl urea structure), while the variation in selectivity over RXF393, OVCAR-8 and SK-MEL-2 cell lines is probably caused by the differences in the hydrocarbon skeleton holding the cyclic urea structure in the three series. These variations could be also correlated to the small difference in the distance between the cores of the two aryl moieties of the diarylsulfonylurea structure, where this distance is almost the same in compounds 6a-l and 8a-l, while a little bit longer in compounds **3a-r**. This variation in distance can account for the similar inhibitory profiles for series 6 and 8, and its variation in the compounds belonging to series 3. An odd result was observed with compound 3q (Figure 3, Table 5), where beside the strong inhibition of IGROV1 cells (97.89 %) and RXF393 cells (95.74 %), a great inhibition (199.62 %) for M14 Melanoma cells was observed at the tested concentration (10 µM). This great inhibition at the mentioned concentration indicates a great potency for the compound with a strong lethal effect over (M14) melanoma cells (99.6% lethality), and suggests an IC₅₀ value in the nanomolar scale.

2.3. Molecular modeling Results

Modeling studies are required in order to construct molecular models that incorporate all experimental evidence reported. These models are necessary to obtain a consistent and more precise picture of the biological active molecules at the atomic level and furthermore, provide new insights that can be used to design novel therapeutic agents.

2.3.1. Conformational analysis

In an attempt to gain a better insight on the molecular structures of the active compounds 3p, 3q, 6k and 8b compared with the least active species 3b, 6b and 8j as representative examples; conformational analysis of the target compounds has been performed using the MMFF94 force-field [42,43] (calculations in vacuo, bond dipole option for electrostatics, Polak-Ribiere algorithm, RMS gradient of 0.01 kcal/Å mol) implemented in MOE 2009.10 [44]. The most stable conformer was fully optimized by AM1 [45] semi-empirical molecular orbital calculation (Figure 4). Calculations at the AM1 level were considered in order to determine relative energies of the E- and Z-isomers of 5-arylidenehydantoin derivatives (3). It was found that the Z-isomer is approximately more stable by more than 3~4 kcal/mol and thus no double bond isomerisation is anticipated (Figure 4) [46]. Moreover the bond distances between N and SO₂ was found to be 1.67 Å, and a twisting of c.a. 34° between the arylidene moiety and hydantoin plane was also found [46]. As clear from the calculations; series 3 compounds exhibit structural similarity as indicated by their molecular parameters and are slightly different from series 6 and 8 compounds. The results showed that the lowest energy minimized structures of compounds belonging to the three series have exhibited the same arrangement of the arylsulfonyl groups (Figures 4 and 5) around the cyclic urea moiety in which the arylsulfonyl group was out of the plane of cyclic urea group (∠N-CO-N-SO2 torsional angle was 177°, 155°, 133° in case of series 3, 6 and 8 compounds, respectively).

2.3.2. ADME-T prediction

2.3.2.1. Lipinski's rule of five and the effect of lipophilic and steric parameters

As a part of our study; the compliance of compounds to the Lipinski's rule of five was evaluated [47]. In addition, the polar surface area (PSA) of the compounds was also calculated (Table 6), since it is another key property that has been linked to drug bioavailability, where passively absorbed compounds with a PSA > 140 Å2 are thought to have low oral bioavailability [48]. The results disclosed in table 6 show that all of the synthesized compounds comply with these rules. Hence; theoretically, all of these

compounds should present good passive oral absorption and differences in their bioactivity cannot be attributed to this property.

The introduction of cyclic ring fragments incorporating the arylsulfonylurea core and the variation of ring size and the substituents on these fragments have allowed us to evaluate the influence of lipophilicity and steric parameters at the pharmacophoric part of the molecules. Table 6 gathers cytotoxic activity against ovarian human cell line (IGROV1) as a representative example as well as values of ClogP (lipophilic factors), molar refractometry and polar surface area (steric factors) for each compound, determined by using MOE program. Within the series of compounds **3a-d** we have observed sharp increase in the antitumor activity with the increase in molar refractometry from 88.7cm³/mol (**3b** and **3g**) to 99.3~103.9cm³/mol (**3p** and **3q**). This effect of molar refractometry was observed within the other two series too, such as in compounds **6b**, **6k**, **8a** and **8b** with molar refractometris of 86.4cm³/mol, 93.7cm³/mol, 98.1cm³/mol and 102.7cm³/mol respectively. Although lipophilicity does not exert a significant effect on activity in compounds **3** and **6**, an increase in potency was observed in compounds **8a**, **8b** & **8k** with logP values higher than 2.7. Regarding steric parameters; from the data gathered in table 6 there is a clear influence of refractometry on antitumor activity compared with lipophilicity and polar surface area for either series of all compounds. The optimal refractometry for the most active compounds was found to lie in the range of 91.4~103.9 cm³/mol (Table 6).

2.3.2.2. ADME-Tox evaluation [49,50]

To estimate the prospect of series 3, 6 and 8 compounds as antitumor agents compared with the reported antitumor agents A, D and E; their drug-likeliness were calculated according to absorption, distribution, metabolism, elimination, and toxicity (ADME-T) program, and defined human intestinal absorption (HIA) model [49]. It was predicted that the examined compounds could be transported across the intestinal epithelium, they probably have high affinity to the plasma proteins, and they can cross the blood-brain barrier and are of medium aqueous soluble. The values of HIA, protein binding, BBB

crossing and solubility prediction for all compounds are presented in Table 7. In general, all compounds presented some advantages and disadvantages when compared to each other. No marked differences in health effects and in rodent toxicity profiles were observed among the compounds. However, the absorption related parameters call for attention, since the promising compounds 3 and 6 were calculated to be at least as soluble as the reported compounds, and are predicted to have oral bioavailability and absorption significantly higher than that of the reported antitumor agents A, D and E. These values are also comparable (marginally inferior or superior) to those obtained from series 8 compounds. The present results suggest an optimal pharmacokinetic profile. Accordingly; it can be deduced from these results that the pharmacokinetic profile of diarylsulfonylureas is affected and modified by the presence of arylsulfonyl moiety connected to heterocyclic ring systems.

2.3.3. Pharmacophore modelling [51,52]

A molecular modeling experiment was carried out to develop a hypothetical pharmacophore model for the antitumor activity aiming to study the fitting of the designed compounds to this pharmacophore. A ligand-based pharmacophore model was developed using a training set of nine diarylsulfonylureas of diverse chemical structures including compounds **A–E** (Figure 6), in addition to compounds **3h**, **3n**, **6b** and **8a**. The generated hypothetical pharmacophore (Figure 6) showed nine overlapping points with similar chemical properties in the training set; F1: a hydrogen bond acceptor center; F2: an aromatic or hydrophobic center with two parallel places "F3 and F5" for Pi orbital accommodation; F4: an aromatic center with a H-bond donor group; F6: a hydrophobic center; and F7: a second H-bond acceptor center. Fitting of the designed active compounds **3p**, **3q**, **6k** and **8b** to the pharmacophore revealed the presence of the appropriate chemical groups superimposed on the pharmacophoric elements (Figures 6 and 7). The diaryl tail represents the aromatic ring with its Pi orbitals properly oriented to fit to F2, F3 and F5. Also, N-CO-N and C-CO-C of the ring fragment are H-bond acceptors corresponding to F1. The hydrogen bond acceptor sulfonyl group was found to be fit into F6; it is worthy to mention that this

moiety was perfect in adjusting the distance between the other groups in the molecule. This pharmacophoric assumption was in consistence with the reported results for the antitumor arylsylfonylureas [26,53,54].

3. Conclusion

The present work has lead to the development of novel antitumor molecules and some of which have shown promising antitumor activities. As evident from the experimental and calculated data, the structural features (pharmacophores) essential for the antitumor activity of this series are as follows; (1) a cyclic urea that is an essential backbone that carries the recognition feature for biological activity, (2) the presence of arylsulfonyl moiety at the 1-position in case of series 3 and the 3-position in case of series 6 and 8 of cyclic urea core, (3) the two aryl groups of the diarylsulfonylurea skeleton should reside in a certain distance, ranging between 8.7-9.5Å. The new cyclic arylsulfonylureas prepared in this work have good physical properties that qualify them to have good pharmacokinetics and drug bioavailability. They are fully compatible with Lipinski's rule of five (low molecular weight, favourable ClogP, favourable hydrogen bond-donating and accepting capabilities). They have a simple synthetic access and thus low production costs. Further optimization and pharmacokinetic profiling of these series are currently ongoing.

4. Experimental

4.1. Chemistry

All melting points (°C) were measured by fisher-johns apparatus and are uncorrected, ¹HNMR spectra (TMS as internal standard, chemical shifts in ppm) were measured on a varian EM 360 (200 MHZ) instrument. Thin-layer chromatography (TLC) was conducted on silica gel 60F254 plates (Merck KgaA). Elemental analysis (C,H,N,S) were performed at the microanalytical center, Cairo university, all

the compounds were within 0.4% of the theoretical values. Compounds **2a-f** [36], **4a-d** [38,39], **5a-d** [40], and **7a-d** [41] have been synthesized according to the reported procedures.

4.1.1. General procedure for the synthesis of compounds 3a-r.

A mixture of compounds **2a-f** (0.01 mol) and K₂CO₃ (0.69 g, 0.005 mol) was stirred in acetone/water solvent system (1:1; 30 mL) at room temperature for 20 minutes. The reaction mixture was then filtered and to the clear filtrate, a solution of the appropriate aryl sulfonyl chloride (0.012 mol) in acetone/water system (1:1; 5 mL) was added dropwise over a period of 20 minutes. The resulted mixture was further stirred for 24 hours at room temperature. The separated solid was then filtered, washed with cold water, dried and crystallized from ethanol. The yield percentages, melting points, molecular formulae and micro-analytical data for (compounds **3a-r**) are shown in table 1.

5-Benzylidene-3-phenylsulfonylimidazolidine-2,4-diones (**3a**): H¹ NMR (DMSO- d_6); δ 6.61 (s, 1H, =CH-), 7.33-7.39 (m, 3H, Ar-H), 7.60 (d, 2H, J = 6.9 Hz, 2H, Ar-H), 7.68-7.85 (m, 3H, Ar-H), 8.07 (d, 2H, J = 7.6 Hz, Ar-H), 11.33 (s, 1H, NH, exchangeable with D₂O); C¹³ NMR (DMSO- d_6): δ 112.61, 124.92, 128.38, 129.24, 129.63, 130.12, 130.24, 132.60, 135.66, 138.04, 149.85, 160.28.

5-Benzylidene-3-(4-chlorophenylsulfonyl)imidazolidine-2,4-diones (**3b**): IR (KBr, cm⁻¹) v: 3222 (NH), 1783, 1745 (C=O), 1318, 1189 (O=S=O); H¹ NMR (DMSO- d_6) δ : 6.60 (s, 1H, =CH-), 7.32-7.41 (m, 3H, Ar-H), 7.59 (d, 2H, J = 6.9 Hz, Ar-H), 7.74 (d, 2H, J = 8.4 Hz, Ar-H), 8.06 (d, 2H, J = 8.4 Hz, Ar-H), 11.35 (s, 1H, NH exchangeable with D₂O); C¹³ NMR (DMSO- d_6); δ 112.60, 124.97, 129.22, 129.60, 130.17, 130.21, 130.49, 132.59, 136.67, 140.71, 149.79, 160.20.

5-Benzylidene-3-(4-methylphenylsulfonyl)imidazolidine-2,4-diones (**3c**): IR (KBr, cm⁻¹) v: 3221 (NH), 1784, 1752 (C=O), 1318, 1184 (O=S=O); H¹ NMR (DMSO- d_6) δ 2.48 (s, 3H, CH₃), 6.62 (s, 1H, =CH-), 6.62 (s, 1H, =CH-), 7.40-7.65 (m, 7H, Ar-H), 7.96 (d, 2H, J = 7.8 Hz, Ar-H), 11.30 (s, 1H, NH exchangeable with D₂O).

5-(4-Bromobenzylidene)-3-phenylsulfonylimidazolidine-2,4-diones (**3d**): IR (KBr, cm⁻¹) v: 3226 (NH), 1792, 1736 (C=O), 1383, 1190 (O=S=O); H¹ NMR (DMSO- d_6) δ : 6.60 (s, 1H, =CH-), 7.32-7.42 (m, 3H, Ar-H), 7.60 (d, 2H, J = 7.2 Hz, Ar-H), 7.77 (d, 2H, J = 8.4 Hz, Ar-H), 8.05 (d, 2H, J = 8.7 Hz, Ar-H), 11.33 (s, 1H, NH, exchangeable with D₂O); C¹³ NMR (DMSO- d_6); δ 112.53, 125.04, 129.26, 129.63, 130.21, 130.51, 132.61, 136.68, 140.69, 149.79, 160.22.

5-(4-Bromobenzylidene)-3-(4-chlorophenylsulfonyl)imidazolidine-2,4-diones (**3e**): H^1 NMR (DMSO- d_6) δ : 6.60 (s, 1H, =CH-), 7.80 (d, 2H, J = 8.1 Hz, Ar-H), 7.90 (d, 2H, J = 7.9 Hz, Ar-H), 7.98 (d, 2H, J = 8.1 Hz, Ar-H), 8.15 (d, 2H, J = 8.0 Hz, Ar-H), 11.36 (s, 1H, NH, exchangeable with D₂O).

5-(4-Bromobenzylidene)-3-(4-methylphenylsulfonyl)imidazolidine-2,4-diones (**3f**): IR (KBr, cm⁻¹) v: 3228 (NH), 1793, 1736 (C=O), 1383, 1189 (O=S=O); H¹ NMR (DMSO-*d*₆) δ: 2.45 (s, 3H, CH₃), 6.59 (s, 1H, =CH-), 7.51 (d, 2H, *J* = 8.5 Hz, Ar-H), 7.74 (d, 2H, *J* = 7.7 Hz, Ar-H), 7.94 (d, 2H, *J* = 8.5 Hz, Ar-H), 8.01 (d, 2H, *J* = 7.9 Hz, Ar-H), 11.34 (s, 1H, NH, exchangeable with D₂O).

5-(4-Chlorobenzylidene)-3-phenylsulfonylimidazolidine-2,4-diones (**3g**): IR (KBr, cm⁻¹); v: 3224 (NH), 1794, 1736 (C=O), 1384, 1190 (O=S=O); H¹ NMR (DMSO- d_6) δ : 6.63 (s, 1H, =CH-), 7.48 (d, 2H, J = 7.7 Hz, Ar-H), 7.64 (d, 2H, J = 7.8 Hz, Ar-H), 7.70-7.94 (m, 5H, Ar-H), 11.33 (s, 1H, NH, exchangeable with D₂O).

5-(4-Chlorobenzylidene)-3-(4-chlorophenylsulfonyl)imidazolidine-2,4-diones (**3h**): H¹ NMR (DMSO- d_6) δ : 6.60 (s, 1H, =CH-), 7.46 (d, 2H, J = 8.4 Hz, Ar-H), 7.63 (d, 2H, J = 8.4 Hz, Ar-H), 7.78 (d, 2H, J = 8.7 Hz, Ar-H), 8.05 (d, 2H, J = 8.5 Hz, Ar-H), 11.38(s, 1H, NH, exchangeable with D₂O); C¹³ NMR (DMSO- d_6) δ : 110.97, 125.65, 129.27, 130.21, 130.52, 131.61, 131.86, 134.11, 136.66, 140.70, 149.80, 160.13.

5-(4-Chlorobenzylidene)-3-(4-methylphenylsulfonyl)imidazolidine-2,4-diones (**3i**): H^1 NMR (DMSO- d_6) δ : 2.43 (s, 3H, CH₃), 6.60 (s, 1H, =CH-), 7.46 (d, 2H, J = 8.6 Hz, Ar-H), 7.52 (d, 2H, J =

8.4 Hz, Ar-H), 7.65 (d, 2H, J = 8.0 Hz, Ar-H), 7.94 (d, 2H, J = 8.1 Hz, Ar-H), 11.32 (s, 1H, NH, exchangeable with D_2O).

5-(3-Nitrobenzylidene)-3-phenylsulfonylimidazolidine-2,4-diones (**3j**): H¹NMR (DMSO- d_6) δ : 6.76 (s, 1H, =CH-), 7.55-8.06 (m, 7H, Ar-H), 8.18 (d, 1H, J = 3.3 Hz, Ar-H), 8.40 (s, 1H, Ar-H), 11.60 (br.s, 1H, NH, exchangeable with D₂O).

5-(3-Nitrobenzylidene)-3-(4-chlorophenylsulfonyl)imidazolidine-2,4-diones (**3k**): IR (KBr, cm⁻¹) v: 3429 (NH), 1740, 1693 (C=O), 1390, 1166 (O=S=O); H¹NMR (DMSO- d_6) δ : 6.05 (s, 1H, =CH-), 7.52 (dd, 1H, J = 3.9, 7.5 Hz, Ar-H), 7.72 (d, 2H, J = 7.9 Hz, Ar-H), 7.92 (d, 1H, J = 4.1 Hz, Ar-H), 7.98 (d, 2H, J = 7.8 Hz, Ar-H), 8.15 (d, 1H, J = 3.3 Hz, Ar-H), 8.43 (s, 1H, Ar-H), 11.42 (br., s, 1H, NH, exchangeable with D₂O).

5-(3-Nitrobenzylidene)-3-(4-methylphenylsulfonyl)imidazolidine-2,4-diones (**3l**): H¹ NMR (DMSO- d_6) δ : 2.47 (s, 3H, CH3), 6.77 (s, 1H, =CH-), 7.51 (dd, 1H, J = 3.1, 7.7 Hz, Ar-H), 7.61 (d, 2H, J = 8.1 Hz, Ar-H), 7.89 (d, 1H, J = 3.2 Hz, Ar-H), 7.96 (d, 2H, J = 7.9 Hz, Ar-H), 8.16 (d, 1H, J = 4.1 Hz, Ar-H), 8.44 (s, 1H, Ar-H), 11.61 (br., s, 1H, NH exchangeable with D₂O).

5-(4-Methoxybenzylidene)-3-phenylsulfonylimidazolidine-2,4-diones (**3m**): H¹NMR (DMSO- d_6) δ: 3.78 (s, 3H, OCH₃), 6.59 (s, 1H, =CH-), 6.96 (d, 2H, J = 8.1 Hz, Ar-H), 7.59 (d, 2H, J = 8.4 Hz, Ar-H), 7.67-7.84 (m, 3H, Ar-H), 8.06 (d, 2H, J = 7.5 Hz, Ar-H), 11.22 (s, 1H, NH, exchangeable with D₂O); C¹³ NMR (DMSO- d_6) δ: 55.78, 113.23, 114.82, 122.80, 125.08, 128.30, 130.12, 132.19, 135.61, 138.12, 149.79, 160.34, 160.59.

5-(4-Methoxybenzylidene)-3-(4-chlorophenylsulfonyl)imidazolidine-2,4-diones (**3n**): IR (KBr, cm⁻¹) v: 3231 (NH), 1778, 1740 (C=O), 1319, 1186 (O=S=O); H¹NMR (DMSO-*d*₆) δ: 3.80 (s, 3H, OCH₃), 6.60 (s, 1H, =CH-), 6.98 (d, 2H, *J* = 7.9 Hz, Ar-H), 7.62 (d, 2H, *J* = 8.5 Hz, Ar-H), 7.80 (d, 2H, *J* = 7.9 Hz, Ar-H), 8.06 (d, 2H, *J* = 8.2 Ar-H), 11.23 (s, 1H, NH, exchangeable with D₂O).

5-(4-Methoxybenzylidene)-3-(4-methylphenylsulfonyl)imidazolidine-2,4-diones (**3o**): H^1NMR (DMSO- d_6) δ : 2.43 (s, 3H, CH₃), 3.80 (s, 3H, OCH₃), 6.60 (s, 1H, =CH-), 6.98 (d, 2H, J = 7.8 Hz, Ar-H), 7.52 (d, 2H, J = 8.4 Hz, Ar-H), 7.61 (d, 2H, J = 8.2 Hz, Ar-H), 7.94 (d, 2H, J = 8.0 Hz, Ar-H), 11.20 (s, 1H, NH, exchangeable with D_2O).

5-(4-(*N***,***N***-Dimethylamino)benzylidene)-3-phenylsulfonylimidazolidine-2,4-diones** (**3p**): H^1NMR (DMSO- d_6) δ : 2.97 (s, 6H, N(CH₃)₂), 6.55 (s, 1H, =CH-), 6.68 (d, 2H, J = 8.7 Hz, Ar-H), 7.49 (d, 2H, J = 8.7 Hz, Ar-H), 7.67-7.84 (m, 3H, Ar-H), 8.04 (d, 2H, J = 8.0 Hz, Ar-H), 11.04 (s, 1H, NH, exchangeable with D₂O); C^{13} NMR (DMSO- d_6) δ : 112.25, 115.27, 119.66, 119.92, 128.19, 130.13, 132.24, 135.55, 138.29, 149.60, 151.29.

5-(4-(*N*,*N***-Dimethylamino**)**benzylidene**)**-3-(4-chlorophenylsulfonyl)imidazolidine-2,4-diones** (**3q**): IR (KBr, cm⁻¹); v: 3211 (NH), 1729, 1711 (C=O), 1380, 1172 (O=S=O); H1 NMR (DMSO-d6) δ 2.99 (s, 6H, N(CH₃)₂), 6.57 (s, 1H, =CH-), 6.71 (d, 2H, J = 8.5 Hz, Ar-H), 7.52 (d, 2H, J = 7.9 Hz, Ar-H), 7.79 (d, 2H, J = 8.2 Hz, Ar-H), 8.06 (d, 2H, J = 8.4 Hz, Ar-H), 11.06 (s, 1H, NH exchangeable, with D₂O).

5-(4-(*N***,***N***-Dimethylamino)benzylidene)-3-(4-methylphenylsulfonyl)imidazolidine-2,4-diones** (**3r**): $H^{1}NMR$ (DMSO- d_{6}) δ : 2.43 (s, 3H, Ar-CH₃), 2.99 (s, 6H, N(CH₃)₂), 6.56 (s, 1H, =CH-), 6.70 (d, 2H, J = 7.9 Hz, Ar-H), 7.51 (d, 4H, J = 7.5 Hz, Ar-H), 7.94 (d, 2H, J = 7.8 Hz, Ar-H), 11.03 (s, 1H, NH, exchangeable with $D_{2}O$).

4.1.2. General procedure for the synthesis of compounds 6a-l.

A mixture of compounds **5a-d** (0.01 mol) and K_2CO_3 (0.69 g, 0.005 mol) was stirred in acetone/water mixture (1:1; 30 mL) at room temperature for 10 minutes. To the resulted solution; the appropriate arylsulfonyl chloride (0.012 mol) in acetone/water system (1:1; 5 mL) was added dropwise over a period

of 20 minutes. The reaction mixture was further stirred at room temperature for 24 hours. The separated solid was then filtered, washed with cold water, dried and crystallized from the appropriate solvent. The yield percentages, melting points, molecular formulae and micro-analytical data for compounds **6a-1** are shown in table 2:

1-Phenyl-3-phenylsulfonylpyrimidine-2,4,6-(IH,3H,5H)-triones (**6a**): IR (KBr, cm⁻¹) v: 1728, 1655 (C=O), 1374, 1165 (O=S=O); H1 NMR (DMSO-d6); δ 5.36 (s, 2H, CH₂), 7.32-7.86 (m, 8H, Ar-H), 8.06 (d, 2H, J = 7.9 Hz, Ar-H); C¹³ NMR (DMSO- d_6) δ : 112.55, 124.97, 128.37, 129.26, 129.65, 130.13, 130.24, 132.61, 135.67, 138.02, 149.86, 160.30.

1-Phenyl-3-(4-chlorophenylsulfonyl)pyrimidine-2,4,6-(IH,3H,5H)-triones (**6b**): H¹NMR (DMSO- d_6) δ : 5.41 (s, 2H, CH₂), 7.13-7.55 (m, 5H, Ar-H), 7.92 (d, 2H, J = 8.1 Hz, Ar-H), 8.15 (d, 2H, J = 7.9 Hz, Ar-H); MS m/z (%): 380 (5.15, M⁺ + 2), 378 (13.25, M⁺), 204 (14.76), 175 (89.07), 119 (100), 111 (62.28), 77 (25.94).

1-Phenyl-3-(4-methylphenylsulfonyl)pyrimidine-2,4,6-(1H,3H,5H)-triones (6c): H¹NMR (DMSO- d_6) δ : 2.51 (s, 3H, CH₃), 5.35 (s, 2H, CH₂), 7.10-7.50 (m, 5H, Ar-H), 7.61 (d, 2H, J = 7.6 Hz, Ar-H), 8.01 (d, 2H, J = 8.2 Hz, Ar-H); MS m/z (%): 359 (3.22, M⁺ + 1), 358 (5.23, M⁺), 204 (7.94), 155 (37.09), 119 (45.08), 91 (100), 77 (26.53).

1-(4-Chlorophenyl)-3-phenylsulfonylpyrimidine-2,4,6-(IH,3H,5H)-triones (6d): H¹NMR (DMSO- d_6) δ : 5.35 (s, 2H, CH₂), 7.32 (d, 2H, J = 8.1 Hz, Ar-H), 7.54 (d, 2H, J = 8.0 Hz, Ar-H), 7.65-8.10 (m, 5H, Ar-H).

1-(4-Chlorophenyl)-3-(4-chlorophenylsulfonyl)pyrimidine-2,4,6-(1H,3H,5H)-triones (**6e**): H¹NMR (DMSO- d_6) δ : 5.39 (s, 2H, CH₂), 7.30 (d, 2H, J = 7.9 Hz, Ar-H), 7.53 (d, 2H, J = 8.0 Hz, Ar-H), 7.90 (d, 2H, J = 7.7 Hz, Ar-H), 8.15 (d, 2H, J = 8.0 Ar-H).

1-(4-Chlorophenyl)-3-(4-methylphenylsulfonyl)pyrimidine-2,4,6-(IH,3H,5H)-triones (6f): IR (KBr, cm⁻¹); v: 1736, 1650 (C=O), 1381, 1170 (O=S=O); H¹NMR (DMSO- d_6); δ 2.49 (s, 3H, CH₃), 5.35 (s, 2H, CH₂), 7.30 (d, 2H, J = 7.9 Hz, Ar-H), 7.52 (d, 2H, J = 7.9 Hz, Ar-H), 7.61 (d, 2H, J = 8.3 Hz, Ar-H), 8.02 (d, 2H, J = 8.5 Hz, Ar-H).

1-(4-Methylphenyl)-3-phenylsulfonylpyrimidine-2,4,6-(IH,3H,5H)-triones (**6g**): H¹NMR (DMSO- d_6) δ : 2.34 (s, 3H, CH₃), 5.41 (s, 2H, CH₂), 7.12 (d, 2H, J = 8.0 Hz, Ar-H), 7.25 (d, 2H, J = 7.8 Hz, Ar-H), 7.63-8.01 (m, 5H, Ar-H).

1-(4-Methylphenyl)-3-(4-chlorophenylsulfonyl)pyrimidine-2,4,6-(1H,3H,5H)-triones (**6h**): IR (KBr, cm⁻¹) v: 1730, 1662 (C=O), 1381, 1168 (O=S=O); H¹NMR (DMSO- d_6) δ : 2.35 (s, 3H, CH₃), 5.43 (s, 2H, CH₂), 7.11 (d, 2H, J = 8.0 Hz, Ar-H), 7.25 (d, 2H, J = 8.0 Hz, Ar-H), 7.90 (d, 2H, J = 7.8 Hz, Ar-H), 8.15 (d, 2H, J = 8.0 Hz, Ar-H).

1-(4-Methylphenyl)-3-(4-methylphenylsulfonyl)pyrimidine-2,4,6-(1H,3H,5H)-triones (**6i**): H¹NMR (DMSO- d_6) δ : 2.35 (s, 3H, CH₃), 2.52 (s, 3H, CH₃), 5.40 (s, 2H, CH₂), 7.11 (d, 2H, J = 7.6 Hz, Ar-H), 7.26 (d, 2H, J = 7.6 Hz, Ar-H), 7.60 (d, 2H, J = 8.3 Hz, Ar-H), 7.97 (d, 2H, J = 8.0 Hz, Ar-H).

1-(4-Methoxyphenyl)-3-phenylsulfonylpyrimidine-2,4,6-(1H,3H,5H)-triones (**6j**): H¹NMR (DMSO- d_6) δ : 3.79 (s, 3H, OCH₃), 5.34 (s, 2H, CH₂), 7.00 (d, 2H, J = 7.8 Hz, Ar-H), 7.15 (d, 2H, J = 7.8 Hz, Ar-H), 7.68-8.04 (m, 5H, Ar-H).

1-(4-Methoxyphenyl)-3-(4-chlorophenylsulfonyl)pyrimidine-2,4,6-(IH,3H,5H)-triones (6k): H¹NMR (DMSO- d_6) δ : 3.79 (s, 3H, OCH₃), 5.32 (s, 2H, CH₂), 6.96 (d, 2H, J = 8.7 Hz, Ar-H), 7.61 (d, 2H, J = 8.4 Hz, Ar-H), 7.78 (d, 2H, J = 8.4 Hz, Ar-H), 8.04 (d, 2H, J = 8.4 Hz, Ar-H); C¹³ NMR (DMSO- d_6) δ : 114.77, 115.69, 122.96, 128.04, 128.57, 129.28, 129.57, 135.64, 136.23, 140.28, 150.68, 162.69.

1-(4-Methoxyphenyl)-3-(4-methylphenylsulfonyl)pyrimidine-2,4,6-(1H,3H,5H)-triones (**6l**): IR (KBr, cm⁻¹) v: 1729, 1660 (C=O), 1370, 1181 (O=S=O); H¹NMR (DMSO- d_6) δ : 2.42 (s, 3H, CH₃), 3.79 (s, 3H, OCH₃), 5.32 (s, 2H, CH₂), 6.96 (d, 2H, J = 8.7 Hz, Ar-H), 7.50 (d, 2H, J = 8.0 Hz, Ar-H), 7.60 (d, 2H, J = 8.4 Hz, Ar-H), 7.92 (d, 2H, J = 8.1 Hz, Ar-H).

4.1.3. General procedure for the synthesis of compounds 8a-l.

The appropriate compound **3a-d** (0.01 mol) was added in one portion to a solution of metallic sodium (0.345 g, 0.015 mol) in *tert*-butanol (30 mL). The reaction mixture was heated under reflux for 6 hours. The precipitated salt was filtered while hot, washed with hot *tert*-butanol (50 mL) and dried. To a suspension of the separated salt (0.005 mol) in *tert*-butanol (20 mL); the appropriate aryl sulfonyl chloride (0.006 mol) in *tert*-butanol (5 mL) was added dropwise while heating and stirring. The reaction mixture was heated under reflux for 12 hours. The solvent was evaporated under reduced pressure, and the obtained solid was stirred with aqueous NaOH solution (5%, 100 mL) for 30 minutes. The separated solid was filtered, washed with water, dried and crystallized from ethanol. The yield percentages, melting points, molecular formulae and micro-analytical data (for compounds **8a-l** are shown in table 3.

3-Phenyl-1-phenylsulfonylquinazoline-2,4(*1H,3H*)-diones (**8a**): IR (KBr, cm⁻¹) v: 1727, 1679 (C=O), 1378, 1165 (O=S=O); H¹NMR (CDCl₃) δ: 7.25-8.23 (m, 14H, Ar-H); C¹³ NMR (DMSO-*d*₆) δ: 118.43, 120.12, 126.13, 128.55, 128.74, 129.20, 129.49, 130.02, 134.97, 135.27, 135.32, 136.89, 139.03, 149.00, 161.36.

- **3-Phenyl-1-(4-chlorophenylsulfonyl)quinazoline-2,4**(*1H,3H*)-diones (8b): IR (KBr, cm⁻¹) v: 1729, 1681 (C=O), 1377, 1169 (O=S=O); H¹NMR (CDCl₃) δ: 7.24-8.22 (m, 13H, Ar-H).
- **3-Phenyl-1-(4-methylphenylsulfonyl)quinazoline-2,4**(*1H,3H*)-diones (8c): IR (KBr, cm⁻¹) v: 1729, 1679 (C=O), 1377, 1168 (O=S=O); H¹NMR (CDCl₃) δ : 2.47 (s, 3H, CH₃), 7.09-8.25 (m, 13H, Ar-H).

- **3-(4-Chlorophenyl)-1-phenylsulfonylquinazoline-2,4**(*1H,3H*)-diones (**8d**): IR (KBr, cm⁻¹) v: 1727, 1683 (C=O), 1377, 1170 (O=S=O); H¹NMR (CDCl₃) δ: 7.06 (d, 2H, *J* = 7.9 Hz, Ar-H), 7.30 (d, 2H, *J* = 8.2 Hz, Ar-H), 7.44-8.28 (m, 9H, Ar-H).
- **3-(4-Chlorophenyl)-1-(4-chlorophenylsulfonyl)quinazoline-2,4**(*1H,3H*)-diones (**8e**): IR (KBr, cm⁻¹) v: 1729, 1681 (C=O), 1377, 1168 (O=S=O); H¹NMR (CDCl₃) δ: 7.06 (d, 2H, *J* = 8.4 Hz, Ar-H), 7.30 (d, 2H, *J* = 8.5 Hz, Ar-H), 7.40-8.28 (m, 8H, Ar-H).
- **3-(4-Chlorophenyl)-1-(4-methylphenylsulfonyl)quinazoline-2,4**(*1H*,3*H*)-diones (8f): IR (KBr, cm⁻¹) v: 1729, 1681 (C=O), 1376, 1170 (O=S=O); H¹NMR (CDCl₃) δ : 2.47 (s, 3H, CH₃), 7.07 (d, 2H, J = 8.1 Hz, Ar-H), 7.31 (d, 2H, J = 7.8 Hz, Ar-H), 7.44-8.25 (m, 8H, Ar-H).
- **3-(4-Methylphenyl)-1-phenylsulfonylquinazoline-2,4**(IH,3H)-diones (**8g**): IR (KBr, cm⁻¹) v: 1729, 1681 (C=O), 1381, 1174 (O=S=O); H¹NMR (CDCl₃) δ : 2.40 (s, 3H, CH₃), 6.99 (d, 2H, J = 8.4 Hz, Ar-H), 7.28 (d, 2H, J = 8.0 Hz, Ar-H), 7.44-8.26 (m, 9H, Ar-H).
- **3-(4-Methylphenyl)-1-(4-chlorophenylsulfonyl)quinazoline-2,4**(IH,JH)-diones (8h): IR (KBr, cm⁻¹) v: 1730, 1684 (C=O), 1381, 1175 (O=S=O); H¹NMR (CDCl₃) δ : 2.41 (s, 3H, CH₃), 7.02 (d, 2H, J = 7.5 Hz, Ar-H), 7.30 (d, 2H, J = 7.7 Hz, Ar-H), 7.44-8.28 (m, 8H, Ar-H).
- **3-(4-Methylphenyl)-1-(4-methylphenylsulfonyl)quinazoline-2,4**(*1H*,3*H*)-diones (**8i**): IR (KBr, cm⁻¹) v: 1730, 1683 (C=O), 1380, 1175 (O=S=O); H¹NMR (CDCl₃) δ: 2.42 (s, 3H, CH₃), 2.48 (s, 3H, CH₃), 7.01 (d, 2H, *J* = 7.8 Hz, Ar-H), 7.28 (d, 2H, *J* = 7.8 Hz, Ar-H), 7.40-8.24 (m, 8H, Ar-H).
- **3-(4-Methoxyphenyl)-1-phenylsulfonylquinazoline-2,4**(IH,3H)-diones (**8j**): IR (KBr, cm⁻¹) v: 1730, 1684 (C=O), 1384, 1182 (O=S=O); H¹NMR (CDCl₃) δ : 3.77 (s, 3H, OCH₃), 6.97 (d, 2H, J = 8.9 Hz, Ar-H), 7.09 (d, 2H, J = 9.0 Hz, Ar-H), 7.51 (t, 1H, J = 7.5 Hz, Ar-H), 7.67-8.18 (m, 8H, Ar-H); C¹³ NMR

(DMSO- d_6) δ : 55.83, 114.65, 118.42, 120.09, 126.11, 127.69, 128.51, 128.73, 130.00, 130.16, 134.88, 135.24, 136.77, 139.01, 149.08, 159.63, 161.47.

3-(4-Methoxyphenyl)-1-(4-chlorophenylsulfonyl)quinazoline-2,4(*1H,3H*)-diones (**8k**): IR (KBr, cm⁻¹) v: 1732, 1685 (C=O), 1385, 1182 (O=S=O); H¹NMR (CDCl₃) δ: 3.85 (s, 3H, OCH₃), 6.98 (d, 2H, *J* = 8.3 Hz, Ar-H), 7.14 (d, 2H, *J* = 8.5 Hz, Ar-H), 7.40-8.29 (m, 8H, Ar-H).

3-(4-Methoxyphenyl)-1-(4-methylphenylsulfonyl)quinazoline-2,4(1*H***,3***H***)-diones (8l**): IR (KBr, cm⁻¹) v: 1730, 1684 (C=O), 1384, 1182 (O=S=O); H¹NMR (CDCl₃) δ: 2.49 (s, 3H, CH₃), 3.85 (s, 3H, OCH₃), 6.99 (d, 2H, *J* = 7.8 Hz, Ar-H), 7.14 (d, 2H, *J* = 7.6 Hz, Ar-H), 7.44-8.29 (m, 8H, Ar-H).

4.2. Biological evaluation

The human tumor cell lines of the cancer screening panel are grown in RPMI 1640 medium containing 5% fetal bovine serum and 2 mM L-glutamine. For a typical screening experiment, cells are inoculated into 96 well microtiter plates in 100 µL at plating densities ranging from 5,000 to 40,000 cells/well depending on the doubling time of individual cell lines. After cell inoculation, the microtiter plates are incubated at 37° C, 5 % CO₂, 95 % air and 100 % relative humidity for 24 h prior to addition of experimental drugs.

After 24 h, two plates of each cell line are fixed in situ with TCA, to represent a measurement of the cell population for each cell line at the time of drug addition (Tz). Experimental drugs are solubilized in dimethyl sulfoxide at 400-fold the desired final maximum test concentration and stored frozen prior to use. At the time of drug addition, an aliquot of frozen concentrate is thawed and diluted to twice the desired final maximum test concentration with complete medium containing 50 µg/ml gentamicin. Aliquot of 100 µl of this drug dilutions was added to the appropriate microtiter wells already containing 100 µl of medium, resulting in the required final drug concentrations.

Following drug addition, the plates are incubated for an additional 48 h at 37°C, 5 % CO₂, 95 % air, and 100 % relative humidity. For adherent cells, the assay is terminated by the addition of cold TCA. Cells are fixed in situ by the gentle addition of 50 µl of cold 50 % (w/v) TCA (final concentration, 10 % TCA) and incubated for 60 minutes at 4°C. The supernatant is discarded, and the plates are washed five times with tap water and air dried. Sulforhodamine B (SRB) solution (100 µl) at 0.4 % (w/v) in 1 % acetic acid is added to each well, and plates are incubated for 10 minutes at room temperature. After staining, unbound dye is removed by washing five times with 1 % acetic acid and the plates are air dried. Bound stain is subsequently solubilized with 10 mM trizma base, and the absorbance is read on an automated plate reader at a wavelength of 515 nm. For suspension cells, the methodology is the same except that the assay is terminated by fixing settled cells at the bottom of the wells by gently adding 50 µl of 80 % TCA (final concentration, 16 % TCA) [55-57].

4.3. Molecular modeling methods

4.3.1. General methodology:

All molecular modelling calculations were performed using "Molecular Operating Environment (MOE) version 2008.10", Chemical Computing Group Inc., running on "Windows Vista" operating system installed on an Intel core 2du PC with a 1.8 MHz processor and 1000 Mb RAM.

4.3.1.1. Alignment of the training set compounds:

The training set compounds, consisting of nine diarylsulfonylureas of diverse chemical structures including compounds **A**–**E**, in addition to, compounds **3h**, **3n**, **6b** and **8a**, were built using the builder interface of the MOE software. The compounds were aligned using the flexible alignment tool of the program adjusting the energy cut off to 10 kcal/mol and root mean square deviation (RMSD) tolerance to 0.5. The stochastic conformation search option was used as the method of alignment.

4.3.1.2. Target compounds optimization:

Conformational analyses of the built molecules were performed in a two-step procedure. First, the target compounds were subjected to energy minimization tool using the included MOPAC 7.0. The geometry of the compounds was optimized with the semiemperical AM1 Hamiltonian using Restricted Hartree-Fock (RHF) and RMS gradient of 0.05 Kcal/mol. Then, the produced model was subjected to the 'Systematic Conformational Search' of the MOE. All items were set as default with

RMS gradient of 0.01 Kcal/mol and RMS distance of 0.Å. The obtained data were—then saved into a MDB file to be used in the pharmacophore fitting calculations.

4.3.1.3. Pharmacophore Building:

A pharmacophore model was created using the 'Pharmacophore Query Editor'. The aligned training set compounds were used as the template for building the model. The settings of the software parameters were adjusted to: 'Unified' as the scheme of annotation 'Consensus method' for model building. Tolerance was set to 1.2 Å and the threshold was set to 50%. The produced model was used for testing compound pharmacophore fitting and further calculations.

4.3.1.4. Fitting of the target compounds on the built model:

Using the generated pharmacophore model and the saved conformations of each molecule; the fitting of the target compounds into the model was tested. The root mean square deviation value for each conformer was calculated and the one having the lowest RMSD value was taken for further visual and energy inspection.

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Table 1. Physical properties, yields and molecular formulae of the synthesized compounds 3a-r.

				ö	, ₀		A 1 •			
Comp.	v	X 7	Yield	M.P.	Mol. Formula		Analysis	5		
No.	X	Y	%	°C	(Mol. Wt)	Elm.	Calc.	Found		
					$C_{16}H_{12}N_2O_4S$	C	58.53	58.72		
3a	Н	Н	68	274-5	(328.34)	H	3.68	3.28		
					(=====,	S	9.77	9.91		
21		CI.	7.6	206.0	$C_{16}H_{11}CIN_2O_4S$	C	52.97	53.33		
3b	Н	Cl	76	286-8	(362.79)	H	3.06	3.26		
						N C	7.72 59.64	7.42 59.82		
3c	Н	CH_3	63	253-4	$C_{17}H_{14}N_2O_4S$	Н	4.12	4.06		
30	11	C113	0.5	233-4	(342.37)	N	8.18	8.23		
						C	47.19	48.31		
3d	4-Br	Н	41	296-7	$C_{16}H_{11}BrN_2O_4S$	H	2.72	2.55		
					(407.24)	S	7.87	8.03		
					C II D.CIN O C	C	43.51	44.02		
3e	4-Br	Cl	33	330-1	$C_{16}H_{10}BrClN_2O_4S$	H	2.28	2.57		
					(441.68)	N	6.34	6.11		
					$C_{17}H_{13}BrN_2O_4S$	C	48.47	49.14		
3f	4-Br	CH_3	37	294-5	(421.27)	H	3.11	3.02		
					(421.27)	N	6.65	6.79		
			•	•••	$C_{16}H_{11}CIN_2O_4S$	C	52.97	54.17		
3g	4-Cl	Н	38	300-2	(362.79)	H	3.06	3.32		
					(=,	N	7.72	7.48		
21-	4-Cl	Cl	41	326-9	$C_{16}H_{10}Cl_2N_2O_4S$	С	48.38	48.22		
3h			41		(397.23)	H N	2.54 7.05	2.64 6.99		
						C	54.19	53.74		
3i	4-Cl	CH_3	40	310-1	$C_{17}H_{13}CIN_2O_4S$	Н	3.48	3.38		
31	4-C1	C113	70		(376.81)	S	8.51	8.74		
						Č	51.47	51.68		
3j	3-NO ₂	Н	52	277-9	$C_{16}H_{11}N_3O_6S$	H	2.97	2.72		
-3	2 2 . 2 2			_,,,	(373.34)	S	8.59	8.71		
						C	47.13	46.88		
3k	$3-NO_2$	Cl	48	300-2	$C_{16}H_{10}CIN_3O_6S$	Н	2.47	2.61		
					(407.79)	N	10.3	10.47		
					$C_{17}H_{13}N_3O_6S$	C	52.71	52.44		
31	$3-NO_2$	CH_3	45	291-3	(387.37)	Н	3.38	3.61		
					(307.37)	N	10.85	10.93		
	4 0011		65	270.2	$C_{17}H_{14}N_2O_5S$	C	56.98	56.49		
3m	4-OCH ₃	Н	65	270-2	(358.37)	H	3.94	3.70		
					, ,	N	7.82	7.66		
3n	4-OCH ₃	Cl	71	290-2	$C_{17}H_{13}CIN_2O_5S$	C H	51.98 3.34	51.66 3.19		
311	4-00113	CI	/ 1	290-2	(392.81)	S	8.16	8.41		
						Č	58.05	57.78		
30	4-OCH ₃	CH_3	62	255-6	$C_{18}H_{16}N_2O_5S$	H	4.33	4.50		
	,	3			(372.40)	S	8.61	8.54		
					CHMOG	C	58.21	58.61		
3p	4-(CH ₃) ₂ N	Н	22	275-7	$C_{18}H_{17}N_3O_4S$	H	4.61	4.87		
					(371.41)	N	11.31	11.06		
					C ₁₈ H ₁₆ ClN ₃ O ₄ S	C	53.27	53.88		
3q	$4-(CH_3)_2N$	-(CH ₃) ₂ N Cl	18	262-4	(405.86)	Н	3.97	3.52		
					(403.00)	N	10.35	10.60		
		0**	10	202.2	$C_{19}H_{19}N_3O_4S$	C	59.21	59.09		
3r	$4-(CH_3)_2N$	CH_3	18	292-3	(385.44)	H	4.97	4.68		
						S	8.32	8.61		

Table 2. Physical properties, yields and molecular formulae of the synthesized compounds 6a-l.

Comp.	nn.		Yield	M.P.	Mol. Formula		Analysis			
No.	X	Y	% %	°C	(Mol. Wt)	Elm.	Calc.	Found		
	11		50	255.7	C ₁₆ H ₁₂ N ₂ O ₅ S	C	55.81	55.61		
6a	Н	Н	59	255-7	(344.34)	H N	3.51 8.14	3.82 8.36		
						C	50.73	50.41		
6b	Н	Cl	51	218-20	$C_{16}H_{11}CIN_2O_5S$	H	2.93	2.68		
0.0	11 C1 31	210 20	(378.79)	S	8.47	8.90				
					CHNOC	C	56.98	57.22		
6c	Н	CH_3	54	248-50	$C_{17}H_{14}N_2O_5S$	Н	3.94	3.70		
					(358.37)	N	7.82	7.96		
					C ₁₆ H ₁₁ ClN ₂ O ₅ S	C	50.73	50.42		
6d	Cl	Н	47	230-2	(378.79)	Н	2.93	3.06		
					(376.77)	N	7.40	7.28		
		Cl Cl 44 232-4 C ₁₆ H ₁₀ C ₁₂ N ₂ O ₅ (413.23)	C16H10C10N2O6S	C	46.50	46.33				
6e	Cl		44	232-4	(413.23)	Н	2.44	2.61		
					(110120)	S	7.76	7.60		
	Cl	CH ₃		243-5	C ₁₇ H ₁₃ ClN ₂ O ₅ S	С	51.98	52.26		
6f			42		(392.81)	H	3.34	3.39		
					, ,	S	8.16	7.97		
(~	CH	H ₃ H	22	242-3	$C_{17}H_{14}N_2O_5S$ (358.37)	C	56.98 3.94	56.62 3.75		
6g	CH_3	н	33			H S	3.94 8.95	3.75 9.16		
						C	51.98	51.62		
6h	CH ₃	Cl	38	247-8	$C_{17}H_{13}CIN_2O_5S$		3.34	31.02		
OII	C113	CI	30	247-0	(392.81)	H N	7.13	7.33		
						Č	58.05	58.33		
6i	CH ₃	CH ₃	39	252-4	$C_{18}H_{16}N_2O_5S$	H	4.33	4.09		
	5	5			(372.40)	N	7.52	7.68		
						C	54.54	54.23		
6 j	OCH ₃	Н	52	228-30	$C_{17}H_{14}N_2O_6S$	Н	3.77	3.91		
	,				(374.37)	N	7.48	7.52		
					СИСМОС	C	49.95	50.16		
6k	OCH ₃	CH ₃ Cl	46	246-8	$C_{17}H_{13}ClN_2O_6S$ (408.81)	Н	3.21	3.42		
					(400.01)	S	7.84	7.62		
					$C_{18}H_{16}N_2O_6S$	C	55.66	55.41		
61	OCH_3	OCH ₃ CH ₃	50	224-5	(388.39)	Н	4.15	4.31		
						N	7.21	7.06		

Table 3. Physical properties, yields and molecular formulae of the synthesized compounds 8a-l.

a			Y	14 D	3615		Analysis	3
Comp. No.	X	Y	Yield %	M.P. °C	Mol. Formula (Mol. Wt)	Elm.	Calc.	Found
8a	Н	Н	49	195-6	$C_{20}H_{14}N_2O_4S$	C H	63.48 3.73	63.62 3.51
oa .	11	11	47	175-0	(378.40)	N	7.40	7.64
					a II ani o a	C	58.18	58.26
8b	Н	Cl	27	220-2	$C_{20}H_{13}CIN_2O_4S$	Н	3.17	3.28
			(412.85)	(412.83)	S	7.77	7.42	
					$C_{21}H_{16}N_2O_4S$	C	64.27	64.39
8c	Н	CH_3	47	170-1	(392.43)	Н	4.11	4.33
					(372.43)	N	7.14	7.01
				100.1	$C_{20}H_{13}CIN_2O_4S$	C	58.18	57.82
8d	Cl H		26	180-1	(412.85)	H	3.17	3.35
					(,	N	6.79	6.64
8e	CI	Cl Cl	19	213-5	$C_{20}H_{12}Cl_2N_2O_4S$	C H	53.70 2.70	53.89
Se	CI		19		(447.29)	н N	6.26	2.45 6.29
						C	59.09	59.11
8f	Cl	CH_3	24	192-3	$C_{21}H_{15}CIN_2O_4S$	Н	3.54	3.41
OI .			24	172-3	(426.87)	S	7.51	7.39
						Č	64.27	64.02
8g	CH ₃	Н	29	194-6	$C_{21}H_{16}N_2O_4S$	Н	4.11	4.37
					(392.43)	S	8.17	7.86
					C II CIN O C	C	59.09	59.31
8h	CH ₃	Cl	22	202-4	$C_{21}H_{15}CIN_2O_4S$ (426.87)	Н	3.54	3.62
					(420.87)	N	6.56	6.44
					$C_{22}H_{18}N_2O_4S$	C	65.01	65.26
8i	CH ₃	CH_3	33	216-7	(406.45)	Н	4.46	4.29
					(400.43)	N	6.89	6.92
					$C_{21}H_{16}N_2O_5S$	C	61.76	62.03
8j	OCH ₃	Н	32	190-2	(408.43)	Н	3.95	3.77
					(100110)	N	6.86	6.92
01	OCH	CI.		1.67.0	$C_{21}H_{15}CIN_2O_5S$	C	56.95	56.66
8k	OCH ₃	Cl	21	167-8	(442.87)	Н	3.41	3.62
					, ,	S C	7.24 62.55	7.52
QI	OCH	CH	20	179.0	$C_{22}H_{18}N_2O_5S$	H H		62.21
81	OCH ₃	CH_3 CH_3	30	178-9	(422.45)	н S	4.29	4.44 7.34
						<u>s</u>	7.59	7.34

Table 4. The percentages of growth inhibition of the thirteen selected compounds over the most sensitive tumor cell lines.*

Comp. No	IGROV1 (%)	OVCAR-8 (%)	RXF393 (%)	M14 (%)	SK-MEL-2 (%)
3b	-9.05	3.88	0.92	-	11.71
3g	1.13	6.79	7.42	-	19.95
3h	80.99	4.01	76.2	-20.14	17.63
3m	114.67	5.23	96.49	-	11.57
3n	-1.97	-1.23	84.12	-	8.98
3p	106.89	1.17	80.28	-2.88	3.98
3q	97.89	-8.63	95.74	199.62	1.29
6b	34.14	58.86	-	8.19	65.1
6f	65.6	54.13	-	-7.35	73.93
6k	76.55	42.41	-	-3.04	61.07
8a	86.78	33.24	-	1.02	70.4
8b	91.42	40.85	-	17.36	79.27
8j	63.16	26.02	42.95	56.53	-43.25

 $^{\circ}$ The showed inhibition percentages are measured at a single concentration of $10\mu M$. % inhibition is calculated by simple abstraction of the % activity from 100. 100% activity is the activity of cells in presence of test solvent only (DMSO). % Inhibition between 100–200% means that the compound has a lethal effect at cancer cells.

Table 5. The percentages of growth inhibition of compound 3q over the full panel of tumor cell lines*

Cell line	C.H.P.	Inhibition	Cell line	Call Parameter	Inhibition
type	Cell line name	(%)	type	Cell line name	(%)
	A549/ATCC	-8.84		CCRF-CEM	2.95
ਜ਼ .	EKVX	14.7	ia	HL-60(TB)	4.85
2 I S	HOP-92	11.19	Leukemia	K-562	8.89
ral Ran	NCI-H226	-9.94	Ž,	MOLT-4	11.54
မ်ိန္	NCI-H23	-1.8	ĭ	RPMI-8226	-6.72
Non-small cell lung cancer	NCI-H322M	-16.53		SR	34.66
Z	NCI-H460	-15.77		786-0	-0.44
	NCI-H522	9.78	er	A498	-8.94
<u>.</u>	COLO 205	-14.66	nc	ACHN	-5.38
[Se]	HCC-2998	-54.05	ప్	CAKI-1	-5.71
Colon Cancer	HCT-116	-3.55	Renal Cancer	RXF393	95.74
J (HCT-15	1.55	Çe I	SN12C	0.04
<u> </u>	HT29	-2.64	4	TK-10	-33.42
<u> </u>	KM12	-11.59		UO-31	5.5
	SW-620	-1.96		LOX IMVI	6.44
	BT-549	4.63		M14	199.62
er.	HS 578T	14.08	g	MALME-3M	-49.66
in the second	MCF7	-6.37	0	SK-MEL-2	1.29
Breast Cancer	MDA-MB- 231/ATCC	-2.18	Melanoma	SK-MEL-28	-4.69
re	MDA-MB-435	-4.89	4	SK-MEL-5	-3.11
B	NCI/ADR-RES	-6.33		UACC-257	-1.01
	T-47D	-9.29		UACC-62	3.93
	IGROV1	97.89		SF-268	-21.61
п _г	OVCAR-3	-13.88	Se	SF-295	-8.92
Ovarian Cancer	OVCAR-4	7.93	an	SF-539	-0.9
va Van	OVCAR-5	-4.44	S	SNB-19	-6.78
6 5	OVCAR-8	-8.63	CNS cancer	SNB-75	-5.55
	SK-OV-3	-8.45		U251	-0.69
Prostate	DU-145	-4.25			
Cancer	PC-3	-6.65			

 * The showed inhibition percentages are measured at a single concentration of $10\mu M$. % inhibition is calculated by simple abstraction of the % activity from 100. 100% activity is the activity of cells in presence of test solvent only (DMSO). % Inhibition between 100–200% means that the compound has a lethal effect at cancer cells.

Table 6. Molar refractometry and calculated Lipinski's rule of five for the tested compounds.

Comp	IGROV1 ^a				1			
No	(% Inhibition)	MR ^b	LogP ^c	TPSA ^d	MW ^e	$n\mathbf{ON}^{\mathrm{f}}$	<i>n</i> OHNH ^g	Nviolatios ^h
3b	-9.05	88.7	2.5	83.6	362.8	6	1	0
3 g	1.13	88.7	2.5	83.6	362.8	6	1	0
3h	80.99	93.3	3.3	83.6	397.2	6	1	0
3m	114.67	91.4	1.8	92.8	358.4	7	1	0
3n	-1.97	96.0	2.5	92.8	392.8	7	1	0
3 p	106.89	99.3	2.0	86.8	371.4	7	1	0
3q	97.89	103.9	2.7	86.8	405.9	7	1	0
6b	34.14	86.4	2.8	91.8	378.8	7	0	0
6f	65.6	92.3	3.3	91.8	392.8	7	0	0
6k	76.55	93.7	2.7	101.1	408.8	8	0	0
8a	86.78	98.1	3.8	74.8	378.4	6	0	0
8b	91.42	102.7	4.5	74.8	412.9	6	0	0
8j	63.16	105.4	3.7	84.0	408.4	7	0	0

^aData taken from table 1, ^bMolar refractometry, ^cCalculated lipophilicity, ^dTotal polar surface area, ^eMolecular weigh, ^fNumber of hydrogen bond acceptor, ^gNumber of hydrogen bond donor, ^hNumber of violation from Lipinski's rule of five.

34 **Table 7.** The predicted ADME-Tox of the proposed and reported antitumor agents.

ADME-Tox ³	3h	3m	3p	3q	6b	6f	6k	8a	8b	8j	A	D	E
Solubility (LogS)	-6.11 (±0.5)	-4.76 (±0.5)	-4.96 (±0.5)	-5.83 (±0.5)	-4.48 (±0.5)	-4.92 (±0.5)	-4.87 (±0.5)	-5.56 (±0.5)	-6.44 (±0.5)	-5.95 (±0.5)	-5.47 (±0.5)	-4.99 (±0.5)	-6.28 (±0.5)
F (%) ^a	97.38 (±15)	98.27 (±15)	83.78 (±15)	84.27 (±15)	107.62 (±15)	107.25 (±15)	110.04 (±15)	56.88 (±15)	56.18 (±15)	57.08 (±15)	81.41 (±15)	69.04 (±15)	51.15 (±15)
HIA (%) ^b	95.17 (±13)	95.17 (±13)	99.02 (±13)	99.23 (±13)	99.71 (±13)	94.66 (±13)	100.09 (±13)	110.61 (±13)	110.80 (±13)	110.98 (±13)	90.32 (±13)	79.02 (±13)	76.31 (±13)
LogBBB ^c (PPB %) ^d	0.32 (96.63)	-0.32 (73.54)	0.34 (87.38)	0.43 (96.07)	-0.57 (98.65)	-0.90 (98.87)	-1.03 (98.96)	-0.16 (88.70)	-0.06 (95.03)	-0.62 (88.57)	-0.06 (99.21)	0.25 (87.66)	-0.10 (91.16)
LD _{50 rat/mouse} (mg kg ⁻¹ , oral)	560/860	500/690	280/420	290/460	400/730	390/720	380/700	310/570	310/620	290/530	640/530	620/960	470/790
LD _{50 rat/mouse} (mg kg ⁻¹ ,	1500/2200	1500/1700	770/1100	710/1100	1000/2000	980/1400	940/2100	1100/1700	980/1800	1000/1900	1100/1600	1900/1900	1900/2300
intraperitioneal) LD _{50 mouse} (mg kg ⁻¹ , intravenous)	130	150	110	100	170	150	150	120	110	100	110	170	100
LD _{50 mouse} (mg kg ⁻¹ , subcutaneous)	1300	850	570	610	660	620	570	660	700	580	550	1300	730
Ames test (genotoxicity, %)	0.007	0.008	0.015	0.011	0.001	0.002	0.001	0.012	0.009	0.013	0.002	0.006	0.399
Prob. of blood effect	0.53	0.38	0.56	0.61	0.36	0.34	0.31	0.31	0.36	0.26	0.37	0.42	0.37
Prob. of cardiovascular	0.84	0.78	0.75	0.76	0.27	0.22	0.28	0.77	0.80	0.79	0.48	0.80	0.94
system Prob. of gastrointestinal	0.88	0.82	0.93	0.99	0.74	0.74	0.71	0.70	0.73	0.67	0.84	0.47	0.89
system Prob. of kidney effect	0.25	0.15	0.20	0.22	0.10	0.14	0.13	0.12	0.14	0.10	0.24	0.21	0.20
Prob. of liver effect	0.34	0.60	0.53	0.57	0.12	0.13	0.36	0.12	0.13	0.35	0.18	0.25	0.65
Prob. of lung effect	0.31	0.26	0.58	0.57	0.20	0.20	0.18	0.18	0.19	0.22	0.50	0.29	0.17

^aHuman oral bioavailability, ^bHuman intestinal absorption., ^cBlood Brain Barrier, ^dPlasma protein binding.

Scheme 1. Synthesis of 5-(substituted)benzylidene-3-(4-substituted)phenylsulfonyl imidazolidine-2,4-diones **3a-r**.

$$\begin{array}{c} \begin{array}{c} \begin{array}{c} \\ \\ \\ \\ \end{array} \end{array} \begin{array}{c} \\ \\ \\ \end{array} \begin{array}{c} \\ \\ \end{array} \begin{array}{c} \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \end{array} \begin{array}{c} \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \end{array} \begin{array}{c} \\ \\ \\ \\$$

Scheme 2. Synthesis of 1-(4-substituted)phenylsulfonyl-3-(4-substituted)phenylpyrimidine-2,4,6-(*1H*,3*H*,5*H*)-triones **6a–1**.

Scheme 3. Synthesis of 3-(4-substituted)phenyl-1-(4-substituted)phenylsulfonylquinazoline-2,4(1H,3H)-diones **8a-1**.

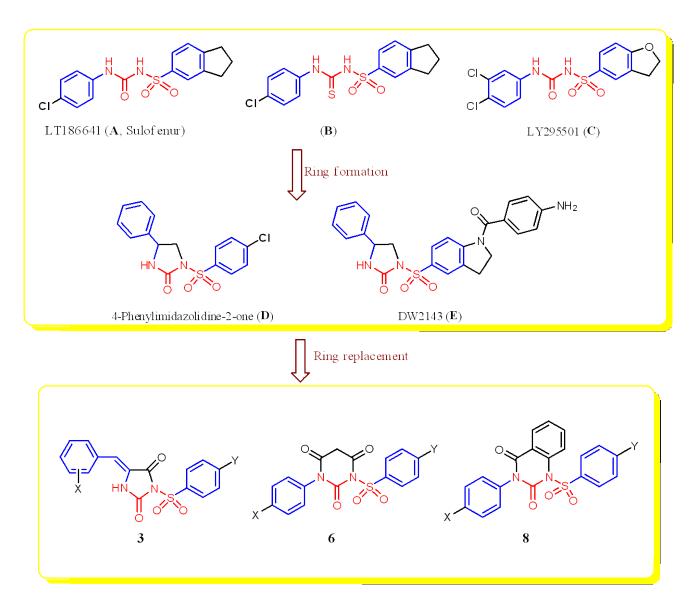


Figure 1. Reported (A - E) and proposed (3, 6 and 8) diarylsulfonylureas.

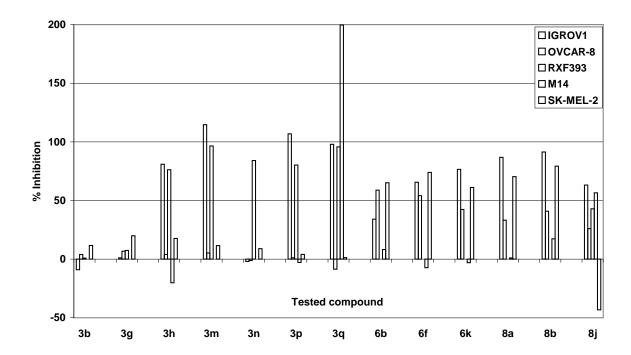


Figure 2. The percentages of growth inhibition of the 13 selected compounds over the most sensitive tumor cell lines.

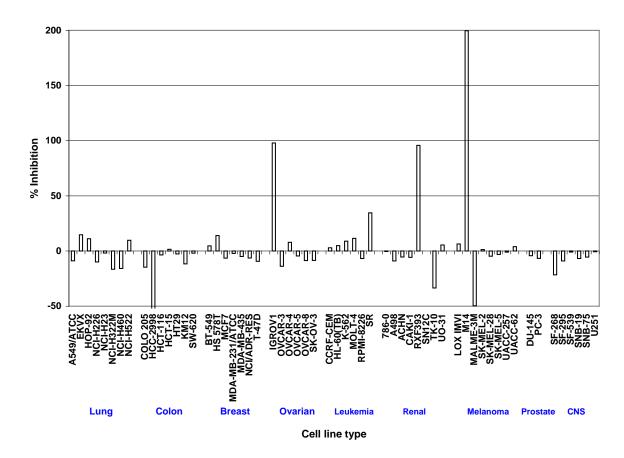
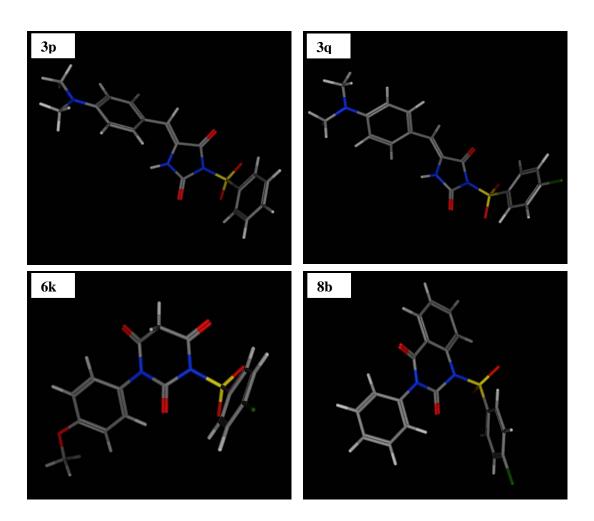


Figure 3. The percentages of growth inhibition of compound 3q over the full panel of tumor cell lines.



 $Figure \ 4. \ Lowest \ energy \ conformers \ of \ the \ most \ active \ compounds \ 3p, \ 3q, \ 6k \ and \ 8b \ as \ representative \ examples.$

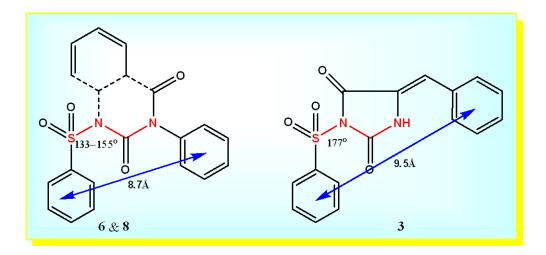


Figure 5. Deduced 2D-cyclic arylsulfonylurea pharmacophore.

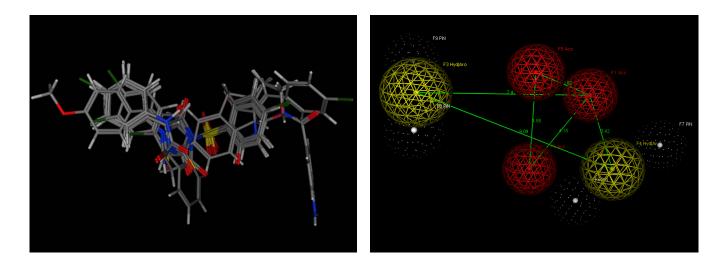


Figure 6. Alignment of a training set (Left panel) and the hypothetical 3D-pharmacophore geometry developed for the proposed cyclic arylsulfonylurea. (Right panel).

F1: Hydrogen bond acceptor center; **F2**: Aromatic or hydrophobic center; **F3** and **F5**: Aromatic or Pi orbital place at the receptor site; **F4**: Aromatic center carrying a H-bond donor; **F6**: Hydrophobic center; **F7**: H-bond acceptor place at the receptor site.

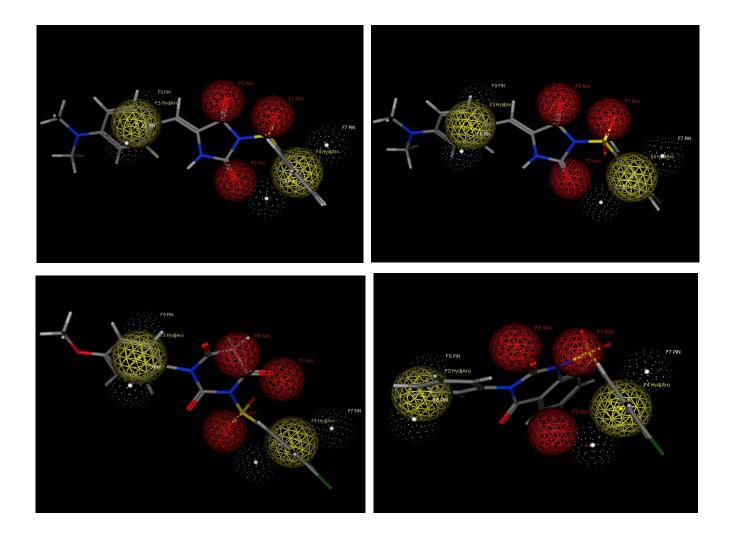


Figure 7. Superimposition of the energy-minimized structures of compounds 3p (Upper left panel), 3q (Upper right panel), 6k (Lower left panel) and 8b (Lower right panel) on the hypothetical 3D-pharmacophore geometry developed for the proposed cyclic arylsulfonylurea.