Research Article

Synthesis, Carbonic Anhydrase II/IX/XII Inhibition, DFT, and Molecular Docking Studies of Hydrazide-Sulfonamide Hybrids of 4-Methylsalicyl- and Acyl-Substituted Hydrazide

Adil Khushal,1 Amara Mumtaz,1 Wamda Ahmed Shadoul,2 Syeda Huda Mehdi Zaidi,3 Hummera Rafique,4 Abida Munir,1 Aneela Maalik,5 Syed Jawad Ali Shah,2 Ayesha Baig,6 Wajiha Khawaja,1 Mariya al-Rashida,7 Muhammad Ali Hashmi,3 and Jamshed Iqbal2

1Department of Chemistry, COMSATS University Islamabad, Abbottabad Campus, Pakistan
2Center for Advance Drug Research, COMSATS University Islamabad, Abbottabad Campus, Pakistan
3Department of Chemistry, University of Education, Attock Campus Attock 43600, Pakistan
4Department of Chemistry, University of Gujrat, Gujrat, Pakistan
5Department of Chemistry, COMSATS University Islamabad, Islamabad Campus, Pakistan
6Department of Biotechnology, COMSATS University Islamabad, Abbottabad Campus, Pakistan
7Department of Chemistry, Forman Christian College, Lahore, Pakistan

Correspondence should be addressed to Amara Mumtaz; amaramumtaz@cuiatd.edu.pk and Jamshed Iqbal; jamshediqb@googlemail.com

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Carbonic anhydrases (CAs and EC 4.2.1.1) are the Zn\(^{2+}\) containing enzymes which catalyze the reversible hydration of CO\(_2\) to carbonate and proton. If they are not functioning properly, it would lead towards many diseases including tumor. Synthesis of hydrazide-sulfonamide hybrids (19-36) was carried out by the reaction of aryl (10-11) and acyl (12-13) hydrazides with substituted sulfonyl chloride (14-18). Final product formation was confirmed by FT-IR, NMR, and EI-MS. Density functional theory (DFT) calculations were performed on all the synthesized compounds to get the ground-state geometries and compute NMR properties. NMR computations were in excellent agreement with the experimental NMR data. All the synthesized hydrazide-sulfonamide hybrids were in vitro evaluated against CA II, CA IX, and CA XII isozymes for their carbonic anhydrase inhibition activities. Among the entire series, only compounds 22, 32, and 36 were highly selective inhibitors of hCA IX and did not inhibit hCA XII. To investigate the binding affinity of these compounds, molecular docking studies of compounds 32 and 36 were carried out against both hCA IX and hCA XII. By using BioSolveIT’s SeeSAR software, further studies to provide visual clues to binding affinity indicate that the structural elements that are responsible for this were also studied. The binding of these compounds with hCA IX was highly favorable (as expected) and in agreement with the experimental data.

1. Introduction

Carbonic anhydrases (CAs and EC 4.2.1.1) are the Zn\(^{2+}\) containing metalloenzyme, belong to the superfamily of enzymes, and are found in all life kingdoms. CAs belong to seven different genetic families, sharing the common mission of catalyzing the reversible hydration of CO\(_2\) to carbonate and proton [1]. In addition to CO\(_2\) regulation, they are also responsible for lipogenesis, gluconeogenesis, and ureagenesis. Vertebrate carbonic anhydrases belong to the \(\alpha\)-CA class with 16 iso-zymes known so far. All these isozymes differ from one another due to their tissue specificity and localization in the cell. Many of them are cytosolic like CA I, CA II, CA III, CA VII, CA VIII, CA X, CA XI, and CA XIII. Some are membrane bound like CA IV, CA IX, CA XII, CA XIV, and CA XV. Some are mitochondrial like CAVA and CAVB, while CA VI is
secreted into the cell’s cytoplasm [2, 3]. So far, nine CA iso- 
yzymes were detected in the human central nervous system; it 
is believed that they are involved in many crucial functions, 
but the exact mechanism is not yet fully understood. Apart 
from their vital role in maintaining many important physio-
logical processes, deregulation of carbonic anhydrases is also 
known to be associated with many pathologies, such as cere-
bral and retinal edema, glaucoma, epilepsy, stroke, retinitis 
pigmentosa, and growth of the tumor cells [2]. The overex-
pression of CA IX is lately been associated with the prolifera-
tion of the tumor cells providing a suitable environment for 
the tumor cells to grow; it has also been related to the poor 
response of patients to common chemotherapeutic reagents 
[4]. Acetazolamide (1) and methazolamide (2) are the clini-
cally recognized carbonic anhydrase inhibitors (CAIs) and 
were tested on some forms of epilepsy in the 1970s (Figure 1). 
Lately, CAIs have been used in combination with other 
medicines in the treatment of obstructive sleep apnea; 
other CAIs of the brain isozymes are applied in the treatment 
of idiopathic intracranial hypertension (IIH), cerebral ische-
mia, neuropathic pain, and migraine [5].

As CAs are the zinc metalloenzymes, so, one of the classic 
types of carbonic anhydrase inhibitors is the zinc ion (Zn^{2+}) 
binders. These CAIs coordinate to the catalytically crucial 
Zn^{2+} from the enzyme site. During this inhibition type, Zn^{2+} 
could also be in tetrahedral or trigonal bipyramidal geomet-
ries. Sulfonamides, sulfamides, sulfamates, most anions, 
thiocarbamates, carboxylates, and hydroxamates are the 
known CAIs that bind through this pathway [6]. Presence of 
the primary amino group make the sulphonamide excellent 
carbonic anhydrase inhibitor [7] but latest research reveals 
that secondary and tertiary sulphonamides also possess selec-
tive carbonic anhydrase inhibition activities [8–11].

Sulfonamides are considered a very important class of 
drugs; their major use is as carbonic anhydrase inhibitors 
and antibacterial agents [12]. The compounds that have 
another electron-withdrawing group or atom attached to the 
sulfanoyl group resulting in a compound with the -NH-SO2-
NH2 group were found to be equipotent to free sulfonamides 
and sometimes stronger inhibitors [13]. This led us to the syn-
thesis of some aryl- and acyl-substituted hydrazide-
sulfonamide hybrids and in vitro investigation of their car-onic anhydrase inhibition activities against CA II, CA IX, 
and CA XII. These isozymes were selected because CA II is 
the most active and abundant isozyme throughout the human 
body; the overexpression of CA IX and CA XII has always 
been related to the proliferation of the tumor cells [4]. NMR 
spectral data was veri
tified by DFT studies. The molecular dock-
ing studies of the most potent derivatives and further con-
rimation by binding affinities studies were also carried out.

2. Results and Discussion

2.1. Chemistry. Synthesis of hydrazide-sulfonamide hybrids (19–36) was carried out starting from the synthesis of 
substituted hydrazides (10-13) [14]. For this reason, the 
methanolic solution of methyl esters (6-9) was refluxed with 
hydrazine monohydrate 64% to get respective hydrazides 
(10-13). Physical data of hydrazides (10-13) is presented in 
Table 1. Schematic representation of the reactions is pre-
sented in Scheme 1.
Structural confirmation of hydrazide synthesis was done by using FT-IR and $^1$HNMR. In FT-IR spectrum, N-H stretching peak at 3018-3406 cm$^{-1}$ and NH$_2$ asymmetric stretch at 3229-3309 cm$^{-1}$ while symmetric stretch at 3212-3329 cm$^{-1}$ confirmed that hydrazide (10-13) has been synthesized. Further structural confirmation was done by the appearance of stretching peaks like C=O at 1612 cm$^{-1}$. C-H stretching peak at 3012 cm$^{-1}$ and C=C stretch at 1495 cm$^{-1}$ of benzene ring also support the presence of functional groups of hydrazides. The presence of the methoxy group substitution in hydrazide 10 and 13 at the benzene ring showed asymmetric and symmetric stretching peaks at 1253 and 1155 cm$^{-1}$, respectively. In the $^1$H NMR spectrum of the hydrazides (10-13), a broad singlet of NH appeared at 6.73-9.02 ppm while a broad singlet of the NH$_2$ group at 3.23-4.26 ppm confirmed the formation of compound (10-13). Two doublets at 8.07 and 7.96 ppm and a singlet at 6.75 ppm confirmed the presence of all aromatic signals [14].

For the synthesis of the compounds (19-36), hydrazide (10-13) (0.5 mmol) was stirred with substituted benzenesulfonyl chloride (14-18) (0.5 mmol) in pyridine (Scheme 2). Physical data of the compounds (19-36) is presented in Table 2.

In the FT-IR spectrum, the appearance of NH stretching peak at 3321-3375 cm$^{-1}$ and asymmetric and symmetric stretching peaks of S=O at 1332-1387 cm$^{-1}$ and 1189-1195 cm$^{-1}$, respectively, confirmed the hydrazide-sulfonamide hybrid synthesis (19-36). Moreover, asymmetric and symmetric stretching at 1553 cm$^{-1}$ and 1376 cm$^{-1}$ confirmed the nitro group, while C-H stretching peak at 3095-3132 cm$^{-1}$ confirmed the aromatic rings. Stretching peak of C=O at 1622-1670 cm$^{-1}$, stretching peak of aliphatic C-H at 3132 cm$^{-1}$, and C-O stretching peak at 1230-1263 cm$^{-1}$ were observed. The structures of all the synthesized compounds were confirmed by the $^1$HNMR data. In the $^1$H NMR data of hydrazide-sulfonamide hybrids (19-36), two singlets...
| Sr. no. | Structure | mp (°C) | Rf | Yield (%) |
|---------|-----------|---------|----|-----------|
| 19      | ![Structure](image1.png) | 220-222 | 0.5 | 89        |
| 20      | ![Structure](image2.png) | 168-169 | 0.4 | 85        |
| 21      | ![Structure](image3.png) | 159-162 | 0.3 | 83        |
| 22      | ![Structure](image4.png) | 161-163 | 0.4 | 76        |
| 23      | ![Structure](image5.png) | 186-187 | 0.4 | 79        |
| 24      | ![Structure](image6.png) | 211-213 | 0.2 | 82        |
| 25      | ![Structure](image7.png) | 231-215 | 0.3 | 81        |
| 26      | ![Structure](image8.png) | 168-169 | 0.2 | 75        |
| 27      | ![Structure](image9.png) | 183-185 | 0.3 | 85        |
| Sr. no. | Structure | mp (°C) | $R_f$ | Yield (%) |
|---------|-----------|---------|-------|-----------|
| 28      | ![Structure 28](image) | 205-206 | 0.5   | 85        |
| 29      | ![Structure 29](image) | 156-157 | 0.5   | 70        |
| 30      | ![Structure 30](image) | 133-134 | 0.3   | 82        |
| 31      | ![Structure 31](image) | 143-144 | 0.4   | 80        |
| 32      | ![Structure 32](image) | 158-159 | 0.4   | 76        |
| 33      | ![Structure 33](image) | 153-154 | 0.4   | 80        |
| 34      | ![Structure 34](image) | 146-147 | 0.2   | 70        |
| 35      | ![Structure 35](image) | 143-144 | 0.3   | 87        |
appeared in the range of 10.45-10.61 and 9.56-10.33 ppm for NH groups which confirmed the formation of the product. Four doublets of all the aromatic protons of both benzene rings appeared in the aromatic region. The methyl group showed signal at 2.32-2.28 ppm [15]. To confirm the structures of the hydrazide-sulfonamide hybrids (19-36), the $^{13}$CNR spectra of the selected compounds were taken. The appearance of the signal at 164.3-164.8 ppm for S=O and 157.5-157.6 ppm for C=O groups confirmed the synthesis of hydrazide-sulfonamide hybrids. To further justify the structures of hydrazide-sulfonamide hybrids EI-MS of the selected compounds were taken and the appearance of $\left[M+1\right]$ molecular ions, peaks confirmed the structures of our desired products. To check the purity of the synthesized compounds, HPLC spectra of the selected compounds were taken in reverse phase in acetonitrile/water (1:1) mixture with a 10-11-minute retention time.

2.2. Computational Studies. All the synthesized compounds have been studied using the density functional theory (DFT) computations to gain an insight into their electronic structure and compute their NMR chemical shifts. The compounds have been subjected to geometry optimization using the PBE0-D3BJ/def2-TZVP/SMD Solvent (Solvent = DMSO or chloroform) level of theory [16, 17] followed by their frequency calculations to verify that they are true minima on the potential energy surface (PES). Figure 2 shows their optimized geometries.

For organic chemists, nuclear magnetic resonance (NMR) is of prime importance and can be used as a vital technique to determine and verify the structures of synthesized molecules. DFT computations of NMR chemical shifts can yield an accurate NMR dataset that can be compared with the experimental data. All of the modeled compounds’ NMR calculations have been performed on the same theoretical level as the

| Sr. no. | Structure | mp (°C) | $R_f$ | Yield (%) |
|---------|-----------|---------|-------|-----------|
| 36      | ![Structure](image) | 139-141 | 0.5   | 84        |

Figure 4: Possible binding mode of the inhibitor 23 inside the CA IX active pocket.
optimizations, and the results are compared with the experimental chemical shifts. Methanol and benzene have been employed as reference standards for sp³ and sp² carbons due to their good and effective results, as formerly demonstrated by Perdew et al. [18]. The ¹H-NMR data of compound 19 is given in Table 3. The supporting information contains a comparison of all of the other compounds. Furthermore, with a mean absolute error (MAE) of 0.19 ppm only, it is evident that the NMR calculation methodology has worked really well. Consequently, some compounds’ NMR data could not be obtained in a sufficient yield to get their precise experimental NMR; however, its accurate prediction from the computations can be utilized as a guide for the production of these compounds.

2.3. Carbonic Anhydrase Inhibition Studies. All the synthesized compounds were tested for their inhibition activity against the three isozymes of CAs, CA II, CA IX, and CA XII, using the optimized colorimetric method [19], and the results are shown in Table 4.

The synthesized compounds showed results against the three isozymes with relatively less Ki values against CA IX and CA XII. In the case of sulfonamide derivatives synthesized from salicylic acid hydrazide, the presence of the methoxy group at the orthoposition to the carbonyl group decreased the activity of compounds 19, 20, 21, 22, and 23, while the unprotected hydroxyl group at the same position has clearly enhanced the activity of the compounds 24, 25, 26, and 27 against CA IX and CA XII [20]. In the case of phenylsubstituted acyl hydrazide derivatives, an enhancement of the activity against the three isozymes was observed in com-

### Table 3: Comparison of experimental and computed NMR data for compound 19.

| Carbon no. | Carbon type | ¹H-NMR (experimental) δ (ppm) | ¹H-NMR (computed) δ (ppm) | Δδ (ppm) |
|------------|-------------|------------------------------|--------------------------|----------|
| 3          | CH          | 6.92                         | 7.06                     | -0.14    |
| 5          | CH          | 6.78                         | 7.08                     | -0.3     |
| 6          | CH          | 7.26                         | 8.42                     | -1.16    |
| 2’         | CH          | 8.39                         | 8.22                     | 0.17     |
| 3’         | CH          | 8.09                         | 8.56                     | -0.47    |
| 5’         | CH          | 8.09                         | 8.7                      | -0.61    |
| 6’         | CH          | 8.39                         | 10.01                    | -1.62    |
| 4-Me       | CH₃         | 2.32                         | 2.24                     | 0.08     |
| 2-OMe      | CH₃         | 3.80                         | 3.74                     | 0.06     |

Mean absolute error (MAE) = 0.19
Root mean square error (RMSE) = 0.44

### Table 4: Ki values and inhibition percentages of the synthesized compounds against CA II, CA IX, and CA XII.

| Sr no. | CAII (μM ± SEM)% inhibition | CAIX (μM ± SEM)% inhibition | CAXII (μM ± SEM)% inhibition |
|--------|------------------------------|-----------------------------|-------------------------------|
| 19     | 0.68 ± 0.02                  | 0.58 ± 0.04                 | 44.4%                         |
| 20     | 0.66 ± 0.04                  | 0.56 ± 0.05                 | 99.9 ± 0.10                  |
| 21     | 0.61 ± 0.01                  | 0.19 ± 0.02                 | 1.22 ± 0.01                  |
| 22     | 0.68 ± 0.01                  | 1.04 ± 0.38                 | 42.89%                       |
| 23     | 0.94 ± 0.02                  | 0.19 ± 0.03                 | 0.75 ± 0.07                  |
| 24     | 0.34 ± 0.01                  | 0.54 ± 0.06                 | 0.52 ± 0.04                  |
| 25     | 0.91 ± 0.02                  | 0.33 ± 0.03                 | 0.35 ± 0.04                  |
| 26     | 0.96 ± 0.09                  | 0.91 ± 0.09                 | 0.58 ± 0.04                  |
| 27     | 1.11 ± 0.04                  | 0.51 ± 0.04                 | 0.43 ± 0.08                  |
| 28     | 0.46 ± 0.01                  | 0.55 ± 0.01                 | 1.02 ± 0.08                  |
| 29     | 0.73 ± 0.02                  | 0.33 ± 0.02                 | 0.55 ± 0.01                  |
| 30     | 0.74 ± 0.04                  | 0.33 ± 0.03                 | 0.13 ± 0.01                  |
| 31     | 0.67 ± 0.01                  | 0.29 ± 0.02                 | 0.40 ± 0.09                  |
| 32     | 0.67 ± 0.06                  | 0.32 ± 0.01                 | 49.25%                       |
| 33     | 0.68 ± 0.05                  | 0.39 ± 0.03                 | 0.17 ± 0.01                  |
| 34     | 1.81 ± 0.03                  | 0.65 ± 0.03                 | 0.22 ± 0.06                  |
| 35     | 3.20 ± 0.14                  | 1.18 ± 0.04                 | 0.34 ± 0.01                  |
| 36     | 0.92 ± 0.10                  | 0.60 ± 0.01                 | 48.88%                       |
| Acetazolamide | 0.31 ± 0.03  | 0.30 ± 0.01 | 0.20 ± 0.02 |

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pounds 28, 29, 30, and 31. While for the compounds having 3-methoxyphenyl acyl derivatives, 32, 33, 34, 35, and 36 lead to variation between the three isozymes and the enhancement or decrease in the activity of the compound depended on other substituents coming from phenyl sulfonyl chloride part [21].

Substitution of the benzene ring containing the sulfonamide moiety with a methoxy and one more benzene greatly enhances the activity of compounds 21 and 23, respectively, against CA IX, also seen in 30. The presence of a nitro group at this position enhances the activity of the compounds against CA II as seen in compounds 19, 24, 28, and 32. Meanwhile, less effect of this group was observed within the activity of the compounds against CA IX and reduction in the activity of these compounds against CA XII. The presence of a bromide at this position showed variation depending of the substituents in the other benzene ring. Studies
suggest that these compounds may play an important role as an anticancer agent with less side effect against the major off-target CA II which is readily available in a wide range of tissues and being the most active isozyme of the family. The presence of the specific functional groups enhanced the activity against the enzyme.

2.4. Molecular Docking Studies. The carbonic anhydrase isozymes (II, IX, and XII) selected for docking studies contained different sulfonamide inhibitors co-crystallized in the active pocket. These co-crystallized inhibitors were selected as reference for docking, and the docking protocol was validated after successfully reproducing the co-crystallized poses. The calculated RMSD values for reference ligands of CA II, CA IX, and CA XII were 0.90, 0.83, and 1.19 Å, respectively. The HYDE assessment shows a binding-free energy of -41, -36, and -23 KJmol⁻¹, respectively.

Compound 24 was docked inside the active pocket of CA II with a FlexX score of -23 and HYDE score of -18 KJmol⁻¹ (Figure 3). Similar to the reference co-crystallized ligand, inhibitor 24 forms hydrogen bonding interaction with residue Glu92 and a metal ion interaction with Zn²⁺ ion in the active pocket. Additionally, the residue Asn67 was found to form two hydrogen bonds with the carboxyl and amino group of compound 24. Likewise, the hydrophobic interactions in reference co-crystallized ligand the inhibitor 24 shows hydrophobic interactions with Glu92, His94, and Val121. Additionally, hydrophobic interactions with Leu60 and Asn67 were also observed.

The inhibitor 23 (Figure 4) was found to dock inside the CA IX active pocket with a FlexX score of -24 and binding affinity (HYDE score) of -18 KJmol⁻¹. Similar to the reference ligand, inhibitor 23 was found to form hydrogen bonding interaction with the amino group of the residue Glu92. Unlike the reference ligand, no metal ion interaction was found due to the bulky naphthalene group in inhibitor 23. However, the sulfonamide group of the inhibitor adjacent to the naphthalene group was found to form hydrogen bonding interaction with residue His68. Additionally, the residue Gln71 was also found to form two hydrogen bonding interactions with amino groups of the inhibitor 23. Similar to the reference ligand, inhibitor 23 was found to form hydrophobic interactions with His94, Val130, Leu134, and Leu199. Additionally, several other hydrophobic interactions of inhibitor 23 with residues Leu91, Glu92, Thr201, and Val121 were also found.

Docking of the inhibitor 30 (Figure 5) inside the CA XII revealed a FlexX docking score of -19 and binding affinity of -18 KJmol⁻¹. The inhibitor 30 was observed to form hydrogen bonding interaction with residues Lys69, Gln89, and Thr199. Interaction with residue Thr199 was also found in the case of co-crystallized sulfonamide inhibitor in the active pocket of CA XII. Unlike the co-crystallized inhibitor’s sulfonamide group interaction with Zn²⁺ ions in the active site, no such interaction was found in the case of inhibitor 30 due to methoxy substitution adjacent to its sulfonamide group. The residues Asn64, Lys69, Gln89, Val119, Val141, Leu197, Thr199, and Val206 were observed to form hydrophobic interactions and pocket lining of inhibitor 30.

2.5. Investigating Selective Binding of 32 and 36 to hCA IX over hCA XII. Among the entire series, only compounds 22, 32, and 36 were highly selective inhibitors of hCA IX and did not inhibit hCA XII (<50% inhibition). We wanted to investigate why binding of these compounds to hCA XII is poor. For this purpose, the compounds 32 and 36 were docked against both hCA IX and hCA XII. Binding of these compounds with hCA IX was highly favorable (as expected) and in agreement with the experimental data.
BioSolveIT's SeeSAR software [22, 23] provides visual clues to binding affinity (whether favorable or unfavorable) and also indicates the structural elements that are responsible for this. The SeeSAR analysis of compounds 32 and 36 are given in Figure 6. For compounds 32 and 36, most of the binding modes indicated highly unfavorable binding.

For compound 32 (Figure 6(a)), four structural elements were found to be highly unfavorable. One of oxygen atom of the sulfonamide group, the oxygen atom of the methoxy group, the carbon atom next to the carbon atom to which methoxy group is attached, and the carbon atom adjacent to the carbonyl group. With the exception of sulfonamide oxygen (that is involved in hydrogen bond formation with Asn62), other atoms (mentioned above) had a very high desolvation energy that had not been compensated by hydrogen bond formation. If the orientation of the inhibitor was such that result in some nonbonded interactions, the penalty on high desolvation energy would have been compensated, which is not the case; this may explain why binding of these molecules is inefficient. Similarly, for compound 36 (Figure 6(b)), four structural elements were found to be highly unfavorable. The sulfonamide NH and oxygen atom of the carbonyl group were contributing unfavorably because of high desolvation energy, although some of the unfavorable, high energy is compensated in part by the presence of hydrogen bonds that -NH is making with Pro201 and -C=O with Thr200; it is not enough and the overall contribution is still somewhat unfavorable. The other two unfavorable structural elements are the oxygen atom of the methoxy group and carbon atom (C25) of the naphthyl group. Both have high desolvation energies that has not been compensated by the formation of any nonbonded interaction (Figure 7).

### 3. Conclusions

A series of sulfonamide-hydrazide hybrids of aryl and phenyl acetyl hydrazides (19-36) were synthesized and tested for their role as future anticancer agents with less side effects against CA II (major target), CA IX, and CA XII isozymes of carbonic anhydrase. It was found that substitution of the aromatic group has a significant role in determining the structure activity relationship studies. In the case of aryl substitution when the 2-OH group was free, an enhanced activity was observed as compared to the compounds having substituted OH group with OMe. In the case of acetyl-substituted sulfonamide-hydrazide hybrids, the addition of CH2 group enhances the activity as compared to the aryl group with one carbon. By using BioSolveIT's SeeSAR software, further studies to provide visual clues to binding affinity indicates that the structural elements that are responsible for this were also studied. Among the entire series, only compounds 22, 32, and 36 were highly selective inhibitors of hCA IX and did not inhibit hCA XII (<50% inhibition). We wanted to investigate why binding of these compounds to hCA XII is poor. For this purpose, compounds 32 and 36 were docked against both hCA IX and hCA XII. Binding of these compounds with hCA IX was highly favorable (as expected) and in agreement with the experimental data.

### 4. Methodology

#### 4.1. General Procedure for the Synthesis of Ester (6-9)

Substituted benzoic acid and phenyl acetic acids were refluxed with excess of methanol in the presence of sulfuric acid as catalyst to get methoxy esters (6-9) [14, 24].

(i) Methyl 2-Methoxy-4-methylbenzoate 6

![Chemical structure](image)

Yield: 88%; \[ R_f = (n - \text{hexane} : \text{EtOAc} = 6 : 4) 0.6; \text{mp (oil)} [24].

(ii) Methyl 2-Hydroxy-4-methylbenzoate 7

![Chemical structure](image)

Yield: 92%; \[ R_f = (n - \text{hexane} : \text{EtOAc} = 7 : 3) 0.8; \text{mp (oil)} [24].

(iii) Methyl 2-(p-Tolyl)acetate 8

![Chemical structure](image)

Yield: 87%; \[ R_f = (n - \text{hexane} : \text{EtOAc} = 4 : 1) 0.8; \text{bp (°C); oil} [24].

(iv) Methyl 2-(3-Methoxyphenyl)acetate 9

![Chemical structure](image)

Yield: 80%; \[ R_f = (n - \text{hexane} : \text{EtOAc} = 4 : 1) 0.7; \text{bp (°C); oil} [24].

#### (v) General Procedure for the Synthesis of Hydrazides (10-13)

The alcoholic solution of methyl esters (6-9) were refluxed with the hydrazine monohydrate for 4-5 hours to get hydrazides (10-13). The solid obtained was purified by recrystallization using appropriate solvent [14, 24].

(i) 2-Methoxy-4-methylbenzohydrazide 10

![Chemical structure](image)

Yield: 92%; \[ R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.2; \text{mp. (109-110°C)} [24].
(ii) 2-Hydroxy-4-methylbenzohydrazide (11)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{OH} & \quad \text{H} \quad \text{NH}_2
\end{align*}
\]

Yield: 77%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.2; \) mp. Melt with decompose [24].

(iii) 2-(p-Tolyl)acetohydrazide (12)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{CH}_3 & \quad \text{H} \quad \text{OH}
\end{align*}
\]

Yield: 85%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) ; \) mp. (153-154°C) [24].

(iv) 2-(3-Methoxyphenyl)acetohydrazide (13)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{OMe} & \quad \text{H} \quad \text{OH}
\end{align*}
\]

Yield: 82%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.2; \) mp. (95-96°C) [24].

(v) General Procedure for the Synthesis of Hydrazide Sulfonamide (19-36)

Acyl- and aryl-substituted hydrazides (10-13) were stirred at room temperature with substituted sulfonyl chloride (14-18) in the presence of pyridine. After overnight stirring, solid product precipitated in the flask which was neutralized with dilute HCl to get rid of pyridine as pyridinium chloride. The solid obtained was filtered, washed with cold water, and recrystallized with appropriate solvent to purify the final product (19-36) [15].

(i) \( N'-(2\text{-Methoxy-4-methylbenzoyl})-4\text{-nitrobenzenesulfonylhydrazide} \) (19)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{OMe} & \quad \text{H} \quad \text{NO}_2
\end{align*}
\]

Yield: 89%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.5; \) mp. (220-222°C); HPLC purity = 96.1% (C18 RP, CH₃CN/H₂O-1:1), TR = 11.1 min, FT-IR (\( \tilde{\nu} \) cm⁻¹): 3231, 3149, 2817, 1664 (C=O), 1403, 1380, 1262, 1181; \(^1\text{H NMR} \) (400 MHz, DMSO-d₆) (\( \delta \) ppm): 10.46 (s, 1H, NH), 10.21 (s, 1H, NH), 8.39 (d, \( J = 8.1 \text{Hz} \), 2H\(_\text{Ar}\)), 8.09 (d, \( J = 8.8 \text{Hz} \), 2H\(_\text{Ar}\)), 7.26 (d, \( J = 7.7 \text{Hz} \), 1H\(_\text{Ar}\)), 6.92 (s, 1H\(_\text{Ar}\)), 6.78 (d, \( J = 7.7 \text{Hz} \), 1H\(_\text{Ar}\)), 3.80 (s, 3H, OCH₃), 2.32 (s, 3H, CH₃), \(^{13}\text{C NMR} \) (100 MHz, DMSO-d₆) \( \delta \) ppm: 165.0, 156.9, 149.9, 145.2, 143.1, 129.9, 128.9, 125.1, 124.1, 121.0, 118.7, 55.8, 21.3, ESI-MS: C₁₅H₁₃N₃O₇S [M+1] 366.2.

(ii) 4-Bromo-\( N'-(2\text{-methoxy-4-methylbenzoyl})\text{-benzenesulfonylhydrazide} \) (20)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{Br} & \quad \text{OMe}
\end{align*}
\]

Yield: 85%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.4; \) mp. (168-169°C); HPLC purity = 91.8% (C18 RP, CH₃CN/H₂O-1:1), TR = 10.1 min, FT-IR (\( \tilde{\nu} \) cm⁻¹): 3321, 3095 (aromatic CH), 2887, 1622 (C=O), 1375, 1263, 1198; \(^1\text{H NMR} \) (400 MHz, CDCl₃) (\( \delta \) ppm): 9.56 (s, 2H, NH), 7.77 (dt, \( J = 8.6, 2.3 \text{Hz} \), 2H\(_\text{Ar}\)), 7.72 (d, \( J = 7.9 \text{Hz} \), 1H\(_\text{Ar}\)), 7.59 (d, \( J = 8.6, 2.3 \text{Hz} \), 2H\(_\text{Ar}\)), 6.86 (d, \( J = 8.0 \text{Hz} \), 1H\(_\text{Ar}\)), 6.81 (s, 1H\(_\text{Ar}\)), 4.03 (s, 3H, OCH₃), 2.41 (s, 3H, CH₃), \(^{13}\text{C NMR} \) (100 MHz, CDCl₃) (\( \delta \) ppm), 164.3, 157.6, 145.6, 135.7, 132.3, 130.1, 129.0, 122.6, 115.4, 112.2, 56.3, 22.0.

(iii) 4-Methoxy-\( N'-(2\text{-methoxy-4-methylbenzoyl})\text{-benzenesulfonylhydrazide} \) (21)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{OMe} & \quad \text{OMe}
\end{align*}
\]

Yield: 83%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.3; \) mp. (159-162°C); FT-IR (\( \tilde{\nu} \) cm⁻¹): 3281, 3142 (aromatic CH), 2925, 1696 (C=O), 1358, 1234, 1184; \(^1\text{H NMR} \) (400 MHz, CDCl₃) (\( \delta \) ppm): 9.56 (s, 2H, NH), 7.83 (d, \( J = 8.8 \text{Hz} \), 2H\(_\text{Ar}\)), 7.72 (d, \( J = 7.9 \text{Hz} \), 1H\(_\text{Ar}\)), 6.90 (d, \( J = 8.8 \text{Hz} \), 2H\(_\text{Ar}\)), 6.83 (d, \( J = 8.1 \text{Hz} \), 1H\(_\text{Ar}\)), 6.80 (s, 1H\(_\text{Ar}\)), 4.02 (s, 3H, OCH₃), 3.83 (s, 3H, OCH₃), 2.40 (s, 3H, CH₃), \(^{13}\text{C NMR} \) (100 MHz, CDCl₃) (\( \delta \) ppm), 166.1, 156.6, 144.3, 134.8, 133.1, 129.8, 129.5, 121.4, 115.9, 112.8, 56.3, 54.6, 21.9.

(iv) \( N'-(2\text{-Methoxy-4-methylbenzoyl})-4\text{-methylbenzenesulfonylhydrazide} \) (22)

\[
\begin{align*}
\text{O} & \quad \text{N} \quad \text{H} \quad \text{NH}_2 \\
\text{OMe} & \quad \text{OMe}
\end{align*}
\]

Yield: 76%; \( R_f = (n - \text{hexane} : \text{EtOAc} = 3 : 2) 0.4; \) mp. (161-163°C); FT-IR (\( \tilde{\nu} \) cm⁻¹): 3361, 3137 (aromatic CH), 2861, 1679 (C=O), 1332, 1221, 1178; \(^1\text{H NMR} \) (400 MHz, CDCl₃) (\( \delta \) ppm): 7.87 (d, \( J = 7.8 \text{Hz} \), 2H\(_\text{Ar}\)),
\( \text{mp. (211-213}^\circ \text{C): 3370, 3055 (aromatic CH), 2805, 1640 (C=O), 1368, 1271, 1192; 1H NMR (400 MHz, CDCl}_3 (\delta, \text{ppm}): 9.61 (s, 2H, NH), 8.48 (s, 1H, Ar), 7.87-7.91 (m, 4H, Ar), 7.63 (dd, \text{J} = 7.0, 0.9 Hz, 1H, Ar), 7.54-7.58 (m, 2H, Ar), 6.78 (s, 1H, Ar), 6.74 (d, \text{J} = 8.0 Hz, 1H, Ar), 4.01 (s, 3H, OCH}_3), 2.37 (s, 3H, CH}_3), \text{ESI-MS: C}_{19}H_{19}N_3O_7S [M+H] = 371.2. \)

(vi) \( \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-nitrobenzenesulfonylhydrazide (24) \)

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-nitrobenzenesulfonylhydrazide (24) \]

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-nitrobenzenesulfonylhydrazide (24) \]

(vii) 4-Bromo-N’-(2-hydroxy-4-methylbenzoyl)benzenesulfonylhydrazide (25)

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-nitrobenzenesulfonylhydrazide (24) \]

(viii) \( \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-methoxybenzenesulfonylhydrazide (26) \)

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-methoxybenzenesulfonylhydrazide (26) \]

(ix) \( \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-methylbenzenesulfonylhydrazide (27) \)

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-methylbenzenesulfonylhydrazide (27) \]

(x) 4-Nitro-N’-(2-(p-tolyl)acetyl)benzenesulfonylhydrazide (28)

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-methoxybenzenesulfonylhydrazide (26) \]

(xi) 4-Bromo-N’-(2-(p-tolyl)acetyl)benzenesulfonylhydrazide (29)

\[ \begin{align*}
\text{O} & \quad \text{N} \\
\text{OH} & \quad \text{S} \\
\text{OH} & \quad \text{N} \\
\text{O} & \quad \text{S}
\end{align*} \]

\[ \text{N}’-(2-Hydroxy-4-methylbenzoyl)-4-methoxybenzenesulfonylhydrazide (26) \]
(xii) 4-Methoxy-N'-[(2-(p-tolyl)acetyl)benzenesulfonohydrazide (30)

\[
\text{Yield: 70%; } R_f = (n - \text{hexane : EtOAc. } 1 : 1)
\]
\[
0.5; \text{ mp. (156-157°C); FT-IR (}\delta, \text{ cm}^{-1}): 3360, 3022 (\text{aromatic CH}), 2918, 1696 (\text{C}=\text{O}), 1328, 1195; ^1\text{H NMR (400 MHz, CDCl}_3 (\delta, \text{ ppm}): 7.99 (d, } J = 7.8\text{ Hz, } 2\text{H}_\text{Ar}), 7.62 (d, } J = 8.4\text{ Hz, } 2\text{H}_\text{Ar}), 7.50 (d, } J = 7.7\text{ Hz, } 2\text{H}_\text{Ar}), 3.37 (s, 2\text{H}, \text{CH}_2), 2.40 (s, 3\text{H}, \text{CH}_3).
\]

(xiii) 4-Methyl-N'-[(2-(p-tolyl)acetyl)benzenesulfonohydrazide (31)

\[
\text{Yield: 82%; } R_f = (n - \text{hexane : EtOAc. } 1 : 1)
\]
\[
0.3; \text{ mp. (133-134°C); FT-IR (}\delta, \text{ cm}^{-1}): 3354 (\text{NH}), 3043, 2919, 1697 (\text{C}=\text{O}), 1327, 1191; ^1\text{H NMR (400 MHz, CDCl}_3 (\delta, \text{ ppm): 7.73 (d, } J = 8.8\text{ Hz, } 2\text{H}_\text{Ar}), 7.15 (d, } J = 7.7\text{ Hz, } 2\text{H}_\text{Ar}), 7.00 (d, } J = 7.8\text{ Hz, } 2\text{H}_\text{Ar}), 6.89 (d, } J = 8.8\text{ Hz, } 2\text{H}_\text{Ar}), 3.87 (s, 2\text{H}, \text{CH}_2), 3.37 (s, 2\text{H}, \text{CH}_2), 2.37(s, 3\text{H}, \text{CH}_3).
\]

(xiv) N'-[(2-(3-Methoxyphenyl)acetyl)-4-nitrobenzenesulfonohydrazide (32)

\[
\text{Yield: 80%; } R_f = (n - \text{hexane : EtOAc. } 1 : 1)
\]
\[
0.4; \text{ mp. (143-144°C); FT-IR (}\delta, \text{ cm}^{-1}): 3343 (\text{NH}), 3043, 2965, 1692 (\text{C}=\text{O}), 1328, 1197; ^1\text{H NMR (400 MHz, CDCl}_3 (\delta, \text{ ppm): 7.69 (d, } J = 8.2\text{ Hz, } 2\text{H}_\text{Ar}), 7.22 (d, } J = 8.0\text{ Hz, } 2\text{H}_\text{Ar}), 7.15 (d, } J = 7.7\text{ Hz, } 2\text{H}_\text{Ar}), 7.00 (d, } J = 7.7\text{ Hz, } 2\text{H}_\text{Ar}), 3.56 (s, 2\text{H}, \text{CH}_2), 2.42 (s, 3\text{H}, \text{CH}_3), 2.38 (s, 3\text{H}, \text{CH}_3).
\]
was extracted according to the kit protocol using SanPrep col-

6. Carbonic Anhydrase Inhibition Assay

Carbonic anhydrase inhibition activity was carried out using an already developed method [19] with slight modification. The principle of the current method is centered on that “CA hydrolyses the p-nitrophenyl acetate to p-nitrophenol” which is determined by spectrophotometrically. Reaction mixture contained 60 μL of 50 mM Tris-sulfate buffer (pH 7.6 containing 0.1 mM ZnCl2) and 10 μL (0.5 mM) test compound in 1% DMSO. All the ingredients were blended and preincubated for 10 min at 25°C. The 96-well plate reader was used to prerread the plates at 348 nm. Preparation of p-nitrophenyl acetate was done by taking 6 mM stock solution in 5% acetonitrile in buffer and was used fresh. Each well was filled with 20 μL solution to attain 0.6 mM concentration. The total reaction volume was made to 100 μL. After 30 minutes of incubation at 37°C, all ingredients were blended and reading was taken at 348 nm. Acetazolamide was used as the standard while DMSO was used as positive controls. The results reported are mean of the three independent experiments (±SEM) and expressed as percent inhibition calculated by the formula,

\[
\text{Inhibition} = \frac{100 - (\text{Abs of test comp/Abs of control}) \times 100}{1}
\]
7. Molecular Docking Studies

Molecular docking study of the most potent inhibitors 24, 23, and 30 was carried out in CA II (PDB ID 3k34), CA IX (PDB ID 5FL4), and CA XII (PDB ID 5MSA), respectively [2–29]. FlexX utility of BioSolveIT’s LeadIT program was used for molecular docking [30]. Default parameters of the protein preparation were used to prepare the receptor for docking. The cocryrstallized inhibitors inside the carbonic anhydrase isozymes obtained from the protein databank were selected as reference ligand, and the protocol validation was carried out by redocking the cocrystallized inhibitors. After validation of the docking protocol, actual docking of the potent inhibitors was carried out. Hybrid enthalpy and entropy approach of FlexX docking was used for scoring and ranking of the docking poses. The top-ranking poses were then subjected to HYDE assessment and selection of the possible binding mode [31–33].

Data Availability

The data is already entered in the manuscript. A series of sulfonamide-hydrazide hybrids of aryl and phenyl acetyl hydrazides (19–36) were synthesized and tested for their role as future anticancer agents with less side effects against CA II (major target), CA IX, and CA XII isozymes of the carbonic anhydrase. It was found that substitution of the aromatic group has a significant role in determining the structure activity relationship studies. In the case of aryl substitution, when 2 OH group was free, an enhanced activity was observed as compared to the compounds having substituted OH group with OMe. In the case of acetyl-substituted sulfonamide-hydrazide hybrids, the addition of CH2 group enhances the activity as compared to the aryl group with one carbon. By using BioSolveIT’s SeeSAR software, further studies to provide visual clues to binding affinity indicates that the structural elements that are responsible for this were also studied. Among the entire series, only the compounds 22, 32, and 36 were highly selective inhibitors of hCA IX and did not inhibit hCA XII. We wanted to investigate why binding of these compounds to hCA XII is poor. For this purpose, the compounds 32 and 36 were docked against both hCA IX and hCA XII. Binding of these compounds with hCA IX was highly favorable (as expected) and in agreement with the experimental data.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Supplementary Materials

The supplementary material files contain the 1H NMR spectra and DFT tables of all the hydrazide-sulfonamide hybrids while 13C NMR, EIMS spectra, and HPLC graphs of the selected compounds. (Supplementary Materials)

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