Sulfonamides incorporating heteropolycyclic scaffolds show potent inhibitory action against carbonic anhydrase isoforms I, II, IX and XII

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Abstract. Three series of polycyclic compounds possessing either primary sulfonamide or carboxylic acid moieties as zinc-binding groups were investigated as inhibitors of four physiologically relevant CA isoforms, the cytosolic hCA I and II, as well as the transmembrane hCA IX and XII. Most of the new sulfonamides reported here showed excellent inhibitory effects against isoforms hCA II, IX and XII, but no highly isoform-selective inhibition profiles. On the other hand, the carboxylates selectively inhibited hCA IX (K_Is ranging between 40.8 and 92.7 nM) without inhibiting significantly the other isoforms. Sulfonamides/carboxylates incorporating polycyclic ring systems such as benzothiopyranopyrimidine, pyridothiopyranopyrimidine or benzothiopyranopyrazole may be considered as interesting candidates for exploring the design of isoform-selective CAIs with various pharmacologic applications.

Keywords: carbonic anhydrase; sulfonamide; carboxylic acid; benzothiopyranopyrimidine; pyridothiopyranopyrimidine; benzothiopyranopyrazole.

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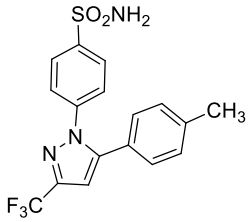
1. Introduction

Sulfonamides possessing the general formula RSO_2NH_2 constitute the historically most important class of carbonic anhydrase (CA, EC 4.2.1.1) inhibitors (CAIs).[1-8] They are in clinical use for more than 70 years as diuretics, antiglaucoma, antiepileptic, and antiobesity agents,[1-7] and, more recently, they have shown applications as antitumor/antimetastatic agents or diagnostic tools, with at least one sulfonamide in Phase I clinical trials for the treatment of advanced, metastatic solid tumors.[8]

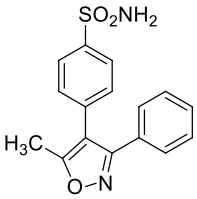
Recently,[1] we have disclosed a new class of sulfonamides **1a-e**, featuring the classical benzenesulfonamide moiety for binding to the catalytically crucial zinc ion forming the enzyme active site. The head part of these molecules is connected to a pyrazole moiety, further annealed with a bulky heterocyclic ring, benzothiopyrano[4,3-*c*]pyrazole (comp **1a-c**) and pyridothiopyrano[4,3-*c*]pyrazole (comp **1d-e**), (Chart 1) in order to explore both alternative chemotypes and the possibility to further enhance the isoform selectivity observed with celecoxib (CLX) and valdecoxib (VLX) as CAIs.[2-8] Actually, compounds **1a-e** may be regarded as geometrically constrained analogues of the two reference leads CLX and VLX.

The most interesting feature of this new class of sulfonamides was their capability to predominantly exert strong inhibition of only hCA I and II, as well as of the mycobacterial β-class enzymes (Rv1284, Rv3273, and Rv3588c), conversely their inhibitory activity against hCA III, IV, VA, VB, VI, VII, IX, XII, XIII, and XIV was at least 2 orders of magnitude lower. The combination of X-ray crystal structure of the hCA II-compound **1e** adduct, and homology modeling allowed to explain this peculiar inhibition profile, which was also quite different from those of the reference coxibs, CLX and VLX. Thus, the benzenesulfonamides **1a-e** constitute a highly interesting class of compounds which, inhibiting only a restricted number of physiologically relevant CA isoforms among the 12 catalytically active human enzymes, should lead to fewer side effects. In addition, the good inhibition profile of some of the new derivatives (**1d-e**) against mycobacterial CAs is also to be considered as relevant because these enzymes are less inhibited by other classes of sulfonamides.

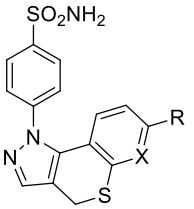
As further development of this project, in the present work we aim to study three novel series of compounds in search for selective CAIs. In the first class (compounds **2a-d**, Chart 1), we decided to move the benzensulfonamido function from position 1 to position 2 of the pyrazole system of benzothiopyrano[4,3-c]pyrazole (**2a,b**) and pyridothiopyrano[4,3-c]pyrazole (**2c,d**), to assess whether this change of position could lead to selective compounds for some CA isoforms. Substituents at 7-position (R) were chosen considering the groups that most contributed to the activity of the above described compounds **1a-e**.[1]



CLX

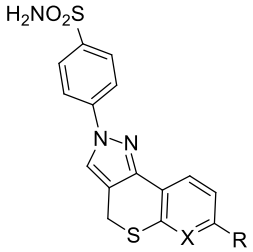


VLX



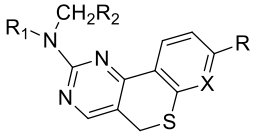
1a-e

a:X = CH, R = OCH_3
b: X = CH, R = Cl
c: X = CH, R = CF_3
d: X = N, R = H
e: X = N, R = CH_3



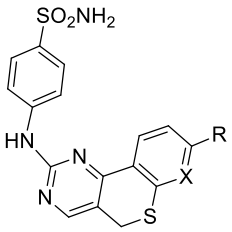
2a-d

a: X = CH, R = OCH_3
b: X = CH, R = Cl
c: X = N, R = H
d: X = N, R = CH_3



3a-e

a: X = CH, R = OCH_3, R_1 = H, R_2 = COOH
b: X = CH, R = OCH_3, R_1 = CH_3, R_2 = COOH
c: X = CH, R = OCH_3, R_1 = H, R_2 = $(CH_2)_2CH(NH_2)COOH$
d: X = N, R = H, R_1 = CH_3, R_2 = COOH
e: X = N, R = CH_3, R_1 = CH_3, R_2 = COOH



4a-e

a: X = CH, R = H
b: X = CH, R = OCH_3
c: X = CH, R = Cl
d: X = N, R = H
e: X = N, R = CH_3

Chart 1: Sulfonamide CAIs of types **1-4** discussed in the paper.

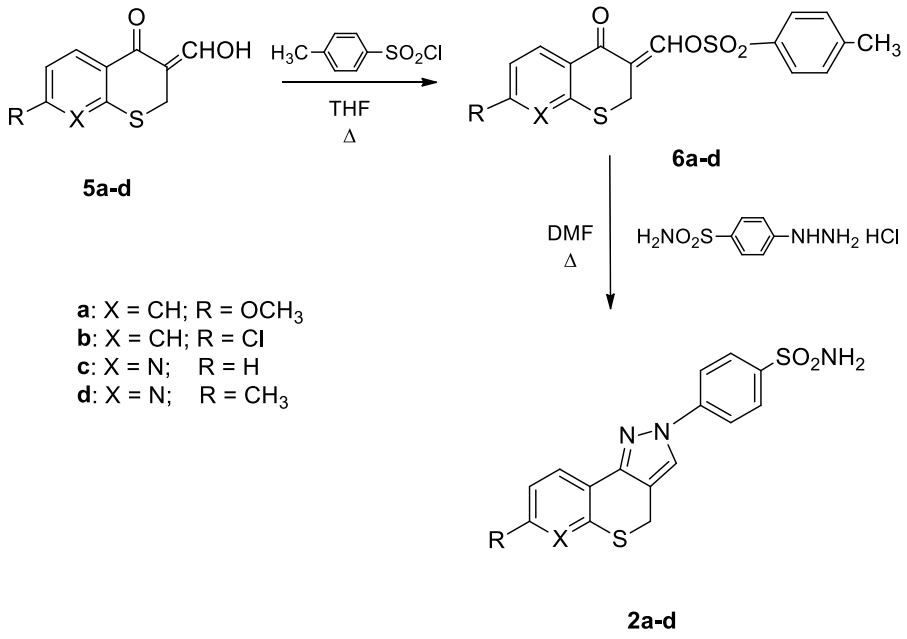
Then, with the aim to identify novel chemotypes to further expand the chemical diversity in CAIs, we searched among our in-house database of heteropolycyclic scaffold-based derivatives synthesized in our laboratories.[9-13] Benzothiopyranopyrimidines (**3a-c**) and pyridothiopyranopyrimidines (**3d-e**) reported by us earlier,[11,13] attracted our attention due to their structural similarity to the pyrazoles of types **1** and **2**. Thus, in this work, we considered compounds **3a-e,** featuring a carboxylic group. Actually, it was reported that carboxylates[14-16] share with dithiocarbamates[17-19] the CA inhibition mechanism of sulfonamides and their bioisosteres (sulfamates, sulfamides),[20,21] representing one of the main class of pharmacologically relevant CAIs.[20-23]

Finally, the benzothiopyranopyrimido and the pyridothiopyranopyrimido scaffolds were further investigated, by the design of compounds **4a-e** (Chart1), that bear a benzensulfonamide moiety, typical of the classical CAIs, in the 2-position of the tricyclic system and spaced by an NH linker.

2. Results and Discussion

2.1. Chemistry.

The preparation of the 2-(*p*-sulfonamidophenyl)substituted-pyrazole derivatives **2a-d** was performed following the synthetic route described in Scheme 1. The starting key intermediates 7-substituted-3-hydroxymethylenebenzothiopyranones **5a-b**[9] or 3-hydroxymethylenepyridothiopyranones **5c-d**[10,11] were converted into the corresponding *p*-toluensulfonates **6a-d**. In these intermediates the reactive methine functionality was protected as previously reported by us.[12] The subsequent condensation of **6a-d** with 4-sulfonamidophenylhydrazine hydrochloride, in anhydrous dimethylformamide at room temperature, involved, as a first step, only the carbonyl functionalization at the 4-position, affording the intermediate arylhydrazones.[12] These latter easily cyclized *in situ* by heating the reaction mixture at 100 °C, to afford the desired 2-substituted derivatives **2a-d**. The compounds were purified by flash chromatography and characterized by analytical and spectral data (see Experimental protocols for details) which were in accordance with analogues compounds of previous works.[1, 9, 12]

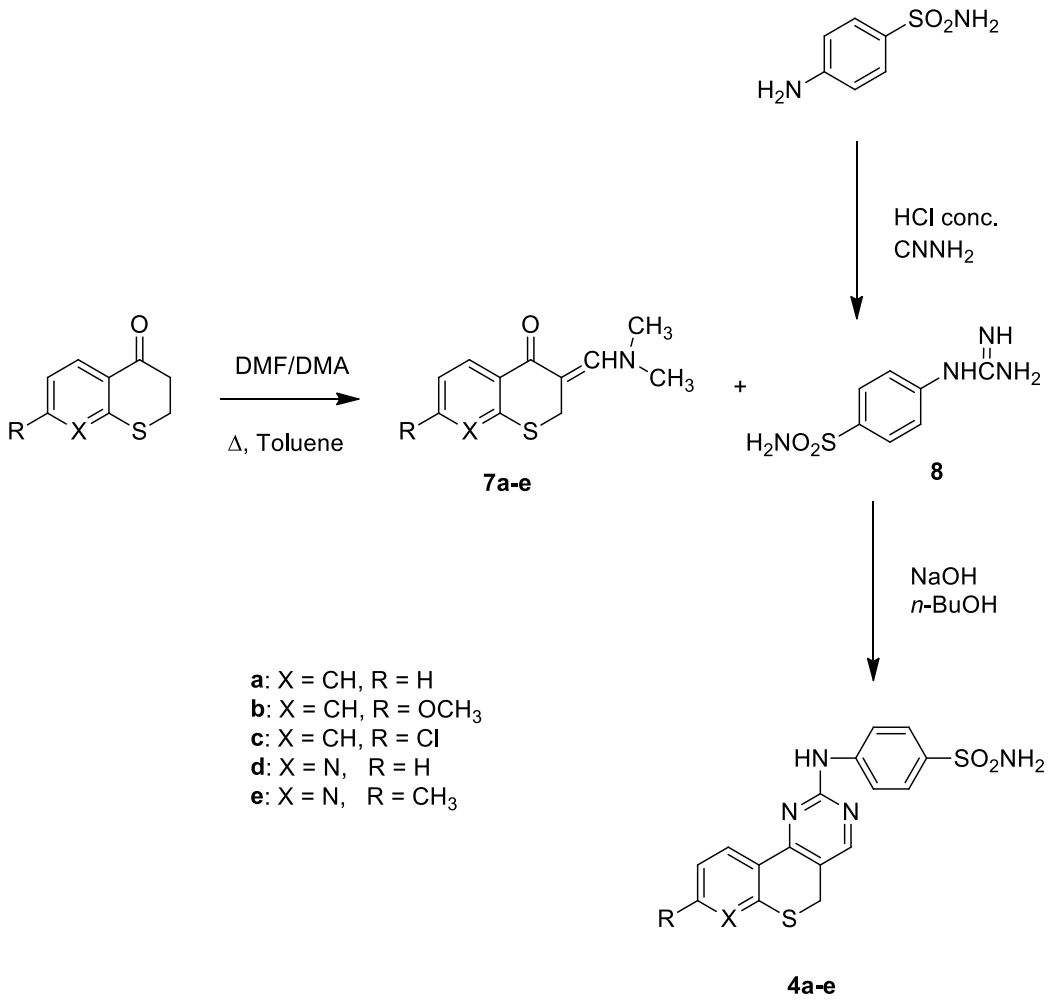


Scheme 1. Preparation of sulfonamides **2a-d**.

The synthetic pathway leading to the target 2-(*p*-benzensulfonamido)benzothiopyranopyrimidines **4a-c** and 2-(*p*-benzensulfonamido)pyridothiopyranopyrimidines **4d-e** takes advantage of the use as "synthetic tool" of the 7-substituted benzothiopyrano or pyridothiopyrano moiety, which demonstrated to be versatile intermediates in many synthetic procedures.[13] The 1,3-bielectrophile reactivity of the 7-substituted-3-dimethylaminomethylene derivatives **7a-e** [13,24-26] in the reaction with

the 4-guanidinobenzenesulfonamide **8**[27] in butanol at reflux, in the presence of sodium hydroxide,[28] allowed to easily obtain the desired 2-benzensulfonamidophenyl substituted pyrimidines **4a-e**, as reported in Scheme 2. The 4-guanidinobenzenesulfonamide **8** was obtained in good yields by reaction of a 50% cyanamide solution in water and a solution of sulfanilamide in concentrated HCl. The mixture was heated at 100 °C for 20 minutes, as already described.[27]

The purity of the target compounds was assessed by TLC analysis and by physicochemical properties, analytical and ^{1}H NMR and ^{13}C NMR spectral data, which were in agreement with the proposed structures and with other previously reported results. (Experimental protocols for details).

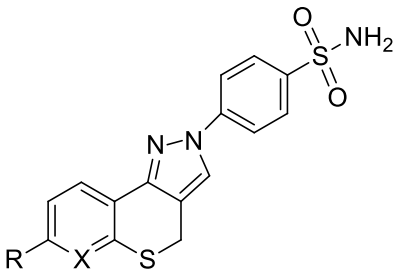


Scheme 2. Synthesis of sulfonamides **4a-e**.

2.2. CA inhibition

The compounds **2a-d, 3a-e** and **4a-e** reported here were investigated for their enzyme inhibitory capacity against four physiologically relevant CA isoforms, the human (h) hCA I, II, IX and XII (Table 1). Acetazolamide (5-acetamido-1,3,4-thiadiazole-2-sulfonamide) was used as standard drug in the assay.[28]

Table 1. Inhibition of isoforms hCA I, II, IX and XII with sulfonamides **2a-d**, by a stopped-flow CO_2 hydrase assay.[28] Acetazolamide (**AAZ**) used as standard inhibitor.



2a-d

N	**X**	**R**	K_I (nM)*			
			hCA I	hCA II	hCA IX	hCA XII
2a	CH	Cl	41.5	8.5	6.1	68.6
2b	CH	OCH_3	68.4	7.4	7.4	38.1
2c	N	H	22.5	7.1	6.3	66.7
2d	N	CH_3	37.1	7.6	7.7	62.5
AAZ	-	-	250	12	25	5.6

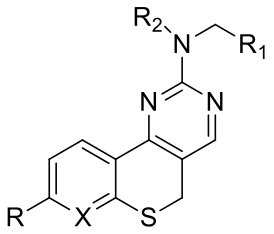
* Mean from 3 different assays. Errors in the range of ±10 of the reported values.

The data listed in Table 1 show that benezenesulfonamides **2a-d**, bearing the bulky condensed tricyclic tail, do inhibit significantly all four investigated isoforms, with inhibition constants in the range of 22.5 - 68.4 nM against hCA I, 7.1 - 8.5 nM against hCA II, 6.1 - 7.7 nM against hCA IX and 38.1 - 68.6 nM against hCA XII, respectively. The structure-activity relationship (SAR) against all four isoforms is quite flat, since the substituent R and the X moiety show to little influence the inhibitory activity. The other salient feature is that the isoform-selectivity, observed with compounds **1** reported earlier, is lost for the sulfonamides **2**. This may be presumably attributed to the capacity of the quite bulky scaffold present in the derivatives investigated here, to interact favorably with the active sites of the four CA isoforms.

Thus, as the shift of the benzensulfonamide moiety from position 1 to position 2 of the pyrazole system (compounds **2a-d**) led to less isoform selective compounds, we decided to continue the study in this area by changing the starting pyrazole with a pyrimidine ring fused on the benzothiopyrano or

pyridothiopyrano moiety, thus obtaining compounds **3** and **4**, whose inhibition data are reported in Tables 2 and 3.

Table 2. Inhibition of isoforms hCA I, II, IX and XII with carboxylic acids **3a-e**, by a stopped-flow CO_2 hydrase assay.[28] Acetazolamide (**AAZ**) used as standard inhibitor



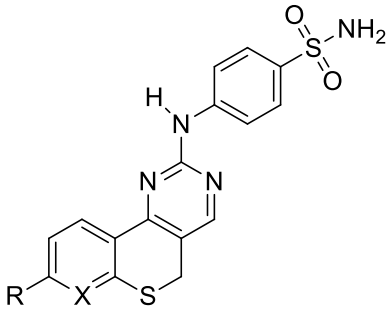
3a-e

N	X	R	R_1	R_2	K_I (nM)*			
					hCA I	hCA II	hCA IX	hCA XII
3a	CH	OCH_3	COOH	CH_3	510	5390	40.8	8390
3b	CH	OCH_3	COOH	H	871	4220	54.1	5975
3c	CH	OCH_3	$(CH_2)_2CH(NH_2)COOH$	H	>50000	>50000	335	9030
3d	N	H	COOH	CH_3	440	638	67.8	7170
3e	N	CH_3	COOH	CH_3	370	7450	92.7	6185
AAZ	-	-	-		250	12	25	5.6

* Mean from 3 different assays. Errors in the range of ±10 of the reported values.

Data of Table 2 show that the carboxylic acids **3** (except the one with the longer aliphatic chain, **3c**) possess a more interesting inhibition profile against the four CA isoforms compared to sulfonamides **2**. Indeed, compounds **3a,b,d** and **e** behaved as hCA IX-selective inhibitors (K_Is in that range of 40.8 - 92.7 nM) with much lower affinity for hCA I, II and XII, for which KIs in the range of 370 - 9030 nM were measured (Table 2). The lysine derivative **3c** did not significantly inhibited hCA I, II and XII, being a weak hCA IX inhibitor too (K_I of 335 nM).

Table 3. Inhibition of isoforms hCA I, II, IX and XII with sulfonamides **4a-e**, by a stopped-flow CO_2 hydrase assay.[28] Acetazolamide (**AAZ**) used as standard inhibitor.



4a-e

N	X	R	K_I (nM)*			
			hCA I	hCA II	hCA IX	hCA XII
4a	CH	H	80.5	96.0	7.0	75.1
4b	CH	OCH_3	66.9	63.2	22.5	48.9
4c	CH	Cl	84.0	218	8.7	15.5
4d	N	H	68.3	9.4	27.6	17.8
4e	N	CH_3	68.9	8.0	8.1	34.4
AAZ	-	-	250	12	25	5.6

* Mean from 3 different assays. Errors in the range of ±10 of the reported values.

Data of Table 3 show that all CA isoforms investigated here were inhibited by sulfonamides **4a-e**. The slow cytosolic isoform hCA I was inhibited moderately, with K_Is ranging between 66.9 and 84.0 nM. Again the SAR is rather flat for this isoform, proving that the nature of the X and R fragments of the molecule do not significantly influence the biological activity. This is however not the case for the inhibition of the physiologically dominant isoform hCA II, for which a more diversified inhibitory behavior has been evidenced for these sulfonamides. Indeed, **4d** and **4e** were low nanomolar highly effective hCA II inhibitors (K_Is ranging between 8.0 and 9.4 nM), being thus more effective than the standard drug **AAZ**, whereas **4a-c** showed a reduced efficacy, with K_Is ranging between 63.2 and 218 nM. Thus, the best substitution pattern is that incorporating pyridine and not benzene in the terminal ring of the polycyclic system. The presence of H or Me as R moieties was not highly influential on the hCA II inhibition profile of these compounds.

The transmebrane isoform hCA IX, a validated antitumor target,[8] was also effectively inhibited by sulfonamides **4**, which showed K_Is ranging between 7.0 and 27.6 nM (Table 3). In this case both benzene- and pyridine in the third ring of the polycyclic system led to effective inhibitors (e.g.,

compare **4a** and **4e** which show very similar K_I values). The methoxy moiety (in **4b**) led to an almost three-fold loss of inhibitory efficacy (compared to **4a**), whereas chlorine (in **4c**) was better tolerated, with the last compound having a similar activity as **4a**. The presence of the methyl moiety in **4e** was this time beneficial for the hCA IX inhibitory effects, with this compound being 3-times more potent compared to **4d**, which has a hydrogen in place of the methyl group (Table 3).

The second transmembrane isoform investigated here, hCA XII, was also effectively inhibited by these sulfonamides, which had K_Is ranging between 15.5 and 75.1 nM. The best inhibitors were the chlorine derivative in the benzene series (**4c**) and the unsubstituted derivative (R = H, **4d**) in the pyridine serie with K_Is of 15.5 nM and 17.8 nM, respectively (Table 3).

3. Conclusions

Primary sulfonamides **2** and **4** or carboxylic acids **3** incorporating polycyclic ring systems such as benzothiopyranopyrimidine, pyridothiopyranopyrimidine or dihydrobenzothiopyranopyrazole were investigated as inhibitors of four physiologically relevant CA isoforms, the cytosolic hCA I and II, as well as the transmembrane hCA IX and XII. An excellent inhibitory activity against isoforms hCA II, IX and XII was shown by most of the new sulfonamides **2** and **4**, although with a low selectivity among the various isoforms. The carboxylates **3**, on the other hand, acted as hCA IX-selective inhibitors (K_Is in that range of 40.8 - 92.7 nM), with much lower affinity for hCA I, II and XII. Thus, sulfonamide or carboxylic acid moieties as zinc-binding groups connected to a pyrazole or a pyrimidine moiety annealed with a bulky heterocyclic ring may be considered as interesting candidates for exploring the design of novel isoform-selective CAIs with various pharmacologic applications.

4. Experimental Section

4.1. Chemistry

General. The uncorrected melting points were determined using a Reichert Köfler hot-stage apparatus. NMR spectra were obtained on a Bruker AVANCE 400 (^{1}H, 400 MHz, ^{13}C, 100 MHz) in DMSO-d_6 or $CDCl_3$ (internal standard tetramethylsilane). The coupling constants are given in Hertz. Magnesium sulphate was used as the drying agent. Evaporations were made in vacuo (rotating evaporator). Analytical TLC have been carried out on Merck 0.2 mm precoated silica gel aluminium sheets (60 F-254). Silica gel 60 (230-400 mesh) was used for column chromatography. Purity of the

target inhibitors **2a-d, 3a-e**, and **4a-e** was determined, using a Shimadzu LC-20AD SP liquid chromatograph equipped with a DDA Detector at 196 nm (column C18 (250 mm x 4.6 mm, 5 µm, Shim-pack)). The mobile phase, delivered at isocratic flow, consisted of acetonitrile (40–60%) and water (60–40%) and a flow rate of 1.0 mL/min. All the compounds showed percent purity values of >95%. Reagents, starting materials, and solvents were purchased from commercial suppliers and used as received. According to the methods described previously the following substrates were obtained:7-Methoxy-2,3-dihydro-3-hydroxymethylene-1-benzothiopyran-4(4H)-one **5a** and 7-chloro-2,3-dihydro-3-hydroxymethylene-1-benzothiopyran-4(4H)-one **5b**[9], 2,3-dihydro-3-hydroxymethylenethiopyrano[2,3-*b*]-pyridin-4(4*H*)-one **5c**[10], 7-Methyl-2,3-dihydro-3-hydroxymethylenethiopyrano[2,3-*b*]-pyridin-4(4*H*)-one **5d** [11], 3-[(p-Methylphenyl)sulfonyl] oxymethylen-2,3-dihydrobenzothiopyran-4(4H)-one **6a**[9], 3-[(*p*-Methylphenyl)sulhonyl] oxymethylen-2,3-dihydrothiopyrano[2,3-*b*]pyridin-4(4*H*)-one **6c** and 7-Methyl-3-[(*p*-Methylphenyl)sulhonyl]oxymethylen-2,3-dihydrothiopyrano[2,3-*b*]pyridin-4(4*H*)-one **6d**[12], 3-Dimethylaminomethylen-2,3-dihydrobenzo[3',2':5,6]thiopyran-4(4*H*)-one **7a**,[26] 7-Methoxy-3-dimethylaminomethylen-2,3-dihydrobenzo[3',2':5,6]thiopyran-4(4*H*)-one **7b**[13], 7-Chloro-3-dimethylaminomethylen-2,3-dihydrobenzo[3',2':5,6]thiopyran-4(4*H*)-one **7c**[26], 2,3-Dihydro-3-dimethylaminomethylenethiopyrano[2,3-b]pyridin-4(4H)-one **7d** and 7-Methyl-2,3-Dihydro-3-dimethylaminomethylenethiopyrano[2,3-b]pyridin-4(4H)-one **7e**[11], N-(4-Aminosulfonylphenyl) guanidine carbonate **8**.[27] Compounds **3a-e** were already described by us; in particular compounds **3a-c** were described in ref.[13] and compounds **3d-e** in ref.[11]

3-[(*p*-Methylphenyl)sulfonyl]chloromethylen-2,3-dihydrobenzothiopyran-4(4H)-one 6b

p-Toluensulphonylchloride (0.801 g, 4.8 mmoles) was added to a solution of **5b** (0.903 g, 2.4mmoles) in 8 mL of anhydrous tetrahydrofurane in the presence of potassium carbonate (1.161 g, 9.6 mmoles). The reaction mixture, under nitrogen atmosphere, was stirred at room temperature for 15 hours then refluxed for 3 hours. After cooling, the suspension was concentrated under reduced pressure, and the residue obtained was treated with water and then extracted with chloroform. The organic layers were dried and evaporated to give crude product **6b** which was purified by flash chromatography on a silica gel column (60/0.040-0.063 mm) using petroleum ether 40-60°C/ethyl acetate 8/2 as the eluting system. Yield 22%, mp 80-82 °C. ^{1}H NMR (400 MHz, $CDCl_3$): δ (ppm) 2.50 (s, 3H, CH_3), 3.83 (s, 2H, CH_2), 7.20 (dd, 1H, Ar-H, *Jmax* = 8.4 Hz, *Jmin* = 2.0 Hz), 7.29 (dd, 1H, Ar-H, *J* = 2 Hz), 7.43 (d, 2H, Ar-H), 7.67-7.68 (m, 1H, CH), 7.87-7.89 (m, 2H, Ar-H), 8.04 (d, 1H, ArH, *J* = 8.4 Hz).

General Procedure for the synthesis of 7-Substituted-2-(*p*-sulfonamidophenyl)-1,4-dihydrobenzothiopyrano[4,3-c]pyrazoles 2a-b and 7-Substituted-2-(*p*-sulfonamidophenyl)-1,4-dihydro-pyrido[3′,2′:5,6]-thiopyrano[4,3-c]pyrazoles 2c-d

4-Hydrazinobenzenesulfonamide hydrochloride (0.300g, 1.3 mmoles) in 9 ml of N,N-dimethylformamide was added dropwise to a solution of the opportune derivative **6a-d** (2.00 mmoles) in 6 mL of the same solvent. The reaction mixture was stirred at room temperature for 15 hours, then refluxed for 2 hours. After cooling, the suspension was poured into a saturated aqueous potassium carbonate solution and extracted with chloroform. The organic layers were dried and evaporated under reduced pressure to give desired crude pyrazoles **2a-d** which were purified by flash chromatography on a silica gel column (60/0.040-0.063 mm) using petroleum ether 40-60 °C/ethyl acetate 4/6 as the eluting system.

7-Methoxy-2-(*p*-sulfamidophenyl)-1,4-diidrobenzothiopyranopyrazole 2a

Yield 35%, mp 230-232 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 3.74 (s, 3H, OCH_3), 3.99 (s, 2H, CH_2-S), 6.67 (d, 1H, Ar-H, *Jmax* = 8.8 Hz; *Jmin* = 2.4 Hz), 6.76-6.74 (m, 1H, Ar-H), 7.09 (d, 1H, Ar-H, *J* = 2.4 Hz.), 7.53 (s, 2H, NH_2 *exch.*), 77.61 (d, 2H, Ar-H *J* = 8.8 Hz), 7.71 (s, 1H, Ar-H), 7.95 (d, 2H, Ar-H, *J* = 8.8 Hz). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 23.24, 55.87, 112.53, 114.30, 117.06, 118.54, 126.23, 126.30, 127.52, 135.63, 137.87, 137.90, 143.16, 143.98, 159.33.

7-Cloro-2-(*p*-sulfamidophenyl)-1,4-diidrobenzothiopyranopyrazole 2b

Yield 51%, mp: 210-212 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 4.04 (s, 2H, CH_2), 6.81 (d, 1H, Ar-H, *J* = 8.8 Hz), 7.16 (dd, 1H, Ar-H, *Jmax* = 8.4, *Jmin* = 2.0 Hz), 7.53 (bs, 2H, NH_2 *exch.*), 7.60-7.64 (m, 3H, Ar-H), 7.78 (s, 1H, Ar-H), 7.94-7.96 (m, 2H, Ar-H). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 23.12, 118.81, 124.48, 126.21, 126.34, 126.40, 127.63, 128.61, 133.12, 136.29, 137.06, 138.04, 142.81, 144.20.

2-(*p*-Sulfamidophenyl)-1,4-diidropiridothiopyranopyrazole 2c

Yield 30%, mp 213-215 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 4.19 (s, 2H, CH_2), 7.05-7.07 (m, 2H, Ar-H), 7.54 (bs, 2H, NH_2 *exch.*), 7.61-7.63 (m, 2H, Ar-H), 7.78 (s, 1H, Ar-H), 7.94-7.96 (m, 2H, Ar-H), 8.29-8.30 (m, 1H, Ar-H). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 22.90, 118.13, 120.77, 121.69, 126.35, 127.64, 131.52, 136.75, 138.20, 142.64, 144.35, 148.76, 157.44.

7-Methyl-2-(*p*-sulfamidophenyl)-1,4-diidropiridothiopyranopyrazole 2d

Yield 25%, mp 235-238 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 2.38 (s, 3H, CH_3), 4.15 (s, 2H, CH_2S), 6.90 (d, 1H, Ar-H, *J* = 8.0 Hz), 6.95 (d, 1H, Ar-H, *J* = 8.8 Hz), 7.52 (s, 2H, NH_2 *exch.*), 7.59-7.61 (m, 2H, Ar-H), 7.75 (s, 1H, Ar-H), 7.93-7.95 (m, 2H, Ar-H). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 22.99, 24.03, 117.41, 118.97, 120.15, 126.28, 127.61, 131.80, 137.00, 138.13, 142.70, 144.29, 156.73, 157.74.

General procedure for the synthesis of 4-((8-substituted-5*H*-thiochroman[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamides 4a-c and 4-((8-substituted-5*H*-pyrido[3',2':5,6]thiopyrano[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamides 4d-e

N-(4-Aminosulfonylphenyl)guanidine carbonate **8** (0.332 g, 1.2 mmol) and NaOH (0.096 g, 2.4 mmoles) were added to a solution of the appropriate 3-dimethylaminomethylen-2,3-dihydrobenzo[3',2':5,6]thiopyran-4(4*H*)-one **7a-c** or 2,3-Dihydro-3-dimethylamino-methylenethiopyrano[2,3-b]pyridin-4(4*H*)-one **7d-e** (1.2 mmoles) in 10 mL of *n*-BuOH. The solution was heated at 120 °C for 4 hours and, after cooling, the precipitate obtained was collected by filtration to give crude pyrimidines which were purified by flash chromatography on a silica gel column (60/0.040-0.063 mm) using ethyl acetate/Hexane = 5/5 as the eluting system.

4-((5*H*-thiochroman[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamide 4a

Yield 44%, mp 275-278 °C. ^{1}H-NMR (400 MHz, DMSO-d_6): δ (ppm) 4.07 (s, 2H, CH_2), 7.20 (s, 2H, NH_2 *exch.*), 7.41-7.47 (m, 3H, Ar-H), 7.76-7.78 (m, 2H, Ar-H), 7.97-8.00 (m, 2H, Ar-H), 8.32-8.34 (m, 1H, Ar-H), 8.56 (s, 1H, Ar-H), 10.15 (bs, 1H, NH, *exch*). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 26.42, 116.66, 118.21, 126.83, 127.10, 127.67, 128.43, 131.83, 132.40, 136.58, 137.12, 144.16, 157.00, 158.41, 159.43.

4-((8-Methoxy-5*H*-thiochroman[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamide 4b

Yield 31%, mp 228-230 °C. ^{1}H-NMR (400 MHz, DMSO-d_6): δ (ppm) 3.85 (s, 3H, -OCH_3), 4.05 (s, 2H, CH_2), 6.98-7.01 (m, 2H, Ar-H), 7.19 (bs, 2H, NH_2 *exch.*), 7.76 (d, 2H, Ar-H, *J* = 8.8 Hz), 7.98 (d, 2H, Ar-H, *J* = 9.2 Hz), 8.27 (d, 1H, Ar-H, *J* = 8.8 Hz), 8.48 (s, 1H, Ar-H), 10.07 (bs, 1H, NH *exch.*). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 26.64 56.09, 112.68, 113.63, 115.47, 118.10, 125.11, 127.08, 129.36, 136.40, 139.0, 144.26, 156.50, 158.42, 159.33, 161.93.

4-((8-Chloro-5*H*-thiochroman[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamide 4c

Yield 45%, mp 268- 270 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 4.10 (s, 2H, CH_2), 7.21 (s, 2H, NH_2 *exch.*), 7.47-7.50 (dd, 1H, Ar-H, *Jmax = 8.6, Jmin = 2.4 Hz*), 7.60 (d, 1H, Ar H, *J = 2.4 Hz*), 7.77 (d, 2H, Ar-H, *J* = 8.8 Hz), 7.97 (d, 2H, Ar-H, *J* = 8.8 Hz), 8.30 (d, 1H, Ar-H, *J* = 8.8 Hz), 8.57(s, 1H, Ar-H), 10.19 (s, 1H, NH *exch.*). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 26.40, 116.27, 118.25, 126.94, 127.12, 127.68, 129.20, 131.22, 136.41, 136.67, 139.46, 144.05, 157.24, 157.59, 159.43.

4-((5*H*-Pyrido[3',2':5,6]thiopyrano[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamide 4d

Yield 45%, mp 283-285 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 4.23 (s, 2H, CH_2), 7.19 (s, 2H, NH_2 *exch.*), 7.41-7.44 (m, 1H, Ar H), 7.78 (d, 2H, Ar H, *J* = 8.8 Hz), 7.97 (d, 2H, Ar H, *J* = 8.8 Hz), 8.52-8.54 (m, 1H), 8.57-8.59 (m, 1H), 8.60 (s, 1H, Ar H), 10.18 (bs, 1H, NH *exch.*). ^{13}C NMR (100 MHz, DMSO-d_6): δ (ppm) 26.31, 115.62, 118.36, 121.84, 127.14, 128.66, 134.75, 136.76, 143.95, 151.90, 157.57, 157.75, 159.41, 160.13.

4-((8-Methyl-5*H*-pyrido[3',2':5,6]thiopyrano[4,3-d]pyrimidin-2-yl)amino)benzenesulfonamide 4 e

Yield 45%, mp 283-285 °C. ^{1}H NMR (400 MHz, DMSO-d_6): δ (ppm) 4.20 (s, 2H, CH_2), 7.21 (s, 2H, NH_2 *exch.*), 7.27 (d, 2H, Ar-H, *J* = 8.8 Hz), 7.96 (d, 2H, Ar-H, *J* = 8.8 Hz), 8.46 (1, 2H, Ar-H, *J* = 8.0 Hz), 8.56 (s, 1H, Ar-H), 10.17 (s, 1H, NH *exch*.). ^{13}C NMR (400 MHz, DMSO-d_6): δ (ppm) 24.42, 26.36, 115.20, 118.27, 121.38, 125.97, 127.13, 135.01, 136.66, 144.01, 157.31, 157.98, 159.36, 159.46, 161.28.

4.2. CA inhibition. An Applied Photophysics stopped-flow instrument has been used for assaying the CA catalysed CO_2 hydration activity.[28] Phenol red (at a concentration of 0.2 mM) has been used as indicator, working at the absorbance maximum of 557 nm, with 20 mM Hepes (pH 7.5) as buffer, and 20 mM Na_2SO_4 (for maintaining constant the ionic strength), following the initial rates of the CA-catalyzed CO_2 hydration reaction for a period of 10-100 s. The CO_2 concentrations ranged from 1.7 to 17 mM for the determination of the kinetic parameters and inhibition constants. For each inhibitor at least six traces of the initial 5-10% of the reaction have been used for determining the initial velocity. The uncatalyzed rates were determined in the same manner and subtracted from the total observed rates. Stock solutions of inhibitor (0.1 mM) were prepared in distilled-deionized water and dilutions up to 0.01 nM were done thereafter with the assay buffer. Inhibitor and enzyme solutions were preincubated together for 15 min at room temperature prior to assay, in order to allow for the formation of the E-I complex. The inhibition constants were obtained by non-linear least-squares methods using PRISM 3 and the Cheng-Prusoff equation, as reported earlier,[29-31] and represent the mean from at least three different determinations. All CA isofoms were recombinant ones obtained in-house as reported earlier.[29-31]

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