ORIGINAL ARTICLE

Binding of Carbonated Anions to Cationic Hexaureachromium(III): Synthesis, Characterization and Antimicrobial Activity of $[Cr(CO(NH_2)_2)_6](HCO_3)_3$ and $[Cr(CO(NH_2)_2)_6]_2(CO_3)_3$

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Abstract

Aim: The aim of the study is to synthesize two new *hexaureachromium* complexes: $[Cr(CO(NH_2)_2)_6](HCO_3)_3$ (1), $[Cr(CO(NH_2)_2)_6]_2(CO_3)_3$ (2) followed by the analysis of binding ability of hexaureachromium(III) cation towards carbonated anions (HCO_3^- and CO_3^{2-}) and their antimicrobial activities against *Escherichia coli, Staphylococcus aureus S. aurses* (for anti-bacterial), and *Aspergillus niger* (for anti-fungal). **Materials and Methods:** The synthesized compounds **1** and **2** were characterized by spectroscopic studies (fourier-transform infrared and ultraviolet [UV]-visible). The binding properties of $[Cr(CO(NH_2)_2)_6]^{3+}$ ($[HuCr]^{3+}$) with carbonated anions (HCO_3^- and CO_3^{2-}) in aqueous medium have been determined with standard UV–visible spectrophotometerthrough titration method. Further, the stoichiometric ratios for complexes **1** and **2** were found through Job's plot. All compounds were also tested for antimicrobial activity against selected strains. **Results and Discussion:** The cation, $[HuCr]^{3+}$, contains ligand urea bearing H-bond donors which are capable of forming hydrogen bonds. The binding constant values obtained are found to be 10.5334 for and 15.7377 for . Further, the stoichiometric ratios for complexes **1** and **2** have been found to be 1:3 and 2:3, respectively. $[HuCr]Cl_3$, **1** and **2** show the maximum zone of inhibition at 200 µg/mL but the starting material $[HuCr]Cl_3$ and compound **1** does not show any activity against A. niger at 50 and 100 µg/mL concentration. **Conclusion:** The ionic reactions between anion receptor $[HuCr]^{3+}$ and carbonated anions in aqueous solution have been investigated and characterized by spectroscopic (infrared and UV–visible) techniques. The results obtained indicate that the binding ability of the cation $[HuCr]^{3+}$ towards carbonated anions is in the order CO_3^{2-} > HCO_3^-. Thus, the selectivity of receptors for particular anion can be chosen. The results predict that the octahedral geometry of $[HuCr]^{3+}$ is capable enough to target both the carbonated anions. $[HuCr]Cl_3$ and compound **1** do not show any activity against *A. niger* at 50 and 100 µg/mL concentration while compound **2** is found to be potent against all the tested organisms *(E. coli, S. aurses*, and *A. niger*).

Key words: Anion receptor, Carbonated anions, Coordination chemistry, Hexaureachromium(III), Spectroscopy

INTRODUCTION

Anion receptors are receiving increased attention of analysts in recent years and are adding new thrust in research area of coordination chemistry.[1,2] Anion plays innumerable roles in the field of catalysis,[3] biology,[4] medicines[5-7] and to control environmental pollution.[8-11] They pose more challenges as compare to corresponding cations because (1) they possess different geometries (halides (spherical), (tetrahedral), (linear) and (octahedral)), (2) their size is larger than cations which make them less efficient for electrostatic binding to receptors, and (3) pH sensitivity. Hence, to design anion receptors with complex sizes and geometries, a great deal of reciprocity must be taken into consideration for the

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selective binding of the anions. Modern supramolecular chemistry utilizes "hydrogen bonding" in the advancement of receptors for the anions recognition.[12] As compare to the relatively simple design principles for cation receptor, there are many more factors which may affect the efficacy of artificial anion receptors. Essential points which are required to be undertaken in the designs are the physical features of the units to be assembled and the interaction through which the units are held.[13] Previously, many organic based anion receptors have been outlined, viz. cyclic polyamines,[14-16] sapphyrins,[17] tripodal amines,[18] azacryptands,[19] calixarenes,[20] and azacage[21] etc. but a very little reports are available with inorganic anion receptors specially transition metal complexes except a few complexes such as alkoxide-bridged dinuclear Zn(II),[22] urea based Pt(II)[23] and bipyridine Ru(II).[24]

The complex cation, $[HuCr]^{3+}$ not only fulfills the properties of cationic metal-based receptors but also has positive charge (3+), 24 hydrogen donor groups (N-H), and stable Oh geometry (hourglass shape) which may bind the carbonated anions effectively. Moreover, $[HuCr]^{3+}$ is also very important as it enhances the glucose tolerance factor in rats and pigs.[25]

Thus, in continuation of our research to explore interactions of hexaureachromium(III) complex with a variety of anions,[26,27] this article reports two new hexaureachromium complexes, $[HuCr](HCO_3)_3$ and $[HuCr]_2(CO_3)_3$ which have been synthesized and characterized by spectroscopic studies (Fourier-transform infrared [FT-IR] and ultraviolet [UV]-visible). Further, binding properties of cation $[HuCr]^{3+}$ with carbonated anions have been studied using standard UV–visible spectroscopic titrations in an aqueous medium.

MATERIALS AND METHODS

$[HuCr]Cl_3 \cdot 3H_2O$ was synthesized by standard method.[28] Estimation of chromium was carried out by the gravimetric method.[29] Solid UV/visible spectra were recorded using Cary 5000 UV-visible NIR Spectrophotometer. For titrations, UV/visible spectra were determined with Shimadzu 1800 at 25 (±1)°C in thermostate. The absorption spectra were recorded in the range 200–800 nm. Infrared (IR) spectra of the said compounds were determined with Varian Resolution Pro 660 FT-IR Spectrophotometer.

Synthesis of $[HuCr](HCO_3)_3$ (1)

The solutions of 1 g of $[HuCr]Cl_3 \cdot 3H_2O$ and 0.486 g of sodium bicarbonate each in 10 mL of distilled water were mixed together which resulted immediately into grayishgreen colored precipitates which were filtered, washed, and air dried. The reaction yield was 78.47%.

Synthesis of $[HuCr]_2(CO_3)_3$ (2)

The solutions of 1 g of $[HuCr]Cl_3 \cdot 3H_2O$ and 0.277 g of sodium carbonate each in 10 mL of distilled water were mixed together which resulted immediately into grayishgreen colored precipitates which were filtered, washed, and air dried. The reaction yield was yield is 79.86%.

Job's plot

Stock solution of $[HuCr]Cl_3$ and the anions () were prepared in aqueous medium in same concentration (1×10^{-3} M). An aliquot (0,1,2…10 mL) of sodium salt of carbonated anions was added in receptor solution in such a way so that the total concentration of the solution remain 1×10^{-3} M. The composition of receptor to anion varied from 10:0 to 0:10.

The stoichiometric ratios of said solutions were determined with the help of UV–visible spectra and Job's plot (continuous variation method) at $\lambda_{max} = 619$ nm for both the complexes.

UV-visible titrations

The binding capability of $[HuCr]^{3+}$ for carbonated anions was determined with the help of UV-visible titrations in double-distilled water. The stock solution of sodium salt of carbonated anions (1×10^{-4} M) and receptor $[HuCr]Cl_3$ (1×10^{-2} M) were prepared and their titrations were performed by placing 3 mL solution of sodium salt of carbonated anions in quartz cuvette against addition of 2 µL cation solution. The spectra were recorded after 2 min. of each addition. The data of absorption spectra were fitted in the global analysis program Hypspec2014[30] to determine the binding constant.

Antimicrobial activity

Microbial strain and culture conditions

Two strains of bacteria namely *Escherichia coli* (MTCC 452), *Staphylococcus aureus* (MTCC 737), and one strain of pathogenic fungus *Aspergillus niger* (MTCC 1344) were purchased from the Microbial Type Culture Collection (MTCC, IMTECH), Institute of Microbial Technology, Chandigarh, India. All the strains had been stored at freeze temperature (4°C) before use. Nutrient agar (NA) and Potato dextrose agar (PDA) (Hi-media) had been used for the initiation of bacteria and fungus. Inoculation of bacteria had been prepared by developing freeze-dried cells in NA for 24 h at 37°C and fungal strain had been inoculated in PDA for 72 h at 30°C. For positive reference standard, ciprofloxacin and fluconazole (Central Drug House Pvt. Ltd., India) had been used and all the samples were prepared in dimethylsulfoxide (DMSO).

Preparation of test sample

The starting material ($[HuCr]Cl_3$) and synthesized compounds **1** and **2** were dissolved in DMSO to attain different concentrations (50, 100, and 200 µg/mL).

Anti-microbial assays

The anti-microbial activity was analyzed by the well diffusion method. 40 mL of NA was used to prepare the Petri plates for the selected bacteria and PDA was used for the preparation of Petri plates for fungus. After that, the selected test organisms were inoculated over the solidified agar plate by using a micropipette, spread it by the spreader and allowed to dry it for 10 min. Three wells were prepared in agar Petri plate by a sterilized steel borer and were finally filled with the standard and solutions of test compounds. All these work were done under aseptic conditions for microbial assay. Bacterial plates were incubated at 37 ± 1°C for 24 h and fungal was incubated at 28 ± 1°C for 72 h. The anti-microbial potential of the tested compounds were found on the basis of mean diameter of the zone of inhibition around the wells in millimeters (mm). Each assay was done in a triplicate form.

RESULTS AND DISCUSSION

Synthesis

Compound 1

In aqueous medium hexaureachromium(III) chloride could react with sodium bicarbonate in three possible ways according to their stoichiometric ratios (equations (1-3)). However, the reaction was carried out as per stoichiometry of equation (3).

$$[HuCr]Cl_3 + MX' [HuCr]Cl_2X' + MCl \quad (1)$$

$$[HuCr]Cl_3 + 2MX' [HuCr]Cl(X')_2 + 2MCl \quad (2)$$

$$[HuCr]Cl_3 + 3MX \; [HuCr](X')_3 + 3MCl \quad (3)$$

Where $M = Na^+$, $X' = HCO_3^-$

Compound 2

In aqueous medium hexaureachromium(III) chloride could react with sodium carbonate in three possible ways according to their stoichiometric ratios (equations (4-6)). However, the reaction was carried out as per stoichiometry of equation (6).

$$[HuCr]Cl_3 + M_2X'' [HuCr]ClX'' + 2MCl \quad (4)$$

$$[HuCr]\,Cl_3 + 2M_2X'' M[HuCr](X'')_2 + 3MCl \quad (5)$$

$$2[HuCr]Cl_3 + 3M_2X'' [HuCr]_2(X'')_3 + 6MCl \quad (6)$$

Where $M = Na^+$, $X'' = CO_3^{2-}$

Infrared spectroscopy

The IR spectrum peaks observed in both the compounds **(1** and **2)** were compared with the peaks observed in case of urea and other similar hexaureachromium(III) compounds.[28] For both the complexes, symmetric and asymmetric vibrational modes of NH_2 group found to be in the range 3450–3200 cm^{-1} which appears to be strong and broad alongwith an additional less intense band which attributed to free NH_2 (non-coordinated). The NH_2 bending vibration was observed near 1620 cm^{-1} for both the complexes. The stretching frequency due to $\nu(CO) + \delta(NH_2)$ is observed at 1595 cm^{-1}

Table 1: FT-IR band assignments of complexes 1, 2 and their comparison with $[HuCr]Cl_3$

ν (cm^{-1})	$[HuCr]Cl_3$	1	2
νa (NH_2)	3421s	3435b	3429b
νs (NH2)	3295s	3332b	3332b
ν (NH2 free)	3220s	3190b	3210b
δ_s (NH_2)	1617s	1625s	1620s
ν (CO) + δ (NH_2)	1535s	1595s	1595s
ν_a (CO_3)	-	1446*s	1461*s
ν_a (CN)	1485s	1446*s	1461*s
ν_s (CO_3)	-	1341s	1349s
ρ_r (NH_2)	1148m	1155m	1155m
ν_s (CN)	1034m	1080m	1028m
δ (NCO)	626m	692m	695m
δ (NCN)	521m	477m	462m

νas = asymmetric stretch, ν_s = symmetric stretch, δ = bending, ρ = rocking, ω = wagging, s = strong, m = medium, w = weak, * = merged peaks. FT-IR: Fourier-transform infrared

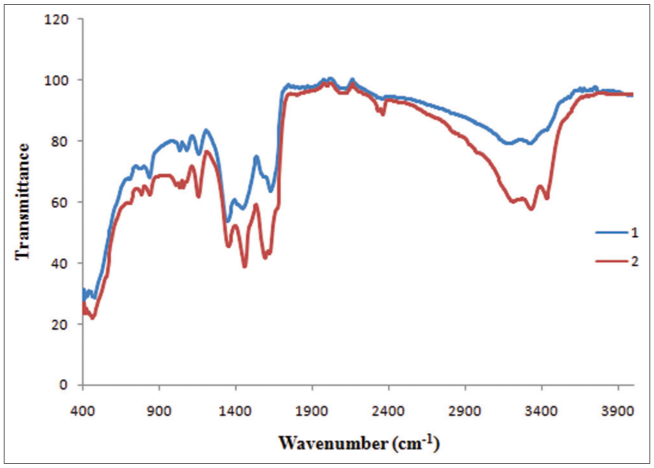

Figure 1: Fourier-transform infrared spectrum of compound 1 and 2

for both the complexes. Moreover, two very strong bands for asymmetric and symmetric carbonyl group of carbonate appeared at 1446 and 1341 cm^{-1} for compound **1**, 1461 and 1349 cm^{-1} for compound **2**. The asymmetric CN stretching frequency observed for free urea at 1485 cm^{-1} shift towards lower frequency in both complexes which also may be due to hydrogen bonding of C-N-H (from cation) with oxygen of carbonyl group and merging of this peak with asymmetric stretching frequency of carbonyl group. The NH_2 rocking and symmetric CN stretching frequencies were obtained at 1155 and 1080 cm^{-1} for compound **1** and at 1155 and 1028 cm^{-1} for compound **2** respectively [Table 1]. The medium absorption bands were observed at 692 and 447 cm^{-1} for compound **1** and 695 and 462 cm^{-1} for compound **2** which are assigned to δ(NCO) and δ(NCN) respectively. All the peaks of compounds 1 and 2 have been assigned in consultation with literature values[28,31] and their FT-IR spectra are shown in Figure 1.

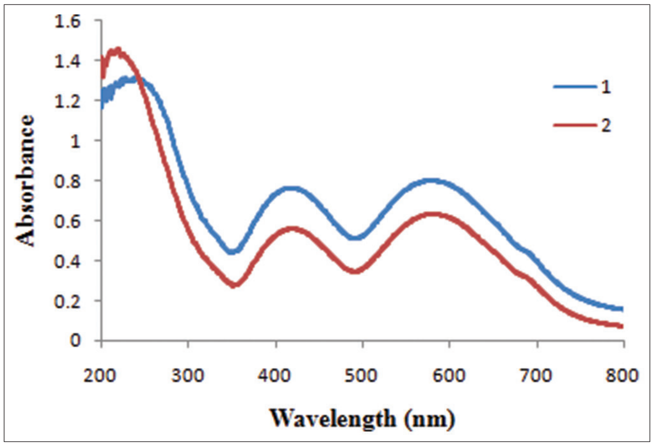

Figure 2: Ultraviolet-visible spectrum of compound 1 and 2

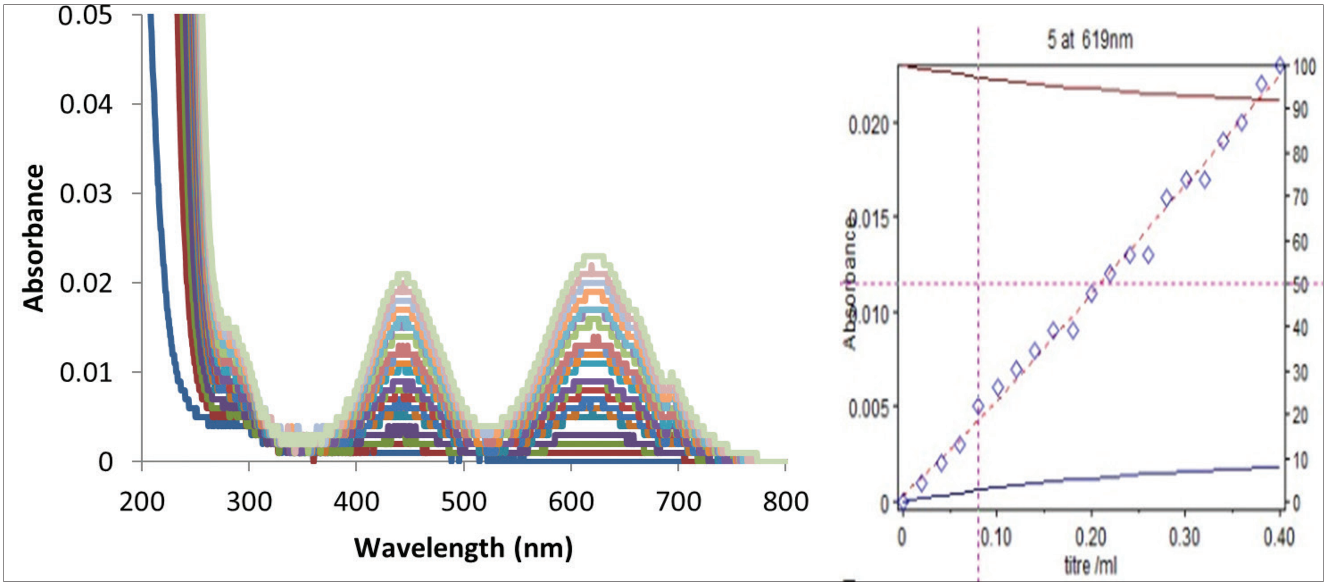

Figure 3: Ultraviolet/visible titration spectra of sodium salt of bicarbonate (1 x 10^{-4} M) in aqueous medium after the addition of 2 µL of cation $[HuCr]Cl_3$ (1 x 10^{-2} M)

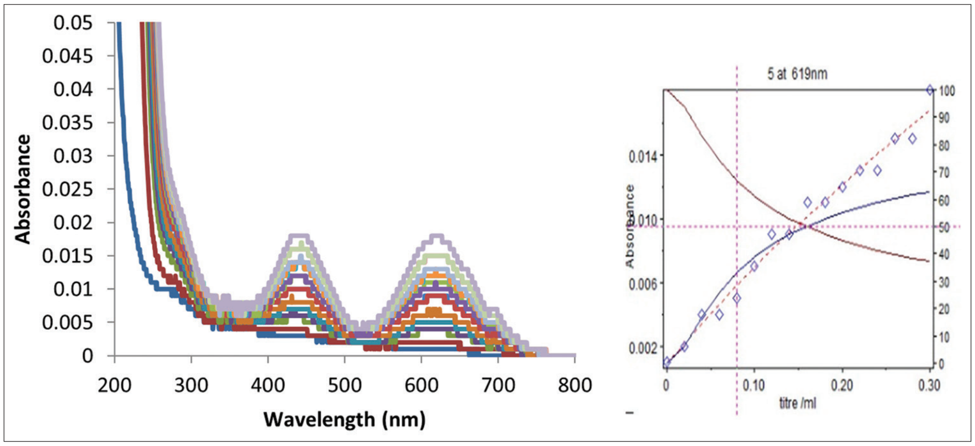

Figure 4: Ultraviolet/visible titration spectra of sodium salt of carbonate (1 x 10^{-4} M) in aqueous medium after the addition of 2 µL of cation $[HuCr]Cl_3$ (1 x 10^{-2} M)

UV-visible spectroscopy

The UV-Visible spectrum of $[HuCr]Cl_3$ shows purely three d-d transitions $^4A_{2g} \rightarrow {}^4T_{2g}(F)$ at 619 nm $^4A_{2g} \rightarrow {}^4T_{1g}(F)$ at 444 nm and $^4A_{2g} \rightarrow {}^4T_{1g}(P)$ at 298 nm (sh). The new Cr(III) complexes show three bands at 579, 419, 228 nm in case of **1** and 579, 418, 220 in case of **2** as shown in Figure 2.

Binding properties

For investigating the binding property of $[HuCr]^{3+}$ for carbonated anions $(HCO_3^-$ and $CO_3^{2-})$, the titration experiment was performed by as given in the experimental section. Firstly, the spectrum of the stock solution of sodium salt of carbonated anions $(HCO_3^-$ and $CO_3^{2-})$ has been taken which show only one absorption peak at 265 nm for both the anions. After constant addition of aliquots of 2 µl of $[HuCr]Cl_3$, the gradual increase in this absorption intensity is observed (hyperchromic shift) which further leads to red shift in bands and found to be at 288 nm in case of sodium bicarbonate [Figure 3] and 282 nm in case of sodium carbonate [Figure 4]. The red shift in the presence of sodium salt of carbonated anions () may results from the interaction between $[HuCr]Cl_3$ and anion. Two new peaks in the range 430–470 nm and 610–630 nm have been generated on addition of cation with a gradual increase in absorption intensity (hyperchromic shift) which further goes to shift in bands as well. The peak observed at 433 and 430 nm in case of bicarbonate and carbonate respectively shifted towards longer wavelength (red shift) and observed at 443 and 441 nm. Peaks at 621 and 616 nm were also observed but there is no shift in wavelength has been observed in case of bicarbonate while there is shift of 4 nm in case of carbonate (621 nm in case of bicarbonate and 620 nm in case of carbonate). The emergence of isobestic points in case of bicarbonate and carbonate were observed at 330 and 347 nm respectively, which shows the complete transfer of free carbonated anion into compound **1** and **2** as shown in Figures 3 and 4. The spectral fitting of the titration data gives values of log β [Table 2]. The results obtained indicate that the binding ability of the cation $[HuCr]^{3+}$ towards carbonated anions is in the order $CO_3^{2-} > HCO_3^-$.

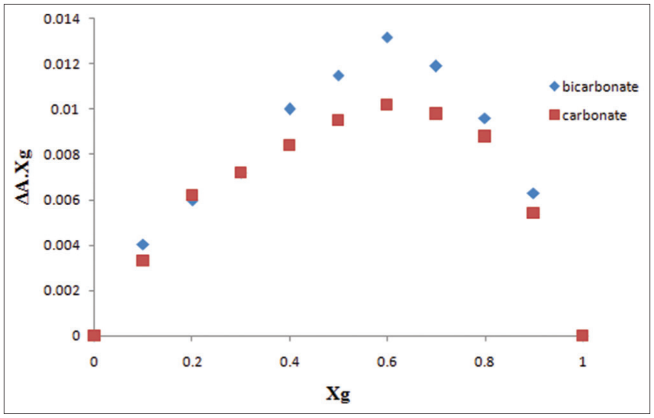

Figure 5: Job's plot of receptor with bicarbonate and carbonate at λ = 619 nm

Job's plot was employed to determine stoichiometric ratios for both complexes at λ_{max} = 619 nm. The inflection point was observed at 0.75 w.r.t. anion which implied the stoichiometry to be 1:3 for **1**, and 2:3 for **2** as shown in Figure 5.

Antimicrobial activity

The anti-microbial effects were determined in different concentrations such as 50, 100 and 200 µg/mL. The maximal inhibition zone value for *E. coli*, *S. aureus* and *A. niger* of the $[HuCr]Cl_3$, compounds **1** and **2** were recorded at 200 µg/mL concentration. However, standard (ciprofloxacin and fluconazole) had a significant effect against all these

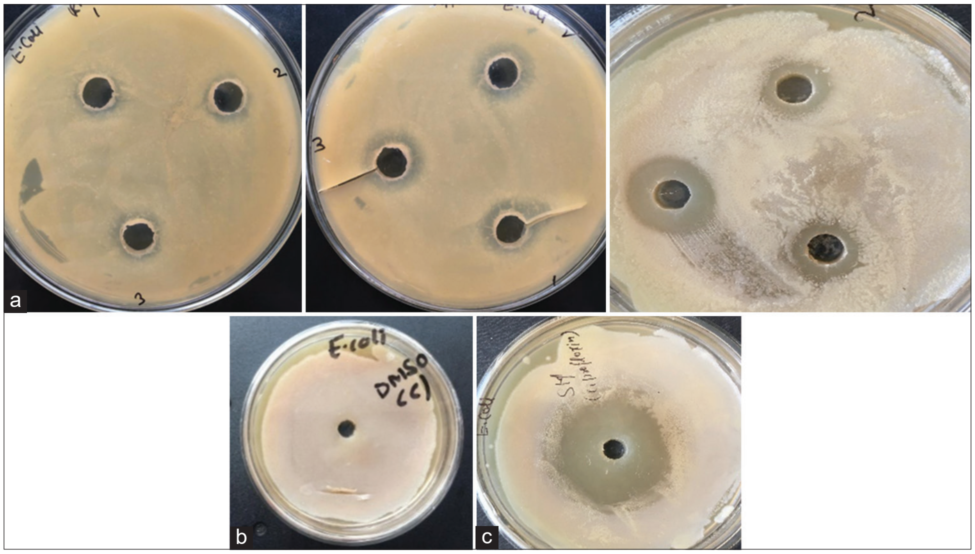

Figure 6: (a) Effect of antibacterial activity of $[HuCr]Cl_3$, 1 and 2, (b) with Control (dimethylsulfoxide), (c) with standard (ciprofloxacin) against *Escherichia coli*

microbial strains. The compounds **1** and **2** were found to be very potent against the tested organisms as shown in Figures 6-8. The antimicrobial activity was determined by measuring the inhibition zone in millimeters around the well

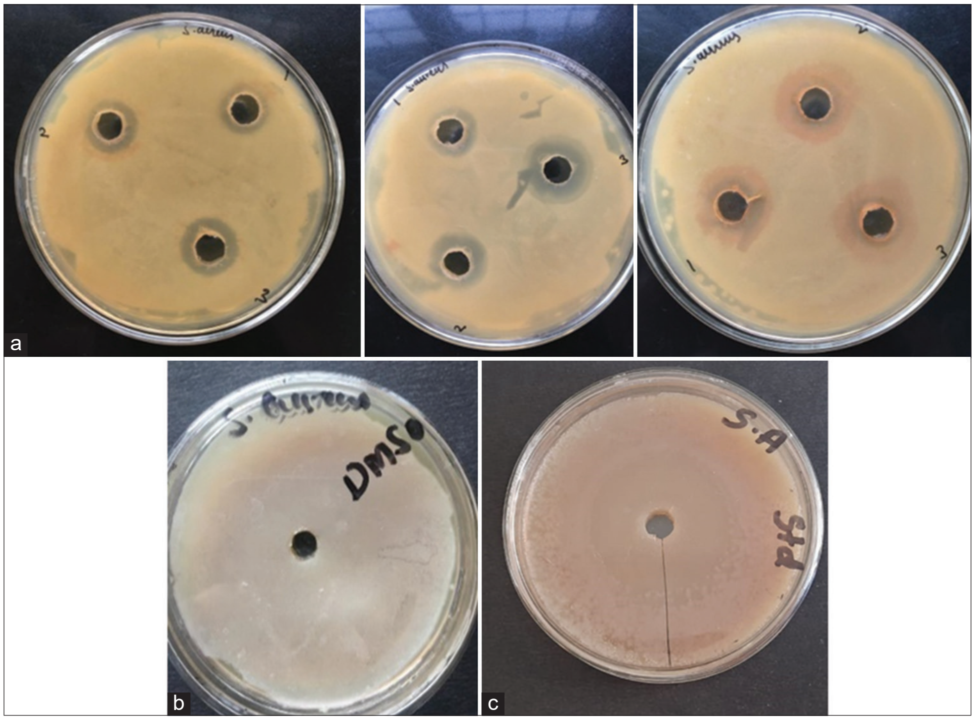

Figure 7: (a) Effect of antibacterial activity of [HuCr]Cl_3, 1 and 2, (b) with Control (dimethylsulfoxide), (c) with standard (ciprofloxacin) against *S. aureus*

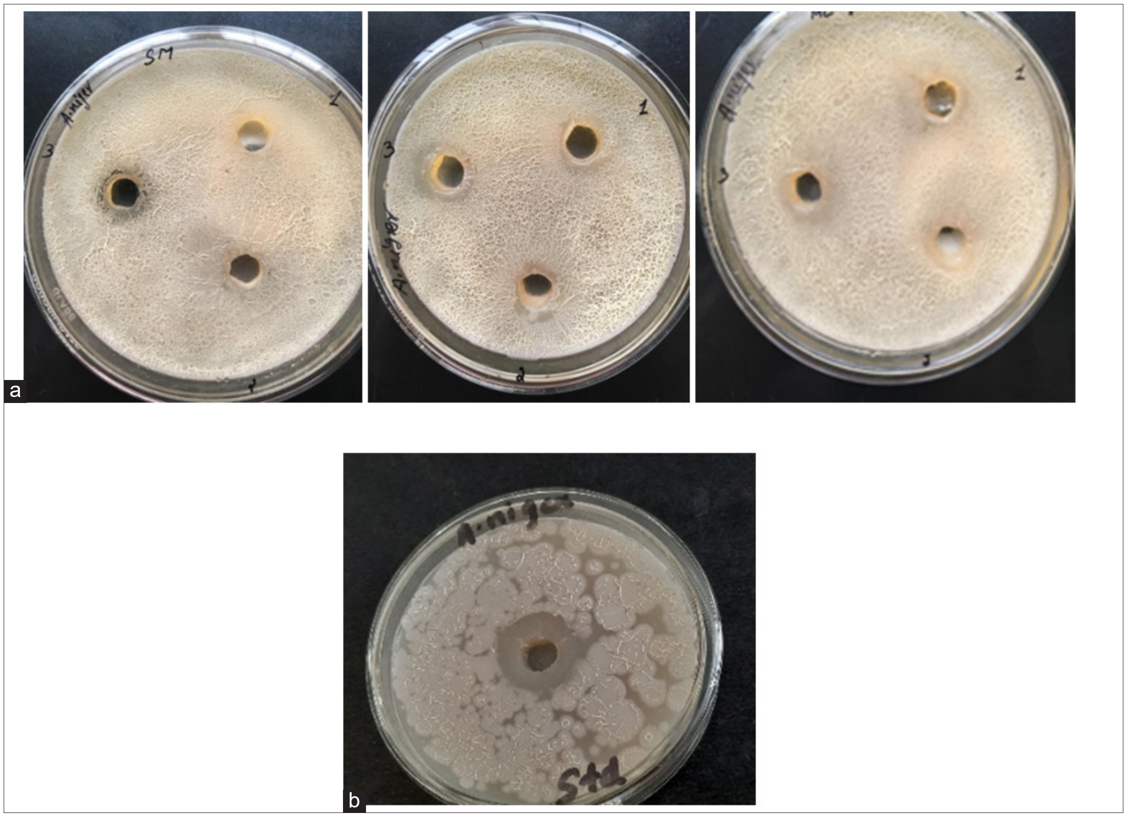

Figure 8: (a) Effect of antifungal activity of [HuCr]Cl_3, 1 and 2, (b) with standard (fluconazole) against *Aspergillus niger*

Table 2: Log β of newly synthesized $[HuCr]^{3+}$ complexes

Complex cation $[HuCr]^{3+}$ with anion	log β
HCO_3^-	10.534±0.0175
CO_3^{2-}	15.7377±0.0064

Table 3: Antimicrobial activity of $[HuCr]Cl_3$, compounds 1 and 2

Compounds	Doses (µg/mL)	Well-diffusion method (inhibition zone, diameter (mm))		
		E. coli	*S. aureus*	*A. niger*
$[HuCr]Cl_3$	50	0.5±0.2	1±0.2	-
	100	1±0.1	2±0.1	-
	200	2±0.1	3.5±0.2	1±0.1
Compound **1**	50	1±0.12	1.1±0.1	-
	100	2.2±0.1	2.6±0.1	-
	200	4.2±0.1	5±0.2	0.5±0.1
Compound **2**	50	1.2±0.2	1.5±0.1	0.5±0.3
	100	2.5±0.1	3±0.1	1±0.2
	200	3±0.1	5.7±0.2	2±0.1
Ciprofloxacin	100	20.5±0.1	20±0.1	-
Fluconazole	100	-	-	18±0.1

E. coli: Escherichia coli, A. niger: Aspergillus niger

and compared with ciprofloxacin and fluconazole presented in Table 3.

CONCLUSION

The ionic reactions between anion receptor $[HuCr]^{3+}$ and carbonated anions (HCO_3^- and CO_3^{2-}) in aqueous solution has been investigated and characterized by spectroscopic (IR and UV–visible) techniques. The binding properties of this cation with carbonated anions (and) in aqueous medium have been determined with standard UV–visible spectrophotometer through titration method (log β for HCO_3^- = 10.534, CO_3^{2-} = 15.7377). The results obtained indicate that the binding ability of the cation $[HuCr]^{3+}$ towards carbonated anions is in the order $CO_3^{2-} > HCO_3^-$. Thus the selectivity of receptors for particular anion can be choosen. The results predicts that the octahedral geometry of $[HuCr]^{3+}$ is capable enough to target both the carbonated anions.

All compounds were found to be potent against the tested organisms (*E. coli, S. aurses* and *A. niger*) and it was found that $[HuCr]Cl_{3,}$ **1** and **2** shows maximum zone of inhibition at 200 µg/mL concentration but the starting material i.e. $[HuCr]Cl_3$ and compound **1** does not show any activity against *A. niger* at 50 and 100 µg/mL concentration.

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REFERENCES

1. Gale PA. A colourimetric calix[4]pyrrole–4-nitrophenolate based anion sensor. Chem Commun 1999;18:1851-2.
2. Wu B, Yang XJ, Janiak C, Lassahn PG. Large size anion binding with iron(II) complexes of a 5,5′-disubstituted-2,2′-bipyridine ligand. Chem Commun 2003;7:902-3.
3. Scheele J, Timmerman P, Reinhoudt DN. A significant effect of anion binding ureas on the product ratio in the palladium(II)-catalyzed hydrocarbonylation of alkenes. Chem Commun 1998;23:2613-4.
4. Busschaert N, Caltagirone C, Rossom WV, Gale PA. Applications of supramolecular anion recognition. Chem Rev 2015;115:8038-155.
5. Gale PA. From anion receptors to transporters. Acc Chem Res 2011;44:216-26.
6. Gogoi PK, Bordoloi S. Supramolecular chemistry of anion receptors - A review. Proc Natl Acad Sci India A Phys Sci 2008;78:179-96.
7. Renkawek K, Bosman K, Giel JC. Anion exchange proteins are a component of corpora amylacea in alzheimer disease brain. Neuroreport 1995;6:929-32.
8. Glidewell C. The nitrate-nitrite controversy. Chem Br 1990;26:137.
9. Moss B. Water pollution by agriculture. Chem Ind 1996;11:407-11.
10. Holloway JM, Dahlgren RA, Hansen B, Casey WH. Contribution of bedrock nitrogen to high nitrate concentrations in stream water. Nature 1998;395:785-8.
11. Langton MJ, Serpell CJ, Beer PD. Anion recognition in water: Recent advances from a supramolecular and macromolecular perspective. Angew Chem Int Ed Engl 2016;55:1974-87.
12. Sun S. Highly sensitive luminescent metal-complex receptors for anions through charge-assisted amide hydrogen bonding. Inorg Chem 2003;42:3445-53.
13. Dalrymple SA, Parvez M, Shimizu GK. Intra- and intermolecular second-sphere coordination chemistry: Formation of capsules, half-capsules, and extended structures with hexaaquo- and hexaamminemetal ions. Inorg Chem 2002;41:6986-96.
14. Llinares JM, Powell D, Bowman-James K. Amide based receptors for anions. Coord Chem Rev 2003;240:57-75.
15. Sessler JL, Katayev E, Pantos GD, Ustynyuk YA. Synthesis and study of a new diamidodipyrromethane macrocycle. An anion receptor with a high sulfate-to-nitrate binding selectivity. Chem Comm 2004;11:1276-7.
16. Ilioudis CA, Tocher DA, Steed JW. A highly efficient,

preorganized macrobicyclic receptor for halides based on CH and NH anion interactions. J Am Chem Soc 2004;126:12395-402.

17. Sessler JL, Davis JM. Sapphyrins: versatile anion binding agents. Acc Chem Res 2001;34:989-97.
18. Hossain MA, Liljegren JA, Powell D, Bowman-James K. Anion binding with a tripodal amine. Inorg Chem 2004;43:3751-5.
19. Nelson J, McKee V, Morgan G. Coordination chemistry of azacryptands. Progr Inorg Chem 1998;47:167-316.
20. Roundhill DM, Koch HF. Methods and techniques for the selective extraction and recovery of oxoanions. Chem Soc Rev 2002;31:60-7.
21. Farrell D, Gloe K, Gloe K, Goretzki G, McKee V, Nelson J. *et al*. Towards promising oxoanion extractants: azacages and open-chain counterparts. Dalton Trans 2003;47:1961-8.
22. Ellis AB, Walt DR. Guest editorial. Chem Rev 2000;100:2477-8.
23. Bondy CR, Gale PA, Loeb SJ. Metal-organic anion receptors: arranging urea hydrogen-bond donors to encapsulate sulfate ions. J Am Chem Soc 2004;126:5030-1.
24. Bondy CR, Loeb SJ. Amide based receptors for anions. Coord Chem Rev 2003;240:77-99.
25. Mertz W, Roginski EE, Schwarz K. Effect of trivalent chromium complexes on glucose uptake by epididymal fat tissue of rats. J Biol Chem 1961;236:318-22.
26. Bala R, Kashyap M, Kaur A, Golobič A. A hexaureachromium(III) complex as a molecular receptor for oxoanions. J Mol Struc 2013;1031:246-53.
27. Bala R, Kashyap M, Kaur A, Golobič A. A new binuclear Cr(III) citrate anion: Synthesis, characterization and crystal structure of $[Cr(CO(NH_2)_2)_6]_2[Cr_2(CO(NH_2)_2)_2(C_6H_4O_7)_2]_3$. Inorg Chem Comm 2013;29:56-9.
28. Bala R, Sachdeva D, Kumar M, Prakash V. Advances in coordination chemistry of hexaurea complexes of chromium(III). J Coord Chem 2020;73:2801-37.
29. Vogel AI. A Text Book of Quantitative Inorganic Analysis. Vol. 3. London: Longmans; 1961.
30. (a) Gans P, Sabatini A, Vacca A. Investigation of equilibria in solution. Determination of equilibrium constants with the HYPERQUAD suite of programs. Talanta 1996;43:1739-53. (b) Available from: http://www.hyperquad.co.uk/HypSpec.html. [Last accessed on 2021 Apr 15].
31. Nakamoto K. Infrared and Raman Spectra of Inorganic and Coordination Compounds. 5th ed. New York: John Wiley and Sons; 1997.

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