Synthesis, Characterization and Antimicrobial Evaluation of Cobalt(III) Complexes of 4-(2-Substituted Phenylimino)-2-(4-Substituted Phenyl)-4H-chromen-3-ol

ASHOK K. SINGH^{1,*}, SURESH K. PATEL^{1,†} and ASIF JAFRI²

¹Department of Chemistry, University of Lucknow, Lucknow-226007, India

²Department of Zoology, University of Lucknow, Lucknow-226007, India

*Corresponding author: E-mail: singhaks3@rediffmail.com

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A series of eight Co(III) complexes [CoL¹⁻⁸(H₂O)₂Cl] (**I-1** to **I-8**) incorporating 4-(2-substituted phenylimino)-2-(4-substituted phenyl)-4H-chromen-3-ol, as a tridentate imino flavone ligands (L₁ to L₈, 2-sub. = NH₂, SH, 4-sub. = OMe, OH, Cl, NMe₂) have been synthesized, characterized and the geometry of the complexes were optimized by DFT. The chemical structure of synthesized imino flavone ligands and their complexes were characterized by elemental analysis, ¹H NMR, ¹³C NMR, UV-visible, IR, ESI-mass spectral data, conductometric and magnetic measurements. The synthesized compounds have been screened for their *in vitro* antibacterial activities against bacteria *Vibrio cholerae*, *Salmonella typhi*, *Staphylococcus aureus*, *Escherichia coli* and antifungal activities against fungi *Candida albicans* and *Aspergillus flavus* by paper disc diffusion method. The complexes **I-3**, **I-4**, **I-7** and **I-8** showed good antimicrobial activities against pathogens.

Keywords: Iminoflavone, Co(III) complexes, Optimized geometry, Antimicrobial activities.

INTRODUCTION

Antibiotics have become revolutionary medicine in the treatment of various pathogenic diseases [1]. But recently intensive use of it, resulted in the emergence of microbial resistance against present antimicrobial agents, which concern with the global health problem of 21st century [2]. Therefore, to design the improved versions of antimicrobial drug with novel mode of action is urgently needed in present and near future. Now a days, in order to synthesizing new antimicrobial drugs, cobalt complexes have highly attracted the researchers as they possess diverse biological activities such as antiviral [3,4], antitumor [5], tumor imaging agent [6], antimycobacterial [7], anti-inflammatory activities [8], etc. Cobalt is a trace mineral which is needed by human body in small amount [9]. Vitamin B₁₂ (cobalamine) contains a cobalt ion, is necessary for the prevention of pernicious anaemia [10], formation of red blood corpuscles and involved many other functions too [8,11]. Flavones, a naturally occurring heterocyclic compound have possessed versatile biological activity against several diseases [12-14]. The presence of imine group in ligands with potent donor atom

i.e. O, N, S enhanced the biological activity of parent compound [15,16]. Further, the binding of ligands with metal enhance the lipophilicity, selectivity and activity of parent compound [17-19]. Thus, binding of iminoflavones to a metal ions will enhance its biological and medicinal activities. In order to explore the biological activities of 3-hydroxyflavone, we have synthesized iminoflavone ligands containing imine group and their Co(III) complexes. These ligands and Co(III) complexes (**I-1** to **I-8**) were screened for the antibacterial and antifungal activities by the disc diffusion, micro-dilution broth techniques using streptomycin and fluconazole as positive control. These synthesized complexes showed significant antimicrobial activity against *Vibrio cholerae*, *Salmonella typhi*, *Staphylococcus aureus*, *Escherichia coli* and antifungal against *Candida albicans* and *Aspergillus flavus*.

EXPERIMENTAL

All chemicals used were purchased from Sigma-Aldrich. The solvents used were purified by reported method [20]. Double distilled water has been used wherever necessary. The purity of the compound was monitored by TLC (CHCl₃/CH₃OH, 9:1),

using silica gel plate (Merck). Melting points were determined with SSU melting point apparatus. Euro Vector E 3000 Elemental Analyzer was used for elemental analysis. UV-visible spectra were recorded on a double beam UV-Vis near IR Labtronics LT-2900 instrument. IR spectra (KBr discs) were recorded on Agilent Cary 360 FTIR spectrometer. ^1H NMR, ^{13}C NMR spectra were recorded on Bruker Advance 400 MHz FT-NMR spectrometer. ESI mass spectrum was recorded on Waters UPLC-TQD mass spectrometer.

***in vitro* Antibacterial and antifungal assay:** The cobalt(III) complexes (**I-1** to **I-8**) have been tested for *in vitro* antimicrobial activity against *Escherichia coli*, *Vibrio cholerae*, *Salmonella typhi*, *Staphylococcus aureus*, *Candida albicans* and *Aspergillus flavus* by paper disc diffusion method [21]. All the selected microorganisms were cultured on sterile petri-discs containing agar medium. The synthesized compounds were dissolved in DMSO and then 5 mm diameter and 1 mm thickness Whatman filter paper disc were soaked in 0.25, 0.5, 1.0 and 2.0 % of tested compounds. The Whatman discs were then subjected to the petri-discs of selected microorganism and incubated at 37 °C for 36 h. Streptomycin and fluconazole containing discs was used as a positive control for antibacterial and antifungal activities, respectively for the antimicrobial analysis.

Synthesis of imino flavones and their Co(III) complexes: The iminoflavones ligands and their cobalt(III) complexes were synthesized by reported procedure [22,23] with some minor modifications. To a solution of 3-hydroxy-4-substituted flavone derivative (10 mmol) (sub.= 0.268 g (-OCH₃), 0.254 g (-OH), 0.364 g (-Cl), 0.281 g (-N(CH₃)₂) in methanol, *o*-phenylenediamine (0.108 g, 10 mmol)/*o*-aminothiophenol (0.125 g, 10 mmol) dissolved in methanol (20 mL) and few drops of glacial acetic acid were added. Then, the mixture was refluxed for 7 h at 70–80 °C. The resulting solution was cooled to room temperature, and then poured into ice with constant stirring. The product thus obtained was filtered and washed with 10 % ethanol and diethyl ether. The ligand was recrystallized with hot ethanol and dried *in vacuo* over anhydrous CaCl₂. Further, the synthesized imino flavones were interacted with CoCl₂·6H₂O. To the solution of CoCl₂·6H₂O (0.714 g, 3 mmol) in 10 mL of methanol, an imino flavone (3 mmol, **L-1** = 1.075 g, **L-2** = 1.033 g, **L-3** = 1.087 g, **L-4** = 1.113 g, **L-5** = 1.126 g, **L-6** = 1.084 g, **L-7** = 1.139 g and **L-8** = 1.165 g in methanol) was added. The mixture was stirred magnetically, refluxed for 3 h by adding 3 mmol of sodium acetate and the reaction was monitored by TLC. The volume of reaction mixture was reduced up to 5 mL. On cooling the reaction mixture at room temperature, the precipitate was formed, which was filtered, washed with 10 % ethanol and ether and dried in vacuum over anhydrous CaCl₂. The complexes were recrystallized in hot ethanol (**Scheme-I**). The product formed was purified by column chromatography using silica gel. The change in colour of mixture from violet red to brown during the synthesis under aerobic conditions shows the occurrence of oxidation process induced by oxygen in air (Co^{II} → Co^{III}).

(E)-4-((2-Aminophenyl)imino)-2-(4-methoxyphenyl)-4H-chromen-3-ol (L¹**):** Yield: 78 % (0.281 g), colour: brown, m.p.: 113 °C. IR (KBr, ν_{max} , cm⁻¹): 3513 (OH), 3312 (NH), 2812 (CH), 1609 (C=N), 1582 (C=C), 1236 (C-O); ^1H NMR (400

MHz, DMSO-*d*₆), δ (ppm): 3.47 (3H, s), 4.26 (2H, s), 6.79 (2H, d, J = 8.28 Hz), 6.69–6.84 (4H, m), 7.02–7.19 (4H, m), 7.75 (2H, d, J = 8.68 Hz), 9.56 (1H, s); ^{13}C NMR (100 MHz, DMSO-*d*₆), δ (ppm): 69.11, 69.11, 114.24, 114.24, 115.32, 116.22, 119.48, 120.58, 120.58, 127.56, 132.99, 132.99, 137.21, 137.21, 137.87, 146.11, 146.11, 150.97, 150.97, 150.97, 152.92; Elemental analysis (%) of C₂₂H₁₈N₂O₃ calcd. (found): C, 73.73 (73.75); H, 5.06 (5.12); N, 7.82 (7.85); ESI-MS: [M+1]⁺ 359.39 (obs.), 358.39 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2 × 10⁻⁴ M), 256 (π - π^* transition), 360 (n- π^* transition).

(E)-4-((2-Aminophenyl)imino)-2-(4-hydroxyphenyl)-4H-chromen-3-ol (L²**):** Yield: 62 % (0.22 g), colour: reddish brown, m.p.: 210 °C. IR (KBr, ν_{max} , cm⁻¹): 3523 (OH), 3308 (NH), 2906 (CH), 1606 (C=N), 1573 (C=C), 1196 (C-O); ^1H NMR (400 MHz, DMSO-*d*₆), δ (ppm): 4.16 (2H, brs), 6.98 (2H, d, J = 8.3, Hz), 7.06 (2H, d, J = 8.3, Hz), 7.28 (4H, m), 7.19–7.29 (4H, m), 9.11 (2H, s); ^{13}C NMR (100 MHz, DMSO-*d*₆), δ (ppm): 113.74, 115.10, 115.72, 115.72, 118.65, 120.53, 123.79, 124.24, 124.77, 128.10, 129.27, 131.34, 131.42, 131.43, 136.23, 137.87, 154.36, 155.69, 155.82, 157.84, 159.61. Elemental analysis (%) of C₂₁H₁₆N₂O₃ calcd. (found): C, 73.24 (73.76); H, 4.68 (5.02); N, 8.13 (8.85); ESI-MS: [M+1]⁺ 345.36 (obs.), 344.36 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2 × 10⁻⁴ M), 271, (π - π^* transitions), 343 (n- π^* transition).

(E)-4-((2-Aminophenyl)imino)-2-(4-chlorophenyl)-4H-chromen-3-ol (L³**):** Yield: 68 % (0.25 g), colour: brownish black, m.p.: 121 °C. IR (KBr, ν_{max} , cm⁻¹): 3569 (OH), 3348 (NH), 2869 (CH), 1553 (C=N), 1564 (C=C), 723 (C-Cl); ^1H NMR (400 MHz, DMSO-*d*₆), δ (ppm): 4.03 (2H, s), 7.19 (2H, d, J = 8.4 Hz), 7.14 (4H, m), 7.00–7.10 (4H, m), 7.29 (2H, s), 9.62 (1H, brs); ^{13}C NMR (100 MHz, DMSO-*d*₆), δ (ppm): 113.74, 115.13, 118.66, 120.53, 123.79, 124.24, 124.75, 126.68, 126.70, 128.10, 128.96, 128.97, 129.25, 131.35, 135.65, 136.20, 137.87, 154.36, 155.64, 155.80, 159.59. Elemental analysis (%) of C₂₁H₁₅N₂O₂Cl calcd. (found): C, 69.52 (70.12); H, 4.17 (4.42); N, 7.72 (7.85). ESI-MS: [M+1]⁺ 363.81 (obs.), 362.81 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2 × 10⁻⁴ M), 262 (π - π^* transitions), 385 (n- π^* transition).

(E)-4-((2-aminophenyl)imino)-2-(4-(dimethylamino)-phenyl)-4H-chromen-3-ol (L⁴**):** Yield: 73 % (0.27 g), colour: brown, m.p.: 135 °C. IR (KBr, ν_{max} , cm⁻¹): 3469 (OH & NH), 2879 (CH), 1607 (C=N), 1576 (C=C), 1278 (C-O), 1214 (C-N); ^1H NMR (400 MHz, DMSO-*d*₆), δ (ppm): 2.88 (6H, s), 4.69 (2H, s), 6.93 (2H, d, J = 7.5 Hz), 6.99–7.17 (4H, m), 7.24 (4H, m), 7.19–7.26 (2H, s), 9.50 (1H, brs); ^{13}C NMR (100 MHz, DMSO-*d*₆), δ (ppm): 40.31, 40.32, 113.71, 113.83, 113.86, 115.10, 118.63, 120.53, 123.79, 124.24, 124.75, 126.40, 126.41, 129.26, 131.32, 136.24, 137.87, 151.44, 154.36, 155.64, 159.60. Elemental analysis (%) of C₂₃H₂₁N₃O₂ calcd. (found): C, 74.37 (75.10); H, 5.70 (5.83); N, 11.31 (11.86); ESI-MS: [M+1]⁺ 372.43 (obs.), 371.43 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2 × 10⁻⁴ M), 265 (π - π^* transitions), 440 (n- π^* transition).

(E)-4-((2-Mercaptophenyl)imino)-2-(4-methoxyphenyl)-4H-chromen-3-ol (L⁵**):** Yield: 73 % (0.27 g), colour: yellowish brown, m.p.: 121 °C. IR (KBr, ν_{max} , cm⁻¹): 3530 (OH), 2850 (CH), 1550 (C=N), 1524 (C=C), 2562 (SH), 1247 (C-S), 1220 (C-O); ^1H NMR (400 MHz, DMSO-*d*₆), δ (ppm): 2.92 (1H, s, SH), 3.95 (3H, s), 6.89 (2H, d, J = 8.0 Hz), 7.07 (2H, d, J = 8.0 Hz), 7.10

Scheme-I: Synthesis of ligands and their cobalt(III) complexes

(4H, m), 7.17 (4H, m), 9.8 (1H, s); ¹³C NMR (100 MHz, DMSO-*d*₆), δ (ppm): 55.46, 111.82, 113.72, 118.68, 120.51, 124.79, 127.12, 127.49, 127.70, 128.09, 128.10, 131.72, 131.33, 131.75, 114.44, 114.42, 144.99, 154.35, 155.66, 155.80, 159.60, 160.41. Elemental analysis (%) of C₂₂H₁₇NO₃S calcd. (found): C, 70.38 (70.95); H, 4.56 (4.83); N, 3.73 (3.96); S, 8.54 (8.72). ESI-MS: [M+1]⁺ 376.44 (obs.), 375.44 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2 × 10⁻⁴ M), 270 (π-π* transitions), 430 (n-π* transition).

(E)-2-(4-Hydroxyphenyl)-4-((2-mercaptophenyl)imino)-4H-chromen-3-ol (L⁶): Yield: 76 % (0.28 g), colour: brown m.p.: 186 °C. IR (KBr, ν_{max}, cm⁻¹): 3486 (OH), 2950 (CH), 1565 (C=N), 1530 (C=C), 2580 (SH), 1241 (C-S), 1243 (C-O); ¹H NMR (400 MHz, DMSO-*d*₆), δ (ppm): 2.78 (1H, s, SH), 6.97 (2H, d, *J* = 8.3 Hz), 7.03 (2H, d, *J* = 8.3 Hz), 7.11 (4H, m), 7.25 (4H, m), 9.32 (2H, s, OH); ¹³C NMR (100 MHz, DMSO-*d*₆), δ (ppm): 111.82, 113.74, 115.74, 115.75, 118.68, 120.55, 124.80, 127.13, 127.48, 127.70, 128.10, 128.10, 131.33, 131.38,

131.39, 144.96, 154.35, 155.67, 155.80, 157.82, 159.60. Elemental analysis (%) of $C_{21}H_{15}NO_3S$ calcd. (found): C, 69.79 (70.95); H, 4.18 (4.63); N, 3.88 (3.96); S, 8.87 (8.98); ESI-MS: $[M+1]^+$ 362.41 (obs.) 361.41 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 268 (π - π^* transitions), 365 (n- π^* transition).

(E)-2-(4-Chlorophenyl)-4-((2-mercaptophenyl)imino)-4H-chromen-3-ol (L^7): Yield: 68 % (0.26 g), colour: yellowish brown, m.p.: 132 °C. IR (KBr, ν_{max} , cm^{-1}): 3433 (OH), 2950 (CH), 1565 (C=N), 1530 (C=C), 2580 (SH), 1239 (C-S), 1243 (C-O); 1H NMR (400 MHz, DMSO- d_6), δ (ppm): 3.00 (1H, s, SH), 6.90 (2H, d, $J = 7.9$, Hz), 7.00 (2H, d, $J = 8.3$, Hz), 7.14 (4H, m), 7.26 (4H, m), 9.57 (1H, s, OH); ^{13}C NMR (100 MHz, DMSO- d_6), δ (ppm): 111.82, 113.72, 118.62, 120.51, 124.78, 126.71, 126.72, 127.01, 127.49, 127.71, 128.10, 128.10, 128.96, 128.97, 131.34, 135.68, 144.98, 154.36, 155.66, 155.81, 159.60. Elemental analysis (%) of $C_{21}H_{14}NO_2SCl$ calcd. (found): C, 66.40 (66.95); H, 3.71 (3.83); N, 3.69 (3.96); Cl, 9.33 (9.47); S, 8.44 (8.52); ESI-MS: $[M+1]^+$ 380.86 (obs.) 379.86 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 275 (π - π^* transitions), 355 (n- π^* transition).

(E)-2-(4-(Dimethylamino)phenyl)-4-((2-mercaptophenyl)imino)-4H-chromen-3-ol (L^8): Yield: 66 % (0.26 g), colour: reddish brown, m.p.: 145 °C. IR (KBr, ν_{max} , cm^{-1}): 3464 (OH), 2897 (CH), 1593 (C=N), 1578 (C=C), 2571 (SH), 1235 (C-S), 1206 (C-O), 1277 (C-N); 1H NMR (400 MHz, DMSO- d_6), δ (ppm): 2.89 (6H, s), 2.86 (1H, s, SH), 6.61 (2H, d, $J = 8.8$ Hz), 7.04 (2H, d, $J = 7.5$ Hz), 7.40-7.56 (4H, m), 7.31 (4H, m), 9.93 (1H, s, OH); ^{13}C NMR (100 MHz, DMSO- d_6), δ (ppm): 40.31, 40.31, 111.78, 118.66, 113.77, 113.84, 113.84, 120.53, 124.75, 126.42, 126.44, 127.11, 127.49, 127.69, 128.09, 128.10, 131.34, 144.99, 151.40, 154.34, 155.68, 155.81, 159.59. Elemental analysis (%) of $C_{23}H_{20}N_2O_2S$ calcd. (found): C, 71.11 (71.75); H, 5.19 (5.63); N, 7.21 (7.77); S, 8.25 (8.68). ESI-MS: $[M+1]^+$ 389.48 (obs.), 388.48 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 273 (π - π^* transitions), 347 (n- π^* transition).

(E)-((4-((2-Aminophenyl)imino)-2-(4-methoxyphenyl)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-1): Colour: brown; Yield 73 %, m. p.: > 350 °C. IR (KBr, ν_{max} , cm^{-1}): 3530 (OH), 3356 (NH), 2859 (CH), 1557 (C=N), 1548 (C=C), 1298 (C-O), 527 (O-Co), 492 (N-Co), 352 (Co-Cl); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 3.47 (3H, s), 3.78 (2H, s), 7.00-9.80 (m, Ar-H). Elemental analysis (%) of $C_{22}H_{20}N_2O_5ClCo$ calcd. (found): C, 54.28 (54.76); H, 4.14 (4.28); N, 5.75 (5.74); Cl, 7.28 (7.31); Co, 12.11 (12.12). ESI-MS: $[M+1]^+$ 504.82 (obs.), 504.2 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 257 (π - π^* transitions), 402 (n- π^* transition), 542 ($d-d$ transition).

(E)-((4-((2-Aminophenyl)imino)-2-(4-hydroxyphenyl)-4H-chromen-3-yl)oxy)cobalt dehydrate chloride (I-2): Colour: blackish brown; Yield 65 %, m.p.: > 360 °C. IR (KBr, ν_{max} , cm^{-1}): 3523 (OH), 3327 (NH), 2837 (CH), 1563 (C=N), 1629 (C=C), 1302 (C-O), 545 (O-Co), 497 (N-Co), 3364 (Co-Cl); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 3.88 (2H, s), 6.59 (s, 2H), 6.86-8.96 (m, Ar-H). Elemental analysis (%) of $C_{21}H_{18}N_2O_5ClCo$ calcd. (found): C, 53.35 (53.37); H, 3.84 (3.86); N, 5.93 (5.92), Cl, 7.50 (7.49); Co, 12.47 (12.46). ESI-

MS: $[M+1]^+$ 473.56 (obs.), 472.76 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 274 (π - π^* transitions), 402 (n- π^* transition), 575 ($d-d$ transition).

(E)-((4-((2-Aminophenyl)imino)-2-(4-chlorophenyl)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-3): Colour: brown; Yield 68 %, m. p. > 300 °C. IR (KBr, ν_{max} , cm^{-1}): 3486 (OH), 3308 (NH), 3033 (CH), 1585 (C=N), 1624 (C=C), 1314 (C-O), 538 (O-Co), 499 (N-Co), 367 (Co-Cl); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 4.08 (2H, s), 7.3 (s, 2H), 7.46-9.23 (m, Ar-H). Elemental analysis (%) of $C_{21}H_{17}N_2O_4Cl_2Co$ calcd. (found): C, 51.35 (51.37); H, 3.49 (3.50); N, 5.70 (5.69); Cl, 14.43 (14.43); Co, 12.00 (11.98). ESI-MS: $[M+1]^+$ 491.20 (obs.), 491.21 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M) 264 (π - π^* transitions), 407 (n- π^* transition), 527 ($d-d$ transition).

(E)-((4-((2-Aminophenyl)imino)-2-(4-(dimethylamino)phenyl)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-4): Colour: brown; Yield 58 %, m. p.: > 300 °C. IR (KBr, ν_{max} , cm^{-1}): 3526 (OH), 3326 (NH), 3021 (CH), 1585 (C=N), 1654 (C=C), 1296 (C-O), 528 (O-Co), 495 (N-Co), 344 (Co-Cl); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 2.88 (6H, s), 3.96 (2H, s), 7.02 (s, 2H), 7.16-9.86 (m, Ar-H). Elemental analysis (%) of $C_{23}H_{23}N_3O_4ClCo$ calcd. (found): C, 55.27 (55.34); H, 4.64 (4.67); N, 8.41 (8.40), Cl, 7.09 (7.11); Co, 11.79 (11.75). ESI-MS: $[M+1]^+$ 500.64 (obs.), 499.83 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 266 (π - π^* transitions), 382 (n- π^* transition), 562 ($d-d$ transition).

(E)-((4-((2-Aminophenyl)imino)-2-(4-(dimethylamino)phenyl)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-5): Colour: yellow brown; Yield 72 %, m.p.: > 360 °C. IR (KBr, ν_{max} , cm^{-1}): 3545 (OH), 2890 (CH), 1590 (C=N), 1564 (C=C), 1293 (C-S), 1297 (C-O), 527 (O-Co), 498 (N-Co), 356 (Co-Cl), 471 (Co-S); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 3.95 (3H, s), 6.96-8.76 (m, Ar-H). Elemental analysis (%) of $C_{22}H_{19}NO_5SClCo$ calcd. (found): C, 52.44 (52.47); H, 3.80 (3.83); Cl, 7.04 (7.03); N, 2.78 (2.77); S, 6.36 (6.35); Co, 11.70 (11.71). ESI-MS: $[M+1]^+$ 504.32 (obs.), 503.84 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 270 (π - π^* transitions), 390 (n- π^* transition), 550 ($d-d$ transition).

(E)-((4-((2-Mercaptophenyl)imino)-2-(4-methoxyphenyl)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-6): Colour: reddish brown; Yield 69 %, m.p.: > 320 °C. IR (KBr, ν_{max} , cm^{-1}): 3547 (OH), 2990 (CH), 1576 (C=N), 1614 (C=C), 1281 (C-S), 1307 (C-O), 537 (O-Co), 502 (N-Co), 362 (Co-Cl), 478 (C-S); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 9.78 (s, OH), 6.96-8.93 (m, Ar-H). Elemental analysis (%) of $C_{21}H_{17}NO_5SClCo$ calcd. (found): C, 51.49 (51.51); H, 3.50 (3.52); Cl, 7.24 (7.23); N, 2.86 (2.84); S, 6.55 (6.53); Co, 12.03 (12.06); ESI-MS: $[M+1]^+$ 490.58 (obs.), 489.81 (calcd.). UV-vis.: λ_{max} in nm (in DMSO, 2×10^{-4} M), 269 (π - π^* transitions), 372 (n- π^* transition), 532 ($d-d$ transition).

(E)-((2-(4-Hydroxyphenyl)-4-((2-mercaptophenyl)imino)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-7): Colour: blackish brown; Yield 66 %, m.p.: > 300 °C. IR (KBr, ν_{max} , cm^{-1}): 3507 (OH), 2870 (CH), 1570 (C=N), 1627 (C=C), 1274 (C-S), 1316 (C-O), 525 (O-Co), 499 (N-Co), 372 (Co-Cl), 486 (C-S); 1H NMR (DMSO- d_6 , 400 MHz, 25 °C, TMS), δ (ppm): 6.72-8.82 (m, Ar-H). Elemental analysis (%) of $C_{21}H_{16}NO_4SCl_2Co$

calcd. (found): C, 49.63 (49.65); H, 3.17 (3.19); Cl, 13.95 (13.94); N, 2.76 (2.75); S, 6.31 (6.30); Co, 11.60 (11.62). ESI-MS: $[M+1]^+$ 509.22 (obs.) 508.26 (calcd.). UV-vis.: $\lambda_{\max}$ in nm (in DMSO, 2×10^{-4} M), 277 (π - π^* transitions), 390 (n - π^* transition), 520 (d - d transition)..

(E)-((2-(4-Chlorophenyl)-4-((2-mercaptophenyl)imino)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride (I-8): Colour: reddish brown; Yield 71 %, m.p.: $> 310^\circ\text{C}$. IR (KBr, $\nu_{\max}$, cm^{-1}): 3542 (OH), 2965 (CH), 1562 (C=N), 1579 (C=C), 1263 (C-S), 1309 (C-O), 525 (O-Co), 492 (N-Co), 347 (Co-Cl), 474 (C-S); ^1H NMR (DMSO- d_6 , 400 MHz, 25°C , TMS), δ (ppm): 3.31 (6H, s), 7.52-9.87 (m, Ar-H). Elemental analysis (%) of $\text{C}_{23}\text{H}_{22}\text{N}_2\text{O}_4\text{SClCo}$ calcd. (found): C, 53.44 (53.47); H, 4.29 (4.30); N, 5.42 (5.41); Cl, 6.86 (6.89); S, 6.20 (6.22), Co, 11.40 (11.38). ESI-MS: $[M+1]^+$ 517.45 (obs.), 516.88 (calcd.). UV-vis.: $\lambda_{\max}$ in nm (in DMSO, 2×10^{-4} M), 274 (π - π^* transitions), 397 (n - π^* transition), 517 (d - d transition).

RESULTS AND DISCUSSION

FT-IR spectra: The band of substituted 3-hydroxyimino-flavone was compared with those of Co(III) complexes in order to infer the coordination mode. The stretching frequency of ligands were observed at $3600\text{--}3500\text{ cm}^{-1}$ $\nu(\text{O-H})$ phenolic, at $3450\text{--}3370\text{ cm}^{-1}$ $\nu(\text{N-H})$ (I-5 to I-8), at $1625\text{--}1600\text{ cm}^{-1}$ $\nu(\text{C=N})$, at $1300\text{--}1250\text{ cm}^{-1}$ $\nu(\text{C-O})$ phenolic, at $1250\text{--}1230\text{ cm}^{-1}$ $\nu(\text{C-S})$, at $1225\text{--}1175\text{ cm}^{-1}$ $\nu(\text{C-N})$ and at $2550\text{--}2500\text{ cm}^{-1}$ $\nu(\text{S-H})$. In all complexes, $\nu(\text{C=N})$ band is shifted to lower frequency, $1605\text{--}1580\text{ cm}^{-1}$ indicated the coordination of amino flavones through azomethine N-atom. A strong band observed at $1300\text{--}1250\text{ cm}^{-1}$ in the free imino flavones is due to phenolic C-O stretching. In complexes, the C-O stretching vibration appears at higher frequency $1322\text{--}1295\text{ cm}^{-1}$ inferred coordination occurred through phenolic O-atom. Moreover, the absorption due to $\nu(\text{C-S})$ of the ligands (L^5 to L^8) at $1250\text{--}1230\text{ cm}^{-1}$ shifted to $1306\text{--}1266\text{ cm}^{-1}$ (I-5 to I-8) and the absorption due to $\nu(\text{C-N})$ of the ligands (L^1 to L^4) at $1225\text{--}1175\text{ cm}^{-1}$ shifted to $1260\text{--}1210\text{ cm}^{-1}$ in the complexes indicates the coordination through phenolic S and N atom. The disappearance of absorption bands due to $\nu(\text{O-H})$ and $\nu(\text{S-H})$ in the complexes occurred during coordination shows deprotonation of phenolic and thiophenolic protons. The broad band in the region $3450\text{--}3220\text{ cm}^{-1}$ and two weaker bands in the region $825\text{--}755\text{ cm}^{-1}$ in complexes due to $\nu(\text{O-H})$ rocking and wagging mode of vibration respectively, indicated the presence of coordinated water molecule [24]. The new bands appeared in the metal complexes in the region $550\text{--}515$, $504\text{--}488$, $372\text{--}344$ and $486\text{--}448\text{ cm}^{-1}$ are attributed to $\nu(\text{Co-O})$, $\nu(\text{Co-N})$, $\nu(\text{Co-N})$ and $\nu(\text{Co-S})$, respectively [25]. On the basis of vibrational bands, it is inferred that the ligands are behaving as a dibasic tridentate ligands.

^1H NMR spectra: ^1H NMR spectra of imino flavone ligands and its Co(III) complexes were recorded in DMSO- d_6 and the chemical shift δ (ppm) are referenced to internal TMS. The protons of imino flavones appeared in the region δ (ppm) $6.90\text{--}9.98$, δ $3.20\text{--}3.80$, δ $2.2\text{--}2.9$, δ $8.90\text{--}9.83$, δ $3.0\text{--}5.0$ and δ $2.5\text{--}3.5$ of aromatic (Ar-H), methoxy ($-\text{OCH}_3$, L^1 , H-1 & I-1, I-5), N-methyl (NCH_3 , L^4 , H-4 and I-4, I-8), phenolic (OH), amino (NH, L^1 to L^4 , I-1 to I-4) and SH (H-1 to H-4) protons, respectively. The downfield shift of aromatic protons in the

complexes from δ $6.90\text{--}9.98$ to δ $6.25\text{--}8.63$, shows metal ion coordinated to the ligand. Furthermore, the disappearance of the phenolic and thiophenolic proton in the complexes shows that the deprotonation occurred during complexation. The downfield shift of C-N-H protons from δ $3.0\text{--}5.0$ to δ $2.6\text{--}4.5$, indicate coordination of N of amino group with Co(III) metal ions with loss of one proton (I-1 to I-4).

Electronic spectral and magnetic studies: The electronic spectral data of imino flavone and complexes were recorded in 1×10^{-3} M solution of DMSO. Electronic spectra of Co(III) complexes (I-1 to I-8) exhibited three absorption bands in the region $250\text{--}280$, $380\text{--}405$ and $505\text{--}572\text{ nm}$ due to π - π^* , n - π^* and d - d transitions. The absorption bands of ligands due to π - π^* and n - π^* transitions shifted at higher wavelength in complexes and a new band observed in region $505\text{--}560\text{ nm}$ due to metal to ligand charge transfer (MLCT). This d - d bands originate from the $^1\text{A}_{1g} \rightarrow ^1\text{T}_{1g}$ transition for the distorted octahedral Co(III) ion in complexes [26]. Thus spectral data confirm the octahedral geometry with low spin d^6 configuration.

Conductometric and magnetic moment measurements: The molar conductivity of Co(III) complexes was measured in DMF by digital TDS-conductivity meter. The molar conductance (in $\Omega^{-1}\text{ mol}^{-1}\text{ cm}^2$) of the complexes I-1 to I-8 was found 19, 23, 16, 21, 18, 25, 17 and 22, respectively which indicated that all the complexes are non-ionic.

The magnetic measurement of Co(III) complexes (I-1 to I-8) exhibited very low value of magnetic moment, which showed the low spin d_6 octahedral complexes [27]. Thus, Co(III) ions in complexes are in a low spin magnetic state with $S = 0$ [28].

Optimized geometry of complexes (I-1 to I-8): Quantum chemical calculations were carried out with the Gauss View 5 and Gaussian 09 programs using B3LYP functional with 6-31G (d, p) basis set for carbon, hydrogen, nitrogen, oxygen and chlorine and LanL2DZ basis set for Co. The ground state energy of complexes I-1 to I-8 [(4-(2-substituted phenylimino)-2-(4-substituted phenyl)-4H-chromen-3-yl)oxy)cobalt dihydrate chloride] are found to be -1653.9461, 1653.9351, 1653.9241, 1653.9456, 1653.9125, 1653.9615, 1653.9561 and 1764.2356 Hartree. All complexes possess C1 symmetry and the optimized structure with numbering of atoms and symbols are presented in Fig. 1.

Antimicrobial analysis: The cobalt complexes [I-1 to I-8] have been tested for *in vitro* growth inhibition against *Escherichia coli*, *Vibrio cholerae*, *Salmonella typhi*, *Staphylococcus aureus*, *Candida albicans* and *Aspergillus flavus* by paper disc diffusion method. The complexes I-3, I-4, I-7 and I-8 showed good antibacterial activity against the pathogens (Table-1). Remaining complexes exhibited lesser activity against pathogens in comparison to that of standard drug. The variation in antimicrobial effectiveness of various compounds in different microorganisms mainly depends on the permeability of selected test compounds against microbial cells. Interestingly, the antibacterial activity of metal chelates increasing with concentration increment, because of the metal ion effect on a normal cell. Overtone's concept and chelation theory explain the activity of metal chelates. In Overtone's concept of cell permeability, the lipid membrane allows rapid soluble materials, these liposolubility

Fig. 1. Optimized geometry of the cobalt(III) complexes

properties mainly control the antimicrobial activity of various test compounds. In chelation theory, the metal ion polarity reduces due to the sharing of ligand orbital and partial delocalization of positive charge of the metal ion with their coordinating groups. In addition to this, metal ion delocalizes the π -electrons over the chelate ring and enhances the lipophilicity

by enhancing the penetration power of complexes on the lipid membrane of microorganism.

Conclusion

Tridentate 3-hydroxy-4-substituted iminoflavone ligands (L1-L4), H(H1-H4) and their Co(III) complexes (I1-I8) were

TABLE-1
ANTIBACTERIAL AND ANTIFUNGAL EVALUATION OF Co COMPLEXES OF (4-((2-SUBSTITUTED PHENYL)IMINO)-2-(4-SUBSTITUTEDYPHENYL)-4H-CHROMEN-3-YL)OXY)COBALT TRIHYDRATE

Cobalt complexes	Diameter of inhibition zone (mm)					
	<i>V. cholerae</i> 0.25 %	<i>S. typhi</i> 0.5 %	<i>S. aureus</i> 1.0 %	<i>E. coli</i> 2.0 %	<i>C. albicans</i> 2.0 %	<i>A. flavus</i> 1.0 %
I-1	7	9	10	10	7	9
I-2	8	10	11	11	8	10
I-3	12	14	19	17	14	18
I-4	16	19	18	21	16	17
I-5	8	8	9	11	05	03
I-6	9	10	11	12	04	06
I-7	12	13	16	15	13	15
I-8	15	16	13	16	17	18
Streptomycin	18	20	22	24	—	—
Fluconazole	—	—	—	—	20	23

synthesized and characterized by spectroscopic methods and physical measurements. The spectral data and physical measurements showed all the Co(III) complexes are neutral having octahedral geometry of low spin d^6 configuration. The optimized structures of complexes (**I-1–I-8**) have been studied by Gaussian 09 program. The Co(III) complexes (**I-1–I-8**) were screened for the antibacterial and antifungal activities by the disc diffusion, microdilution broth techniques. The antimicrobial activities of Co(III) complexes exhibited better antimicrobial properties and showed enhanced inhibitory activities as compared to the standard drugs.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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