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ARTICLE

Six Coordinate Transition Metal (II) Complexes of Mixed Ligands of Eflornithine Hydrochloride Hydrate and 2,2-Bipyridine: Synthesis, Characterization and Antibacterial Study

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Abstract: Transition M(II): Cu(II), Ni(II) or Co(II) metal complexes of mixed Eflornithine hydrochloride hydrate (EFN) and 2,2-bipyridine (bipy) ligands have been synthesized by 1:1:1 ratio of EFN:bipy:M(II). The metal complexes have been characterized using elemental analysis, FTIR, electronic spectra, melting point, magnetic susceptibility measurements and conductivity measurements. The physicochemical data obtained revealed $[M(EFN)(bpy)X_2]\bullet(H_2O)_m\bullet(HCl)_n$ as a proposed molecular formula of the complexes, where M= Ni(II), Co(II) and Cu(II); X= Cl, H_2O, m= 2 or 3 and n = 1 or 2. The results of conductivity measurement showed that the ligand (EFN) and metal complexes are sensitive to electric current in the solution. The FTIR spectral data suggests that EFN and bipy behave as bidentate ligands coordinating to the metal ions through an oxygen atom of the carboxylate and a nitrogen atom of amino group of EFN and through nitrogen atoms of bipy. Electronic spectral and magnetic studies data suggests octahedral geometry around metal ions. For the *in-vitro* anti-bacterial activities, the ligand and metal complexes were screened using agar diffusion method against two gram-positive bacteria and two gram-negative bacteria. Metal complexes showed higher antibacterial activities than the parent ligand and compete favorably well with the antibiotic used as control. The enhanced activities of metal complexes can be adduced to the presence of bipy ligand.

Keywords: Eflornithine hydrochloride hydrate, 2,2-Bipyridine, Carboxylate, Bidendate ligand, *In-vitro* anti-bacterial activities.

Introduction

Some metal ions are known to exhibit very important roles in biological processes in the human body[1, 2]. Copper (II) ions, for example, represent the third most abundant transition metal in humans. They are found either at the active sites or as structural components of a good number of enzymes, such as superoxide dismutase, cupredoxins, azurin, plastocyanin,… and so on[3].

Copper (II) complexes are known to play a significant role either in naturally occurring biological systems or as pharmacological agents[4]. Copper complexes containing polypyridine ligands (bipy/phen/dmp) and their derivatives are of great interest, since they

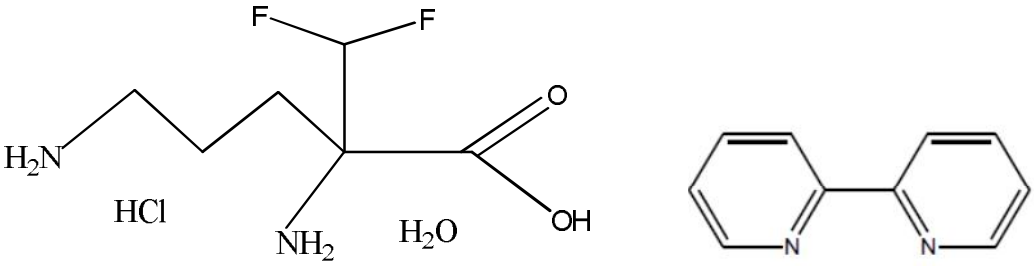
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exhibit numerous biological activities, such as anti-tumor[5], anti-candida[6] and antimicrobial activities[7,8]. Copper(II) complexes are also active species for DNA cleavage[9].

The major role of cobalt in biological systems is its involvement in vitamin $B_{12,}$ a co-enzyme in some biochemical processes[3]. This metal and some of its complexes have been found to exhibit antimicrobial activities[10-12].

The ligand 2,2'-bipyridine (bipy) is a strong field bidentate ligand that forms very stable chelates with many first-row transition metals[13]. This ligand, as well as some of its derived complexes, exhibit antimicrobial properties[14,15]. Nitrogen-containing chiral ligands have found wide applications in chemotherapy and asymmetric catalysis. Among them are bipyridines which are particularly attractive for their ability to coordinate several metal ions and thus to generate different catalytic species involved in a great variety of reactions, such as catalysis, photochemical reactions ,… and so on[16]. Although a good number of metal mixed-ligand complexes containing 2,2'-bipyridine with some other ligands are reported in the literature[16-19], to our knowledge, there is no report on the synthesis and biological activities of metal mixed-ligand complexes containing Eflornithine hydrochloride hydrate (EFN) and 2,2'-bipyridine as ligands (see Figure **1**).

We report here on the synthesis, characterization and biological activities of the new cobalt (II), copper (II) and nickel (II) mixed-ligand complexes containing Eflornithine hydrochloride hydrate and 2,2'-bipyridine as ligands. The synthesized complexes are characterized using elemental analysis, FTIR, electronic spectra, melting point, magnetic susceptibility measurements and conductivity measurements.



EFN **bipy**

Figure 1. Molecular structure of the ligands.

Materials and Methods

Materials

The ligand Eflornithine hydrochloride hydrate (EFN) was commercially obtained and used without further purification. Hydrated metal salts used for complexation ($Cu(CH_3COO)_2{\cdot}H_2O$; $NiCl_2.6H_2O$; and $CoCl_2.6H_2O$) were obtained from British Drug House Chemical Limited Co., Poole, England. Isolates of *Escherichia coli, Pseudomonas aeruginosa,* S*taphylococcus aureus* and *Bacillus substilis* were obtained from the University of Ilorin Teaching Hospital through the Microbiology Department, University of Ilorin, Nigeria.

Instrumentation

The CHN elemental analysis was performed on Thermo Flask 112 CHNSO elemental analyzer from Micro-analytical Laboratory at Medac Limited, Surrey, United Kingdom.The FTIR spectra were collected on FTIR -8501 Shimadzu spectrophotometer over 4000 - 400 cm^{-1} using KBr pellets. Melting points were determined using MPA100 OptiMelt Automated Melting Point system. Solution electronic absorption spectra of the ligand and complexes were run in the range of 180-400 nm and 180-1100 nm, respectively, on Jenway 6405 uv/vis.

The conductivity of the ligand and its complexes was determined in distilled water using EC214 conductivity meter, Hanna Instruments with a cell constant of 1.013. Mass magnetic susceptibilities of the complexes were measured at room temperature with a Johnson Matthey magnetic susceptibility balance calibrated with $HgCo(SCN)_4$.

Synthesis of Complexes

[Cu(EFN)(bipy)(H2O)$_2$]HCl 1

The mixture of Copper (II) acetate monohydrate $Cu(CH_3COO)_2{\cdot}H_2O$ (0.0998 g, 0.5 mmol) and the ligand (0.1184 g, 0.5 mmol) dissolved in 10 mL methanol and 10 mL ammonia, respectively, was stirred continuously for 1 h. 2,2⊇– Bipyridine (0.0781 g, 0.5 mmol) in 10 mL methanol was then dropwise added to Cu solution and stirring is continued for 2 h. The deep blue precipitate formed was filtered, washed with methanol and dried over silica gel.

M.wt 474.40 $gmol^{-1}$, Yield 0.211 g (88.99 %); M.pt: 159-160 ^{0}C, Anal. Calc. for $C_{16}H_{25}F_2N_4O_4ClCu$ (%): C, 40.51; H, 5.31; N, 11.81. Found (%) C, 40.49; H, 4.97; N, 11.40. UV-Vis (H_2O, nm): 299, 329, 615.

[Ni(EFN)(bipy)(Cl)2]·3H$_2$O·2HCl 2

$NiCl_2.6H_2O$ (0.1188 g, 0.5 mmol) dissolved in 10 mL methanol was slowly added to (0.1184 g, 0.5 mmol) of EFN in 10 mL ammonia resulting in immediate formation of violet colour. The mixture was refluxed for 2 h. Methanolic solution of 2,2≠-Bipyridine (0.0781 g,0.5 mmol) was added and the colour changed into purple which was maintained at reflux for 3 h. The purple solution was allowed to evaporate slowly at room temperature. The pale blue precipitate formed was separated out by filtration, washed and dried over silica gel.

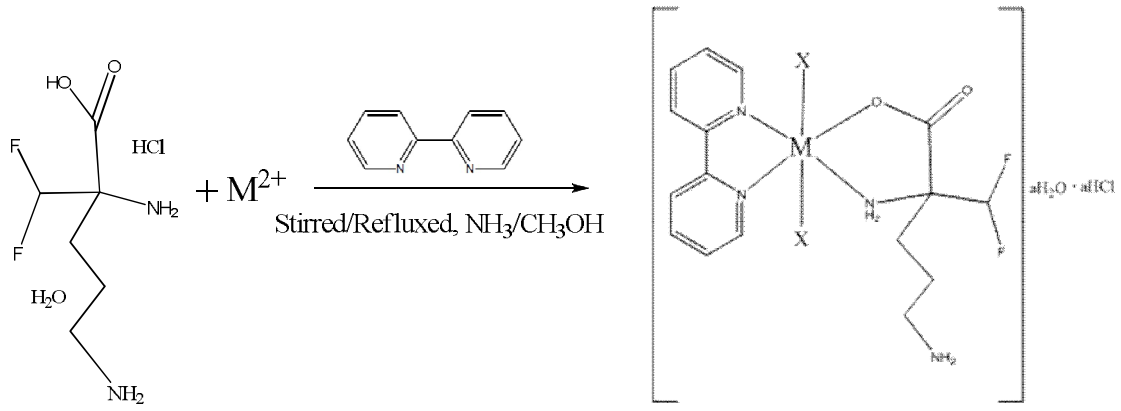
M.wt 594.92 $gmol^{-1}$, Yield 0.197 g (66.23 %); M.pt: 204-206 ^{0}C, Anal. Calc. for $C_{16}H_{28}F_2N_4O_5Cl_4Ni$ (%): C, 32.30; H, 4.74; N, 9.42. Found (%) C, 32.49; H, 4.62; N, 9.24. UV-Vis (H_2O, nm): 295, 348, 585, 750, 865.

[Co(EFN)(bipy)(Cl2)] 2H$_2$O.2HCl 3

EFN (0.1184 g, 0.5 mmol) was dissolved in 10 mL ammonia solution followed by the addition of (0.1190 g, 0.5 mmol) of $CoCl_2{\cdot}6H_2O$ in 10 mL methanol. The mixture was stirred under reflux for 2h after which (0.0781 g, 0.5 mmol) of 2,2≠- Bipyridine in 10ml methanol was added. The mixture was stirred for 5 h. The reddish brown solution was subjected to slow evaporation at room temperature. The light brown precipitate obtained was washed with methanol and dried over silica gel.

M.wt 577.14 $gmol^{-1}$, Yield 0.219 g (86.85 %); M.pt: 180-181 ^{0}C, Anal. Calc. for $C_{16}H_{26}F_2N_2O_4Cl_4Co$ (%): C, 33.30; H, 4.54; N, 9.71. Found (%) C, 33.54; H, 4.18; N, 9.50. UV-Vis (H_2O, nm): 295, 348, 585, 750, 865.

Scheme 1. Synthesis of metal complexes.



M^{2+} = $Cu(CH_3COO)_2.H_2O$; $NiCl_2.6H_2O$; $CoCl_2.6H_2O$

M = Co, Cu, Ni; X = H_2O, Cl; a = 1, 2 or 3

Results and Discussion

All the complexes conform to the general molecular formula *(M(EFN) (bipy)X_2). mH_2O. nHCl*, where X = Cl or H_2O; m = 2 or 3, n = 1 or 2. The molecular compositions are formulated on the basis of elemental analysis results. The complexes are formed by 1:1:1 molar ratio of EFN, bipy and transition metals with appreciable yield. The presence of uncoordinated water molecules in all the complexes except complex 1 was confirmed by the use of cobalt chloride paper. The complexes were heated gently in dry test tubes; droplets of colourless liquid found on the sides of test tubes turned cobalt chloride paper from blue to pink. Complex 1 has no effect on cobalt chloride paper when heated gently showing the non-availability of water molecules outside the coordination sphere.

The melting points of the metal complexes differ from those of EFN and bipy which are 236 - 237 ^{0}C and 70 – 73 ^{0}C, respectively. This gives an insight into the formation of coordination compounds. Also, the high purity of the complexes can be predicted from their sharp melting point.

The colours of copper (deep blue), cobalt (light brown) and nickel (pale blue) complexes are distinctly different from that of the ligand (white). Thus, it can be inferred that the colours displayed by the metal complexes are determined by the metal ions, a possible indication to the formation of coordination compounds.

The metal complexes were completely soluble in polar solvents such as water and methanol and also in DMF and DMSO, but they were practically insoluble in non-polar solvents indicating that the metal complexes are polar in nature and have tendencies to conduct electricity in solution. This is evidenced from the conductivity values presented in Table 3.

Fourier Transform Infrared Spectra (FTIR)

The characteristic FTIR bands of the ligands and metal complexes are shown in Table 1 and the principal bands attributed to asymmetric (υ_{asy}) and symmetric (υ_{sym}) stretching frequencies of (COO) groups are reported in Table 2. The characteristic FTIR bands of the complexes differed from that of the free ligand and showed either a shift or disappearance of some characteristic frequencies and an appearance of some new frequencies as a proof of coordination.

The IR spectrum of the ligand (EFN) shows a medium intensity band at 3048 cm^{-1} which is attributable to υ(OH) of carboxylic acid group. This band shifted in the spectra of metal complexes as a result of complexations suggesting possible coordination through carboxylate oxygen atom through deprotonation[20]. This is further supported by out-of-plane bending (OPB) frequencies of δOH(carboxylic acid) as contained in Table 1. The involvement of hydroxyl of carboxylic acid group in coordination is confirmed by asymmetric υ_{asy}(OCO) and symmetric υ_{sym}(OCO) stretching frequencies of carboxylate group as contained in Table 2. The separation $\Delta\upsilon$ = Δasy (OCO) – Δsym (OCO) characterizes the nature of the metal-carboxylate bond. When $\Delta\upsilon_{Ligand} > \Delta\upsilon$ complexes, the OCO group is a bidentate-chelating while OCO group exhibits a monodentate mode of coordination when the differences of ligand ($\Delta\upsilon_L$) is less than that of metal complexes ($\Delta\upsilon_{complexes}$)[21,22]. The separation ($\Delta\upsilon$) of the metal complexes 1, 2 and 3 of 243, 198 and 198 cm^{-1}, respectively, is greater than that of EFN (148 cm^{-1}). This indicates that carboxylate group of EFN coordinated to the metal ion in a monodentate mode through the hydroxyl oxygen atom *via* deprotonation[20-21, 23-24].

The bands in the region 3254-3173 cm^{-1} which could be attributed to asymmetric and symmetric stretching frequencies of primary amine (NH_2) in the spectrum of the ligand have undergone a red shift in the spectra of complexes, indicating involvement of NH_2 in chelation[21,25]. The observation was further strengthened by the sharp absorption band at 754 cm^{-1} in the spectrum of the ligand, due to NH_2 deformation (out-of-plane band) which shifted to higher frequencies after coordination through nitrogen with metal ions.

The spectra of EFN and bipy exhibited bands at 1138 and 1096 cm^{-1} region, respectively, attributed to that υ(C-N) stretching frequency has undergone shift in the spectra of complexes due to complexation. Also, the band at 1550 cm^{-1} region in the spectrum of bipy attributed to υ(C=N) also shifted in the spectrum of metal

complexes as a result of coordination of nitrogen atoms with metal ions[26].

New bands with medium to weak intensities which provide direct evidence for complexation (metal – ligand bond) were observed in the spectra of the complexes, but were conspicuously absent in the spectra of ligands, hence bands in the range of 682 –463 cm^{-1} in the spectra of complexes are assigned to **υ** (M – N/M-O/M-Cl) stretching frequencies[27].

Table 1. Major FTIR (cm^{-1}) data of the ligand and the metal complexes.

Compound	L(EFN)	Cplx. 1	Cplx. 2	Cplx. 3
υ(H_2O)/(HCl)	3393	3441	3404	3403
υ(NH_2)	3254	3221	3233	3212
(asy/sym)	3173	3113	3146	-
υ(OH) carboxylic	3048	3082	3038	3082
υ((COO)	1647	1604	1601	1653
(asy/sym)	1499	1402	1404	1459
υ(C-N)	1138	1159	1157	1163
(EFN/bipy)	1096	1074	1067	1030
υ(C=N) bpy	1550	1545	1544	1540
δ(OH)carboxylic acid OPB	947	922	-	979
δ(NH_2) OPB	754	772	771	773
υ(M-N/(M-O/M-Cl)	-----	655, 569	653, 471	682, 463

Table 2. Principal FTIR bands (cm^{-1}) for (COO) groups in ligand and metal complexes.

	L(EFN)	Cplx. 1	Cplx. 2	Cplx. 3
υ_{asy} (COO)	1647	1604	1601	1653
υ_{sym} (COO)	1499	1402	1404	1459
$\Delta\upsilon = \upsilon_{asy} - \upsilon_{sym}$	148	243	198	194

Electronic Spectra and Magnetic Properties of the Complexes

The electronic spectra data of the metal complexes and their assignments are presented in Table 3. The copper complex displayed a single broad absorption band at 615 nm in the visible region corresponding to $^2Eg \longrightarrow {}^2T_{2g}$ transition which is the expected transition for copper(II) complex in an octahedral environment. The magnetic susceptibility measurements also revealed that the copper (II) complex has an effective magnetic moment of 1.88 B.M[28] (see Figure **2**).

The absorption spectra of Ni (II) complex showed three bands at 422 nm, 600 nm and 805 nm corresponding to $^3A_{2g}(F) \longrightarrow {}^3T_{1g}(P)$, $^3A_{2g}(F) \longrightarrow {}^3T_{1g}(F)$ and $^3A_{2g}(F) \longrightarrow {}^3T_{2g}(F)$ electronic transitions, respectively.

This is consistent with Ni (II), d^8 ion in an octahedral environment. The effective magnetic moment of 3.27 B.M. obtained for the Ni (II) complex strengthens the octahedral stereochemistry formulated for the complex with two unpaired electrons[29].

Solution electronic spectra of Co (II) complex of EFN and bipy in the visible region displayed three bands typical of octahedral geometry around cobalt (II) ions with d^7 configuration. These are 585 nm, 750 nm and 865 nm regions assignable to $^4T_{1g}(F) \longrightarrow {}^4T_{2g}(F)$, $^4T_{1g}(F) \longrightarrow {}^4A_{2g}(F)$ and $^4T_{1g}(F) \longrightarrow {}^4T_{1g}(P)$ transitions, respectively. The magnetic moment of 4.07 B.M. observed for Co (II) complex is typical of Co (II) ion in an octahedral environment (with three unpaired electrons)[30-32].

Table 3. Magnetic moment, conductance and electronic spectra of ligand and metal complexes.

	Magnetic moment μ_{eff} (B.M.)	Molar conductance (Scm^2mol^{-1})	λ_{max} (nm)	λ_{max} (cm^{-1})	λ_{max} Energy ($kJmol^{-1}$)	Assignment
			228	43, 860	525	n – π*
L	-	115	240	41, 667	498	n – π*
			307	32, 573	390	n – π*
			299	43,668	522	n – π*
Cplx 1	1.88	124	329	30,395	364	LMCT
			615	16,260	194	$^2Eg \rightarrow {}^2T_2g$
			296	33,784	404	n – π*
			321	31,153	373	LMCT
Cplx 2	3.27	326	422	23,697	283	$^3A_{2g}(F) \rightarrow {}^3T_{1g}(P)$
			600	16,667	199	$^3A_{2g}(F) \rightarrow {}^3T_{1g}(F)$
			805	12,422	148	$^3A_{2g}(F) \rightarrow {}^3T_{2g}(F)$
			295	33,898	405	n – π*
			348	28,736	345	LMCT
Cplx 3	4.07	316	585	17,094	204	$^4T_{1g}(F) \rightarrow {}^4T_{1g}(P)$
			750	13,333	159	$^4T_{1g}(F) \rightarrow {}^4A_{2g}(F)$
			865	11,561	138	$^4T_{1g}(F) \rightarrow {}^4T_{2g}(F)$

LMCT – Ligand Metal Charge Transfer.

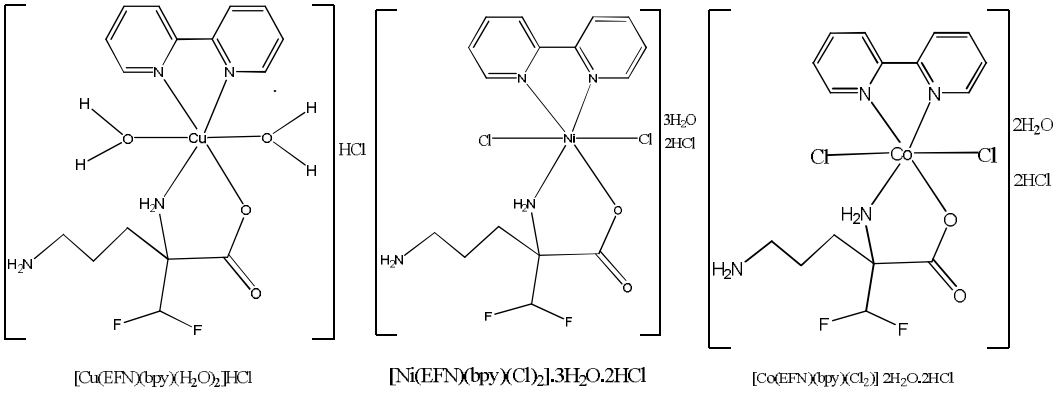


Figure 2. Proposed structure of metal complexes.

Antibacterial Screening Results

The *in-vitro* antibacterial activity of the ligand (EFN) and metal complexes was evaluated using agar well diffusion technique[33,34] against gram-positive bacteria, *Staphylococcus aureus* and *Bacillus substilis* and gram-negative bacteria, *Escherichia coli* and *Pseudomonas aeruginosa*. The activity evaluation was carried out at concentrations of 100ppm, 200ppm and 300ppm using distilled water as a solvent. A known antibiotic, streptomycins was used as a standard. The susceptibility of these bacteria strains towards the metal complexes was estimated by measuring the zone or size of inhibition diameter. The results of antimicrobial evaluation of the metal complexes and ligand are presented in Table 4 (see Figure **3**).

The solvent (distilled water) showed no zone of inhibition, confirming non-involvement of solvent in the activity of the metal complexes and the EFN. Generally, the results of antibacterial screening show appreciable activity of the metal complexes when challenged with the test pathogens.

The inhibitions are much larger by metal complexes when compared to the free ligand[35]. Metal complexes showed enhanced activities and compete favorably well or even displayed greater activities than the antibiotic (streptomycin) used. The enhanced activity can be attributed to the presence of bipy in the coordination sphere. The complexes of 2,2▪-bipyridine and substituted bipyridine have been found to show antibacterial[14,15] properties.

This is equally established from the results that the antibacterial potency is concentration-dependent, which generally agrees with the finding of other researchers who asserted that antimicrobial potency is usually concentration-dependent[31, 34, 36]. It was also observed that the most resistant pathogens to the metal complexes were, *Bacillus substilis* and *Pseudomonas aeruginosa*, while the most susceptible were *Staphylococcus aureus* and *Escherichia coli*.

Table 4. Zone of inhibition (ppm) of the ligand and metal complexes on test organisms.

	Gram (-)			Gram (-)			Gram (+)			Gram (+)		
Compounds	*E. coli*			*P. aeruginosa*			*S. aureus*			*B. substilis*		
	100	200	300	100	200	300	100	200	300	100	200	300
Distilled Water (Solvent)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Standard (Streptomycin)	10.0	16.0	22.0	4.5	8.0	12.5	6.0	12.0	18.0	4.0	8.5	12.0
Ligand (EFN)	NA	8.5	12.5	NA	NA	5.0	NA	7.5	10.0	NA	2.0	6.5
Complex 1	11.5	18.0	25.0	6.0	10.5	15.0	8.0	14.5	21.5	5.3	9.8	13.5
Complex 2	10.5	16.5	24.0	5.0	9.5	13.5	7.2	12.8	19.6	4.8	8.8	13.0
Complex 3	10.0	16.0	23.3	4.0	8.0	12.6	6.5	12.3	18.2	4.1	8.4	12.3

E. coli - *Escherichia coli* (Ec)
P. aeruginosa - *Pseudomonas aeruginosa* (Pa)
S. aureus - *Staphylococcus aureus* (Sa)
B. substilis - *Bacillus substilis* (Bs)
NA – Not active.

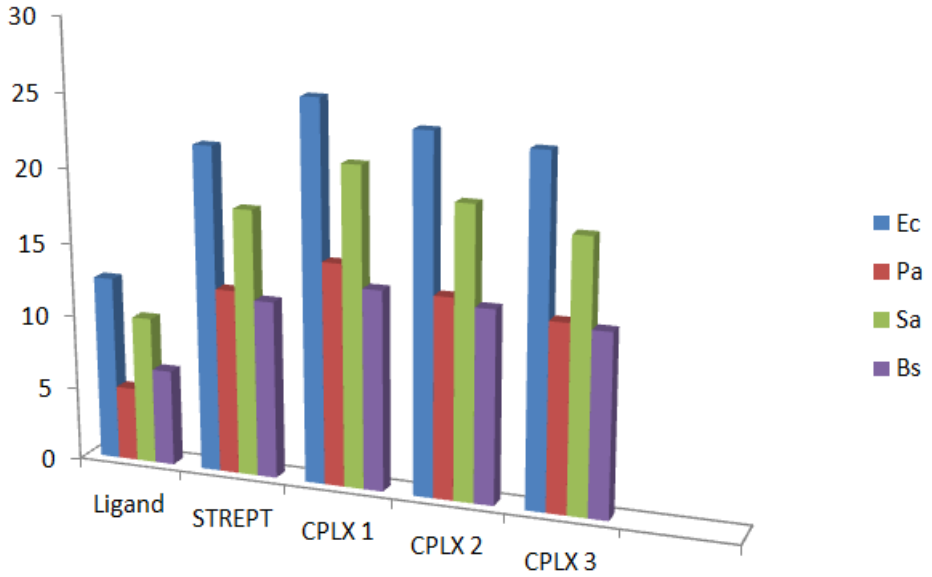


Figure 3. Inhibitory level of the ligand and metal complexes on test organisms at a concentration of 300ppm.

Conclusion

Novel transition metal (Cu (II), Co (II) and Ni (II)) complexes of Eflornithine hydrochloride hydrate (EFN) and 2,2-bipyridine (bipy) were synthesized and characterized using melting point determination, conductivity measurement, elemental analysis, FTIR spectroscopy, electronic spectroscopy and magnetic susceptibility measurement. The FTIR spectral data suggests that each of the ligands behave as a bidentate ligand; EFN coordinates to the metal ions through an oxygen atom of the carboxylate group and a nitrogen atom of the amino group, while bipy coordinates through azomethine nitrogen atoms. Electronic spectral and magnetic studies suggest octahedral geometry around metal ions. The results of the antibacterial screening show appreciable activity of the metal complexes when challenged with the test pathogens. The inhibitions are much larger by metal complexes when compared to the free ligand. The enhanced antibacterial activity of the metal complexes is attributed to the presence of 2,2-bipyridine.

References

[1] Kaim, W.; Schwederski, B. "Bioinorganic Chemistry: Inorganic Elements of Life", John Wiley and Sons, London, **1996**, 39-262.

[2] Xiao-Ming, C.; Bao-Hui, Y.; Xiao, C. H.; Zhi-Tao, X. J. Chem. Soc. Dalton Trans., **1996**, 3465.

[3] Cotton, F. A.; Wilkinson, G. "Advanced Inorganic Chemistry", 5th ed., John Wiley and Sons, New York, **1988**, 1358-1371.

[4] Miura, T.; Hori-i, A. Mototani, H. ; Takeuchi, H. *Biochemistry*, **1999**, *38*, 11560.

[5] Majella, G.; Vivienne, S.; Malachy, M.; Michael, D.; Vickie, M. *Polyhedron*, **1999**, *18*, 2931.

[6] Saha, D. K.; Sandbhor, U.; Shirisha, K.; Paddye, S.; Deobagkar, D.; Ansond, C.E.; Powell, A. K. *Bioorg. Med. Chem. Lett*. **2004**, *14*, 3027

[7] Zoroddu, M. A.; Zanetti, S.; Pogni, R.; Basosi, R. J. *Inorg. Biochem.*, **1996**, *63*, 291.

[8] Patel, R. N.; Singh, N.; Shukla, K. K.; Gundla, V. L. N.; Chauhan, U. K. *Spectrochim. Acta A* **2006**, *63*, 21.

[9] Lu, L-P.; Qin, S.; Yang, P.; Zhu, M-L. *Acta Cryst* **2004**, *60*, 574-576.

[10] Faundez, G.; Troncoso, M.; Navarette, P.; Figueroa, G. B. *Microbiol*. **2004**, *4*, 1471.

[11] Khan, F.; Patoare, Y.; Karim, P.; Rayhan, I.; Quadir, M. A.; Hasna, A. *Pak. J. Pharm*. **2005**, *18*, 57.

[12] Baena, M. I.; Marquez, M. C.; Matres, V.; Botella, J.; Ventosa, A. *Curr. Microbiol*. **2006**, *53*, 491.

[13] Lee, J. D. "Concise Inorganic Chemistry", 4th ed., Chapman and Hall: London; **1991,** 607-1074.

[14] Coyle, B.; Kwanagh, K.; Mcxcann, M.; Devereux, M.; Geraghty, M. *Biometals* **2003**, *16*, 1572.

[15] Bapna, M. S.; Mukherjee, S.; Murphy, R. J. *Oral Rehabit*. **2007**, *19*, 111.

[16] Puglisi, A.; Benaglia, M.; Annunziata, R.; Bologna, A. *Tetrahedron Lett*. **2003**, *44*, 2947–2951.

[17] Onawumi, O. O. E.; Faboya, O. O. P.; Odunola, O. A.; Prasad, T. K.; Rajasekharan, M. V. *Polyhedron*, **2008**, *27*, 113–117.

[18] Ouf, A. M.; Ali, M. S.; Soliman, M. S.; El-Defrawy, A. M.; Mostafa, S. I. *J. Kor. Chem. Soc*. **2010**, *54*(4), 402-410.

[19] Amani, V.; Safari, N.; Khavasi, H. R. *Polyhedron* **2007**, *26*, 4257–4262.

[20] Sharma, S. S.; Ramani, J. V.; Dalwadi, D. P.; Bhalodia, J. J.; Patel, N. K.; Patel, D. D.; Patel, R. K. *E-Journal Chem.***2011**, *8*, 361 – 367.

[21] Angela, K.; Lucia, V. A.; Nicoleta, C.; Ileana, R.; Nicolae, S. *J. Serb. Chem. Soc.* **2010**, *75*, 229 – 242. JSCS – 3955.

[22] Deacon, G. B.; Philips, R. J. *Coord. Chem. Rev*. **1980**, *33*, 227 – 250.

[23] Li, Xi.; Zhang, Z.; Wang, C.; Zhang, T.; He, K.; Deng, F. *J. Inorg. Biochem.* **2011**, *105*, 23 – 30.

[24] Viossat, V.; Lemoine, P.; Dayan, E.; Dung, N.; Viossat, B. *J. Mol. Struct.* **2005**, *741*, 45–52.
[25] Ajibade, P. A.; Kolawole, G. A. *Bull. Chem. Soc. Ethiop*. **2008**, *22*, 261 – 268.
[26] Choudhary, A.; Sharma, R.; Nagar, M.; Mohsin, M.; Meena, H. S. *J. Chil. Chem. Soc.* **2011**, *56*, 911-917
[27] Abdelbaky, S. M.; Amghouz, Z.; Fernández-Zapico, E.; García-Granda, S.; García, J. R., *J. Solid State Chem.* **2015**, *229, 197-207.*
[28] Rafat, F.; Siddiqi, M. Y.; Sidiqqi, K. S. *J. Serb. Chem. Soc.* **2004**, *69*, 6641–6649.
[29] Bernhardt, P. V.; Moore, E. G.; Riley, M. J. *Inorg. Chem*. **2001**, *40*(23), 5799 – 5805.
[30] Chandra, S.; Gautam, A.; Tyagi, M. *Russ. J. Coord. Chem.* **2009**, *35*, 25-29.
[31] Patel, K. S.; Patel, J. C.; Dholariya, H. R.; Patel, V. K.; Patel, K. D. *Open J. of Metal* **2012**, *2*, 49-59. http://dx.doi.org/10.4236/ojmetal.2012.23008.
[32] Najeeb, D. A. *J. Al-Nahrain University Sci.* **2011**, *14*, 35-39.
[33] Kaushal, R.; Kumar, N.; Awasthi, P.; Nehra, K. *Turk. J. Chem*. **2013**, *37*, 936 – 945.
[34] Bianca, F.; Georgiana, P.; Ioana, O. G.; Rodica, M. D.; Gabriela, B.; Martine, D. *Molecules* **2014**, *19*, 11572 – 11585.
[35] Shelke, V. A.; Jadhav, S. M.; Patharkar, V. R.; Shankarwar, S. G.; Munde, A. S.; Chondhekar, T. K. *Arabian J. Chem*. **2012**, *5*, 501 – 507.
[36] Azu, N. C.; Onyeagba, R. A. *The Internet J. Trop. Med.* **2007**, *3*, 277 – 286.