Spectroscopic and Antimicrobial Studies of Transition Metal Complexes of a Schiff Base Macrocyclic Ligand

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Abstract

Cr(III) and Mn(II) complexes of a Schiff base macrocyclic ligand viz. 1,3,7,9-tetraaza-4,6,10,12-tetraphenyl-2,8-dithiacyclododecane (L) were characterized by elemental analysis, molar conductance measurements, magnetic susceptibility measurements, mass, ^1H NMR, IR, electronic and EPR spectral studies. An octahedral geometry is suggested for Cr(III) and Mn(II) complexes on the basis of various spectral studies.

The ligand and its complexes were evaluated in vitro for antifungal activity against three plant pathogenic fungi namely, Aspergillus niger, Aspergillus glaucus, and Aspergillus flavus and antibacterial activity against two pathogenic bacteria namely, Sarcina lutea (Gram-positive) and Escherchia coli (Gram-negative). The studied complexes exhibit mild antifungal and antibacterial activity against these organisms.

Keywords: Schiff base macrocycle, Cr(III), Mn(II), Spectral and antimicrobial studies.

Introduction

Schiff bases were first reported in 1864 by Hugo Schiff, a German scientist. They are synthesized by the reaction of primary amine with an aldehyde or a ketone under specific conditions. Schiff bases are also known as azomethine or imine. In last few decades, Schiff bases have gained a lot of attention in the field of coordination chemistry. This is because of the fact that Schiff base ligands coordinate readily with various metal ions to form stable complexes having important chemical, physical, catalytical and biological properties.[14,21] A number of Schiff base macrocyclic compounds have been reported for their antibacterial[17,18], antifungal[1,3], catalytic[1,2], anticonvulsant[2,20], antioxidant[20] and antitumor[16] activities.

Chemically, Schiff base macrocycles containing N, O and S donor atoms are of great interest because of their versatility as ligands, the availability of a wide range of potential donor atoms, their flexibility, and ability to coordinate in either neutral or deprotonated states. They can form mononuclear or polynuclear complexes, many of which are biologically important.

Specifically, first row transition metal complexes, containing such ligands exhibit a broad range of biological properties. In the present study, the synthesis, spectral characterization, and antimicrobial activities of some Cr(III) and Mn(II) complexes of a Schiff base macrocyclic ligand (L) have been reported.

Material and Methods

Materials: All the chemicals used were of AnalaR grade and procured from Fluka and Sigma Aldrich. Metal salts were obtained from E. Merck and were used as received.

Instrumentation: C, H and N were analyzed on a Carlo-Erba 1106 elemental analyzer. Magnetic susceptibility was measured at room temperature on a Gouy balance using $CuSO_4.5H_2O$ as a calibrant. Molar conductance was measured on the Elico (CM82T) conductivity bridge. Electron impact mass spectra were recorded on TOF MS ES+ mass spectrometer. IR spectra(KBr) were recorded on FTIR Spectrum BX-II spectrophotometer. ^1H NMR spectra were recorded on Hitachi FT-NMR, model R-600 spectrometer using $CDCl_3$ as a solvent. The electronic spectra were recorded in DMF on Shimadzu UV mini-1240 spectrophotometer.

EPR spectra of the complexes were recorded as polycrystalline sample and in the solution of DMSO, at room temperature for Cr(III) and Mn(II) complexes on E_4 –EPR spectrometer using the DPPH as the g-marker.

Synthesis of ligand: Ligand was prepared and characterized by the method reported earlier[4]. The solid white coloured ligand was filtered, washed with cold EtOH, and dried under vaccum over P_4O_{10}. The ligand was obtained with 65% yield and the melting point was found to be 80° C.

Synthesis of complexes: Hot ethanolic (20 mL) solution of ligand (0.528 g, 0.001 mol) was mixed with hot ethanolic solution of corresponding metal salts (0.001 mol) with constant stirring. The mixture was refluxed for 5-8 h at 70-80° C. On cooling, coloured complexes precipitated out which were filtered, washed with cold EtOH and dried under vaccum over P_4O_{10}. The colour, yield, m.p., molar conducdance and elemental analysis data of the synthesized complexes are reported in table 1.

Antifungal study: The Agar plate technique was used to test the compounds for antifungal activity *in vitro*.[6-8,22,23] Chlorothalonil was used as a reference, while *Aspergillus niger*, *Aspergillus glaucus*, and *Aspergillus flavus* were used as test strains (Fig. 5). To obtain concentrations of 125 and 250 ppm, the test compounds were taken in appropriate amounts and mixed with properly cooled potato dextrose agar medium.

Table 1
Molar conductance and elemental analysis data of the complexes

Complexes	Colour	Molar cond. $\Omega^{-1}cm^2mol^{-1}$	Yield (%)	M.P. (^{0}C)	Elemental analysis found (calculated) (%)			
					Cr	C	H	N
$[Cr(L)Cl_2]Cl$ $CrC_{32}H_{24}N_4S_2Cl_3$	Light green	102	60	280	7.65 (7.58)	55.85 (55.97)	3.41 (3.49)	8.25 (8.16)
$[Cr(L)(NO_3)_2]NO_3$ $CrC_{32}H_{24}N_7O_9S_2$	Light green	99	55	282	6.90 (6.78)	50.22 (50.13)	3.24 (3.13)	12.68 (12.79)
$[Mn(L)Cl_2]$ $MnC_{32}H_{24}N_4S_2Cl_2$	Light Brown	13	58	290	8.32 (8.39)	58.80 (58.71)	3.72 (3.66)	8.63 (8.56)
$[Mn(L)(NO_3)_2]$ $MnC_{32}H_{24}N_6O_6S_2$	Light Brown	11	55	286	7.68 (7.76)	54.24 (54.31)	3.47 (3.39)	11.79 (11.88)

The media was poured into sterile Petri plates and mycelial discs of the test pathogen were extracted from a one-week-old culture. The treated Petri plates were incubated at 26^{o}C until the fungal growth in the control petriplate was complete (Table 4). The mycelial growth of fungi (mm) was then measured diametrically in order to calculate the growth inhibition (I) using the formula:

$$I(\%) = \frac{C - T}{C} \times 100$$

where C is the growth of the fungus (mm) in control plate and T is the growth of test compounds.

Antibacterial study: The compounds were tested for antibacterial activity against *Sarcina lutea* (Gram-positive) and *Escherichia coli* (Gram-negative) using the Disc Diffusion Method[6-8,22,23], with streptomycin serving as the control drug (Fig. 6). Peptone, beef extract, NaCl, agar-agar, and distilled water were used to make the medium. The test compounds were dissolved in DMF at the appropriate concentrations of 125 and 250 ppm. After pouring 25 mL of prepared media into Petri plates, 0.1 mL of test bacteria were dispersed throughout the medium. These Petri plates were initially refrigerated for 24 hours to allow for pre-diffusion before being incubated for 28 hours at 27^{o}C. After completion of time, the zone of inhibition was measured in millimetres (Table 5).

Results and Discussion

On the basis of elemental analysis, the complexes were assigned to possess the composition as shown in table 1. The molar conductance measurements in DMF/DMSO for Cr(III) complexes correspond to 1:1 electrolyte, thus these complexes formulated as $[Cr(L)X_2]X$ and non-electrolytic nature for Mn(II) complexes, thus formulated as $[Mn(L)X_2]$ [where $X = Cl^-, NO_3^-$].

Mass Spectrum: The electron impact mass spectra of ligand (L) confirm the proposed formula by showing a peak at 550 amu [i.e. atomic mass 528 corresponding to the macrocyclic moiety $(C_{32}H_{24}N_4S_2)^+$ + 23 atomic mass of Na^+ ion][9].

^{1}H NMR spectrum and IR spectra: The ^{1}H NMR spectrum of the ligand does not exhibit any signal attributed to primary diamine or alcoholic protons. The absence of bands corresponding to free primary diamine or hydroxyl group in the IR spectra of ligand[9] implied that the keto group was completely condensed with the amino group.

Magnetic moment, Electronic spectra, EPR spectra and Various ligand field parameters of Cr(III) complexes: At room temperature, the magnetic moment of Cr(III) complexes was found to be 3.78-3.80 B.M. These values were similar to the spin-only value, implying an octahedral geometry surrounding the Cr(III) ion.[15] The infrared spectrum of Cr(III) nitrate complex exhibited three bands at 1452 (ν_5), 1316 (ν_1), and 1068 (ν_2) cm^{-1} (Fig. 1). It implies that both nitrate groups coordinate with the centrally located Cr(III) metal ion in an unidentate manner. The electronic spectra of Cr(III) complexes recorded in DMF (Fig. 2) display three bands in the range 14880-15503, 18621, 28571-28653 cm^{-1} (Table 2). The first two bands may be assigned to transitions $^4A_{2g}$ (F) → $^4T_{2g}$ (F) and $^4A_{2g}$ (F) → $^4T_{1g}$ (F) respectively and the third band may be due to charge transfer.

EPR spectra of the complexes were recorded as a polycrystalline sample at room temperature[12] (Table 3). The EPR spectra of Cr(III) complexes (Fig. 3) revealed a broad line, with the 'g' value ranging from 1.9538 to 1.9558. Various ligand field parameters for Cr(III) complexes are calculated and listed in table 3. The first spin allowed transition directly gives the value of 10*Dq*. Racah interelectronic repulsion parameter *B* was calculated by the equation:

$$B = (2\nu_1^2 + \nu_2^2 - 3\nu_1\nu_2) / (15\nu_2 - 27\nu_1).$$

The nephelauxetic parameter β was calculated by the relation:

$$\beta = B(\text{complex})/B(\text{free ion})$$

where B(free ion) is 918 cm^{-1} for Cr(III). The β values indicate that there is appreciable covalent character in the metal-ligand σ bond.

Magnetic moment, Electronic spectra, EPR spectra and Various ligand field parameters of Mn(III) complexes: Mn(II) complexes exhibited magnetic moments in the range 5.98-6.02 B.M. corresponding to five unpaired electrons. The infrared spectra of Mn(II) nitrate complex showed three bands at 1457 (ν_5), 1227 (ν_1) and 1056 (ν_2) cm^{-1} respectively (Fig.1). This implies that the nitrate group is unidentately coordinated to the metal ion.[11] The electronic spectra of Mn(II) complexes (Fig.2) exhibited four absorption bands in the range 18248-18621**,** 22015-24198**,** 26595-28011 and 33670-37453 cm^{-1}[10] (Table 2). These bands may be assigned to transitions $^6A_{1g} \rightarrow {}^4T_{1g}$ (^4G), $^6A_{1g} \rightarrow {}^4E_g$ (^4G), $^6A_{1g} \rightarrow {}^4E_g$ (^4D) and $^6A_{1g} \rightarrow {}^4T_{1g}$ (^4P) respectively. At room temperature, the EPR spectra were recorded as a polycrystalline sample (Fig.3). The polycrystalline spectra showed a single broad isotropic signal with 'g' values ranging from 2.1458 to 2.2115. The ligand field parameter values *Dq, B, C, β* for Mn(II) are calculated and given in table 3.

$$^6A_{1g} \rightarrow {}^4E_g, {}^4A_{1g}(^4G) = 10B + 5C$$

$$^6A_{1g} \rightarrow {}^4T_{1g}(^4P) = 17B + 5C$$

The energy of these transitions is unaffected by crystal field splitting and is exclusively determined by the parameters B and C[19]. B and C values were determined from the second and third transitions.[13] The structures illustrated in fig. 4 are suggested for the complexes based on the above spectral studies.

Table 2
Magnetic moment and electronic spectra of the complexes

Complexes	$\mu_{eff.}$ (BM)	λ_{max}(cm^{-1})
$[Cr(L)Cl_2]Cl$	3.80	15503, 18621, 28653
$[Cr(L)(NO_3)_2]NO_3$	3.78	14880, 18621, 28571
$[Mn(L)Cl_2]$	6.02	18248, 22015, 26595, 33670
$[Mn(L)(NO_3)_2]$	5.98	18621, 24198, 28011, 37453

Table 3
Ligand field parameters and EPR spectra of the complexes

Complexes	Dq (cm^{-1})	B (cm^{-1})	B	LFSE ($kJmol^{-1}$)	g_{iso}
$[Cr(L)Cl_2]Cl$	1550	277	0.30	222	1.9558
$[Cr(L)(NO_3)_2]NO_3$	1488	344	0.37	213	1.9538
$[Mn(L)Cl_2]$	1824	654	0.83	--	2.2115
$[Mn(L)(NO_3)_2]$	1862	545	0.69	--	2.1458

Table 4
Antifungal screening data of the ligand (L) and its complexes

Compounds	Fungal Inhibition (%) (conc. in μgml^{-1})					
	Aspergillus niger		*Aspergillus glaucus*		*Aspergillus flavus*	
	125	250	125	250	125	250
L	33	58	31	54	23	52
$[Cr(L)Cl_2]Cl$	33	50	29	55	--	45
$[Cr(L)(NO_3)_2]NO_3$	--	47	--	52	22	46
$[Mn(L)Cl_2]$	33	59	30	54	22	51
$[Mn(L)(NO_3)_2]$	34	58	29	56	24	52
Chlorothalonil (standard)	52	76	48	67	61	82

Table 5
Antibacterial screening data of the ligand (L) and its complexes

Compounds	Diameter (mm) of compounds at concentrations (μgml^{-1})			
	Sarcina lutea		*Escherchia coli*	
	125	250	125	250
L	11	17	--	14
$[Cr(L)Cl_2]Cl$	06	14	--	13
$[Cr(L)(NO_3)_2]NO_3$	--	12	08	14
$[Mn(L)Cl_2]$	09	16	--	13
$[Mn(L)(NO_3)_2]$	11	18	07	15
Streptomycin (standard)	24	28	20	25

Antimicrobial screening: According to antimicrobial screening data, metal chelates have more inhibitory effects than free ligand. Chelation theory[24] can be used to explain the enhanced activity of metal chelates. The ligand and its metal complexes inhibited fungal growth in the following order:

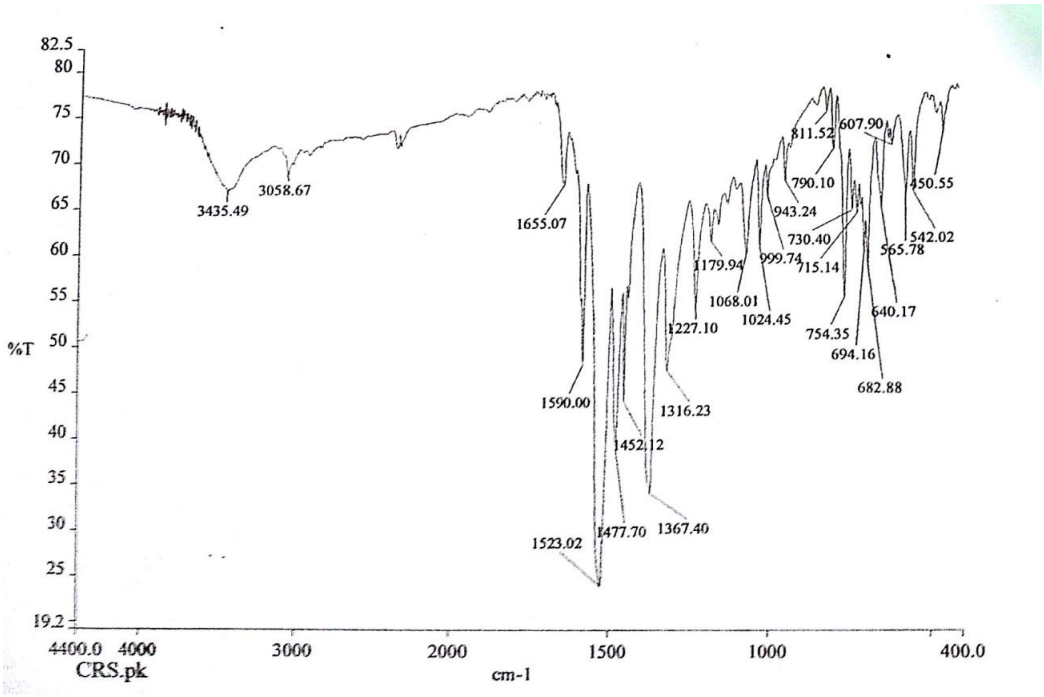
Mn(II) > Cr(III) > ligand

The ligand and its metal complexes showed bacterial growth inhibitory activity in the following order:

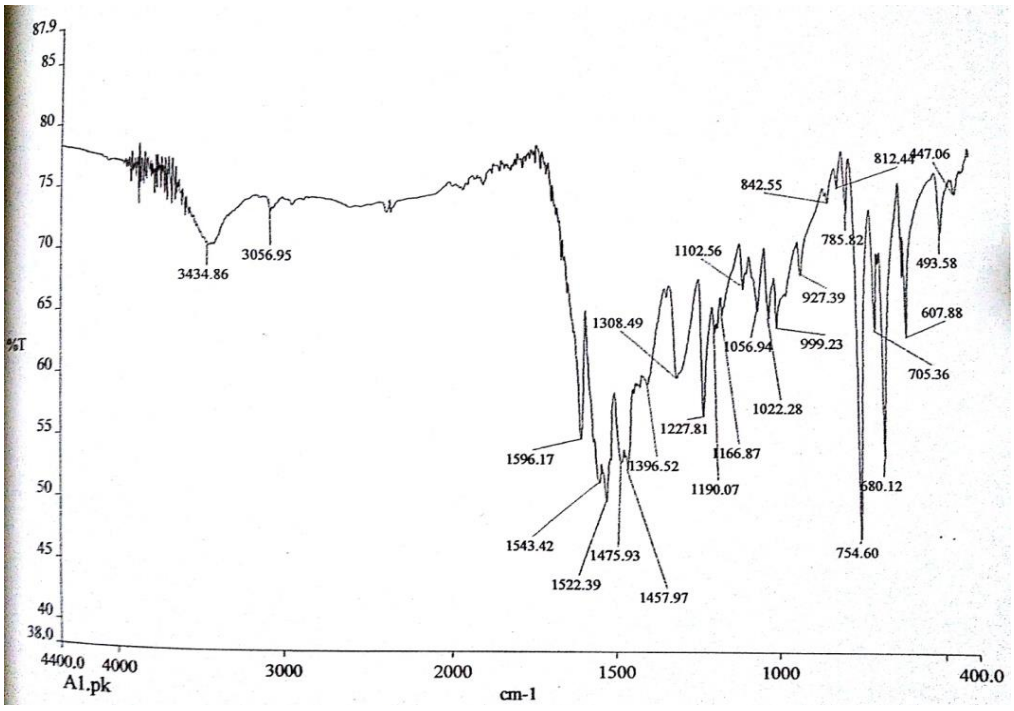
Mn(II) > Cr(III) ≅ ligand

Conclusion

Cr(III) and Mn(II) complexes have been assigned an octahedral geometry on the basis of present spectral studies. According to antimicrobial screening, metal chelates have a stronger inhibition effect than metal free ligand. The studied complexes exhibit mild antifungal and antibacteria activity against tested organisms.

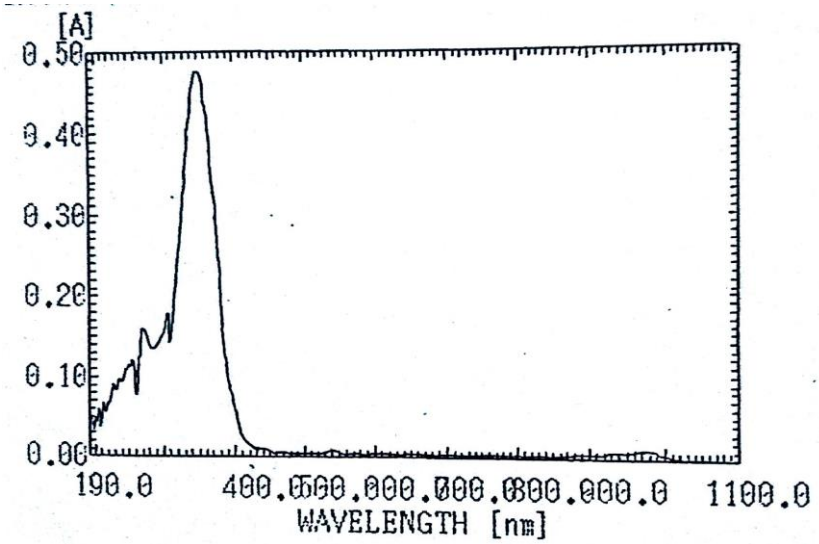


(a)

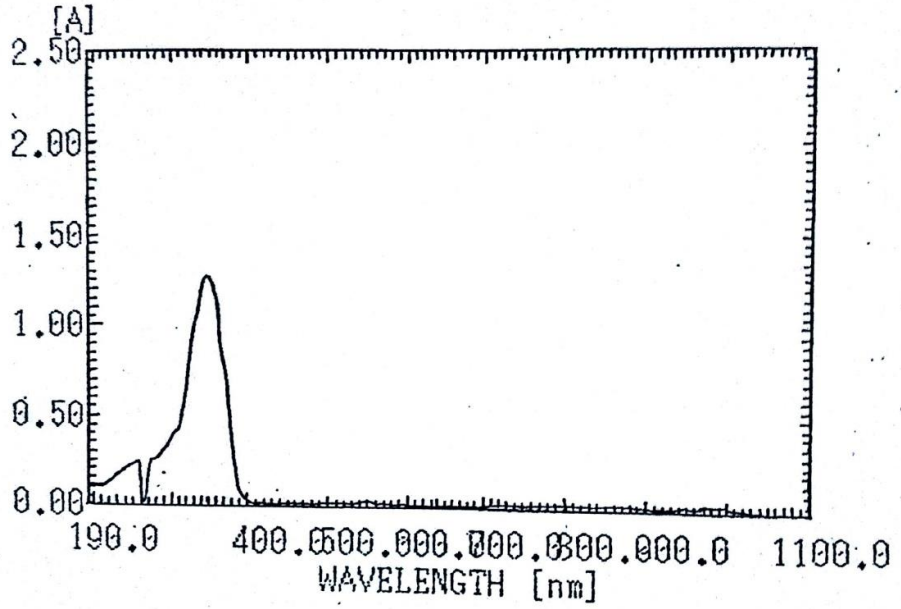


(b)

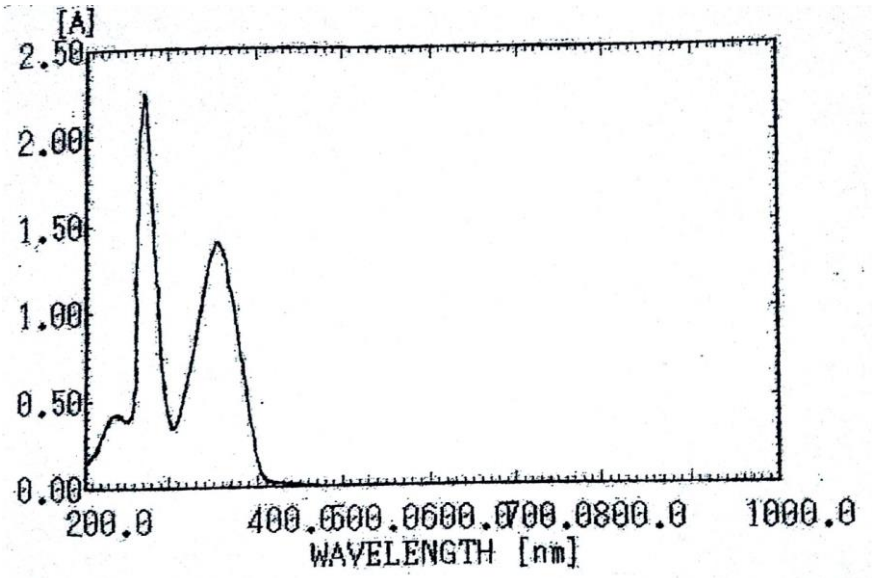
Fig. 1: IR spectral bands due to anions. (a) $[Cr(L)(NO_3)_2]NO_3$, (b) $[Mn(L)(NO_3)_2]$


[A]
0.50
0.40
0.30
0.20
0.10
0.00
190.0
400.0
600.0
800.0
1000.0
1100.0
WAVELENGTH [nm]

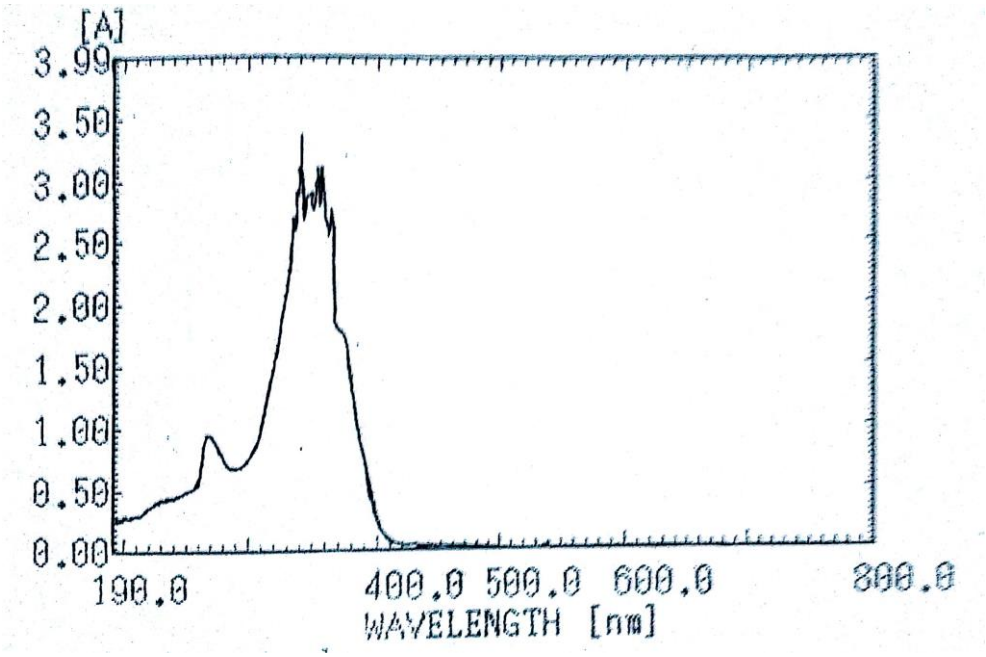
(a)


[A]
2.50
2.00
1.50
1.00
0.50
0.00
190.0
400.0
600.0
800.0
1000.0
1100.0
WAVELENGTH [nm]

(b)

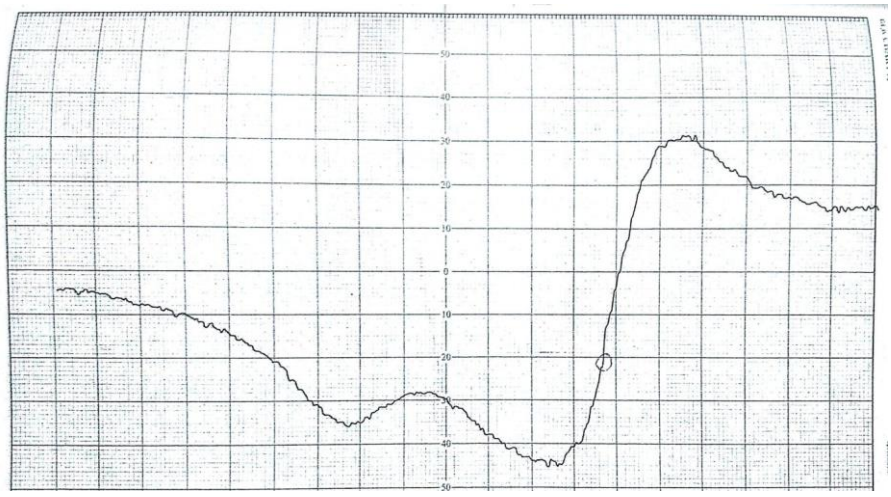

[A]
2.50
2.00
1.50
1.00
0.50
0.00
200.0
400.0
600.0
800.0
1000.0
WAVELENGTH [nm]

(c)

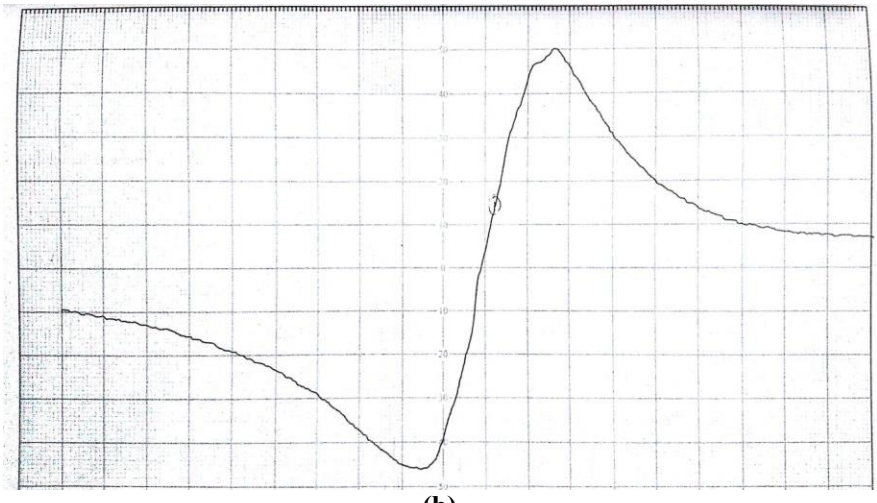


(d)

Fig. 2: Electronic spectra of the complexes. (a) $[Cr(L)Cl_2]Cl$, (b) $[Cr(L)(NO_3)_2]NO_3$, (c) $[Mn(L)Cl_2]$ and (d) $[Mn(L)(NO_3)_2]$



(a)



(b)

Fig. 3: EPR spectra of the complexes. (a) $[Cr(L)Cl_2]Cl$, (b) $[Mn(L)(NO_3)_2]$

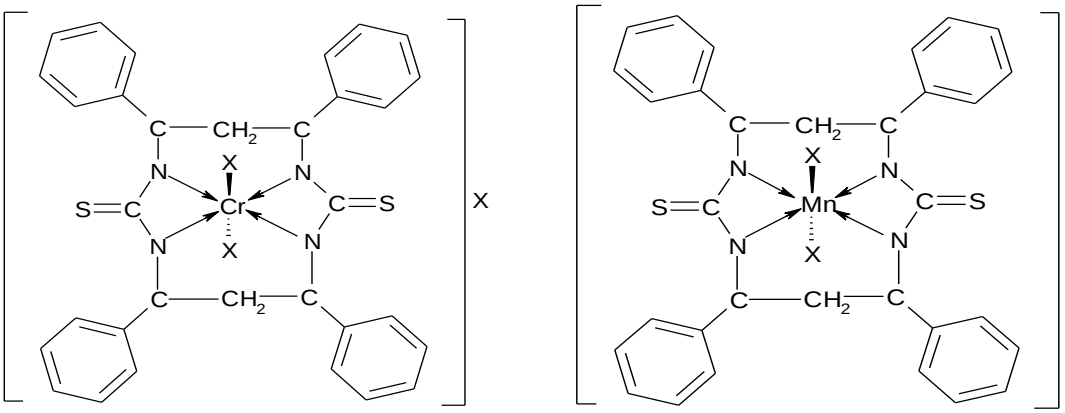


Fig. 4: Suggested structure of Cr(III) and Mn(II) complexes (where X = Cl^- and NO_3^-)

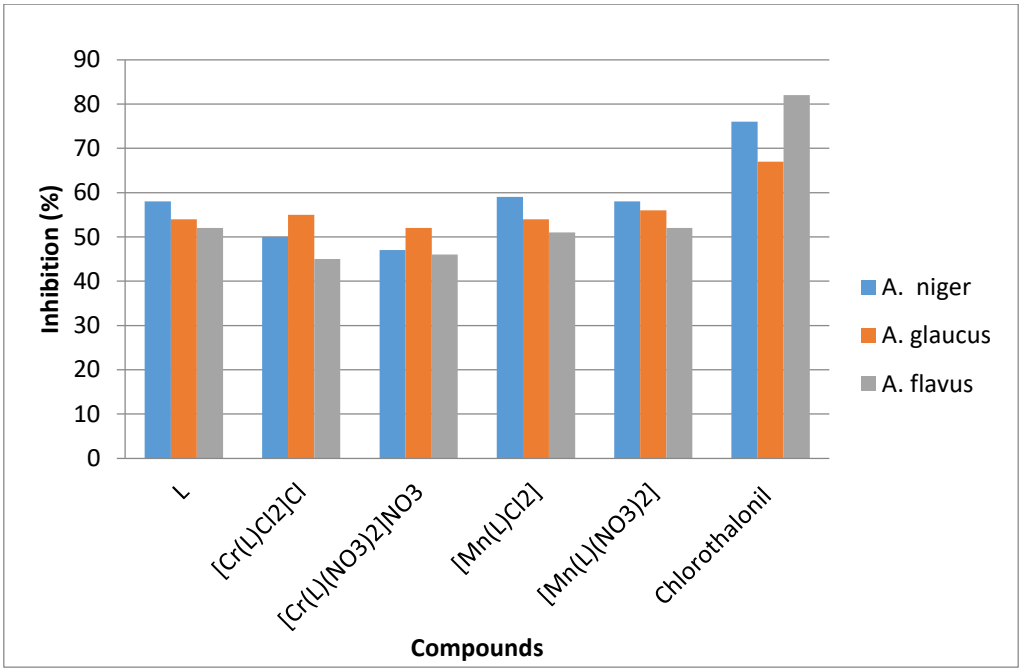


Fig. 5: Antifungal screening data of the ligand (L) and its complexes at 250 ppm

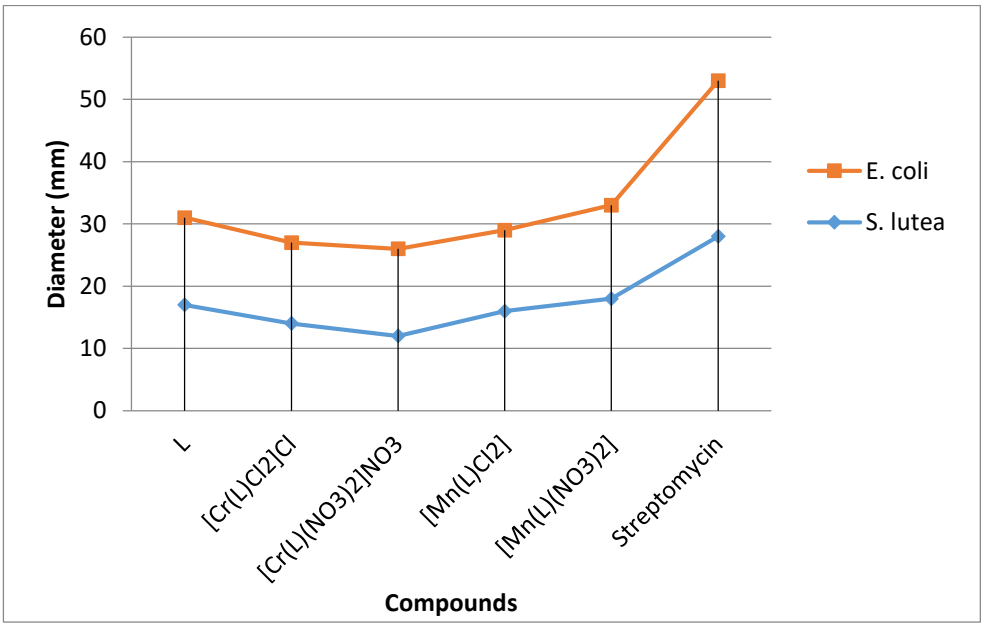


Fig. 6: Antibacterial screening data of the ligand (L) and its complexes at 250ppm

It is also suggested that concentration plays an important role in increasing the degree of inhibition. As concentration rises, activity also rises.

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