Journal of Enzyme Inhibition and Medicinal Chemistry, 2013; 28(1): 33–40

ISSN 1475-6366 print/ISSN 1475-6374 online
DOI: 10.3109/14756366.2011.625022

informa
healthcare

RESEARCH ARTICLE

Template synthesis, spectroscopic studies, antimicrobial, nematicidal and pesticidal activities of chromium(III) macrocyclic complexes

Iffat Masih, Nighat Fahmi, and Rajkumar

Department of Chemistry, University of Rajasthan, Jaipur, India

Abstract

A new series of Cr(III) macrocyclic complexes have been synthesized by template condensation of ligands 2-[4-chloro-2-(2-oxo-1,2-diphenyl-ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone (ML^1) and 2-[4-fluro-2-(2-oxo-1,2-diphenyl-ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone (ML^2) respectively, with appropriate diamines i.e. 1,2-phenylenediamine, 4- chloro 1,2-phenylenediamine and 4-fluro- 1,2-phenylenediamine in the presence of $CrCl_3.6H_2O$. The ligands and their complexes have been characterized on the basis of elemental analyses, molecular weight determinations, conductance and magnetic susceptibility measurements and spectral studies including IR, ESR, electronic spectra and X-ray powder diffraction studies. On the basis of these studies, a six-coordinated octahedral geometry has been proposed for all these complexes. The newly synthesized ligands and their complexes have been screened for their antimicrobial, nematicidal and pesticidal activities. The results are indeed positive.

Keywords: Cr(III) macrocyclic complexes, spectral studies, antimicrobial activity, nematicidal activity, pesticidal activity, minimum inhibitory concentration

Introduction

The chemistry of macrocyclic ligands and their complexes have been extensively studied in recent years.[1,2] Template reactions have been widely used for the syntheses of macrocyclic complexes, where a transition metal ion is used as templating agent.[3] Macrocyclic complexes of transition metal ions have attracted considerable attention because of various applications in catalysis,[4] bioinorganic[5] and supramolecular chemistry[6] and a number of unique properties offered by the macrocyclic, environment, such as extremely high thermodynamic stability and the ability to access unusual oxidation states of a metal centre.[7] Nowadays interest is focused on the synthesis of macrocyclic complexes with potential medicinal applications, as contrast-enhancing agents in magnetic resonance imaging (MRI),[8] as N.M.R shift and relaxation reagents[9] and as RNA cleavage catalyst.[10,11] Macrocyclic complexes of transition metals exhibit antibacterial,[12] anticarcinogenic,[13] antifertility,[14] and antifungal[15] activities.

The present article deals with the synthesis, characterization and biological properties of chromium(III) macrocyclic complexes. These complexes have been characterised with the help of various physicochemical techniques. The antibacterial and antifungal activities of the ligands and their metal complexes have been determined by screening of the compounds against various bacterial and fungal strains. The results obtained, were compared with antibacterial and antifungal activities shown by standard bactericide Streptomycin and fungicide Bavistin. These complexes were also evaluated for their nematicidal and pestcidal activity and the results were quite encouraging.

Experimental

Material

All the chemicals used were of AnalaR grade. Chromium chloride ($CrCl_3.6H_2O$) and various diamines were purchased from Sigma–Aldrich. Solvents of analytical grade were distilled from appropriate drying agents immediately prior to use.

Address for Correspondence: Dr. Nighat Fathmi, Department of Chemistry, University of Rajasthan, Jaipur 302004, India. Tel: 91-141- 2704677(O), 91-141-2763337(R). Fax: 91-141-2708621. E-mail: nighat.fahmi@gmail.com

(Received 03 June 2011; revised 13 September 2011; accepted 13 September 2011)

Synthesis of the ligands (ML¹ and ML²)

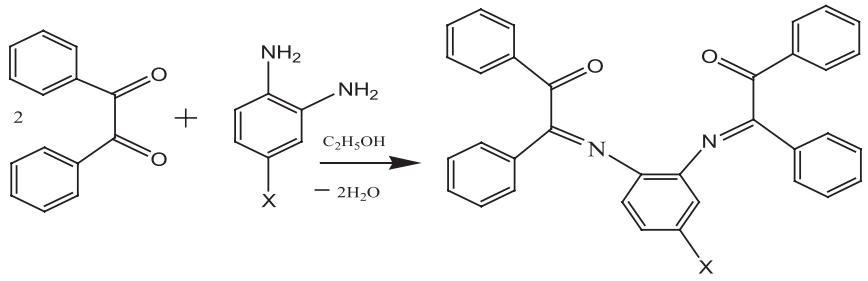
The ligands (ML^1 and ML^2) were prepared by dissolving 1,2-diphenyl-1,2 ethanedione (benzil) (20 mmol, 4.20 g) in 40 mL of ethanol, then calculated amount of diamines i.e. 4-chloro 1,2-phenylenediamine (10 mmol, 1.42 g) or 4-fluro 1,2-phenylenediamine (10 mmol, 1.26 g) were added respectively in 2:1 molar ratio. The reaction mixture was heated under reflux for 4–6 h on a ratio head. It was then concentrated to half of the volume. The solution was cooled and the excess solvent was removed by slow evaporation by keeping it in a desiccator overnight. The coloured crystalline products so obtained were purified by recrystallization in the same solvent and dried *in vacuo*. The analysis and physical properties of these ligands are given in Supplementary Table S1. The synthetic route of the ligands has been shown in Scheme 1 and the structure of 2-[4-chloro-2-(2-oxo-1,2-diphenyl-ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone (ML^1) is given in Supplementary Figure S1. This figure has been drawn with the help of Chem3D Ultra software.

Synthesis of the Cr (III) macrocyclic complexes

The complexes were synthesised by the template condensation of ligands 2-[4-chloro-2-(2-oxo-1,2-diphenyl-ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone (ML^1)or2-[4-fluro-2-(2-oxo-1,2-diphenyl-ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone (ML^2) with various diamines such as 1,2-phenylenediamine, 4-chloro 1,2-phenylenediamine and 4-fluro 1,2-phenylenediamine in the presence of $CrCl_3.6H_2O$.

Synthesis of the [Cr($C_{40}H_{26}N_4Cl_3F$)]Cl complex

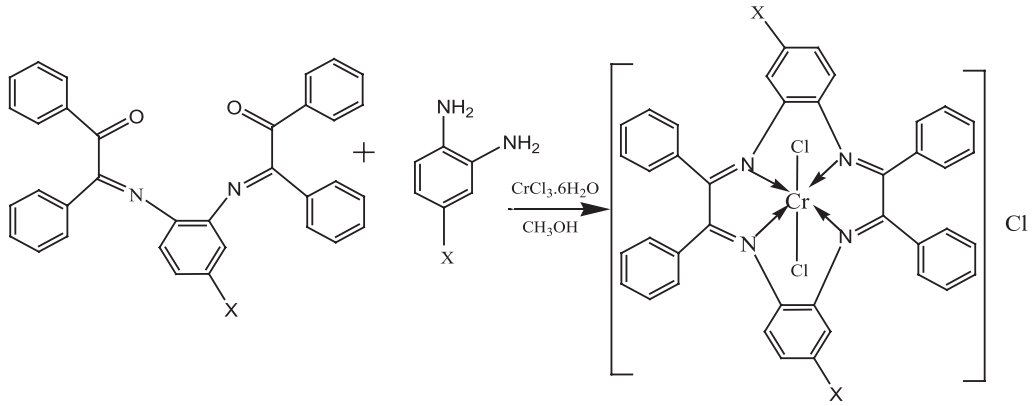
A weighted amount of methanolic solution of the ligand ML^1 (10 mmol, 2.63 g) was taken in a 100 mL round bottom flask. The solution of the ligand was mixed with the methanolic solution of 4-fluro 1,2-phenylenediamine (10 mmol, 0.63 g) and $CrCl_3.6H_2O$ (10 mmol, 1.33 g). After addition of



1,2 diphenyl-1,2 ethanedione (Benzil) — 4-halo 1,2- phenylenediamine — 2-[4-halo-2-(2-oxo-1,2-diphenyl-ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone

Where X= Cl, F

Synthetic route of the ligands



2-[4-halo-2-(2-oxo-1,2-diphenyl- ethylideneamino)-phenylimino]-1,2-diphenyl-ethanone — diamine — Cr (III) macrocyclic complex

Where X= Cl, F

Scheme 1. Synthetic route of the Cr (III) macrocyclic complexes

all the reagents, the contents were boiled under reflux for about 7–8 h on a ratio head; the reaction mixture was concentrated to half of its volume and kept in a desiccator at room temperature. The complex obtained as solids, were washed with methanol and dried under vacuo.

Synthesis of the [Cr($C_{40}H_{27}N_4Cl_2X$)]Cl complexes (X = Cl, F)

To obtain this type of complexes the methanolic solution of ligand ML^1 (10 mmol, 2.63 g) or ML^2 (10 mmol, 2.55 g) was mixed with the methanolic solution of 1,2-phenylenediamine (10 mmol, 0.54 g) in the presence of $CrCl_3.6H_2O$ (10 mmol, 1.33 g). After addition was completed, the contents were refluxed for 7–8 h on a ratio head. It was then concentrated to half of the volume by removing the solvent and kept in a desiccator at room temperature. The complexes obtained as solids, were washed with methanol and dried under vacuo.

Synthesis of the [Cr($C_{40}H_{26}N_4Cl_2X_2$)]Cl complex (X = Cl)

This type of complex was prepared by mixing a methanolic solution of ML^1 (10 mmol, 2.63 g) with methanolic solution of 4-chloro 1,2-phenylenediamine (10 mmol, 0.71 g) and $CrCl_3.6H_2O$ (10 mmol, 1.33 g). The reaction mixture was heated under reflux for 7–8 h. The reaction mixture was concentrated to half of its volume. After cooling, the solution was kept overnight in a desiccator at room temperature. The complex obtained as solid, was washed with methanol and dried under vacuo.

Synthesis of the [Cr($C_{40}H_{26}N_4Cl_2X_2$)]Cl complex (X = F)

This complex was prepared by following the above procedure, using the ligand ML^2 and 4-fluro 1,2-phenylenediamine in the presence of $CrCl3.6H_2O$ in 1:1:1 molar ratio.

All the complexes were recrystallised from 1:1 molar solution of methanol and benzene. The purity of the complexes was checked by thin layer chromatography (TLC). The analysis and physical properties of these complexes are given in Supplementary Table S1. The template synthesis of the complexes may be represented by the following scheme 1.

Analytical and physical measurements

The nitrogen and chlorine contents of the complexes were estimated by the Kjeldahl's and Volhard's method, respectively.[16] The metal contents were estimated gravimetrically.[17] Elemental analysis of C and H were performed at CDRI, Lucknow. Molecular weights were determined by Rast Camphor method. Melting points were determined by using capillaries in electrical melting point apparatus. The electronic spectra were recorded on an Ultraviolet visible spectrophotometer 752/752N, Mohali, India, infrared spectra of the ligands and their complexes were recorded with the help of FTIR-8400S Fourier Transform infrared spectrophotometer Shimadzu, Japan on KBr pellets. XRD were measured on Panalytical make Xpert Pro 3040 Almelo, Netherlands, electron paramagnetic resonance (EPR) spectra of the complexes were monitored on a Varian E-4X band spectrometer, USA at SAIF, IIT Madras, Chennai, and magnetic susceptibility was measured on a Lakeshore VSM 7410 model 155 vibrating sample magnetometer, USA at RSIC,IIT Chennai. The conductivity values were measured on 10^{-3} mol dm^{-3} solution in DMF at room temperature on century digital conductivity meter model CC601 Chandigarh, India.

Biological assay

Test microorganism

All the compounds were evaluated for their antimicrobial properties. MIC was recorded as minimum concentration, which inhibits the growth of microorganism. The results obtained were compared with those of the standard drug Streptomycin for bacteria and Bavistin for fungi. The microorganisms used were *Escherichia coli* (ATCC25922), *Bacillus subtilis* (ATCC6633), *Fusarium oxysporum* (ATCC7808) *and Rhizopus nigricans* (ATCC6227b). The synthesised macrocyclic complexes were also tested for the nematicidal and pesticidal activity against *Meloidogyne incognita* and fifth instar larva of *Corcyra cephalonica* respectively.

In vitro *antibacterial activity*

The newly prepared compounds were screened for their antibacterial activity against *Escherichia coli* (ATCC25922) and *Bacillus subtilis* (ATCC6633) by paper-disc plate method.[18] Each compound was dissolved in DMSO and solutions of the concentrations (500 and 1000 ppm) were prepared separately. Paper discs of Whatman filter paper (No. 42) of uniform diameter (5 mm) were cut and sterilised in an autoclave. The paper discs soaked in the desired concentration of the complex solutions were placed aseptically in the Petri dishes containing nutrient agar media (agar 20 g + beef extract 3 g + peptone 5 g) seeded with *Escherichia coli* (ATCC25922) and *Bacillus subtilis* (ATCC6633) separately. The Petri dishes were incubated at 37°C and the inhibition zones were recorded after 24 h of incubation. The antibacterial activity of standard antibiotic Streptomycin was also recorded using the same procedure. The medium with DMSO as a solvent was used as a negative control. The experiments were performed in triplicates. The % activity index for the compounds was calculated by the formula given in equation 1 and the results are shown in the Figure 1a.

$$\%\ \text{Activity index} = \frac{\text{Zone of inhibition by test compound (diameter)}}{\text{Zone of inhibition by standard (diameter)}} \times 100 \quad (1)$$

In vitro *antifungal activity*

The newly prepared complexes were also screened for their antifungal activity against *Fusarium oxysporum* (ATCC7808) and *Rhizopus nigricans* (ATCC6227b) by the agar-plate technique.[19] The media was prepared by dissolving starch (20 g), D-glucose (20 g) and agar-agar (20 g)

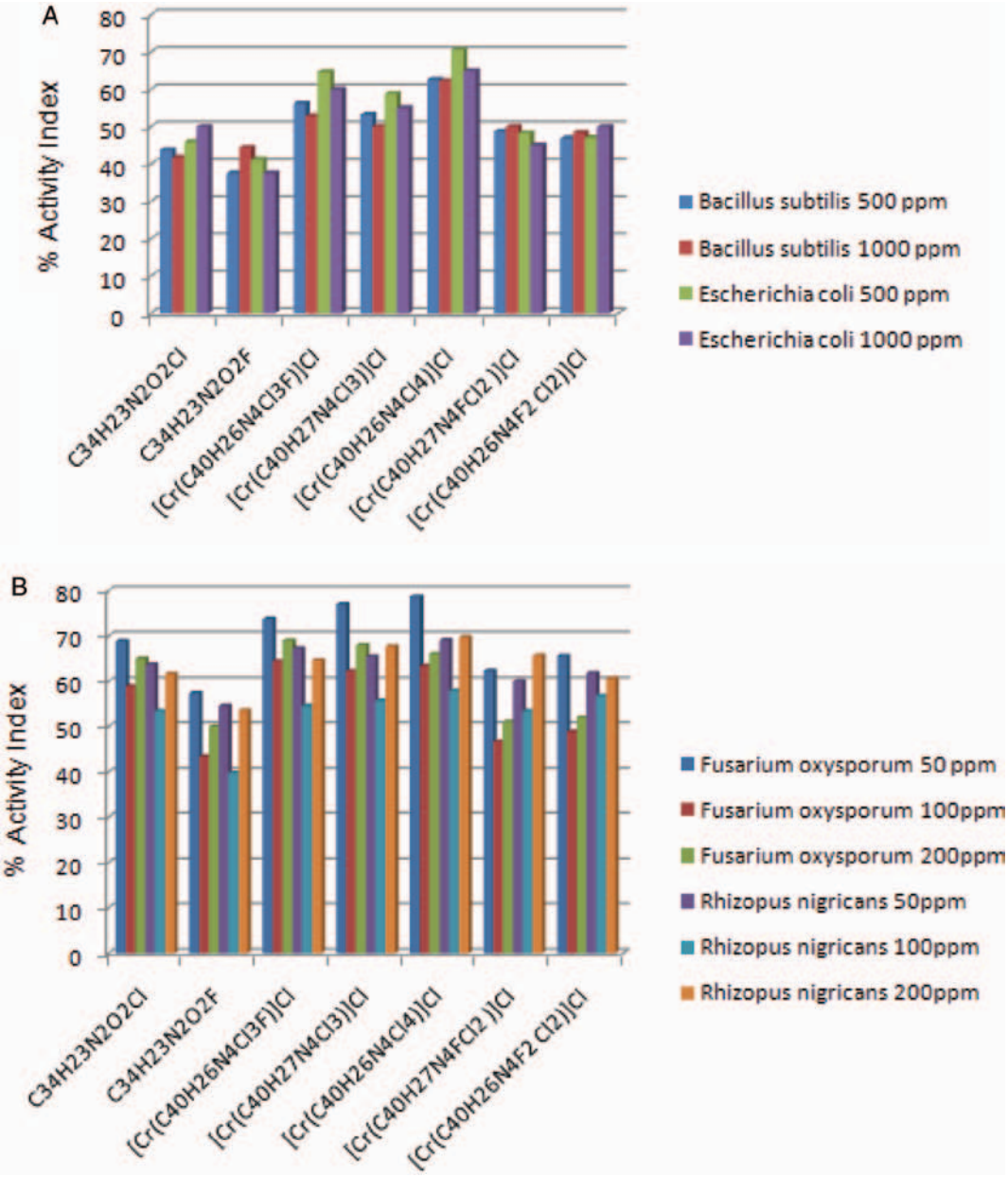


Figure 1. (a) % Activity index data for antibacterial activity of ligands and their complexes. (b) % Activity index data for antifungal activity of ligands and their complexes.

in distilled water (1000 mL). The compounds were dissolved in 50, 100 and 200 ppm concentrations in DMSO and then were mixed with the medium. The medium was then poured into Petri plates and the spores of fungi were placed on the medium with the help of inoculum's needle. These Petri plates were wrapped in polythene bags containing few drops of alcohol and were placed in an incubator at 30 ± 2°C. The controls were also run and three replicates were used in each case. The fungal activity of each compound was compared with Bavistin as a standard drug. The medium with DMSO as a solvent was used as a negative control.

The linear growth of the fungus was recorded by measuring the diameter of the fungal colony after 96 h and the percentage of inhibition was calculated by equation 2. The % activity index for fungal strain is also calculated with the help of equation 1, which is presented in Figure 1b,

$$\%\ \text{of inhibition} = \frac{C-T}{C} \times 100 \qquad (2)$$

where C and T are the diameters of the fungal colony in the control and the test plates, respectively.

Determination of minimum inhibitory concentration (MIC)

The minimum inhibitory concentration (MIC) is the lowest concentration of the antimicrobial agent that prevents the development of viable growth after overnight incubation.[20] The determination of the MIC involves a semi quantitative test procedure, which gives an approximation to the least concentration of an antimicrobial needed to prevent

microbial growth. The minimum inhibitory concentration was determined by microbroth dilution method.[21] In this method, the test concentrations of chemically synthesised compounds were made from 100 to 3.125 μg /mL in the DMSO. Inoculum of the overnight culture was prepared. In a series of tubes, 1 mL each of Cr(III) complex solution with different concentrations was taken and 0.4 mL of the inoculum was added to each tube. Further 3.5 mL of the sterile water was added to each of the test tubes. These test tubes were incubated for 18 h and observed for the presence of turbidity. The absorbance of the suspension of the inoculum was observed with spectrophotometer at 555 nm. The end result of the test was the minimum concentration of the antimicrobial agent (test materials), which gave a clear solution, i.e. no visual growth.[22,23]

Nematicidal activity

A step-by-step procedure[24] was followed for obtaining quantities of clean *Meloidogyne incognita* eggs. Brinjal roots heavily infected by *Meloidogyne incognita*, were washed thoroughly under running water and cut into small pieces. The pieces were placed in a beaker in 100 mL of tap water. The suspension was shaken vigorously for 5 min after adding 500 mL of 1% NaOCl and then the suspension was poured quickly through nested 150- and 400-mesh sieves. Eggs that passed through the 400-mesh sieves were recovered by repeated sieving and rinsing. The eggs that were retained on the 400-mesh sieves were washed with sufficient quantities of distilled water. From the sieves, eggs were eluted and transferred to 40 mL of water. A centrifuge tube was filled two-thirds with 20% sucrose solution and the egg–water suspension was centrifuged at 500 *g* for 5 min. At the junction of sugar solution, a silver layer containing the suspended eggs and egg suspension was removed with the help of a pipette and quickly poured on to a 400-mesh sieve. The eggs retained on the sieve were washed three times thoroughly with distilled water and collected in a beaker. A total of 230 eggs of nematode *Meloidogyne incognita* were used per replicate sample and each treatment was replicated three times. The experiment was conducted at room temperature 30 ± 2°C. The eggs were treated with 25, 50 and 100 ppm solution of the complexes for 24 h and hatching of *Meloidogyne* eggs were noted. The nematicidal property was calculated by using the equation 3,

$$\text{NP}\,(\%) = \frac{\text{HT} \times 100}{\text{HC}}$$

where NP is the nematicidal property, HC is the amount of hatching in the control and HT is the amount of hatching in the test plate.

Pesticidal activity

Fifth instar larvae of *Corcyra cephalonica* were obtained from stock culture maintained at the storage section of Division of Entomology, Durgapura Agricultural Research Institute, Jaipur. Insects were reared on wheat grain at 27 ± 1°C and 70% relative humidity. Glass jars containing 500 g of wheat cereals were labeled to indicate the date of introduction of adults and new emergence. On alternate days larvae were shifted to fresh jars so that successive rearing jars can be maintained and insects of known age can be obtained regularly. Pesticidal activity of the synthesised compounds was tested by immersion method. All the synthetic compounds were weighed and dissolved in methanol to prepare 1000 mg L^{-1} stock solution. Further concentrations *viz*., 900, 800, 700, 600, 500, 400, 300, 200, 100 mg L^{-1} were prepared by serial dilution. Twenty larvae were released in each Petri plate and then one mL of each concentration of various compounds was directly poured in each Petri plate with the help of a brush. Petri plates with test solution were rotated vigorously and were kept at 27 ± 1°C and 70% relative humidity. Mortality was observed after 96 h. Larva was considered dead if it failed to respond to stimulus by touch. Control mortality was corrected by using Abbott's formula[25] and data was subjected to probit analysis according to Finney.[26]

$$\text{Corrected \% mortality} = \frac{\text{\% mortality observed} - \text{\% mortality in control}}{100 - \text{\% mortality in control}} \times 100$$

Result and discussion

Chemistry

The elemental analysis and spectral data suggested the formation of the ligands (ML^1 and ML^2) and their macrocyclic complexes of the type $[Cr(C_{40}H_{26}N_4Cl_3F)]Cl$, $[Cr(C_{40}H_{27}N_4Cl_2X)]Cl$ and $[Cr(C_{40}H_{26}N_4Cl_2X_2)]Cl$, where X = Cl, F. The resulting macrocyclic complexes are coloured, solids, stable at room temperature and non hygroscopic.[12] They are soluble in DMF and DMSO. Molecular weight determination showed that they are monomeric in nature. The values of molar conductance measurements of 10–3M solution in DMF indicate that the complexes are 1:1 electrolytes (Supplementary Table S2).

Magnetic moment and electronic spectra

The magnetic moment of the chromium(III) complexes lie in the range 3.70–3.83 B.M, which is close to the spin only value, suggesting an octahedral geometry around the chromium ion[27]. The electronic spectra of the high-spin chromium(III) complexes display three spin allowed transitions in the range 16,550–17,880, 21,000–3300 and 30,038–32,970, which may be assigned to $^4A_{2g} \rightarrow {}^4T_{2g}$ (F) υ_1, $^4A_{2g} \rightarrow {}^4T_{1g}$ (F) υ_2 and $^4A_{2g} \rightarrow {}^4T_{1g}$ (P) υ_3 transitions respectively, suggesting an octahedral geometry around Cr(III).[28] Various ligand field parameters like Dq, B, and β have been calculated and given in Supplementary Table S2. Energy of the first spin allowed transition $^4A_{2g} \rightarrow {}^4T_{2g}$ (F) υ_1 directly gives the value of 10Dq. Electronic repulsion parameter is expressed in terms of Racah parameter and "B" has been evaluated during these studies. The nephelauxetic ratio β indicates that the complexes have appreciable covalent character.

ESR spectra

The electron spin resonance (ESR) spectra of the macrocyclic complexes of chromium were recorded at room temperature. These consist of a single broad peak in each case and from which the Lande splitting factor ("g" values) has been calculated. These g values lie in the range 1.9783–1.9831 with g_{iso} (2.04), which are characteristic of an octahedral geometry.[29]

IR- spectra

The tentative absorption frequencies of the ligands and their Cr(III) complexes along with their assignment are recorded and listed in Supplementary Table S3. The bands due to $\upsilon_{as}(NH_2)$ at 3380 cm^{-1}, $\upsilon_s(NH_2)$ at 3250 cm^{-1} and υ(C=O) in the region 1670–1680 cm^{-1} were present in the spectra of the diamines and ligands respectively, but were absent in the infrared spectra of all the complexes. The disappearance of the υ_{as} (NH_2), υ_s (NH_2) and υ(C=O) bands and appearance of absorption band around 1610–1615 cm^{-1} indicates the formation of macrocyclic framework, as these bands may be assigned to υ(C=N).[30] The value of absorption band due to υ(C=N) is lower than that usually occur for azomethine group, which supports the coordination of this group to the metal atom and formation of macrocyclic complexes. The phenyl ring absorptions appear in the 1465–1495 and 1355–1390 cm^{-1} region are assigned to $\upsilon_{asym}C_6H_5$ and υ_{sym} C_6H_5 respectively. The single band observed from 310 to 320 cm^{-1} is due to υ(Cr–Cl) vibration[31] and bands at 415–460 cm^{-1} are assigned to υ(Cr ← N).[32]

On the basis of analytical and spectral data the structures of the complexes have been proposed. Supplementary Figure S5 represents 3D structure of [Cr $(C_{40}H_{27}N_4Cl_3)$] Cl macrocyclic complex. This structure is also drawn with the help of Chem3D Ultra software.

X-ray powder diffraction studies

The possible lattice dynamics of the complex, $[Cr(C_{40}H_{26}N_4Cl_3F)]Cl$ has been deduced on the basis of X-ray powder diffraction studies and the XRD pattern of compound [Cr(C40H26N4Cl3F)]Cl is given in Supplementary Figure S3. The observed interplanar spacing values ("d" in Å) have been measured from the diffractogram of the compound and the Miller indices h, k, and l have been assigned to each d value and 2θ angles are reported. The results show that the compound belongs to "orthorhombic" crystal system having unit cell parameters as $a=9.05$, $b=17.15$, $c=21.15$, maximum deviation of $2\theta=0.046$ and $\alpha=90$, $\beta=90$, and $\gamma=90$ at wavelength = 1.93728. Table showing XRD measurement data of $[Cr(C_{40}H_{26}N_4Cl_3F)]Cl$, is given in Supplementary Table S4.

Biological results and discussion

The results of antimicrobial activity are shown in Supplementary Figures S4 and S5. All the ligands and their Cr(III) complexes were sensitive against all the fungal and bacterial strains. The antimicrobial screening data indicate that the metal complexes are more potent antimicrobial agents than the free ligands.

MIC values for the ligands and their chromium (III) complexes are shown in Supplementary Figure S6. Minimum inhibitory concentration of the ligands and their metal complexes was determined against four tested strains. Compound $[Cr(C_{40}H_{27}N_4Cl_3)]Cl$ and $[Cr(C_{40}H_{26}N_4Cl_4)]Cl$ show low MIC values at 30 µg/mL for bacterial strain *Escherichia coli*, *Bacillus subtilis* and at 5.125 µg/mL for fungal strain *Fusarium oxysporum*. Metal complexes are more active against fungal strains in comparison to bacterial strains.

The biological activity of the ligands exhibited a marked enhancement on coordination with the metal ions against all the test bacterial/fungal strains, which shows that metal chelates are more active than the ligands. This may be explained by Tweedy's Chelation theory[33] according to which chelation reduces the polarity of the central metal atom because of the partial sharing of its positive charge with the ligand,[34] which favours permeation of the complexes through the lipid layer of cell membrane.[35] Other factors such as solubility, conductivity and dipole moment, which are affected by the presence of metal ions may also be possible reasons for increasing the biological activity of the metal complexes as compared to the corresponding ligands.

The results of nematicidal activity indicate that the newly synthesised complexes are more active in inhibiting the hatching of eggs as compared to the ligands and the maximum hatching was recorded in the control (H_2O). The results are summarized in Table 1.

Table 1. Nematicidal activity and pesticidal activity of the ligands and their complexes.

	Nematicidal activity			Pesticidal activity		
	Hatching in *Meloidogyne incognita* (%)					
Compound	25 ppm	50 ppm	100 ppm	LC_{50}	χ^2	Corrected mortality (%)
$C_{34}H_{23}N_2O_2Cl$	25.5	20.5	14.0	410	0.274	55.55
$C_{34}H_{23}N_2O_2F$	22.2	19.0	15.0	840	0.431	50
$[Cr(C_{40}H_{26}N_4Cl_3F)]Cl$	20.2	18.5	–	210	0.547	60.11
$[Cr(C_{40}H_{27}N_4Cl_3)]Cl$	17.9	15.0	–	195	0.684	65.66
$[Cr(C_{40}H_{26}N_4Cl_4)]Cl$	15.1	12.5	–	165	0.150	76.77
$[Cr(C_{40}H_{27}N_4FCl_2)]Cl$	18.6	14.0	–	410	0.49	65.66
$[Cr(C_{40}H_{26}N_4F_2Cl_2)]Cl$	19.6	16.4	–	170	0.282	70.22
control				–	1.142	–

LC, lethal concentration.

Both the ligands and their chromium complexes were also evaluated for pesticidal activity and they have a potent inhibitory effect on growth and development of *Corcyra cephalonica* larva. The LC50 values in mg L^{-1} are shown in Table 1. The data indicate that all Cr(III) complexes exhibit greater pesticidal activity than the respective ligands, but compound $[Cr(C_{40}H_{26}N_4Cl_4)]Cl$ was highly effective as a pesticide with LC50 165 mg L^{-1} against *Corcyra cephalonica*. A possible explanation is that, the compound inhibit molting hormone of pest larva[36] i.e. ecdysis disruption.

Conclusion

We describe the synthesis, characterization and biological activity of Cr(III) macrocyclic complexes. On the basis of magnetic, analytical and spectral data an octahedral geometry has been proposed for the Cr(III) macrocyclic complexes. The antimicrobial activity results indicated that the complexes showed promising antibacterial and antifungal activities, but compound $[Cr(C_{40}H_{27}N_4Cl_3)]Cl$ and $[Cr(C_{40}H_{26}N_4Cl_4)]Cl$ showed highest activity against bacterial strain *Escherichia coli* ATCC25922, *Bacillus subtilis* ATCC6633 (MIC = 30 μg/mL) and fungal strain *Fusarium oxysporum* ATCC7808 (MIC = 5.125 μg/mL). The enhanced activity of the macrocyclic complexes than the parent ligands has been explained on the basis of chelation theory. The newly synthesised complexes exhibited considerable nematicidal and pesticidal activity. Compound $[Cr\ (C_{40}H_{26}N_4Cl_4)]Cl$ was found to be highly effective as a pesticide with LC_{50} 165 mg L^{-1} against *Corcyra cephalonica*.

Declaration of interest

The authors are grateful to UGC, New Delhi for financial assistance through grant No: 36 - 282/2008 (S.R.).

References

1. Paryzek WR, Patroniak V, Lisowski J. M etal complexes of polyaza and polyoxaaza Schiff base macrocycles. Coord Chem Rev 2005;249:2156–2175.
2. Masih I, Fahmi N. Synthesis, spectroscopic studies and electrochemistry of palladium (II) macrocyclic complexes derived from a new tetraazahalogen substituted ligands by template method and their antimicrobial and pesticidal activities. Spectrochim Acta A Mol Biomol Spectrosc 2011;79:940–947.
3. Singh DP, Kumar R, Malik V, Tyagi P. Template synthesis, spectroscopic studies and biological activities of macrocyclic complexes derived from thiocarbohydrazide and glyoxal. J Enzy Inhib Med Chem 2007;221:77–182.
4. Anbu S, Kandaswamy M, Suthakaran P, Murugan V, Varghese B. Structural, magnetic, electrochemical, catalytic, DNA binding and cleavage studies of new macrocyclic binuclear copper(II) complexes. J Inorg Biochem 2009;103:401–410.
5. Singh RV, Chaudhary A. Biologically relevant tetraazamacrocyclic complexes of manganese: synthetic, spectral, antimicrobial, antifertility and antiinflammatory approach. J Inorg Biochem 2004;98:1712–1721.
6. Campbell K, McDonald R, Tykwinski RR. Functionalized macrocyclic ligands for use in supramolecular chemistry. J Org Chem 2002;67:1133–1140.
7. Paryzek WR, Patroniak V, Lisowski J. M etal complexes of polyaza and polyoxoaza Schiff bases macrocycles. Coord Chem Rev 2005;249:2156–2175.
8. Kong D, Meng L, Song L, Xie Y. Synthesis, structure and antitumor activities of a new macrocyclic ligand with four neutral pendent groups: 1,4,7,10-tetrakisbenzyl-1,4,7,10-tetraazacyclododecane (L) and its Co, Ni and Cu complexes. Trans Met Chem 1999;24:553–557.
9. Sharma K, Joshi SC, Singh RV. Synthesis, Characterization and Antifertility Activity of New Unsymmetrical Macrocyclic Complexes of Tin(II). Met Based Drugs 2000;7:237–243.
10. Rossiter CS, Mathews RA, Morrow JR. Uridine binding by Zn(II) macrocyclic complexes: diversion of RNA cleavage catalysts. Inorg Chem 2005;44:9397–9404.
11. Baker BF, Khalili H, Wei N, Morrow JR. Cleavage of the 5′ cap structure of mRNA by a europium(III) macrocyclic complex with pendant alcohol groups. J Am Chem Soc 1998;119:8749–8755.
12. Reddy PM, Shanker K, Rohini R, Ravinder V. Antibacterial active tetraaza macrocyclic complexes of chromium (III) with their spectroscopic approach. Int J Chem Tech Res 2009;1:367–372.
13. Chandra S, Pundir M. Spectroscopic characterization of chromium(III), manganese(II) and nickel(II) complexes with a nitrogen donor tetradentate, 12-membered azamacrocyclic ligand. Spectrochim Acta A Mol Biomol Spectrosc 2008;69:1–7.
14. Chandra S, Gupta R, Gupta N, Bawa SS. Biologically relevant macrocyclic complexes of copper spectral, magnetic, thermal and antibacterial approach. Trans Met Chem 2006;31:147–151.
15. Chandra S, Gupta LK, Agrawal S. Synthesis spectroscopic and biological approach in the characterization of novel [N4] macrocyclic ligand and its transition metal complexes. Trans Met Chem 2007;32:558–563.
16. Vogel AI. A Textbook of Quantitative Chemical Analysis, 6th edition. Pearson Education Ltd.: Thames Polytechnique, London, 2006, pp. 387.
17. Vogel AI. A Text Book of Quantitative Inorganic Analysis. Longmans Green: ELBS London, 1962.
18. Gaur S, Fahmi N, Singh RV. Coordination behavior of unsymmetrical ligand complexes of diorganotin and diorganosilicon derived from Schiff bases. Phosphorus Sulfur Silicon Relat Elem 2007;182:853–862.
19. Shrivastava S, Fahmi N, Singh R V. Studies on chromium(III) complexes with active nitrogen, oxygen and sulfur donor ketimines synthesized under microwave conditions. J Sulfur Chem 2010;31:515–524.
20. Greenwood D, Slack R, Peutherer J. Medical microbiology. A guide to microbial infections: pathogenesis, immunity, laboratory diagnosis and control. 15th ed. Edinburgh: ELST Publishers; 1997.
21. Shanker K, Rohini R, Ravinder V, Reddy PM, Ho YP. Ru(II) complexes of N4 and N_2O_2 macrocyclic Schiff base ligands: their antibacterial and antifungal studies. Spectrochim Acta A Mol Biomol Spectrosc 2009;73:205–211.
22. Davidson PM, Parish ME. Methods for testing the efficacy of food antimicrobials. Food Technol 1989;43:148–155.
23. Collins CH. Antibiotics and antibacterial substances. In: Microbiological Methods. Butterworths, London, 1964, pp. 296–305.
24. Jain M, Gaur S, Singh VP, Singh RV. Organosilicon(IV) and organotin(IV) complexes as biocides and nematicides: Synthetic, spectroscopic and biological studies of N∩N donor sulfonamide imine and its chelates. Appl Organometal Chem 2004;18:73–82.
25. Abbott WS. A method of computing the effectiveness of an insecticide. J Econ Entomol 1925;18:265–267.
26. Finney DJ. Probit Analysis, 3rd edn. Univ Press: Cambridge, UK, 1971, 333.
27. Figgis BN. Introduction to Ligand Field Theory. Wiley, New York, 1978.

28. Fabretti AC, Preti C, Tassi L, Tosi G, Zannini P. Magnetic and spectroscopic studies on copper(II) and chromium(III) complexes with sulfur chelating ligands. Aust J Chem 1986;39:605–612.
29. El-Ajaily MM, Maihub AA, Hudere SS, Bensaber SM. Nickel II chelate of Schiff base derived from 4-dimethyl-amino-benzaaldehyde with systeine. Asian J Chem 2006;18:2427–2430.
30. Borisova NE, Reshetova MD, Ustynyuk YA. Metal-free methods in the synthesis of macrocyclic schiff bases. Chem Rev 2007;107:46–79.
31. Bhoon YK. Magnetic and EPR properties of Mn(II), Fe(III), Ni(II) and Cu(II) complexes of thiosemicarbazone of α-hydroxy-β-napthaldehyde. Polyhedron 1983;2:365–368.
32. Shrivastava S, Fahmi N, Singh D, Singh RV. Structural, spectroscopic, and biological aspects of S∩N donor Schiff-base ligands and their chromium(III) complexes. J Coord Chem 2010;63:1807–1819.
33. Geeta B, Shravankumar K, Reddy PM, Ravikrishna E, Sarangapani M, Reddy KK et al. Binuclear cobalt(II), nickel(II), copper(II) and palladium(II) complexes of a new Schiff-base as ligand: synthesis, structural characterization, and antibacterial activity. Spectrochim Acta A Mol Biomol Spectrosc 2010;77:911–915.
34. Keshavan B, Gowda HK. Synthesis, spectral and fungicidal studies on dioxobridged binuclear niobium (V) and tantalum (V) complexes of N-alkylphenothiazines. Turk J Chem 2002;26: 237–243.
35. Varnes AW, Dodson RB, Wehry EL. Interactions of transition-metal ions with photoexcited states of flavins. Fluorescence quenching studies. J Am Chem Soc 1972;94:946–950.
36. Guerrero A, Rosell G. Biorational approaches for insect control by enzymatic inhibition. Curr Med Chem 2005;12:461–469.