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Synthesis, Characterization and Antimicrobial Activities of Bis-2-Hydroxybenzylidene-N, N′-Ethylenediamine and its Cd(II), Co(II) and Cr(III) Complexes

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Abstract

Three Schiff base complexes [CdL_2] (**1**), [CrL_2]Cl(**2**) and [CoL_2] (**3**) with L= bis-2-hydroxybenzylidene-N, N′-ethylenediamine were synthesized by microwave assisted technique and analysed by melting point determination, solubility, molar conductivity, magnetic susceptibility, UV-Vis and IR spectroscopy. All solvent-bound analyses were conducted in DMSO. Molar conductivity measurements showed that complex **1** and **3** are non-electrolytic while **2** were found to be electrolytic with their composition corresponding to a metal-ligand ratio of 1:2 with respect to the Schiff base ligand. The IR spectra showed that the Schiff base ligands acted in bidentate fashion to the metal centres with coordination involving the azomethine nitrogen atoms and the methanolic oxygen atom of the Schiff base. Electronic spectra and magnetic susceptibility measurements suggested a six-coordinate local symmetry around the metal ions in an octahedral geometry. Magnetic susceptibility studies also revealed that the complexes of Cr(III) and Co(II) are paramagnetic while that of Cd(II) was diamagnetic ([CdL_2] = 0.00 BM, [CrL_2]Cl = 3.92 BM and [CoL_2] = 4.91 BM). The result also suggested the Schiff base ligands to be weak field ligands as they formed high spin complexes with the Co(II) ion. The obtained structural data thus allows for the proposition of an octahedral structural arrangement for the studied metal complexes. The antimicrobial studies indicated that the Schiff base ligands are only weakly active against the studied bacteria but inactive against the studied fungi. In contrast to the free ligands, the metal complexes of this ligand significantly increased or induced antimicrobial sensitivity against the studied microbial strains. Thus, the Schiff base complexes hold promise as powerful and all-around antibacterial agents.

Keywords: Synthesis, Antimicrobial activities, Complexes

Introduction

Schiff-bases and their metal complexes arevital in various fields such as biomedical, cytotoxicity [1, 2], analytical, catalyticstudies and many more. Also, they had been used as antimicrobial [3], antioxidant [4], chemotherapeutic [5], antitumor agents[6], and antiproliferation [7]. In addition to itsuse in inorganic chemistry, materials science, and considerably increasingbioactivity[8], Schiff-bases and their accompanyingmetal complexes have a wide range of potentialapplications in other fields. Numerous branches of chemistryhave been motivated to develop metallic complexes dueto the benefits they provide. These ligands were tested ina wide range of stimulatory, anticancer, and antibacterialtests[9]owing to their potent biological effect.One example is the excellent antimicrobial activities [10] and the great potential to address microbial resistance to antibiotics which has recently emerged as a global health challenge [11] and requires urgent and concerted efforts [12, 13]. As excellent drugs for antibiotic resistance, proposed interacting metal ions with organic ligands; to create a reversed mechanism of microbial resistance, produce new drugs and harnesses the varied mechanisms new to the microbes and reduce toxicity of metals through complex formation. The improved antimicrobial activity of metal-based complexes justifies the investigation of new drugs with unknown mechanism of action against pathogenic bacteria [14].Humans have been hit by several pandemics due to viral/bacterial attacks, compounded more recently by microbial resistance to antibiotics and other health challenges [15, 16]. In the quest for alternative drugs to address these health challenges, metallodrugs described as variegate and attractive class of compounds have demonstrated tremendous potential to support the discovery of modern medicaments [17, 18]. The promising medical chemistry of metal-based drugs is faced with the limitations of major side effects as aforementioned.

However, Schiff bases and their metal complexes are found to be a favorable option in the quest [19, 20]. They are relatively safe, less foreign to the body and show great potential in addressing microbial resistance to antibiotics and other viral diseases [21].

MATERIALS AND METHODS

Materials

Reagents

All chemicals and solvents used were of analytical grade, obtained from Sigma-Aldrich. They include, chromium(III) chloride heptahydrate ($CrCl_37H_2O$), cadmium(II) chloride hemihydrate ($CdCl_2.5H_2O$), cobalt(II)chloridehexahydrate ($CoCl_2.6H_2O$), 2-hydroxybenzaldehyde and ethylenediamine, methanol and ethanol.

Apparatus

Aside the basic analytical tools for characterization, other basic tools for the synthesis and studies include microwave oven, electronic weighing balance and glass wares (Pyrex).

Methods

Preparation of Schiff base

A mixture of 2-hydroxybenzaldehyde (0.02mol) and Ethylenediamine (0.01mol), using water as a solvent was stirred to homogeneity and then irradiated in a microwave oven at 10 % intensity for about 2-5 minutes for complete reaction, with four to six pulses each of 30 seconds [22]. The reaction mixture was then allowed to cool, with the crystals washed and further purified by recrystallization and dried in the oven. Scheme 3.1 shows the expected reaction pathway.

Preparation of Schiff base metal complexes

The Schiff base metal complexes were prepared by direct reaction (Madhavan, 2012). A tincture solution of the Schiff base containing a proportion of 2:1 of the metal salt was reacted together. A solution of the Cd(II), Co(II) and Cr(III) chloride salts was added to the methanol solution of the Schiff base in drop wise. The solution was stirred magnetically and refluxed for an hour. The metal complexes obtained were filtered, washed with methanol, and dried in an oven. The reaction was carried out as shown in Schemes 2.2 and 2.3

Characterization

Some standard analytical tools and procedures were adopted for the characterization of the Schiff base and the complexes synthesized. They include molar conductivity, colour, solubility test, spectrometric (IR and UV-Vis) test and melting point determination [20].

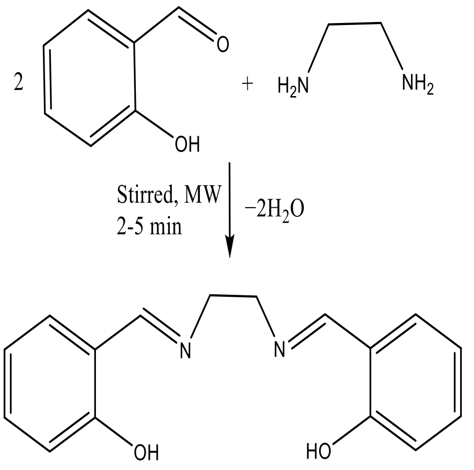
Physicochemical properties

Melting point determination

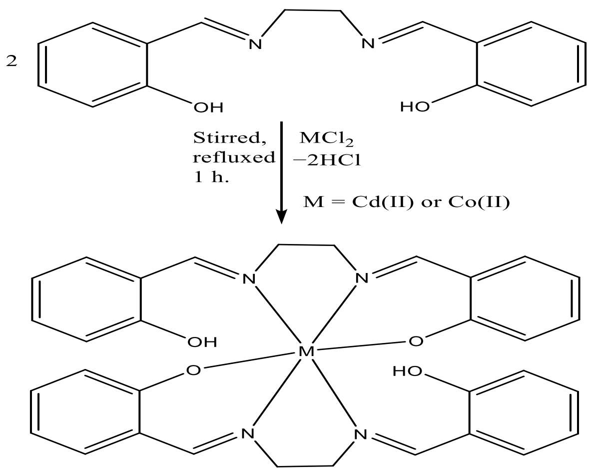
The melting point determination for the samples was carried out using a melting point apparatus "Barnstead Electrotherma (9100) melting point apparatus". Schiff base with the metal complexes was placed in separate capillary tubes and inserted into the heating block of the apparatus and heated until the substances melt, then the melting temperatures was read from the screen and recorded [20, 21].

Solubility test

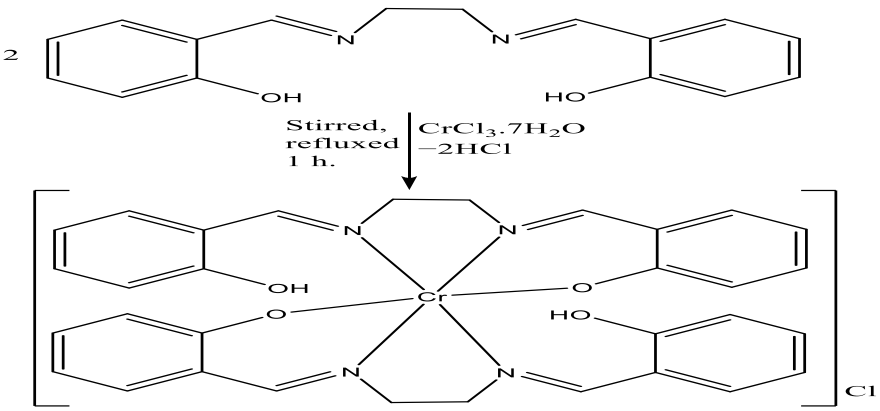
The solubility of the individual samples; ligand and the complexes was ascertained by placing a little quantity of the individual sample separately into about 10 mL portion of the following solvents; distilled water, methanol, ethanol, dimethyl sulfoxide, N,N'-dimethylformamide and acetone and was shaken vigorously then the behaviour of the samples in the various liquid as regards solubility was noted. The solubility was judged thus: If the entire samples disappear from the naked eyes vision, the samples were considered soluble. If a fraction of the samples dissolved and disappeared, the samples were said to be partially soluble. However, in the case where the entire samples remained intact and visible to the eyes without disappearing, the samples were judged to be entirely insoluble.



Scheme I: Synthesis of Bis-2-hydroxybenzylidine-N, N'-ethylenediamine



Scheme 2: Synthesis of Cd(II) and Co(II) complexes



Scheme 3: Synthesis of Cr(III) complex

Molar conductivity measurement

The molar conductivities of the Schiff base metal complexes in DMSO was obtained using pH/conductivity series 510 conductivity meters [20].

Infrared spectra studies

The infrared spectra data of the synthesized Schiff base alongside with the complexes were ascertained by using carry 630 FT-IR spectrophotometer for the Schiff base ligand while proRamman-L-785-B1S FT-IR spectrophotometer will be used for the complexes.

Electronic spectra studies

The electronic spectra of the samples were recorded on a Shimadzu UV 160 I PC UV – VIS Spectrophotometer, scanned between 190 and 800 nm wavelength range, at the Multipurpose Laboratory of Ahmadu Bello University, Zaria, Nigeria.

Magnetic measurements

The magnetic susceptibility measurement for the synthesized complexes wasevaluated at ambient temperature using an AUTO (Sherwood scientific) magnetic susceptibility balance (MSB) at the Department of Chemistry, Bayero University, Kano, Nigeria. The assessment was completed in accordance with the findings of previous studies [23, 24].

Antimicrobial Studies

Antimicrobial studies were carried out in the microbiology laboratory of Ahmadu Bello University, Zaria, with the agar-well diffusion technique employed as described elsewhere [25]. The test organisms used for this analysis were clinical isolates of bacteria and fungi obtained from Department of Microbiology, Ahmadu Bello University, Zaria. The isolates were:*Bacillus subtilis, Staphylococcus aureus, Escherichia coli, Salmonella typhi, Klebsiella pneumoniea, Pseudomonas aeruginosa, Candida albican, Aspergillus niger, Aspergillus flavus*.

Culture media

The culture media used include Mueller Hinton agar (MHA), Mueller Hinton broth (MHB), Potato dextrose agar (PDA) and Nutrient agar (NA), the media were used for sensitivity test, determination of minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC). All media were prepared according to manufacturer's instructions and sterilized by autoclaving at 121 °C for 15 min.

Determination of inhibitory activity (sensitivity test) of the synthesized compounds using agar well diffusion method

The standardized inoculant of both the bacterial and fungal isolate were streaked on sterilized Mueller Hinton agar and Potato dextrose agar plates respectively with the aid of a sterile swab sticks. Four wells were punched on each inoculated agar plate with a sterile cork borer. The well was properly labelled according to different concentrations of the extract prepared which were 100, 50, 25 and 12.5 mg/mL respectively. Each well was filled up with approximately 0.2 mL of the extract. The inoculated plates with the extract were allowed to stay on the bench for about one hour; this is to enable the extract to diffuse on the agar. The plates were then incubated at 37 °C for 24 h (plates of Mueller Hinton agar), while the plates of Potato dextrose agar were incubated at room temperature for about 3-5 days.At the end of incubation period, the plates were observed for any evidence of inhibition which will appear as a clear zone that was completely devoid of growth around the wells (zone of inhibition). The diameter of the zone was measured using a transparent ruler calibrated in millimetre and the result was recorded.

Determination of minimum inhibitory concentration (MIC)

The minimum inhibitory concentration of the extract was determined using tube dilution method with the Mueller Hinton broth used as diluents. The lowest concentration of the compounds showing inhibition for each organism when the compound was tested during sensitivity test was serially diluted in the test tubes containing Mueller Hinton broth. The standardized organisms were inoculated into each tube containing the broth and extract. The inoculated tubes were then incubated at 37 °C for 24 h. At the end of incubation period, the tubes were examined/ observed for the presence or absence of growth using turbidity as a criterion, the lowest concentration in the series without visible sign of growth (turbidity) was considered to be minimum inhibitory concentration (MIC).

Determination of minimum bactericidal concentration (MBC)/minimum fungicidal concentration (MFC)

The result from the minimum inhibitory concentration (MIC) was used to determine the minimum bactericidal concentration (MBC) of the compounds. A sterilized wire loop was dipped into the test tubes that did not show turbidity (clear) in the MIC test and a loopful was taken and streaked on sterile Nutrient agar plates. The plates were incubated at 37°C for 18-24 hrs. At the end of incubation period, the plates were examined/ observed for the presence or absence of growth. This is to determine whether the antimicrobial effect of the extract is bacteriostatic or bactericidal.

Results and Discussions

Physical Properties Results

The physical properties of the synthesized complexes and their percentage yields are shown in Table 3.1.

Table 1: Physical properties of the ligand and metal complexes

Compound	Formula weight $(gmol^{-1})$	Decomposition temperature (°C)	Colour	Yield (%)
L	272.34	49.10−51.20	Off white	87.84
$[CdL_2]$	382.75	347.20−350.40	Yellow	76.23
$[CrL_2]Cl$	322.34	296.70−300.10	Light green	81.14
$[CoL_2]$	329.27	191.10−193.80	Dark pink	78.32

The synthesized metal complexes were all coloured with complex **1** giving a yellowish colour, **2** being light green and **3** showing a dark pink colour while the Schiff base ligand gave an off-white colour. Good yields were also obtained for the complexes (50-70 %), with the highest yield recorded for complex **2**(81.14 %), while complex**1** gave the lowest percentage yield (76.23 %). The complexes were formed according to scheme2 and 3.

Solubility Results

The findings of the complexes' solubility analysis, which was carried out in a few solvents, are shown in Table 2. Dimethyl sulphoxide (DMSO) was found to be the best solvent for complex compounds. Thus, studies of electronic spectroscopy and conductivity measurements were carried out by dissolving the complexes in DMSO solvent.

Table 2: Solubility of complexes in selected solvents

Compound	Water	Methanol	Ethanol	Ethyl acetate	DMSO
L	IS	SS	SS	IS	S
[CdL$_2$]	IS	SS	SS	IS	S
[CrL$_2$]Cl	IS	SS	IS	IS	S
[CoL$_2$]	IS	I	IS	IS	S

IS= Insoluble, SS= sparingly soluble, S =Soluble, DMSO=dimethyl sulphoxide, L = Schiff base

Spectroscopic results

Electronic spectra data recorded in Table 3. The electronic spectra of ligand, L and its complexes **1**, **2** and **3**were measured in DMSO and the spectra data is presented in Table 3. The electronic spectrum of free ligand shows a strong band at 314 nm due to π–π* of the aromatic ring. The absorption bands observed at 351 nm may be assigned ton–π* transition associated with the azomethine (-C=N-) linkages. Following complexation, the position of these bands shifted and appeared at 361 nm, 384 nm, and 372 nm for complexes **1**, **2** and **3**respectively suggesting the coordination of the iminic nitrogen to the metal centres. The bands observed at 665and508 nm in the spectra of complexes **2** and **3** may be assigned to *d-d* transitions, and the signal at 662 nm in the spectrum of complex **1** has been ascribed to ligand to metal charge transfer. These spectral bands are consistent with that of a six coordinated metal complexes, on the bases of which a six-coordinate octahedral geometry may be assigned for these complexes [26].

Table 3.3: UV-vis spectra data for the ligand and the synthesized complexes

Compound	(π- π*) transition	(n- π*) transition	*d-d* transition	*CT* spectra
L	314	351	-	-
[CdL$_2$]	299	361	-	662
[CrL$_2$]Cl	296	384	665	-
[CoL$_2$]	327	372	508	-

CT = charge transfer

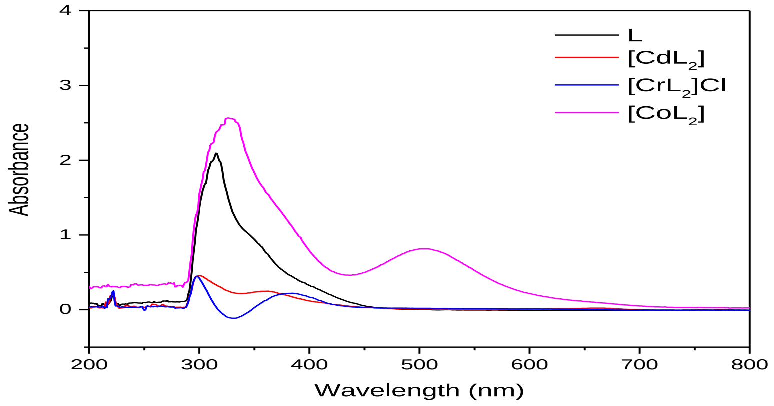


Figure 1: UV-vis spectra of the ligand and the synthesized complexes

FTIR Studies

A comparative study of IR spectral data of the reported complexes with that of the free ligand has proven to offer sufficient evidence towards a better understanding of the coordinating behaviour of Schiff base ligand towards metal ions. Thus, the FTIR analyses were carried out on the Schiff base ligand and the synthesized metal complexes with the spectra data presented in Table 3.4 and the spectra shown in Appendixes 6-10.

The absorption band due to *v*(C=N) observed at 1633 cm^{-1} in the spectrum of the free ligand, L was observed to be shifted to lower wave numbers appearing at 1591 cm^{-1}, 1596 cm^{-1} and 1567 cm^{-1} for $[CdL_2]$,$[CrL_3]Cl$ and $[CoL_2]$ complexes, respectively, indicating the coordination of M(II)/M(III) ions to the imines nitrogen of *v*(C=N) group. This is consistent with the presence of bands at ~680–730 cm^{-1} for all the complexes, attributed to *v*(M-N) vibrations. The lower value of *v*(C=N) stretching observed in the spectra of the complexes may be explained based on a drift of lone pair density of azomethine nitrogen towards the metal atom indicating that coordination has taken place through nitrogen of (C=N) groups [27].

Furthermore, in the spectrum of the free ligand, the v(O-H) stretching vibrations appeared at 3061 cm^{-1}. This band is observed to have shifted to 3150cm^{-1}, 3051 $cm^{-1}$and 3211 cm^{-1} for $[CdL_2]$,$[CrL_3]Cl$ and $[CoL_2]$ complexes respectively. This is an indication of the presence of the phenolic OH group in the structure of the complex compounds just as in the free ligands. Interestingly, the band assigned to *v*(C-N) vibrations in the spectrum of the ligand was observed at 1148 cm^{-1}. In the spectra of the synthesized complexes however, this band is shifted lower wave numbers viz 1016 cm^{-1}, 1082 cm^{-1} and 1044cm^{-1} for the complexes $[CdL_2]$,$[CrL_3]Cl$ and $[CoL_2]$ respectively [25]. The fact that this peak appears to have shifted bathochromically in the spectra of the respective complexes can be additional evidence for the involvement of the imines nitrogen in M-N bonding. In addition, the low intensity bands appearing at ca. 510-540 cm^{-1} in the spectra of the complexes can be ascribed to the *v*(M-O) vibrations. This is also strong evidence suggesting that the intended complex compounds were formed with the result in agreement with the findings of other researchers for similar compounds [27, 28].

Table 4: **FTIR spectra data for the ligand and the synthesized complexes**

Compound/ bands (cm^{-1})	**Ar-H**	**O-H**	**C-H**	**C=N**	**C-N**	**M-N**	**M-O**
L	3273	3061	2840	1633	1148	-	-
$[CdL_2]$ (1)	3518	3150	2905	1591	1016	729	540
$[CrL_2]Cl$ (2)	3433	3051	2905	1596	1082	686	507
$[CoL_2]$ (3)	3673	3211	2976	1567	1044	724	512

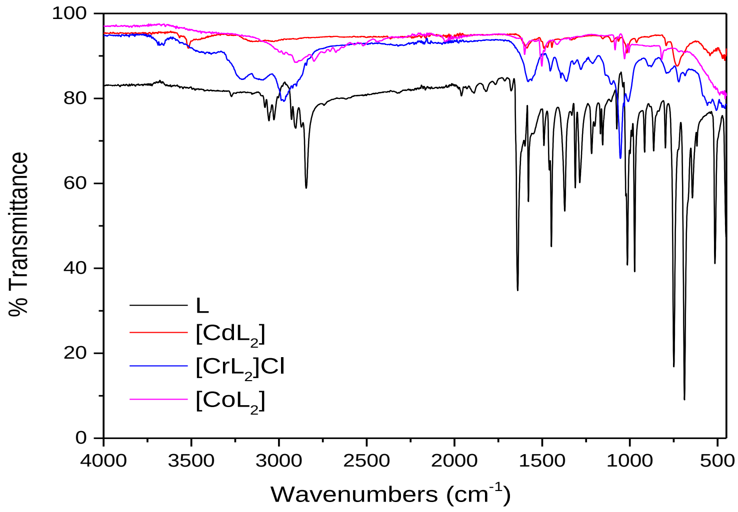


Figure 2: FTIR spectra of the ligand and the synthesized complexes

Magnetic and Molar Conductivity Studies

The results of experiments on the synthesized complexes gave molar conductivity and magnetic susceptibility values which are presented in Table 4. The complex of Cd(II) was discovered to be diamagnetic, but magnetic moments obtained suggested that Co(II) and Cr(III) complexes were paramagnetic. The complex of Cr(III) was observed to be electrolytic while those of Cd(II) and Co(II) were non-electrolytic according to conductivity measurements.

Biological Assays

Antimicrobial zone of inhibition

Tables 6 and 7 display the zone of antimicrobial inhibition for the ligands and complexes. The foundation for determining activity was the CLSI (2016) standard zones of inhibition for the standard medicines. The complexes utilized in this study's clinical strains of bacteria and fungus proved to restrict their development, with the ligands' activity rising with complexation.

Minimum inhibition concentration

The MIC values for the standard medicines, ligands, and complexes were calculated for the test organisms (Tables 8 and 9). The findings showed that, except for a few microbes, conventional medications have the lowest MICs against most of the pathogens under study.

Minimum bactericidal concentration/minimum fungicidal concentration

To determine whether the test microorganisms were only suppressed or killed, the MBC and MFC were assessed (Tables 10 and 11). The lowest bactericidal concentrations and minimum fungicidal concentrations for all the active complexes ranged between 3.13 and 100 μgmL^{-1}.

Table 5: Room temperature magnetic susceptibility and Molar Conductivity of the M(II) complexes

Compound	μ_{eff} (B.M)	Temperature (K)	$\Lambda(\Omega^{-1}$ mol^{-1} cm$^2)$
L	-	299.00	37.42
[CdL$_2$] (**1**)	0.00	300.00	68.34
[CrL$_2$]Cl (**2**)	3.92	299.50	113.72
[CoL$_2$] (**3**)	4.91	300.50	62.41

Table 6: Results of zone of antimicrobial inhibition (mm)for ligand and complexes on some bacteria strains

Test organisms	L	[CdL$_2$] (1)	[CrL$_2$]Cl (2)	[CoL$_2$] (3)	C
S. aureus	13	33	0	20	34
B. subtilis	12	28	21	30	40
E. coli	0	25	0	22	33
S. typhi	16	22	17	29	33
K. pneumoniae	13	25	18	22	38
P. aeruginosa	11	16	15	38	45

C= ciprofloxacin, L = Schiff base ligand

Table 7: Results of zone of antifungal inhibition (mm) for ligand and complexes

Test organisms	L	[CdL$_2$] (1)	[CrL$_2$]Cl (2)	[CoL$_2$] (3)	E
C. albicans	0	33	0	21	32
A. niger	0	40	28	14	40
A. flavus	0	42	19	0	35

E = Econazole, L = Schiff base ligand

Table 8: Minimum inhibition concentration (μgmL^{-1}) for ligand andcomplexes on some bacteria strains

Test organisms	L	[CdL$_2$] (1)	[CrL$_2$]Cl (2)	[CoL$_2$] (3)
S. aureus	100.00	6.25	–	25.00
B. subtilis	50.00	12.50	25.00	6.25
E. coli	100.00	12.50	–	12.50
S. typhi	25.00	25.00	25.00	6.25
K. pneumoniae	100.00	6.25	12.50	25.00
P. aeruginosa	25.00	6.25	50.00	3.13

L = Schiff base ligand, − = Not determined for MIC

Table 9: Results of minimum inhibition concentration (μgmL^{-1})for ligand andcomplexes on somefungi strains

Test organisms	L	[CdL$_2$] (1)	[CrL$_2$]Cl (2)	[CoL$_2$] (3)
C. albicans	–	12.50	–	50.00
A. niger	–	25.00	25.00	100.00
A. flavus	–	25.00	50.00	–

L = Schiff base ligand, − = Not determined for MIC

Table 10: Results of minimum bactericidal concentration (μgmL^{-1}) for ligand and complexes on some bacteria strains

Test organisms	L	$[CdL_2]$ (1)	$[CrL_2]Cl$ (2)	$[CoL_2]$ (3)
S. aureus	**	12.50	–	50.00
B. subtilis	100.00	25.00	50.00	12.50
E. coli	**	25.00	–	12.50
S. typhi	50.00	50.00	50.00	25.00
K. pneumoniae	**	12.50	25.00	50.00
P. aeruginosa	50.00	12.50	100.00	6.25

L = Schiff base ligand, − = Not determined for MBC. ** = No MBC (compound is bacteriostatic not bactericidal)

Table 11: Results of minimum fungicidal concentration (μgmL^{-1}) for ligand and complexeson some fungi strains

Test organisms	L	$[CdL_2]$ (1)	$[CrL_2]Cl$ (2)	$[CoL_2]$ (3)
C. albicans	--	25.00	--	100.00
A. niger	--	50.00	50.00	**
A. flavus	--	50.00	100.00	--

L = Schiff base ligand, − = Not determined for MBC. ** = No MFC (compound is fungistatic not fungicidal

DISCUSSION

Molar Conductivity Measurements

Within the bounds of their solubility, conductivity measurements have frequently been used to determine the structure of metal complexes (mode of coordination). The molar ions a complex liberates in solution can be used to determine the degree of ionization of the complexes (Refat, 2007; Refat*et al.,* 2013).The molar conductivity values for the Schiff base ligand and its complexes in 1.0 x 10^{-3} $moldm^{-3}$ DMSO are presented in Table 5.The observed values of 68.34 and 62.41Ω^{-1} mol^{-1} cm^2 for complexes **1** and **3** respectively suggest that the complex compounds of Cd and Co are non-electrolytic in nature. This suggests the absence of an outer coordination sphere in the structure of complexes **1** and **3** since charge neutrality is maintained when an M^{2+} ion combines with $2L^-$ to give the most likely structure $[ML_2]$. The implication of this observation is that a metal ligand ratio of 1:2 could be at play.

Furthermore, higher conductivity readings are usually observed in the electrolytic range (106-311 Ω^{-1} mol^{-1} cm^2) when ions beyond the coordination sphere (electrolytes) are present (Refat*et al.,* 2013). It thus becomes evident that the molar conductivity value of complex **2** falls in the electrolytic range (113.72Ω^{-1} mol^{-1} cm^2) suggesting the presence of an outer coordination sphere in the structure of **3**. This strongly infers that a Cl^- ion is present in the outer coordination sphere of the Cr complex, afact supported by qualitative analysis where Cl^- ions are precipitated on addition of aqueous solutions of silver nitrate to a solution of the complex **3**.

Magnetic Susceptibility Studies

Magnetic moments for the complexes are shown in Table 3.5 with the results suggesting paramagnetic behaviour for the complexes of Cr(III) and Co(II), while diamagnetic character was observed for the Cd(II) complex. Complex **2** showed a magnetic moment of 3.92 BM which is close to the theoretical spin only moments predicted for three unpaired electrons in the metal ion suggesting an octahedral geometry around Cr(III) ion. Again, the magnetic moment of complex 3 was observed at 4.91 BM suggesting their existence of this complex in a high spin state. This could infer that the Schiff base ligand under study is a weak field ligand as it gave a high spin complex of Co which is an indication that the complex **3** formed from the Schiff base ligand, has the Co(II) ion located in an octahedral environment. This claim is backed by *d-d* transitions that are indicative of an octahedral local symmetry around Co ion as seen in the visible spectrum of the Co(II) complex at 508 nm.

As expected for a d^{10} electronic system, the cadmium complex was found to be diamagnetic and have magnetic moments of zero. This shows that there are no unpaired electrons in the degenerate 4*d* orbitals of Cd(II) ion. However, the UV-vis spectrum of complex **1** showed a weak intensity peak at ca. 662 nm. This signal is most likely to be from ligand to metal charge transfer (LMCT) spectra since the possibility of *d-d* transition is ruled out by the presence of a d^{10} configuration for which reason complex **1** is unexpectedly coloured. The result is in concomitance with the findings of other researchers for some complexes of Cd(II) (Dubey and Kaushik, 1987).

Thus, based on the structural data obtained from the present study, the geometries of the synthesized metal complexes are proposed in Figure 3.1 and 3.2.

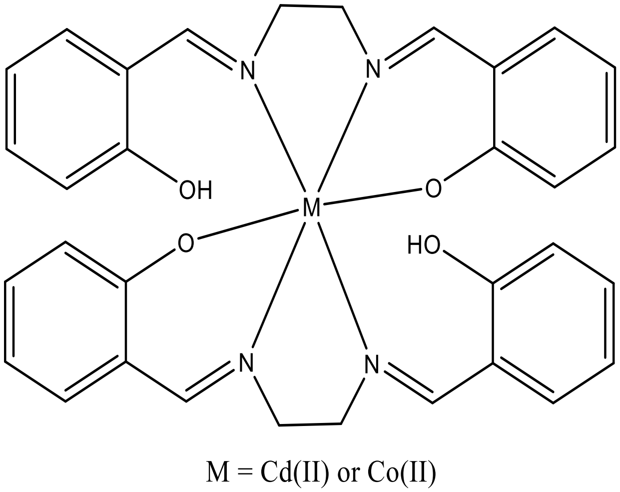


Figure 3: Proposed structure of the Schiff base complexes of Cd(II) and Co(II)

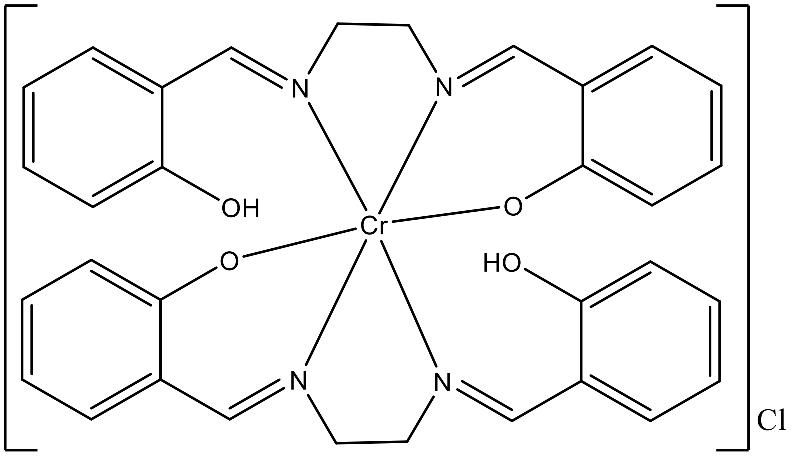


Figure 4: Proposed structure of the Schiff base complexes of Cr(III)

Antimicrobial Screening Result

A study by comparison of the antimicrobial potency of the Schiff base ligand **L**, and the synthesized complexes, **1-3** was carried out against some microbial strains; two Gram-positive, four Gram-negative bacteria and three fungi (Tables 3.8 and 3.9). The standard drug, ciprofloxacin appeared to show slightly better activity on the bacteria species than all the synthesized complexes. Interestingly, the Schiff base ligand proved active against all the bacteria strains except *E. coli* where no activity was observed. However, the complexes demonstrated significantly increased biological potency than the parent ligand which infer an enhanced lipophilicity of the complexes following coordination [27]. Complexes **1** and **3** showed better activity on the bacteria strains than complex **2** which induced minimal activity in the bacteria but no activity at all on *S. aureus* and *E. coli* suggesting that the microbes are resistant to the Cr(III) complex. Interestingly, this complex has a primary coordination sphere which is missing in the other two candidates. Thus, it may be indicative that activity is linked with chemical structural dynamics which in turn affect the lipophilicity of metallodrug candidates. Complex **1** appears to be a very promising candidate as its activity is not so much at deviance with that of the standard drug.

Furthermore, the Schiff base ligand demonstrated no activity on the studied fungi strains. However, after complexation, the complex compounds showed induced potency except that complexes **2** and **3** were found to be inactive against *C. albicans* and *A. flavus* respectively. The complex of cadmium, **1**, proved to be a better candidate than the standard drug against *C. albicans* and *A. flavus* with a similarity in inhibitory performance observed for the complex and the standard drug indicating their potential as alternative antifungal agents. Thus, the activity of these metallodrug candidates is induced rather than enhanced as the Schiff base ligands are all inactive against the fungi strains under investigation which again is in concomitance with earlier reports that metal centres induce or enhance antimicrobial activity of ligands.

The MIC and MBC results for the bacteria (Tables 3.8 and 3.10) also revealed that the metal complexes are more effective against the microbial strains compared to the free ligands. Thus, among all the metal complexes synthesized, **3** proved to be the best drug candidate against *P. aeruginosa* with minimum inhibitory concentration and minimum bactericidal concentration of 3.13 and 6.25 μgmL^{-1}. This is closely followed by complex **1** with MIC and MBC values of 6.25 and 12.50 μgmL^{-1} respectively against *K. pneumoniae* and *P. aeruginosa*. It is important to state that complex **2**demonstrated no bactericidal or bacteriostatic potential against*S. aureus* and *E. coli*as the complex compound was inactive against the microbes.

Similarly, the most promising metallodrug candidate against the studied fungi strains was found to be complex **1** with MIC and MFC values of 12.50 and 25.00μgmL^{-1} against *C. albicans*. Fungicidal activities were absent for complex **2** against *C. albicans* and **3** against *A. niger* and *A. flavus* which suggests that the complexes are not fungicidal but fungistatic against the respective organisms. The findings herein suggest that the Schiff base complexes under investigationare promising potential antibacterial and antifungal agents.

CONCLUSION

Three Schiff base complexes [CdL$_2$], [CrL$_2$]Cl and [CoL$_2$] with L= Schiff base derived from 2-hydroxybenzaldehyde and ethylenediamine were synthesized by microwave assisted technique and analysed by melting point determination, solubility, molar conductivity, magnetic susceptibility, UV-Vis and IR spectroscopies. Molar conductivity measurements showed that complex **1** and **3** are non-electrolytic while **2** were found to be electrolytic with their composition corresponding to a metal-ligand ratio of 1:2. The IR spectra showed that the Schiff base ligands acted in bidentate fashion to the metal centres with coordination involving the azomethine nitrogen atoms and the methanolic oxygen atom of the Schiff base. Electronic spectra and magnetic susceptibility measurements suggested a six-coordinate local symmetry around the metal ions in an octahedral geometry. Magnetic susceptibility studies also revealed that the complexes of Cr(III) and Co(II) are paramagnetic while that of Cd(II)was diamagnetic. The result also suggested the Schiff base ligands to be weak field ligands as they formed high spin complexes with the Co(II) ion. The obtained structural data thus allows for the proposition of the structural formula for the studied metal complexes. The antimicrobial studies suggested that the Schiff base ligands are slightly active against the studied bacteria but inactive against fungi, and their metal complexes showed significantly enhanced or induced antimicrobial sensitivity against the studied microbial strains in comparison to the free ligands. The Schiff base complexes are thus promising potent broad-spectrum antimicrobial agents.

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