

Antimicrobial Properties of Cu(I) and Cu(II) Complexes of a Schiff Base Ligand

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ABSTRACT A Schiff base ligand was synthesized from m-phenylenediamine and 2-hydroxybenzaldehyde in a molar ratio of 1:2 and the (Cu⁺ & Cu²⁺) complexes were synthesized from the ligand by refluxing the mixture at 60 °C for 2 hours. Characterization of the synthesized compounds was carried out using UV-Vis, FT-IR, NMR and mass spectrometry. The electronic spectral band and magnetic moment of the Cu⁺ and Cu²⁺ complexes are 402 nm, 0.9 BM and 356 nm, 1.13 BM respectively and assigned ²B_{1g} → ²A_{1g} transition, while the FT-IR spectral of the ligand when compared with that of the complexes shifted in the azomethine and phenolic-OH band of by about 14.29 to 62. 18 cm⁻¹. Spectra of the complexes indicate that coordination of ligand and metal occurred through the carbonyl Oxygen and the azomethine Nitrogen which agrees with slight difference between the chemical shift value of the ligand and its complexes in the carbon-13 NMR data. The electronic data for the complexes were consistent with a distorted octahedral geometry. The synthesized ligand and its Cu⁺ and Cu²⁺ complexes were screened against gram positive, gram negative bacterial and some fungi. The result indicates that the ligand and its copper (I) and (II) complexes had high activity against Methicillin Resistant Staph aureus and Staphylococcus Aureus with MIC of 6.25 µg/ml, zone of inhibition of 29, 30, 32 cm respectively which is almost equal and higher than the zone of inhibition of standard drugs with zone of inhibition of 32 and 29 cm at 10 µg/ml.

Keywords: Schiff base; Complexes; Spectroscopy; Antimicrobial activity; Ligand

INTRODUCTION

Schiff bases derived from an amino and carbonyl compound are an important class of ligands that coordinate to metal ions via azomethine nitrogen and have been studied extensively (Vigato and Tamburini, 2004). In azomethine derivatives, the C=N linkage is essential for biological activity and several azomethine compounds have been reported to possess antibacterial, antifungal, anticancer and antimalarial activities (Bahl and Bahl, 1993; Barboiu *et al.*, 1996; Tumer *et al.*, 1999; Dholakiya and Patel, 2002; Shalin *et al.*, 2009).

The complexes of copper with Schiff bases have wide applications in food industry, dye industry, analytical chemistry, catalysis, agrochemicals, anti-inflammable activity, antiradical activities and biological activities (Cozzi, 2004). Schiff-base complexes are considered to be among the most important stereo chemical models in main group and transition metal coordination chemistry due to the ease in their preparation and structural variety (Keypour *et al.*, 2009 and Ahmed O. O., *et al.*, 2023). Owing to the relatively simple preparation procedures of Schiff bases, it is possible to obtain ligands of different designs and characteristics by selecting appropriate reactants.

The metal complexes of Schiff bases derived from derivatives 2-hydroxybenzaldehyde and the heterocyclic compounds containing nitrogen, sulphur and oxygen as ligand are of interest, as simple structural models of more complicated biological systems (Jai and Nisha, 2015). Schiff bases, having multidentate coordination

sites are attractive analytical reagents, since many of them form complexes with transition metal ions (Sharma *et al.*, 1999; Sakyan *et al.*, 2004). The Schiff base with a chemical formula $H_2L(C_{31}H_{26}O_6N_2)$ from a dialdehyde and 2-aminobenzic acid as well as the corresponding metal chelates of Cu(II), Ni(II) and Co(II) as binuclear complexes have been synthesized and characterized (Ciolan *et al.*, 2012). Similarly, the coordination compounds of Cd(II), Zn(II) and Pb(II) ions with chemical formula $[ML(OH)_2(H_2O)_2]$ in which the primary amine was phenylenediamine have been synthesized and characterized, using the various spectrophotometric studies which were considered as common tools of analysis (El-Ajaily *et al.* 2013). All conducted studies have supported the chelation phenomena between the positively charged metal ions and the Schiff base. The solubility in different solvents gives a lot of indications about the nature of the chelates and can be examined to be electrolytic or non-electrolytic in nature (El-Ajaily *et al.* 2013). Most bases containing nitrogen atoms as well as 2-hydroxybenzaldehyde moiety are of significant importance in their chelation or in the other uses. The synthesis, characterization and antimicrobial properties of Cu(I) and Cu(II)-Schiff base complexes obtained from m-phenylenediamine and 2-hydroxybenzaldehyde is hereby reported.

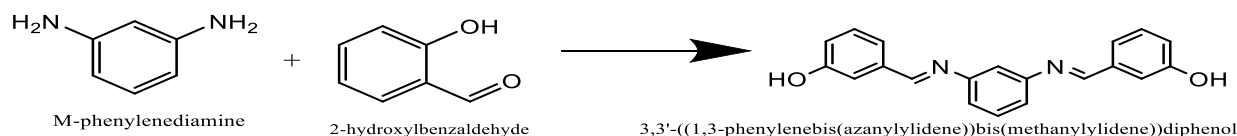
Experimental

Chemicals and reagents

m-phenylenediamine (Sigma Aldrich, $\geq 98\%$), while 2-hydroxybenzaldehyde, anhydrous copper (II) chloride, anhydrous copper (I) chloride and sodium hydroxide pellets are Merck product, 97 - 99 % purity, other reagents are ethanol, methanol, acetone, fused calcium chloride, dimethyl Sulfoxide (all Analgrade, 99.9% assay v/v). All reagents and chemicals were of analytical grade and used as supplied without further purification.

Preparation of -3,3'-((1,3-phenylenebis(azanylylidene))bis(methanylylidene))diphenol (PAMAP)

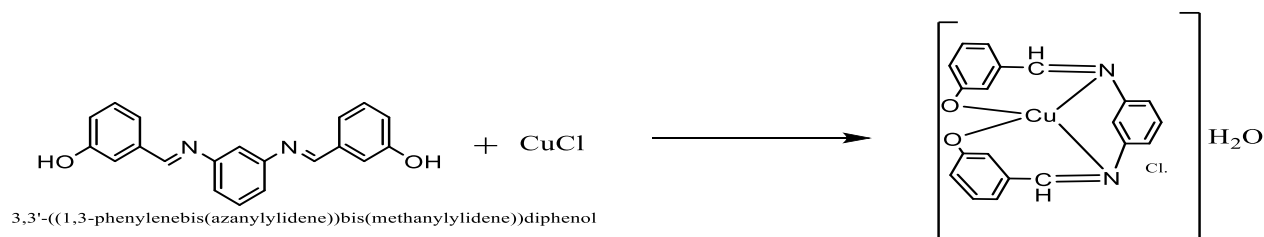
Synthesis of the Schiff base ligand was carried out according to the method described by (Kim *et al.*, 2007 and Ahmed O. O., *et al.*, 2023). To a hot stirred solution of m-phenylenediamine (5.4 g, 10 mmol.) in ethanol (50 ml) was added a solution of 2-hydroxybenzaldehyde (12.2 g, 20 mmol.). This mixture was heated under reflux at 50 °C for 2 h, allowed to cool to room temperature and the orange solid product formed was collected by filtration. The crude product was re-crystallized from ethanol and dried in a desiccator over fused $CaCl_2$. The percentage yield is 61.7%.



Scheme 1. Synthesis of 3,3'-((1,3-phenylenebis(azanylylidene))bis(methanylylidene))diphenol (PAMAP)

Preparation of Copper(I) complex

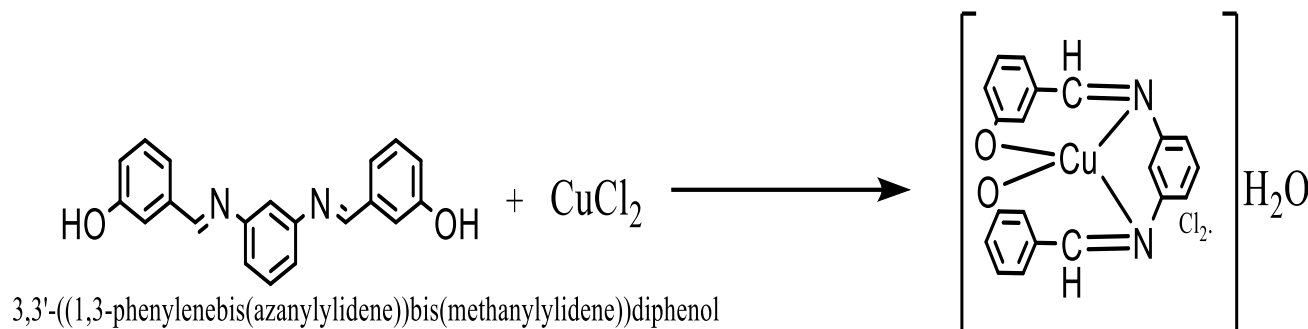
To a solution of the copper(I) chloride (0.85 g ;0.0072mol) in hot ethanol (25 ml) was added a solution of the ligand (1.6 g ;0.005mol) in hot ethanol (50 ml). The mixture was stirred and refluxed at 60 °C for 2h. The dark blue amorphous precipitate formed was filtered, and recrystallized with ethanol and allowed to dry in a desiccator over fused $CaCl_2$. The percentage yield is 79.1%.



Scheme 2: Synthesis of PAMAP Cu(I) complex

Preparation of Copper(II) complex

To a solution of the copper (II) chloride (0.51 g ;0.003mol) in hot ethanol (20 ml) was added a solution of the ligand (0.96 g ;0.003mol) in hot ethanol (40 ml).The solution was stirred and refluxed at 60 °C for 2 h. The dark blue amorphous precipitate formed was filtered, recrystallized with cold ethanol and allowed to dry in a desiccator over fused CaCl₂.The percentage yield is 58.2%.



Scheme 3: Synthesis of PAMAP Cu(II) complex

Characterization of the synthesized Schiff base and Cucomplexes

The melting point/decomposition temperature of the ligand and the metal complexes were determined on a Gallenkampmelting point apparatus (Ra-152). The molar conductance was determined in DMSO solvent using total dissolved solid and TDS&EC (total dissolved solid and electrical conductivity) meter. The magnetic moments were determined on a Sherwood Scientific Magnetic Moment balance (Model No. MK1). The UV spectra of the Schiff base and its copper ion chelates were run in DMSO using an Agilent Technology Carry 300 UV-Visible spectrophotometer in the range of 200 – 900 nm. The IR spectra were obtained by using KBr disk technique on a Thermo Scientific NICOLET iS5 FTIR Spectrophotometer in the range of 400 – 4000 cm⁻¹. The proton-NMR (400MHz) Spectra was acquired on a Bruker AVHD-500MHz spectrophotometer with DMSO-d₆ as solvent and TMS as internal standard. The mass spectrometric analysis was with a Thermo Finnigan LCQ DUO machine. The digested samples of the copper complexes were then analyzed for metal content using AAS-HP MY1447001.

Antimicrobial test

The ligand and its complexes were screened for antibacterial and antifungal activities against three gram-positive bacterial; *Methicillin Resistant Staphylococcus aureus*, *Staphylococcus aureus*, *Streptococcus pyogenes*, five gram-negative bacteria; *Vancomycin Resistant. Enterococci*, *Escherichia coli*, *Helicobacter pylori*, *Proteus mirabilis*, *Salmonella typhi* and four fungi; *Candida albicus*, *Candida krusei*, *Candida stellatoides* and *Candida tropicalis*. The bacteriological growth medium was nutrient agar. The size of the inhibition zone generated around the wells on the seeded nutrient agar was used to estimate the antibacterial and antifungal activity of the complexes.

RESULTS AND DISCUSSION

Physical properties of the ligand and complexes

The ligand was obtained as a light yellow powdery solid is 12.09 g(61.70% yield, Wt= 195.90) and a melting point of 165°C. Dark blue amorphous complexes were obtained for both Cu(I) and Cu(II) with a yield of 58.2 (Wt= 272.3) and 79.1(Wt= 384.7) % respectively and melting points of 187°C and 188°C. The higher melting points of the complexes compared to the ligands (Table 1) may be due to the increase in the molecular weights of the complexes and possibly because the complexes are more stable than the ligand (Ommenya *et al.*, 2020).

The ligand shows zero conductance while the copper (I) and copper (II) complexes showed conductance of 38 and 26 S⁻¹cm²mol⁻¹ respectively. These indicate that the complexes have low ionic character, therefore they are

non-electrolytes. The conductance values are below $50 \text{ ohm}^{-1}\text{cm}^2\text{mol}^{-1}$ which is in agreement with the results obtained by Medhat *et al.*, 2017 for similar complexes. This suggests that there were no anions (such as Cl^-) present outside the coordination sphere of the complexes.

The ligand and complexes were generally soluble in dimethyl-formamide, dimethyl sulfoxide, acetone and benzene, but slightly soluble in water and common polar organic solvents such as methanol and ethanol at room temperature (Table 2). This is in agreement with the solubility of similar complexes reported by Ibrahim *et al.*, 2017.

Table 1: Some physical properties of the ligand and the copper complexes

Compounds	Texture	Color	Yield %	%metal found	%metal found(calcd)	MP/ $^{\circ}\text{C}$	Conductivity/ $\text{Ohm}^{-1} \text{cm}^2 \text{mol}^{-1}$
PAMAP	powdery	Light yellow	61.7	-	-	165	0
$[\text{Cu}(\text{II})\text{L}(\text{H}_2\text{O})]\text{Cl}_2 \cdot \text{H}_2\text{O}$	Amorphous	Dark blue	79.1	13	12.6	188	26
$[\text{Cu}(\text{I})\text{L}(\text{H}_2\text{O})_2]\text{Cl} \cdot \text{H}_2\text{O}$	Amorphous	Dark blue	58.2	13	12.55	187	38

Table 2: Solubility data of the ligand and the copper complexes

Compound	Water	Methanol	Ethanol	Acetone	Benzene	DMF	DMSO
PAMAP	INS	SS	SS	S	S	S	S
$[\text{Cu}(\text{II})\text{L}(\text{H}_2\text{O})_2]\text{Cl}_2 \cdot \text{H}_2\text{O}$	INS	SS	SS	S	S	S	S
$[\text{Cu}(\text{I})\text{L}(\text{H}_2\text{O})_2]\text{Cl} \cdot \text{H}_2\text{O}$	INS	SS	SS	S	S	S	S

S- Soluble SS- Sparingly soluble INS- Insoluble L- PAMAP

Magnetic and electronic spectral data of PAMAP and its complexes

The magnetic susceptibility of the Cu(I) and Cu(II) complexes determined at room temperature using $\text{Hg}[\text{Co}(\text{SCN})_4]$ as calibrant and magnetic moments were 0.90 and 1.13 BM respectively. This indicates one unpaired electron therefore ruling out the possibility of Cu-Cu interactions or coupling as obtained by Ojo and Nwabueze (2016) for similar metal complexes.

As shown in table 3, a band observed for the ligand at 368nm with molar absorptivity of $352 \text{ Lmol}^{-1}\text{cm}^{-1}$ is due to the $n \rightarrow \pi^*$ transition of the phenolic group similar to results obtained by Chen *et al.*, 1993. The electronic spectra of the Cu(I) and Cu(II) complexes show a band at 402 nm and 356 nm respectively with molar absorptivities of 66.3 and $65.6 \text{ Lmol}^{-1}\text{cm}^{-1}$ respectively. The band is assigned to $a^2B_{1g} \rightarrow ^2A_{1g}$ transition. The electronic spectra were consistent with that of a spin free distorted octahedral geometry which is close to findings by Reddy *et al.*, 2012 for similar metal complexes.

Table 3. Summary of results of the UV absorbance for ligand and the Cu complexes in DMSO

Ligand/ Complex	$\lambda_{\max}(\text{nm})$	$\epsilon (\text{dm}^3\text{mol}^{-1}\text{cm}^{-1})$	Transition
PAMAP	316	352	$n \rightarrow \pi^*$
$[\text{Cu(I)L}(\text{H}_2\text{O})_2\text{Cl}]\cdot\text{H}_2\text{O}$	402	66.3	${}^2\text{B}_{1g} \rightarrow {}^2\text{A}_{1g}$
$[\text{Cu(II)L}(\text{H}_2\text{O})_2\text{Cl}_2]\cdot\text{H}_2\text{O}$	356	65.6	${}^2\text{B}_{1g} \rightarrow {}^2\text{A}_{1g}$

Infrared spectra of PAMAP and its complexes

The data obtained from the FTIR spectra is given in Table 4. FTIR spectra of the ligand showed the absence of bands at 1735- 3360 cm^{-1} due to carbonyl $\nu(\text{C}=\text{O})$ and instead, appearance of a strong new band at 1621.77 cm^{-1} assigned to the azomethine, $\nu(\text{C}=\text{N})$ linkage similar to the report by Mahmoud *et al* 2018 and Shafaatian *et al.*, 2014 for similar complexes. It suggests that one of the amino groups and the aldehyde group of the starting materials is absent and have been converted to an azomethine moiety.

The comparison of the IR spectrum of the Schiff base and its metal complexes showed a band at 1621.77 cm^{-1} due to the azomethine being shifted to lower frequency by 14.29 cm^{-1} indicating participation of the azomethine nitrogen in complexation which is in agreement with the results obtained by Satheesh and Jayanthi, 2017. The ligand showed bands at 1279.33 cm^{-1} assigned to phenolic-OH. These bands were shifted to higher regions in the complexes.

The broad diffused band at 3204.53-3015.56 cm^{-1} and new bands at 758.33–759.84 cm^{-1} are attributed to the stretching rocking and wagging mode of $\nu(\text{OH})$ vibration of the coordinated water (H_2O) molecules present in the complexes. This is close to the findings reported by Shafaatian, 2014; Mohamed, 2019 and Ojo *et al*, 2022 for similar metal complexes. The spectrum of the free ligand shows strong bands at 1359.32 cm^{-1} assigned to $\nu(\text{C}-\text{N})$ stretching vibration of the ligand. However, after complexation *via* nitrogen to the metal ion, this band was observed at 1387.58–1466.08 cm^{-1} in the complexes. Further, new bands appeared in the far infrared region at 537.28 cm^{-1} and were due to the $\nu(\text{M}-\text{O})$, stretching of coordinated water.

Table 4. IR spectra data for ligand and the Copper complexes $\nu(\text{cm}^{-1})$

Compound	O-H	$\text{C}=\text{C}$	$\text{C}=\text{N}$	C-O	M-O
PAMAP	-	1461.24	1621.17	1359.32	-
$[\text{Cu(II)L}(\text{H}_2\text{O})_2\text{Cl}]\cdot\text{H}_2\text{O}$	3204.53	1466.08	1607.48	1313.60	759.94
$[\text{Cu(II)L}(\text{H}_2\text{O})_2\text{Cl}_2]\cdot\text{H}_2\text{O}$	3015.56	1466.08	1607.19	1296.14	758.33

NMR spectra of the ligand and metal complexes

The proton NMR spectrum showed a symmetrical molecule. Proton chemical shifts were observed at $\delta(\text{ppm})$ 13.00 (s,2H, Ar-OH), 9.06 (s,2H, H-C=N), 7.69-7.00 (m,10H,Ar-H), 6.98 (d,2H, Ar-H). This is similar to the chemical shifts reported by Parmer *et al.*, 2013.

Carbon-13 chemical shifts were observed at $\delta(\text{ppm})$ 164.6 (C=N), 160.8 (C-10, C-19) 117.1, 133.0, 134.0 (C-1 & C-18, C-14 & C-15, C-9 & C-20), 119.7 (C-12, C-13, C-16 & C-17), 149.8, 120.6, 130.8 and 114.3 (C-2 & C-6, C-3 & C-5, C-4 and C-7).

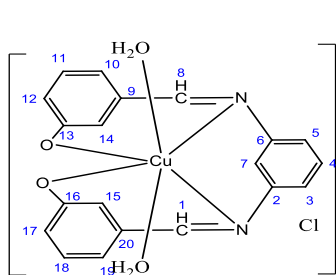
The slight difference between the chemical shifts for the ligand (Table 5) and the complexes (Table 6) can be attributed to the coordination between the metal and the ligand to form the complex which has caused further de-shielding to the center.

Table 5: ${}^1\text{H}$ NMR spectral data of ligand and its complexes

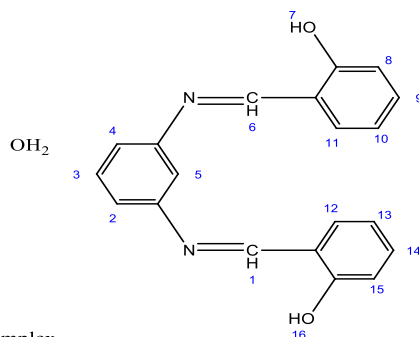
PAMAP δ [ppm]	[Cu(I)L(H ₂ O) ₂ Cl].H ₂ O	[Cu(II)L(H ₂ O) ₂ Cl ₂].H ₂ O	Assignment
13.00(2H,s)			H-7&H-16
9.06(2H,s)			H-1&H-6
7.69(2H,dd)			H-11&H-12
7.55(1H,t)			H-3
7.53(1H,s)			H-5
7.44(2H,t)			H-9&H-14
7.37(2H,d)			H-2&H-4
7.02(2H,t)			H-10&H-13
6.99(2H,d)			H-8&H-15

Table 6: ¹³C NMR spectral data of ligand and complexes

PAMAP δ [ppm]	[Cu(I)L(H ₂ O) ₂ Cl]. H ₂ O δ [ppm]	[Cu(II)L(H ₂ O) ₂ Cl ₂]. H ₂ O δ [ppm]	Assignment
164.6	163.7	163.7	C-1&C-8
160.8	157.4	157.4	C-10&C-19
149.8	154.5	154.5	C-2&C-6
134.0	135.1	135.1	C-9&C-20
133.0	130.2	130.2	C-14&C-15
130.8	132.9	132.9	C-4
120.6	120.8	120.8	C-3&C-5
119.7	118.2	118.2	C-12,C-13,C-16&C-17
117.1	114.9	114.9	C-11&C-18
114.3	116.8	116.8	C-7



Structure 2: structure of Cu complex

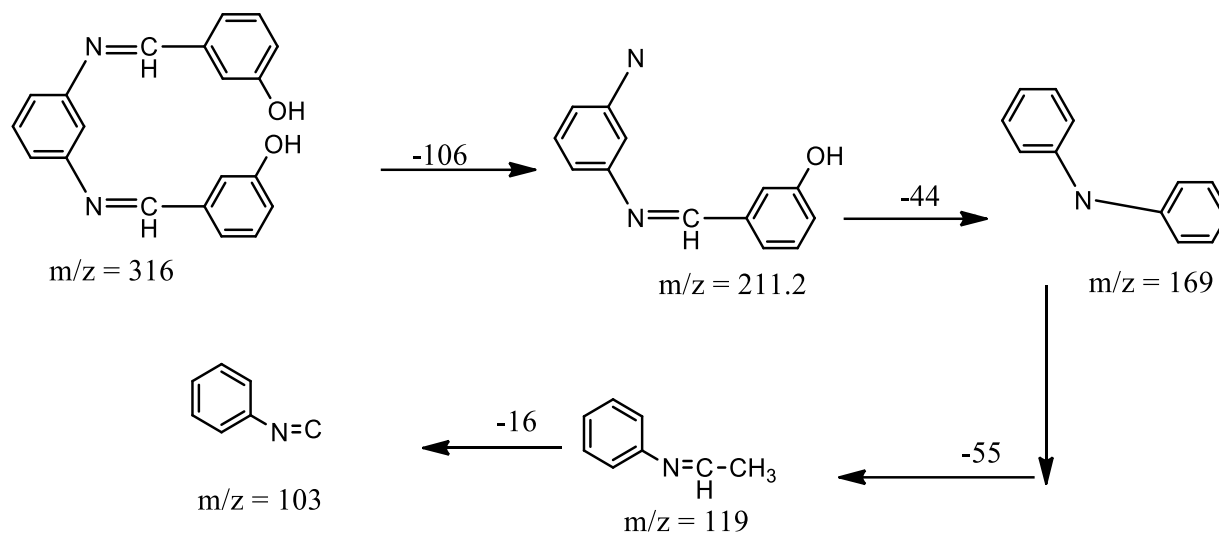


Structure 1: structure of ligand

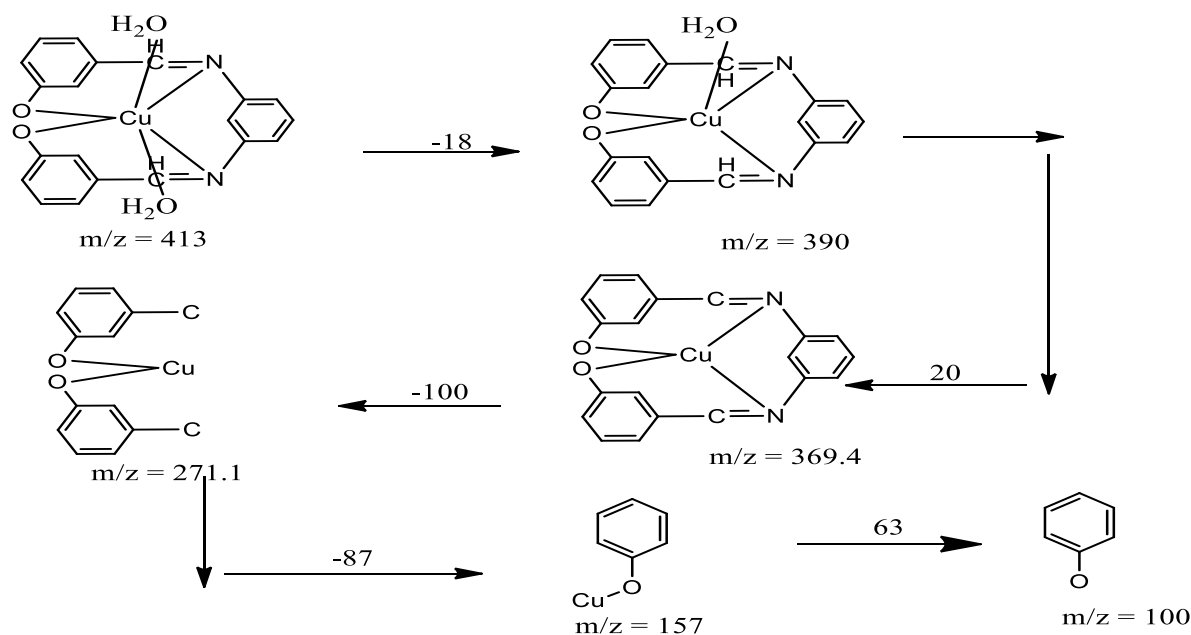
Mass spectrum of the ligand and the metal complexes

The mass spectral fragmentations of the Schiff base and its Cu (II) chelate are shown in schemes 3 and 4 respectively. For the Schiff base, base peak at $m/z = 316$ indicates its molecular ion. Meanwhile, the peak at $m/z = 211.2$ is from the loss of C_7H_6O from the Schiff base. The loss of CH_2ON gives a peak at $m/z = 169.0$. The peak at $m/z = 119$ due to loss of C_4H_4 . The spectrum also showed a peak at $m/z = 103.0$ corresponding to

loss of CH_4 . For Cu(II) complex, the spectrum exhibits a peak at $m/z = 390.0$ due to the loss to C_6H_5 . The peak at $m/z = 369.4$ corresponding to the loss of H_2O molecule. The peak at $m/z = 271.1$ due to the loss of $\text{C}_4\text{H}_3\text{N}$ and two H_2O molecules. The appearance of a peak at $m/z = 188.0$ was attributed to the loss of $\text{C}_3\text{H}_5\text{NO}_2$ (Mishra & Jain, 2010).



Scheme 3: Mass fragmentation of the ligand



Scheme 4: Mass fragmentation of the Cu(II) complex

Antimicrobial studies

The in-vitro activities of the ligand and its metal complexes tested against microorganism and the results are presented in Table 7-9. The result indicates that the ligand and its copper (I) and (II) complexes had high activity against *Methicillin Resistant Staphaureus* and *Staphylococcus Aureus* with MIC of $6.25\mu\text{g/ml}$, zone of inhibition of 29, 30, 32 cm respectively which is almost equal and higher than the zone of inhibition of standard drugs with zone of inhibition of 32 and 29 cm at $10\mu\text{g/ml}$.

The results also show that the ligand had minimal activity against *Staphylococcus Aureus*, *Streptococcus Pyogenes*, *Vanocomycin Resitant. Enterococci*, *Escherichia Coli*, *Heliobacter Pylori*, *Proteus Mirabilis*, *Salmonella Typhea*, *Candida Albicans*, *Candida Krusei*, *Candida Stellatoidea* and *Candida Tropicalis* with zone of inhibition ranging between 23-25cm which is much lower than standard drugs with zone of inhibition

between 27-40cm. Also the copper (I) and (II) complexe had minimal activity against *Methicillin Resistant Staphylococcus Aureus*, *streptococcus pyogenes*, *Vancomycin Resitant. Enterococci*, *Escherichia Coli*, *Helicobacter Pylori*, *Proteus Mirabilis*, *Salmonella Typhoea*, *Candida Albicans*, *Candida Krusei*, *Candida Stellatoidea* and *Candida Tropicalis* with zone of inhibition ranging between 23-28cm which is lower than that of the standard drugs ranging between 27-40cm.

Compounds containing C=N group have enhanced antimicrobial activity. This can be explained on the basis of Overtone's concept (Dharamaraj *et al.*, 2001) and Tweedy's Chelation theory (Malhota *et al.*, 1993). The results obtained are in agreement with these mentioned theories.

Table 7. Zone of Inhibition of the ligand and complexes against the test microorganisms

Test organism	[Cu(I)L(H ₂ O) ₂ Cl].H ₂ O (mm)	[Cu(II)L(H ₂ O) ₂ Cl ₂].H ₂ O (mm)	PAMAP (mm)	Ciprofloxacin* (mm)	Sparfloxacin* (mm)	Fluconazole** (mm)
<i>Methicillin Resistant staphylococcus aureus</i>	27	25	29	0	32	0
<i>Vancomycin Resistant enterococci</i>	0	29	24	29	30	0
<i>Staphylococcus aureus</i>	30	32	0	0	29	0
<i>Staphylococcus pyogenes</i>	25	0	0	27	0	0
<i>Escherichia coli</i>	24	28	23	35	0	0
<i>Helicobacter pylori</i>	0	26	0	37	30	0
<i>Proteus mirabilis</i>	27	0	24	0	31	0
<i>Salmonella typhii</i>	0	0	25	40	30	0
<i>Candida albicans</i>	0	0	24	0	0	34
<i>Candida krusei</i>	24	25	0	0	0	32
<i>Candida stellatoidea</i>	28	0	23	0	0	35
<i>Candida tropicalis</i>	0	27	0	0	0	34

*- Standard Antibacterial drugs ** - Standard Antifungal drugs

Table 8. Minimum Inhibition Concentration of the Ligand and Complexes against the Test Microbes

	[Cu(I)L(H ₂ O) ₂ Cl]. H ₂ O	[Cu(II)L(H ₂ O) ₂ Cl ₂]. H ₂ O	PAMAP
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Test Organism	50 µg/ml					25 µg/ml					12 µg/ml					6.25 µg/ml					3.13 µg/ml				
	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml					
<i>Methicillin Resist staph aureus</i>	-	-	OX	+	++	-	OX	+	++	+++	-	-	-	OX	X										
<i>Vancomycin Resist enterococci</i>						-	-	-	OX	+	-	OX	+	++	+++										
<i>Staphylococcus aureus</i>	-	-	-	OX	+	-	-	-	OX	+															
<i>Staphylococcus pyogenes</i>	-	OX	+++	+++																					
<i>Escherichia coli</i>	-	OX	+	++	+++	-	-	-	OX	+	-	OX	+	++	+++										
<i>Helicobacter pylori</i>						-	OX	+	++	+++															
<i>Proteus mirabilis</i>	-	-	OX	+	++						-	OX	+	++	+++										
<i>Salmonella typha</i>											-	OX	+	++	+++										
<i>Candida albicans</i>											-	OX	+	++	+++										
<i>Candida krusei</i>	-	OX	+	++	+++	-	OX	+	++	+++															
<i>Candida stellatoidea</i>	-	-	OX	+	++						-	OX	+	++	+++										
<i>Candida tropicalis</i>						-	-	OX	+	++															

Key => -=>No turbidity (no growth), oX=>MIC, +=>Turbid (light growth), +=>Moderate turbidity, +++=>High turbidity

Table 9. Minimum Bactericidal/Fungicidal Concentration of the Ligand and Complexes against the Test Microbes

Test organism	[Cu(I)L(H ₂ O) ₂]Cl. H ₂ O						[Cu(II)L(H ₂ O) ₂]Cl ₂ . H ₂ O						PAMAP					
	100 µg/ml	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml	100 µg/ml	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml	100 µg/ml	50 µg/ml	25 µg/ml	12 µg/ml	6.25 µg/ml	3.13 µg/ml
<i>Methicillin resist staph aureus</i>	-	-	OX	+	++	+++	-	OX	+	++	+++	++++	-	-	-	OX	+	++
<i>Vancomycin Resist enterococci</i>							-	-	-	OX	+	++	-	OX	+	++	+++	++++
<i>Staphylococcus aureus</i>	-	-	-	OX	+	++	-	-	-	OX	+	++						
<i>Staphylococcus pyogenes</i>	-	OX	+	++++	++++													
<i>Escherichia coli</i>	-	OX	+	++	+++	++++	-	-	OX	+++	+++	OX	+++	+++	++++	++++	++++	
<i>Helicobacter pylori</i>							-	OX	++	+++	++++							

<i>Proteus mirabilis</i>	- - oX + ++ +++		- oX ++ +++ +++++
<i>Salmonella Typhaea</i>			- oX ++ +++ +++++
<i>Candida albicans</i>			- oX ++ +++ +++++
<i>Candida krusei</i>	- oX ++ +++ +++++	- oX ++ +++ +++++	
<i>Candida stellatiodea</i>	- - oX + ++ +++		oX + ++ +++ +++++ +++++
<i>Candida tropicalis</i>		- - oX + ++ +++	

Key => - =>No colony growth, oX=>MBC/MFC, +=>Scanty colonies growth, +++=>Moderate colonies growth, +++++=> Heavy colony growth

CONCLUSION

The synthesis of a Schiff base ligand and its copper complexes were carried out in this study and they were characterized by FT-IR, UV-Visible, NMR and mass spectroscopy. The results of these investigations support the suggested structure of the complexes which were found to have distorted octahedral geometry. The high melting point of the complexes confirmed the formation of the complexes. The colour of the Cu complexes are due to ${}^2B_{1g} \rightarrow {}^2A_{1g}$ electron transitions or charge transfer from the ligand to the metal ion. The IR spectra of the complexes when compared to that of the ligand indicating that the ligand coordinated with the metal ion through the carbonyl oxygen and the azomethine nitrogen. The IR spectra also show the presence of water of coordination. The electronic data for the complexes in DMSO showed that the copper complexes were consistent with a distorted octahedral geometry. The magnetic data also showed the presence of one unpaired electron which also accounts for octahedral geometry. There was no 1H NMR for the complexes, this affirms that the complexes are paramagnetic and the ${}^{13}C$ NMR affirms that there was complexation of the metal ion with the ligand. The result of the antimicrobial activities of the ligand and complexes show that the complexes were more active against most microbes than the ligand. This indicates that the copper in the complexes enhanced their antimicrobial activity.

Conflicts of interest

The authors declare no conflict of interest that could have appeared to influence the work reported in this paper.

REFERENCE

1. Ahmed O. O., Saratu M., Adiat I. A., Pius O. U., Yuanfeng W. (2023). Stability and reactivity of dinuclear iron(III)-salen complexes as catalysts in ethylene polymerization: A computational approach. *Results in Chemistry*, Volume 5, 2023, 100959.
2. Bahl, B. S. and Bahl, A. (1993). *Elementary Organic Chemistry*, Schand and Company Ltd., New Delhi p. 60
3. Barboiu, M., Cimpoesu, M., Guran, C., & Supuran, C.T. (1996). 1,3,4-Thiadiazole derivative. Part 91. Synthesis and biological activity of metal complexes of 5-(2-aminoethyl)-2-amino-1,3,4-thiadiazole. *Metal based drugs*, 3(5), 227-232.
4. Carlin, R. L. (1965). *Electronic structure and stereochemistry of cobalt (II)*. *Transition Metal Chemistry*, 1.
5. Chen, L., Thompson, L. K., Bridson, J. N., Xu, J., Ni, S., & Guo, R. (1993). Synthesis and characterization of 5, 12-dimethyl-7, 14-diphenyl-1, 4,8,11-tetraazacyclotetradecane-4, 11-diacetic acid and its transition metal complexes; crystal structure of copper (II) complex of macrocycle. *Canadian journal of chemistry*, 71(11), 1805-1809.

6. Ciolan, F., Patron, L., Mureseanu, M., Rotaru, P., & Georgescu, I. (2012). Synthesis and characterization of Cu(II), Ni(II) and Co(II) Binuclear complexes with new Schiff base (1, 3-bis[ortho(2-carboxy-phenyliminomethyl)-phenoxy]propane). *REVISTA DE CHIMIE*, 63(1), 34-39.
7. Cozzi, P. G. (2004). Metal-salen Schiff base complexes in catalysis: practical aspects. *Chemical Society Reviews*, 33(7), 410-421.
8. Devi, J., & Batra, N. (2015). Synthesis, characterization and antimicrobial activities of mixed ligand transition metal complexes with isatinmonohydrazone Schiff base ligands and heterocyclic nitrogen base. *Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy*, 135, 710-719. doi:10.1016/j.saa.2014.07.041
9. Dharamaraj, N., Viswanathamurthi, P., & Natarajan, K. (2001). Ruthenium (II) complexes containing bidentate Schiff bases and their antifungal activity. *Transition Metal Chemistry*, 26(1), 105-109.
10. Dholakiya, P. P., & Patel, M. N. (2002). Synthesis, spectroscopic studies, and antimicrobial activity of Mn (II), Co (II), Ni (II), Cu (II), and Cd (II) complexes with bidentate Schiff bases and 2, 2'-bipyridylamine. *Synthesis and reactivity in inorganic and metal-organic chemistry*, 32(4), 753-762.
11. El-Ajayi, M. M., Abou-Krishna, M. M., Etoriki, A. M., Al-assbaly, F., & Maihub, A. (2013). Schiff base derived from phenylenediamine and sacliPylaldehyde as precursor techniques in coordination chemistry. *J. Chem. and Pharmaceutical Research*, 5(12), 933-938.
12. Figgis, B. N., & Lewis, J. (1965). *Techniques of Inorganic Chemistry*. Jonassen, HB, Weissberger, A.(eds.), 4, 137.
13. Ibrahim, A. K., Yusuf, B. A., & Hamisu, A. (2017). Synthesis, characterization and antimicrobial studies of Cu (II) and Zn (II) complexes with the Schiff base N- salicylidene-4-choroaniline. *Chemserach Journal*, 8(2), 68-74.
14. Keypour, H., Rezaeivala, M., Valencia, L., Pérez-Lourido, P., & Khavasi, H. R. (2009). Synthesis and characterization of some new Co (II) and Cd (II) macrocyclic Schiff-base complexes containing piperazine moiety. *Polyhedron*, 28(17), 3755-3758.
15. Kim, W. S., Chun, C., Kim, H. W., Lough, A. J., Kim, B., & Chin, J. (2007). Electronic and steric effects in diamine recognition with a highly rigid Zn (II) complex. *Bulletin of the Korean Chemical Society*, 28(1), 133-135.
16. Mahmoud, W. H., Deghadi, R. G., & Mohamed, G. G. (2018). Metal complexes of novel Schiff base derived from iron sandwiched organometallic and 4-nitro-1, 2-phenylenediamine: Synthesis, characterization, DFT studies, antimicrobial activities and molecular docking. *Applied Organometallic Chemistry*, 32(4), e4289.
17. Malhotra, L., Kumar, S., & Dhindsa, K. S. (1993). Synthesis, characterization and microbial activity of Co (II), Ni (II), Cu (II) and Zn (III) complexes of aryloxyacetic acid and hydrazine. *India J Chem*, 32, 457-9.
18. Medhat, A., Mansour, S., El-Sonbaty, S., Kandil, E., & Mahmoud, M. (2017). Evaluation of the antitumor activity of platinum nanoparticles in the treatment of hepatocellular carcinoma induced in rats. *Tumor biology*, 39(7), 1010428317717259.
19. Mishra, A. P., & Jain, R. K. (2010). Microwave synthesis, spectroscopic, thermal and biological significance of some transition metal complexes containing heterocyclic ligands. *Journal of Chemical and Pharmaceutical Research*, 2(6), 51-61.
20. Mohamed, G. G., Mahmoud, W. H., Diab, M. A., El-Sonbati, A. Z., & Abbas, S. Y. (2019). Synthesis, characterization, theoretical study and biological activity of Schiff base nanomaterial analogues. *Journal of Molecular Structure*, 1181, 645-659.
21. Ommenya, F. K., Nyawade, E. A., Andala, D. M., & Kinyua, J. (2020). Synthesis, characterization and Antibacterial activity of Schiff Base, 4-Chloro-2-2{(E)-[(4-Flurophenyl) imino] methyl} phenol metal (II) complexes. *Journal of chemistry*, 2020.
22. Ojo A. S, Nwabueze J. N. (2016). Synthesis and characterization of the complexes of isovaleric acid hydrazide with M (II) Chlorides (M= Co, Ni, Cu). *Journal of Pharmaceutical, Chemical and Biological Sciences*. 4(2):281-290.
23. Ojo, A. S., Mamman, S., & Ukoha, P. O. (2022). Synthesis, characterization and antimicrobial studies of 3-bromobenzaldehyde nicotinic acid hydrazone and it's Co(II), Cu(II), Mn(II) and ni(ii) complexes. *Journal of applied physical science international*, 14(1), 1-9. <https://doi.org/10.56557/japsi/2022/v14i17456>

24. Pavia, D.L., Lampman, G.M. and Kriz, G.S. (2001). "Infrared spectroscopy". Introduction to liquid Spectroscopy, 3 (2001): 308-383.
25. Reddy, S. L., Endo, T., & Reddy, G. S. (2012). Electronic (absorption) spectra of 3d transition metal complexes. Advanced aspects of spectroscopy, 3-48.
26. Satheesh, D., & Jayanthi, K. (2017). An in vitro antibacterial and antifungal activities of Copper (II) and Zinc (II) complexes of N4-methyl-3-thiosemicarbazones. International /journal of Chemical and Pharmaceutical Analysis, 4, 1-7.
27. Sakyan, I., Logoglu, E., Sari, N., & Akiyan, N. (2004). Antimicrobial Activities of N-(2-hydroxy-1-naphthalidene) amino acid Schiff bases and their manganese (III) complexes. Biometals, 17, 115.
28. Sharma, S., & Nguan, O. (1999). The biotechnology industry and strategies of biodiversity conservation: the influence of managerial interpretations and risk propensity. Business Strategy and the Environment, 8(1), 46-61.
29. Shafaatian, B., Soleymanpour, A., Oskouei, N. K., Notash, B., & Rezvani, S. A. (2014). Synthesis, crystal structure, fluorescence and electrochemical studies of new tridentate Schiff base ligand and its nickle (II) and palladium (II) complexes. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 128, 363-369.
30. Shalin, K., Durga, N. D., Saxena, P. N. (2009). Application of metal complexes Schiff bases-A review. Journal of scientific & Industrial Research. Volume 68, pp. 181-187
31. Tümer, M., Köksal, H., Serin, S., & Digrak, M. (1999). Antimicrobial activity studies of mononuclear and binuclear mixed-ligand copper (II) complexes derived from Schiff base ligands and 1, 10-phenanthroline. Transition Metal Chemistry, 24(1), 13-17.
32. Vigato, P. A., & Tamburini, S. (2004). The challenge of cyclic and acyclic Schiff bases and related derivatives. Coordination Chemistry Reviews, 248(17-20), 1717-2128.