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SYNTHESIS, CHARACTERIZATION AND BIOLOGICAL STUDIES: N_2O_2 DONOR NOVEL SCHIFF BASE LIGANDS AND THEIR Co(II), Ni(II), Cu(II), Rh(III), Pd(II) METAL COMPLEXES

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ABSTRACT

Novel Schiff base ligands (L_1 & L_2) were derived from the condensation of O- phthalaldehyde (OPA) with amines, and subsequently used to synthesize the metal complexes of Co(II), Ni(II), Cu(II), Rh(III) and Pd(II). The structures of Schiff base ligands and their metal complexes were characterized by elemental analyses, IR, ^{1}H & ^{13}CNMR, mass and electronic spectroscopy, thermal, magnetic and conductance measurements. Both the ligands and their complexes were screened for their antimicrobial activities against Gram positive, Gram negative bacteria and antifungal activities against Aspergillus flavus and Fusarium oxysporum and determined MIC value.

KEY WORDS

Schiff bases, Metal complexes, Spectral studies, Antimicrobial activity.

INTRODUCTION

Infectious diseases caused by bacteria remain a major worldwide health problem due to many major pathogenic bacteria and parasites have acquired resistance towards currently available antibiotics in the market during the last decade. This has led to the adoption of a resolution on antimicrobial resistance in World Health Assembly during 2011[1]. Development of superbugs has raised fears that infectious diseases may once again become major cause of death in developing/developed countries. Chemotherapeutic agents with novel structure and mode of action should be developed to combat the threat due to the superbugs. Considering the emergence of pathogenic bacteria multidrug resistant strains, the discovery of new antimicrobial compounds is highly important.

In biological processes, inorganic compounds play critical roles and it has been established that many organic compounds used in medicine are activated or biotransformed by metal ions metabolism[2]. Schiff bases are classified as organic ligands derived from the condensation reactions of amines and corresponding carbonyl compounds[3]. Schiff bases have a variety of applications in biological, clinical, and pharmacological areas. The synthesis and application of Schiff bases and their coordination compounds have been highly considered in inorganic, organic and biological fields, since their structural properties similar to some of the biological systems[4–9]. The design and synthesis of macrocycles is one of the fascinating areas for chemists because of their biological applications[10,11]. Macrocycles can be synthesized either by template approach[12] (Gupta & Raina,

1997) or non-template approach[13]. Copious transition metal complexes with polydentate Schiff bases containing nitrogen, oxygen, or sulphur donor atoms contribute immensely in biological systems[14] These complexes exhibit applications in clinical, analytical, and industrial processes[15]. Which is used as model molecules for biological oxygen carrier systems[16]. Additionally, tetradentate Schiff bases composed of N2O2 donor atoms set have been recognized as a kind of important chelating ligands for designing medicinally and catalytically useful metal complexes.[17–19]. Usually, the N, O donor heterodentate Schiff bases can be derived by condensing the aldehydes/ketones with various amines or amino acids[20,21]. Many researcher reported the synthesis, catalytic and biological applications of Schiff bases and their metal complexes derived from *o*-phthalaldehyde (OPA) with various amines[22–30].

Furthermore, it is well known that the human body contains essential metaloelements which play important roles and interact with many biological molecules to fully understand the physiological functions by studying their chemistry coordination and behavior[31,32].

The present manuscript describes the synthesis, characterization and antibacterial activities of cobalt(II), ruthenium(II), nickel(II), copper(II), and palladium(II) complexes with the tetradentate N2O2 Schiff bases derived using Orthophthalaldehyde (OPA) and amines. OPA serves as a good starting material for the synthesis of a large number of macrocycles[33,34]. Literature survey reveals that a little bit of work was done to synthesize macrocycles from OPA by both the methods[35,36]. The template approach was found to have serious limitations [37] because information about the properties of the free macrocyclic ligands is not available in order to interpret and correlate the properties of the respective macrocyclic metal complexes. The ligands synthesized in this work can behave as dianionic tetra dentate donor groups. All the metal complexes have shown moderate to good antimicrobial activity.

EXPERIMENTAL

Materials and methods

All the chemicals used were of AR grade. Solvents were purified and dried before use according to the standard procedures. The solvents were distilled and stored over molecular sieves. $CoCl_2.6H_2O$, $NiCl_2.6H_2O$,$CuCl_2.2H_2O$, $RhCl_3.3H_2O$, $PdCl_2.2H_2O$, O-phthalaldehyde, salicyladehyde hydrazine, 3-amino-1H-pyrazole-4-carboxylic acid, and other chemicals were obtained from Aldrich, USA and all other compounds are AR grade purchased from Merck. Purity of the compounds was checked by TLC using Merck 60F254 silica gel plates. The melting points of all the Schiff base compounds were obtained on a Buchi-510 melting point apparatus. The percentages of C, H & N in Schiff base metal complexes were determined using a Perkin -Elmer CHN analyzer. Conductance measurements were done on 10^{-3} M solution of compounds in dichloromethane at 25 °C using Digisun Digital (DL-909) conductivity meter. The IR spectra were recorded in KBr pellets on Perkin Elmer-283 spectrophotometer, the scanning rate was 6 min. in the range of 4000-200 cm^{-1}. UV-Visible spectra were recorded with Shimadzu UV-160A, a UV-Visible double beam spectrophotometer with matched quartz cells of path length 1 cm. Brucker WH 300 (200 MHz) and Varian Gemini (200 MHz) spectrometers were used for ^1H NMR and ^{13}C NMR spectra. CEC-21-110B, Finningan Mat 1210 and MICROMASS-7070 spectrometers operating at 70 eV using a direct

inlet system were used for mass spectra and VG-Auto-Spec-M mass spectrometer was used for FAB mass spectra. The ESR spectra of Schiff base Cu(II) compounds were recorded at room temperature. Gouy balance calibrated with $Hg[Co(NCS)_4]$ was used for the determination of magnetic susceptibilities of complexes in solid state at room temperature. Vibrating sample magnetometer was also employed for the above purpose when small amounts of complexes were available. Diamagnetic corrections were made using Pascal's constant. TGA and DTA curves were recorded on Leeds and Northrup unit with Pt and Pt +10% Rh thermocouples.

Hot air oven (Instrument and equipment Pvt. Ltd., Mumbai), incubator (Instrument and equipment Pvt. Ltd., Mumbai), laminar airflow unit (Claslaminar technologies Pvt. Ltd. Secunderabad), autoclave (Medica instrument Mfg. Co., Mumbai) were used in the present investigations.

The antimicrobial activity of the Schiff bases and their complexes are determined by the cup plate method and the minimum inhibitory concentration by liquid dilution method against Gram-positive (G^+) (*Bacillus subtilis)* and Gram-negative (G^-) bacteria (*Escherichia coli*), *Aspergillus flavus* and *Fusarium Oxysporum,* respectively[2,38]

RECOMMENDED PROCEDURE

Synthesis of Schiff base ligands:

2[2-1-[2-2-1-(2-hydroxyphenyl)methylidene)hydrozono)methyl)phenyl)methylidene) hydrazono)methyl)phenol(HMMMP) (L_1)

Dropwise addition of a 1:1 aqueous methanolic solution (25 ml) of *o*-phthalaldehyde (2.68 g, 0.02 mol) to a 1:1 aqueous methanolic solution (25 ml) of salicylaldehyde hydrazone (5.44g, 0.04 mol) and stirred. Continued the stirring for about 2.5 h on a hot plate. Completion of the reaction was monitored by TLC. The yellow precipitate obtained was filtered and washed with cold methanol and recrystallized from mixture of chloroform and acetone. The purity of the product was found to be TLC pure in n-hexane and ethylacetate mixture (6:4). Its physical and analytical data given below.

MF $C_{22}H_{18}N_4O_2$; Yield 80 %; mp 240 ^oC; IR (KBr, cm^{-1}) 995, 1331, 1383, 1480, 1618, 3010 w, 3521;^1H NMR (200MHz, $CDCl_3$; δ in ppm) 5.48 (2H, s, OH), 6.65-7.12 (12H, m, Ar-H), 8.28 (2H, s, CH=N), 8.44 (2H, s, CH=N); ^{13}C NMR 114.22, 119.54, 120.11, 129.32, 130.42, 131.22, 132.42, 132.85, 156.82 (18C, Ar-C), 165.55, 168.22 (4C, CH=N). Anal. Found C, 71.32; H, 4.88; N, 15.12 %. Calcd. for $C_{18}H_{12}N_{10}$:C 71.34; H, 4.90; N, 15.13 %, MS: $[M]^+$at m/z 370 (45 %)

3-(2-((4-carboxy-1H-pyrazol-3-ylimino)methyl)benzylideneamino)-1H-pyrazole-4-carboxylic acid (CPBPC) (L_2)

Dropwise addition of a 1:1 aqueous methanolic solution (25 ml) of *o*-phthalaldehyde (2.68 g, 0.02 mol) to a 1:1 aqueous methanolic solution (25 ml) of 3-amino-1H-pyrazole-4-carboxylic acid (6.68g, 0.04 mol) and stirred. Continued the stirring for about 3.5 h on a hot plate. Completion of the reaction was monitored by TLC. The dark brown precipitate obtained was filtered and washed with cold methanol and recrystallized from ethanol. The purity of the product was found to be TLC pure in n-hexane and ethylacetate mixture (7:3). Its physical and analytical data given below.

MF $C_{16}H_{12}N_6O_4$; Yield 78 %; mp 162 ^oC; IR (KBr, cm^{-1}) 1388, 1472, 1630, 1715, 3024 w, 3350, 3475;^1H NMR (200MHz, $CDCl_3$;δ in ppm) 7.48-7.62 (4H, m, Ar-H), 7.82 (2H, s, NH), 7.88 (2H, s, Ar-H), 8.24 (2H, s, CH=N), 11.2 (2H, s, COOH; ^{13}C NMR 127.24, 129.12, 130.46 (6C, Ar-C), 132.55, 134.62, 134.84

(6C, pyrazole), 168.02 (2C, CH=N), 171.34 (2C, COOH). Anal. Found C 54.51; H, 3.41; N, 23.78 %. Calcd. for $C_{18}H_{12}N_{10}$:C 54.54; H, 3.43; N, 23.84 %, MS: $[M]^+$at m/z 352 (51 %)

Synthesis of metal complexes

The complexes were prepared by the reaction of respective Schiff base ligand (HMMMP, CPBPC) with respective the metal precursors/salts $CoCl_2.6H_2O$, $NiCl_2.6H_2O$, $CuCl_2.2H_2O$, $RhCl_3.3H_2O$, $PdCl_2.2H_2O$, in a (1:1; L:M) molar ratio. The 5 mmol of the respective metal precursor/salt dissolved in ethanol was added to 5 mmol of the respective ligand dissolved in ethanol, the resulting solutions were stirred and then refluxed for 3-4h. The reaction mixture was concentrated to 5 ml under reduced pressure and a few ml of diethyl ether was added to initiate the crystallization. The resulting precipitate was separated by suction filtration, washed with diethyl ether, vaccum dried to get a crystalline compound and was recrystallized using dichloromethane and diethyl ether solvent mixture.

RESULTS AND DISCUSSION

In the present studies, ten new Schiff base Co(II), Ni(II), Cu(II), Rh(III). Pd(II) complexes were synthesized by treating $CoCl_2.6H_2O$; $NiCl_2.6H_2O$; $CuCl_2.2H_2O$; $RhCl_3.3H_2O$; $PdCl_2.2H_2O$ with two Schiff base ligands separately using non template method, all the metal complexes were stable in air and soluble in methanol. The purity of the Schiff base ligands were monitored by gas chromatography. The percentages of C, H and N were determined experimentally by using CHN analyzer. The percentage of metal in Schiff base-Metal complexes were determined by literature method[39] [Vogel's, Text book of Quantitative Chemical Analysis, 6th Edn., Pearson Edu., India, 2004. The physical and analytical data for the newly synthesized metal complexes is in good agreement with the proposed molecular formula (**Table 1**).

Characterization of Novel Schiff base Co(II), Ni(II), Cu(II), Rh(III) and Pd(II) metal complexes:

Infrared spectral analysis

The IR spectra of new Schiff base Co(II), Ni(II), Cu(II), Rh(III) and Pd (II) complexes were studied by comparing with the IR spectra of free Schiff base ligands to know the binding mode of metal and ligand (**Table 2**). In the IR spectra of the Schiff base ligands, a medium intensity υC=N band was observed in the range of 1630-1618 cm^{-1}[25]. This band is shifted towards lower side about 1592-1618 cm^{-1} in Schiff base metal complexes. This fact is further supported by the appearance of a medium intensity band in the region of 515-542 cm^{-1} assignable to υM–N vibration [28]. The characteristic bands due to υ_{NH} (heterocyclic ring) band in the spectra of ligand (L_2) was remained almost unchanged[40,41]. It indicates that non-involvement of those nitrogens in bonding with metal center in the complexes. In the Schiff base ligand (L_1) υ_{O-H} band was observed in the range of 3521 cm^{-1}.

Table 1: Analytical, spectral and physical data of Schiff base Co(II), Ni(II), Cu(II), Rh(II) and Pd(II) metal complexes.

Comp. No.	Metal complexes / Molecular formula	Analyses (%) Found (Calculated)				Molar conductance, Magnetic movement and electronic spectral data of Schiff base Metal Complexes		
		C	H	N	M	Λ_M (Ω^{-1} cm^2 mol^{-1})	λ_{max} (nm)	μ_{eff} (B.M.)
1	[Co(HMMMP)($H_2O)_2$] $C_{22}H_{20}N_4O_4Co$	57.00 (57.03)	4.33 (4.35)	12.05 (12.09)	12.70 (12.72)	14.3	1070, 525, 475	4.45
2	[Co(CPBPC))($H_2O)_2$] $C_{16}H_{14}N_6O_6Co$	43.11 (43.15)	3.16 (3.17)	18.79 (18.86)	13.22 (13.23)	12.6	1082, 530, 482	4.76
3	[Ni(HMMMP)($H_2O)_2$] $C_{22}H_{20}N_4O_4Ni$	57.02 (57.06)	4.33 (4.35)	12.08 (12.10)	12.66 (12.67)	16.2	1027, 640, 360	3.12
4	[Ni(CPBPC)($H_2O)_2$] $C_{16}H_{14}N_6O_6Ni$	43.13 (43.17)	3.16 (3.17)	18.84 (18.86)	13.17 (13.19)	12.5	1062, 665, 368	3.21
5	[Cu(HMMMP)] $C_{22}H_{16}N_4O_2Cu$	61.15 (61.17)	3.71 (3.73)	12.95 (12.97)	14.70 (14.71)	13.2	733, 515	1.68
6	[Cu(CPBPC)] $C_{16}H_{10}N_6O_4Cu$	46.40 (46.42)	2.41 (2.44)	20.28 (20.30)	15.32 (15.36)	12.4	738, 518	1.85
7	[Rh(HMMMP)($H_2O)_2$]Cl $C_{22}H_{20}ClN_4O_4Rh$	48.65 (48.68)	3.69 (3.71)	10.30 (10.32)		43.8	418, 315	
8	[Rh(CPBPC)($H_2O)_2$]Cl $C_{16}H_{14}ClN_6O_6Rh$	36.60 (36.62)	2.67 (2.69)	15.98 (16.01)		46.4	440, 330	
9	[Pd(HMMMP)] $C_{22}H_{16}N_4O_2Pd$	55.63 (55.65)	3.38 (3.40)	11.78 (11.80)	22.40 (22.41)	15.2	465, 280	
10	[Pd(CPBPC)] $C_{16}H_{10}N_6O_4Pd$	42.04 (42.07)	2.20 (2.21)	18.36 (18.39)	23.28 (23.30)	16.8	473, 296	

In the Schiff base ligand (L_2) υ_{O-H} band was observed in the range of 3350 cm^{-1} and disappeared in metal complexes. The IR spectra of Metal complexes of 1, 2, 4, 6, 7 and 9 bands were observed in the range of 765-816 cm^{-1} indicates the presence of coordinated water molecule in this complexes. All the characteristic bands due to the aromatic rings[15,37] were also present in the expected regions in all the Metal complexes. (Table-2).

Table 2: Infrared spectral data of Schiff base Pd(II), Co(II), Ni(II), Cu(II) and Pd(II) metal complexes.

Comp. No.	Ligands/metal complexes	Selected IR bands (cm^{-1})						
		$\upsilon_{C=N}$	υ_{NH}/ υ_{N-N^*}/$\upsilon_{OH^{**}}$	$\upsilon_{C=O}$/ υ_{C-O^*}/$\upsilon_{N-N^{**}}$	$\upsilon_{(COO-)}$ asym/ sym	υ_{M-H2O}	υ_{M-N}	υ_{Ni-O}/υ_{Ni-Cl}
L_1	HMMMP	1618	3521**	995*, 1331**	***	***	***	***
1	[Co(HMMMP)($H_2O)_2$]	1594	1025*	1328*	***	780	526	428
2	[Ni(HMMMP)($H_2O)_2$]	1592	1024*	1325*	***	765	524	426
3	[Cu(HMMMP)]	1595	1022*	1327*	***	***	528	424
4	[Rh(HMMMP)($H_2O)_2$]Cl	1595	1020*	1318*	***	812	526	428
5	[Pd(HMMMP)]	1594	1025*	1335*	***	***	515	418
L_2	CPBPC	1630	3475, 3350**	1715	***	***	***	***
6	[Co(CPBPC))($H_2O)_2$]	1612	3315	1695	1590/ 1380	816	534	426
7	[Ni(CPBPC)($H_2O)_2$]	1615	3316	1680	1585/ 1372	805	535	425
8	[Cu(CPBPC)]	1618	3315	1678	1572/ 1365	***	534	426
9	[Rh(CPBPC)($H_2O)_2$]Cl	1614	3312	1696	1575/ 1388	815	542	423
10	[Pd(CPBPC)]	1618	3318	1690	1560/ 1390	***	525	425

However, in L_1 a strong band observed at 1331 cm^{-1} has been assigned to phenolic C-O stretching. On coordination, this band was shifted to lower frequency in the range 1325-1335 cm^{-1} showing that the other coordination is through the phenolic oxygen atom. This fact is further supported by the disappearance of υ_{OH} band in the range of 3521-3350 cm^{-1} in corresponding Schiff base metal complexes. In the Schiff base ligands 2, $\upsilon_{C=O}$ were observed in the range of 1715 cm^{-1} and were shifted towards lower side about 20-37 cm^{-1}, in the complexation indicating coordination of the carbonyl oxygen to the metal atom, this lowering may be attributed to the decrease in electron density at carbonyl group. This is further substantiated by the appearance of a medium intensity band in the region of 423-426 cm^{-1} assignable to υ_{M-O} vibration[42].

The disappearance of characteristic υ_{COOH} of carboxylic acid in ligand 2 at 1715 cm^{-1} and the appearance of two new absorption bands around 1590-1560 and , 1390-1365 cm^{-1} corresponding to $\upsilon_{asy}(COO^-)$ and υ_{sym} (COO^-) respectively in the complexes supports the participation of carboxylic oxygen of carboxylate group in the chelation.

All the characteristic bands due to the aromatic rings were also present in the expected regions[34,43] in all the Schiff base-Metal complexes.

NMR spectral analysis

The ^1H NMR spectra of free ligands and Schiff base metal complexes were recorded to confirm the binding nature of Schiff base ligands to metal ion. The integral intensities of each signal in the ^1H

NMR spectra of the ligands and the corresponding metal complexes were found to agree with the number of different types of protons present. Schiff base ligands and its Co(II), Ni(II), Cu(II), Rh(III) and Pd(II) complexes have been characterized by ^{1}H NMR and ^{13}C NMR spectroscopies and the spectroscopic data was shown in **Table 3**. A signal appeared in the ligands ^{1}H NMR spectrum in of the range of δ 8.24-8.28 ppm is due to CH=N protons. However, in the spectra Co(II), Ni(II), Cu(II), Rh(III) and Pd(II) complexes the signal was moved down field in the range of δ 8.24-8.38 ppm suggests the coordination of imino nitrogen to metal ion[44]. In the ligand (L_1) a broad signal observed in the range of δ 5.48 ppm due to OH proton, this signal is disappeared in the metal complexes suggesting that the OH proton is deprotonated and oxygen atom coordinated with metal ion. The signal due to COOH proton was appeared at the region of δ 11.2 ppm in the ligand (L_2) and this signals was disappeared in the Schiff base metal complex suggesting that the COOH proton are deprotonated and oxygen atom in ligand (L_2) coordinated with metal ion. Multiplets ascertained in the range of δ 6.36-7.88 ppm have been assigned to the aromatic protons[37]. There is no appreciable change in the peak positions corresponding to aromatic protons[45].

^{13}C NMR spectra of free Schiff base ligands were compared with the corresponding Schiff base metal complexes and the chemical shifts in the spectra revealed a consistent pattern. The ^{13}C NMR spectra of the ligands contain signal in the range of δ 164.55–165.46 ppm[46] due to the presence of carbon which is doubly bonded to nitrogen, a down field shift in peak position is observed in the range of δ 165.55-168.22 ppm in complexes and this evidence confirms that the ligands were coordinated to metal ion through imino nitrogen atoms [47]. Appreciable changes in peak positions were not observed with respect to aryl carbons[43]. In the ligand (L_2) the signal due to presence of -COOH group was appeared at 171.34 δ and in the respective Co (II) complex this signal was shifted to the down field region for about δ 175.24-177.56 ppm supporting the coordination of oxygen of this group to the metal center.

Electronic spectroscopic data

The electronic spectrum of all the complexes were recorded in DMF. The electronic spectra of Co(II) complexes with these two ligands exhibit three d-d transition bands in the regions 1070-1082, 525-530 and 475-482-475 nm assigned to $^{4}T_{2g}\leftarrow{}^{4}T_{1g}(F)$ (υ_1), $^{4}A_{2g}\leftarrow{}^{4}T_{1g}(F)$ (υ_2) and $^{4}T_{1g}(P)\leftarrow{}^{4}T_{1g}(F)$ (υ_3) transitions, respectively[48]. This indicates the octahedral geometry for all the Co(II) complexes. The octahedral geometry of Co(II) complexes is further supported by υ_2/υ_1ratio lying in the 2.040 to 2.042 range[49]. Ni(II) complexes also exhibited octahedral geometry. They shown three d-d transition bands (υ_1, υ_2 and υ_3) in the regions 1020–1080, 640-730 and 360-410 nm (Table-1) assignable to $^{3}A_{2g}(F)\rightarrow{}^{3}T_{2g}(F)$, $^{3}A_{2g}(F)\rightarrow{}^{3}T_{1g}(F)$ and $^{3}A_{2g}(F)\rightarrow{}^{3}T_{1g}(P)$ transitions, respectively [48]. The octahedral geometry was further supported by υ_2/υ_1 ratio which was lying in the range of 1..47-1.59. For the Cu(II) complexes showed an intensive band at about 733-738 nm attributed to $^{2}A_{1g}\leftarrow{}^{2}B_{1g}$ transition and a broad band around 518-515 nm attributed to $^{2}E_{g}\leftarrow{}^{2}B_{1g}$ transition of square planar environment[39]. Rh(III) complexes exhibit two main bands (υ_1 and υ_2) around 418-440 and 315-330 nm which were expected to be spin allowed transition and these obscured by charge transfer transitions. These bands correspond to $^{1}A_{1g}\rightarrow{}^{1}T_{1g}$ and $^{1}A_{1g}\rightarrow{}^{1}T_{2g}$ transitions, respectively, suggesting an octahedral geometry. The octahedral geometry

was further supported by υ_2 to υ_1 ratio which was lying in the range of 1.32-1.33[49]. The Pd(II) complexes prepared have been found to show a broad d-d transition band in the region of 465-473 nm assignable to $^1B_{1g} \leftarrow {}^1A_{1g}$ transition typical for the square planar geometry [50,51]. Further a relatively strong charge transfer band has been observed in the spectra of all the Pd(II) complexes in the range of 280-296 nm. From the electronic spectral data and the diamagnetic behaviour of the complexes, the square planar geometry has been proposed to all the Pd(II) complexes.

ESR spectral analysis:

The ESR spectral studies are useful method to determine the arrangement of metal ions in the structure of the metal complexes and to determine the ground state of electrons in metal ion. The ESR spectrum of metal chelates provides information about hyperfine and super hyperfine structures which are important in studying the metal ion environment in complexes i.e. the geometry, nature of the ligating sites from the Schiff base of metal and the degree of covalancy of the metal-ligand bonds. The ESR spectra were recorded for Schiff base Cu(II) complexes at liquid nitrogen temperature. The representative ESR spectra of [Cu(HMMMP)] and [Cu(CPBPC)] (Complexes 5 & 6) were recorded at liquid nitrogen temperature. ESR spectral data of Schiff base Cu(II) complexes given in **Table 5.** The 300 K spectra show an isotropic pattern, expected for Cu^{2+} in solution, but the spectra for the frozen solutions show the usual anisotropic pattern as expected for a powder sample. The absence of a half field signal at 1600 G, corresponding to the ΔMs= ±2 transition, rules out any Cu–Cu interaction in the ESR spectra[50]. The g-tensor values of the Cu(II) complexes can be used to derive the ground state. In square-planar complexes, the unpaired electron lies in the dx^2-y^2 orbitals giving $^2B_{1g}$ as the ground state with $g_{||} > g_{\perp} > 2$, while the unpaired electron lies in the dz^2 orbital giving $^2A_{1g}$ as the ground state with $g_{\perp} > g_{||} > 2$. From the observed values it is clear that $g_{||} \approx 2.20 > g_{\perp} \approx 2.05 > 2$ and the ESR paramaters of the complexes coincide well with related systems which suggest that the complexes have square-planar geometry and the systems are axially symmetric[34,52]. This is also supported by the fact that the unpaired electron lies predominantly in the dx^2-y^2 orbital[53–55], as was evident from the value of the exchange interaction term G, estimated from the expression: $G=(g_{||}-2.0023)/(g_{\perp}-2.0023)$.

These two compounds showed that $g_{||} < 2.3$ indicating that the present complexes exhibit appreciable covalent nature[56]. The G values [$G=(g_{||} -2)/(g_{\perp}-2)$] which measures the exchange interaction between the copper centers in poly crystalline compounds samples have been calculated. According to Hathaway, if G>4, it indicates that the exchange interaction is negligible and if G < 4, it indicates a considerable exchange interaction in solid compounds[57]. The calculated G values which are presented in Table 4 are larger than four suggesting that there is no interaction between the copper centers [58]. The broadening and splitting of the $g_{\perp}$ line is due to the overlap of $g_{||}$ and $g_{\perp}$ components, further indicating lowered site symmetry. Thus, the ESR data supports the binding of the Cu(II) ion with Schiff base ligands in a square planar geometries[53].

Thermal analysis

The thermograms of TG and DTA curves were obtained from the thermal analysis studies of Schiff base Metal complexes over the temperature range 40–900 °C were critically examined to ascertain the presence of latice held, coordinated water molecules and decomposition patterns etc.

The thermal decomposition of the samples presented characteristic pathways, depending on the nature of the ligands, which is observed from the TG/DTA curves. Thermal analysis data of Schiff base Schiff base Co(II), Ni(II), Cu(II), Rh(II) and Pd(II) metal complexes were shown in **Table 4**.

In the Co(II), Ni(II) and Rh(II) complexes were observed two clear cut stages, one is corresponding to loss of water molecule that is dehydration (215-225 °C) and second is corresponding to decomposition of the complex with the loss of organic moiety (300 °C). Water present in complexes is usually of two kinds - lattice water and coordinated water. As the nature of forces by which these two kinds of water are bonded is different, naturally they get lost at different temperatures. Lattice water will be lost at lower temperature (70-115 °C) whereas loss of coordinated water requires higher temperatures (above 150 °C). The percentage weight loss in 215-225 °C temperature range indicates that there are two water molecules in these complex as coordinated water. The DTA curves show no endothermic peaks up to 230 °C confirming the absence of lattice or coordinated water molecules in the complexes [59–61]. The sharp decomposition corresponding to the loss of organic moiety can be seen in the DTA curves which contained one sharp exothermic peak falling in the range of 268–440 °C. The final product of decomposition of all the complexes above 450 °C corresponds to metal oxide. The thermo-gravimetric analysis data (Table-4) of the Metal complexes were obtained using less than 10 mg of the compound.

Magnetic and conductance measurements

The magnetic susceptibility measurements have been carried out for Schiff base Metal complexes**.** The magnetic properties depend on the ground and excited states of the metal complexes. The magnetic moments of Co(II) and Ni(II) metal complexes are in the range of 3.02-5.04 B.M. and thus confirm octahedral geometry around metal ion [62]. These magnetic moment values are higher than spin only value indicating the contributions from orbital angular momentum values. The magnetic moment of Schiff base Cu(II) complexes at room temperature lie in the range of 1.91-1.98 B.M[41], corresponding to one unpaired electron. This indicates that these complexes are monomeric in nature. The magnetic susceptibility measurements have been carried out for Schiff base Rh(III) & Pd(II) complexes and these compounds were found to be diamagnetic and hence Rh(III) & Pd(II) ion is in low spin configuration. The diamagnetic nature of complexes were further confirmed by the sharp well defined signals in the ^{1}HNMR spectra.

Table-3. ^{1}H NMR spectral data of Schiff base Rh(II), Co(II), Ni(II), Cu(II) and Pd(II) metal complexes.

Comp. No.	Ligands/metal complex	^{1}H NMR peak position (δ ppm)	^{13}C NMR peak position (δ ppm)
L_1	HMMMP	5.48 (2H, s, OH), 6.65-7.12 (12H, m, Ar-H), 8.28 (2H, s, CH=N), 8.44 (2H, s, CH=N)	114.22, 119.54, 120.11, 129.32, 130.42, 131.22, 132.42, 132.85, 156.82 (18C, Ar-C), 165.55, 168.22 (4C, CH=N).
1	[Co(HMMMP)($H_2O)_2$]	6.45-7.62 (12H, m, Ar-H), 8.25 (2H, s, CH=N), 8.42 (2H, s, CH=N).	114.22, 119.54, 120.11, 129.32, 130.42, 131.22, 132.42, 132.85, 163.12 (18C, Ar-C), 165.55, 167.82 (4C, CH=N).
2	[Ni(HMMMP)($H_2O)_2$]	6.44-7.62 (12H, m, Ar-H), 8.26 (2H, s, CH=N), 8.40 (2H, s, CH=N)	114.22, 118.82, 120.11, 129.32, 131.04, 131.22, 132.42, 132.85, 163.12 (18C, Ar-C), 165.55, 167.80 (4C, CH=N).
4	[Rh(HMMMP)($H_2O)_2$]Cl	6.62-7.84 (12H, m, Ar-H), 8.24 (2H, s, CH=N), 8.45 (2H, s, CH=N)	114.20, 118.64, 120.31, 129.26, 130.82, 131.25, 132.44, 132.85, 163.12 (18C, Ar-C), 165.54, 167.84 (4C, CH=N).
5	[Pd(HMMMP)]	6.36-7.42 (12H, m, Ar-H), 8.24 (2H, s, CH=N), 8.55 (2H, s, CH=N).	112.02, 118.50, 121.14, 129.32, 130.42, 131.62, 132.45, 132.85, 163.04 (18C, Ar-C), 165.55, 167.84 (4C, CH=N).
L_2	CPBPC	7.48-7.62 (4H, m, Ar-H), 7.82 (2H, s, NH), 7.88 (2H, s, Ar-H), 8.24 (2H, s, CH=N), 11.2 (2H, s, COOH)	127.24, 129.12, 130.46 (6C, Ar-C), 132.55, 134.62, 134.84 (6C, pyrazole), 168.02 (2C, CH=N), 171.34 (2C, COOH)
6	[Co(CPBPC))($H_2O)_2$]	7.48-7.62 (4H, m, Ar-H), 7.82 (2H, s, NH), 7.88 (2H, s, Ar-H), 8.38 (2H, s, CH=N)	127.24, 129.12, 130.46 (6C, Ar-C), 132.55, 134.62, 134.84 (6C, pyrazole), 172.24 (2C, CH=N), 175.68 (2C, COO)
7	[Ni(CPBPC)($H_2O)_2$]	7.48-7.62 (4H, m, Ar-H), 7.82 (2H, s, NH), 7.88 (2H, s, Ar-H), 8.32 (2H, s, CH=N)	127.24, 129.12, 130.46 (6C, Ar-C), 132.55, 134.62, 134.84 (6C, pyrazole), 170.32 (2C, CH=N), 177.56 (2C, COO)
9	[Rh(CPBPC)($H_2O)_2$]Cl	7.48-7.62 (4H, m, Ar-H), 7.82 (2H, s, NH), 7.88 (2H, s, Ar-H), 8.36 (2H, s, CH=N)	127.24, 129.12, 130.46 (6C, Ar-C), 132.55, 134.62, 134.84 (6C, pyrazole), 174.48 (2C, CH=N), 175.36 (2C, COO)
10	[Pd(CPBPC)]	7.48-7.62 (4H, m, Ar-H), 7.82 (2H, s, NH), 7.88 (2H, s, Ar-H), 8.28 (2H, s, CH=N)	127.24, 129.12, 130.46 (6C, Ar-C), 132.55, 134.62, 134.84 (6C, pyrazole), 175.02 (2C, CH=N), 176.24 (2C, COO)

Table 4. Thermal analysis data of Schiff base Schiff base Co(II), Ni(II), Cu(II), Rh(II) and Pd(II) metal complexes.

Sl. No.	Complex	Decomposition temperature		Pyrolysis percentage Found (Calcd.)	
		between 130-230 °C	After 250 °C	Loss of weight on dehydration	Metal oxide formed
1	[Co(HMMMP)($H_2O)_2$]	172	395	7.74 (7.78)	16.20 (16.18)
2	[Ni(HMMMP)($H_2O)_2$]	175	282	7.65 (7.79)	16.08 (16.16)
3	[Cu(HMMMP)]	-	285	-	18.32 (18.41)
4	[Rh(HMMMP)($H_2O)_2$]Cl	-	277	6.71 (6.64)	46.75 (46.83)
5	[Pd(HMMMP)]	-	270	-	25.90 (25.82)
6	[Co(CPBPC)($H_2O)_2$]	221.6	440	8.09 (8.104)	13.87 (13.95)
7	[Ni(CPBPC)($H_2O)_2$]	190	375	8.27 (8.31)	13.99 (13.69)
8	[Cu(CPBPC]	-	273	-	14.52 (18.40)
9	[Rh(CPBPC)($H_2O)_2$]Cl	-	282	6.93 (6.80)	52.11 (50.27)
10	[Pd(CPBPC)]	-	268	-	20.25 (20.17)

Table 5: ESR spectral data of Schiff base Cu(II) complexes.

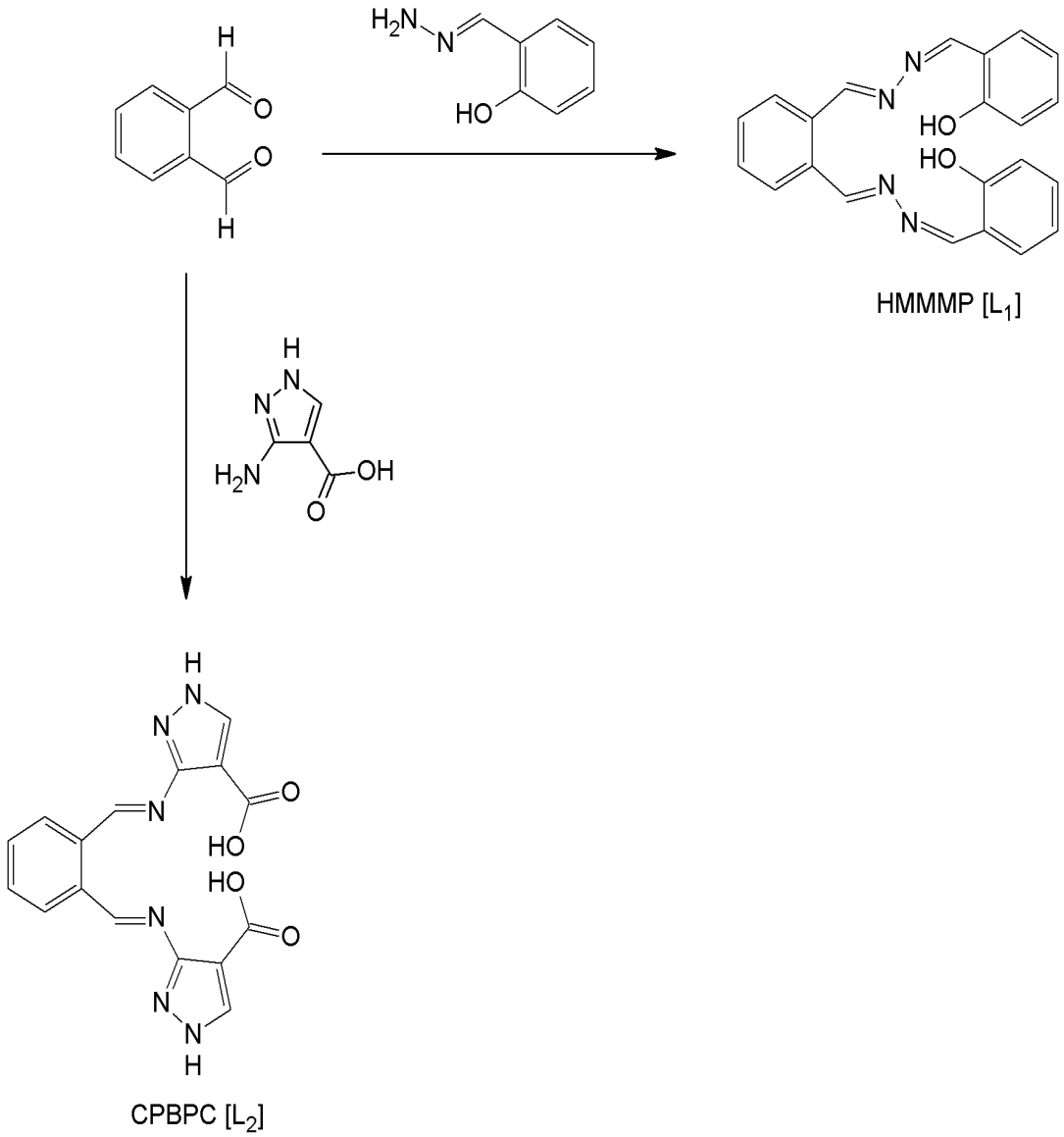
Comp. No.	Cu(II) Metal Complexes	$g_{\|\|}$	$g_{\perp}$	$\|g\|_{avg}$	G
3	[Cu(HMMMP)]	2.210	2.048	2.102	4.615
8	[Cu(CPBPC)]	2.198	2.036	2.090	5.807

Table 6. MIC values of the Schiff Base Ligands and its Co(II), Ni(II), Cu(II), Rh(III) and Pd (II) complexes against standard drugs

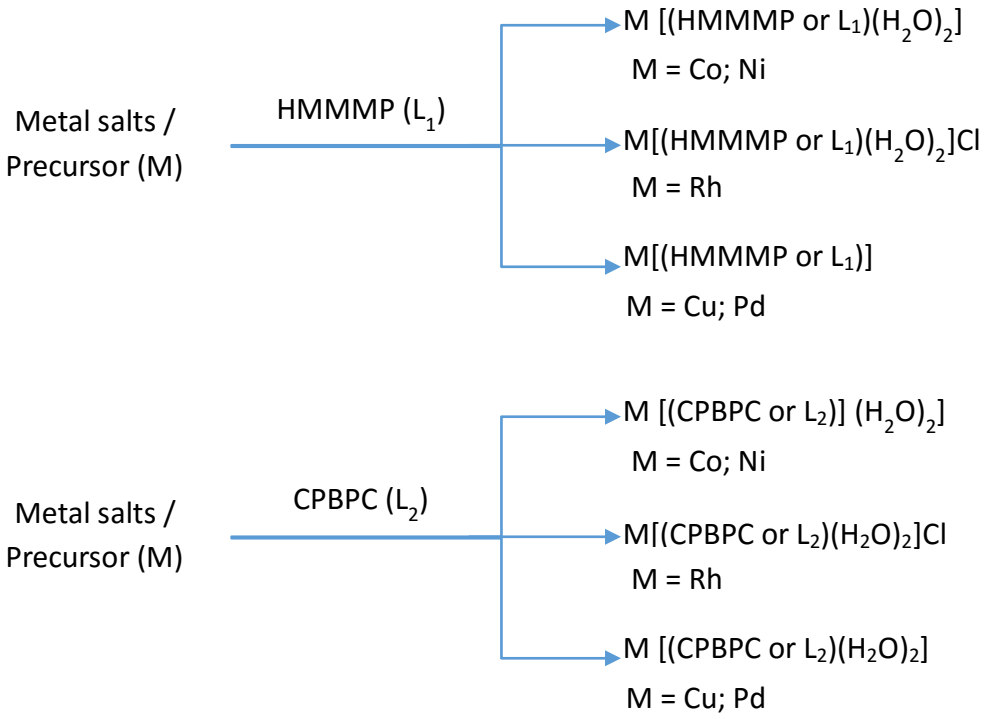
Sl.No.	Ligand /Complexes	Gram (+) ve bacteria	Gram (-) ve bacteria	Fungus	
		B. subtilis	*E. coli*	*A. flavus*	*F. oxysporum*
L_1	HMMMP	50	55	50	50
1	[Co(HMMMP) ($H_2O)_2$]	45	48	39	38
2	[Ni(HMMMP)($H_2O)_2$]	40	44	42	42
3	[Cu(HMMMP)]	22	20	25	25
4	[Rh(HMMMP)($H_2O)_2$]Cl	45	48	50	55
5	[Pd(HMMMP)]	42	40	38	38
L_2	CPBPC	75	70	85	90
6	[Co(CPBPC)($H_2O)_2$]	60	55	50	52
7	[Ni(CPBPC)($H_2O)_2$]	55	50	45	55
8	[Cu(CPBPC]	25	30	32	35
9	[Rh(CPBPC)($H_2O)_2$]Cl	50	60	65	60
10	[Pd(CPBPC)]	45	42	40	43
	Ampicillin	10	14	-	-
	Fluconazole	-	-	12	10

The molar conductance values for all the Schiff base Metal complexes (10^{-3} M) were determined in dichloromethane[63]. These values were found to below (12.4-16.8 $ohm^{-1}cm^2$ mol^{-1}) for compounds 1-6, 9 and 10 indicating non-electrolytic nature. For Metal complexes 7 and 8 was observed between 43.8-46.4 $ohm^{-1}cm^2mol^{-1}$ indicating 1:1 electrolytic nature. The electrolytic nature of compounds 7 and

8 is due to the presence of one chloride ion outside the coordination sphere. The presence of chlorine ion in these compounds was detected by the addition of silver nitrate reagent leading to the formation of white precipitate.



Scheme 1. Reagents and conditions: Methanol, stirring, 2.5 h & 3.5 h for L_1 & L_2 respectively



Scheme 2. Reagents and conditions: Ethanol, Reflux with stirring, 3-4 h.

Mass spectral analysis

The proposed molecular formula of metal complexes were confirmed by the mass spectral analysis by comparing their molecular formula weights with m/z values. The mass spectra of Schiff base Co(II) complexes showed molecular ion peaks at m/z (M^+) 463 (for complex - 1), 444(for complex -2). This data is in good agreement with the respective molecular formulae. The mass spectra of Schiff base Ni(II) complexes showed the molecular ion peaks at m/z (M^+) 462 (for complex-3), 445 (for complex - 4). In the mass spectra of respective Schiff base Cu(II) complexes, molecular ion peaks, m/z (M^+) were observed at 431 (for complex - 5), 413 (for complex - 6). The Schiff base Rh(III) complexes contains molecular ion peaks at m/z (M^+) 542 (for complex - 7), 524 (for complex - 8). These values are in good agreement with the respective weights of the Schiff base Rh(III) complexes calculated on the basis proposed molecular formulae. The Schiff base Pd(II) complexes contains molecular ion peaks at m/z (M^+) 474 (for complex - 9), 456 (for complex - 10).

Antimicrobial activity

The ligands and their metal complexes were tested for their *in vitro* antibacterial activities against pathogenic bacterial strains of *Bacillus subtilis* and *Escherichia coli*. Antifungal activities were evaluated against *Aspergillus flavus* and *Fusarium oxysporum*. The solvent, DMSO did not show any significant inhibition effect against the tested organisms. The antibacterial and antifungal activities of the Schiff base ligands and thier metal complexes were compared with standard reference like ampicillin (antibacterial) and fluconazole (antifungal).

Preliminary screening for all the complexes were performed at the fixed concentration of 1000 µg/ml. Inhibition was recorded by measuring the diameter of the inhibition zone at the end of 24 h for bacteria [54]. All the complexes of the tested series possessed good antibacterial activity against

both Gram-positive (G^+) and Gram-negative(G^-) bacteria. The activities of all these complexes were further confirmed by determining the minimum inhibitory concentration values by liquid dilution method in which the effectiveness was observed at lower concentrations. The comparison of the MICs (in µg/mL) of all complexes and standard drugs against tested strains are presented in **Fig.1**(**Table-6**). It was found that all the metal complexes show very good activity than ligands.

The antibacterial activity of Cu(II), Co(II), Ni(II) and Pd(II) complexes are higher than that of Rh(III) complexes. The antibacterial activity of the metal complexes increase with increase in concentration. It is suggested that the complexes have antibacterial activity inhibit multiplication process of the microbes by blocking their active sites. The bioactivity of the ligand and its metal complexes was found to be in the order: The higher activity of Cu(II) complexes can be explained as, on chelation the polarity of Cu(II) ion is found to be reduced to a greater extend due to the overlap of the ligand orbital and partial sharing of the positive charge of the copper ion with donor groups. Therefore, Cu(II) ions are adsorbed on the surface of the cell wall of microorganisms [55,56]. The adsorbed Cu(II) ions disturb the respiratory process, thus blocking the synthesis of proteins. This, in turn, restricts further growth of the organisms. The antifungal activity of Cu(II) complexes are found to be higher than that of the free ligand as well as other metal complexes.

CONCLUSION

In this report the non-template synthesis of ten new Schiff base complexes. The analytical data show the presence of one metal ion permolecule and suggest a mononuclear structure for these complexes. The magnetic moment values and electronic spectroscopic data are in the favour of octahedral geometry for Co(II), Ni(II), and Rh(III) complexes and square planar geometry for Pd(II) and Cu(II) complexes. In all Schiff base complexes, ligands coordinate through two nitrogen atoms and two oxygen atoms. In addition in compounds 1, 2, 4, 6, 7 and 9 metals are co-ordinate with two water molecules. From the molar conductance values 7 and 8 complexes are having electrolytic nature and others are non-electrolytic nature. All the synthesized ligands and metal complexes were screened for their antibacterial and antifungal activities by MIC method.

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