Synthesis, Characterization and *in vitro* Antibacterial Activity of Co(II), Cu(II) and Ni(II) Complexes with 4-Acylpyrazol-5-one Schiff Bases

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The condensation reactions of 4-acylpyrazol-5-ones with some organic molecules with hydrazide moiety gave ONO and ONS donor Schiff base ligands. The ligands behaved as mono-anionic species when reacted with Co(II), Cu(II) and Ni(II) chlorides to form six coordinate ML₂ type metal complexes. IR spectra show that the ligands act in a tridentate manner and coordinated ONO and ONS donor groups of the ligands to Ni(II), Cu(II) and Co(II) ions. The ligands and complexes were characterized by elemental analysis and spectroscopic methods, while the metal complexes were further characterized by conductivity and magnetic measurements. All the synthesized compounds were screened for their *in vitro* antibacterial activity against some Gram positive and Gram negative clinical bacterial strains. The metal complexes showed better antibacterial activity when compared to the Schiff bases.

Keywords: Synthesis, Schiff base, Spectroscopic methods, Antibacterial activity, Complexes.

INTRODUCTION

Heterocyclic β -diketones with pyrazol moiety and their derivatives possess remarkable capacity for coordination with transition metals giving rise to coordination compounds with varying structural geometry¹⁻⁶. 4-Acylpyrazol-5-one Schiff bases are one of the most studied heterocyclic β -diketones. The presence of various donor atoms such as O, S and N at various positions in these compounds make them to act as multidentate ligands leading to the formation of metal complexes of diverse structural types with a wide range of metals. The tendency of these molecules to form enol and keto tautomers also makes for an interesting study^{7,8}. A variety of 4-acylpyrazolone metal complexes have been described in the literature⁹⁻¹³. In continuation of our series^{14,15} on pyrazolone derivatives and their metal complexes, we present reports on multidentate 4-acylpyrazol-5-one Schiff bases and their Cu(II), Ni(II) and Co(II) complexes.

EXPERIMENTAL

Analytical grade solvents were used without further purification. 1-Phenyl-3-methylpyrazol-5-one, thiosemicarbazide and benzoyl hydrazide were used as supplied by Fluka. 1-Phenyl-3-methyl-4-chlorobenzoyl-pyrazol-5-one, 1-phenyl-3-methyl-4-hexanoyl-pyrazol-5-one and 1-phenyl-3-methyl-4-

butyryl-pyrazol-5-one were synthesized in accordance with the reported procedures⁴. Elemental analyses of C, H and N were performed using Carlo Erba Elemental Analyzer EA 1108. Melting points were obtained with a John Fisher melting point apparatus. Magnetic moments were done on a magnetic susceptibility balance-Sherwood Scientific Cambridge, Model No. MK-I. The molar conductance of the complexes was measured using Innolab conductivity meter Level 1. The percentage of metal in the complexes were determined using an Agilent ICP-MS7500Ce. IR spectra were recorded on a Perkin Elmer Spectrum 100. ¹H and ¹³C NMR spectra were obtained from a Bruker AV 500 MHz for ¹H and 125 MHz for ¹³C using a 5 mm Quadra Nuclei Probe (QNP).

Synthesis of 4-acylpyrazol-5-one Schiff bases: *N'*-(*Z*)-(4-chlorophenyl)(3-methyl-5-oxo-1-phenyl-1,5-dihydro-4*H*-pyrazol-4-ylidene)-methyl]benzohydrazide (ClBepScB), 2-[(1*Z*)-1-(3-methyl-5-oxo-1-phenyl-1,5-dihydro-4*H*-pyrazol-4-ylidene)hexyl]hydrazinecarbothioamide (HepScB) and *N'*-(1*Z*)-1-(3-methyl-5-oxo-1-phenyl-1,5-dihydro-4*H*-pyrazol-4-ylidene)butyl]benzohydrazide (BupScB) were synthesized as follows: A solution of 4-acyl-3-methyl-1-phenylpyrazol-5-one (0.01 mol) in 30 mL ethanol was mixed with a solution of appropriate hydrazide; isonicotinic acid hydrazide, thiosemicarbazide or benzoyl hydrazide (0.01 mol) in ethanol (20 mL). The mixture was refluxed for 2 h and cooled (Fig. 1).

Fig. 1. Synthesis of 4-acylpyrazolone-5 Schiff bases

The precipitate formed was isolated by gravity filtration and recrystallized from ethanol.

Synthesis of Co(II), Cu(II) and Ni(II) metal complexes of 4-acylpyrazolone-5 Schiff bases: To an ethanolic solution (20 mL) of the corresponding Schiff bases ClBepScB, HepScB or BupScB (0.001 mol), ethanolic solution (10 mL) of the respective metal(II) chloride (0.001 mol) was added with constant stirring. The coloured mixture was then refluxed for 4 h. The resulting metal complex was filtered hot, washed with boiling mixture of 1:1 water/ethanol, dried under suction and kept in vacuum over $CaCl_2$.

Antibacterial activity: *Escherichia coli*, *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, *Salmonella gallinarum* and *Bacillus subtilis* were collected from clinical samples. The Gram-positive and Gram-negative

bacteria were identified using bio-chemical methods¹⁶. Antibacterial activity was studied by Agar well diffusion method¹⁷. Colonies of each test bacterium were suspended in sterile normal saline and adjusted to match 0.5 Mcfarland turbidity standard. Each bacterial suspension was used to spread onto the surface of sterile Mueller Hinton agar plates. The surface of the plates were allowed to dry and a sterile cork borer of 6 mm diameter was used to bore wells in the agar plates. 50 mL of dilute solution (20 mg/mL) of each synthesized compound was delivered into each well. The plates were allowed to stand for 30 min to aid diffusion and then incubated at 37°C for 24 h. After incubation the zones of inhibition were measured and the mean recorded.

RESULTS AND DISCUSSION

Analytical and physical data: Table-1 listed the analytical and physical data of all the compounds. The metal complexes are coloured, soluble in polar solvents (dimethyl sulphoxide, dimethyl formamide and anhydrous ethanol) but insoluble in hydrocarbon solvents such as, hexane, pentane and tetrahydrofuran and carbon tetrachloride. The molar conductivity values of the metal complexes in DMSO was in the region of $7-12 \Omega^{-1} cm^2 mol^{-1}$, which suggest that they are non-electrolytes in DMSO¹⁸⁻²⁰.

FT-IR spectra: Table-2 summarizes the most important vibrational bands in the IR spectra of the Schiff bases and their metal complexes. Two strong vibrational bands (cm^{-1}); 1643, 1596 (ClBepScB) and 1646, 1596 (BuPScB) have been assigned to $\nu(C=O)$ of the hydrazide moiety and the pyrazolone ring, respectively²¹⁻²³. The band observed at $1592 cm^{-1}$ was assigned to $\nu(C=O)$ of the pyrazolone ring in HepScB. $\nu(C=O)$ bands of the hydrazide moieties in ClBepScB and BupScB shifted to lower frequencies ($\Delta\nu 20-40 cm^{-1}$), in the metal

TABLE-1
ANALYTICAL AND PHYSICAL DATA OF THE LIGANDS AND THEIR METAL COMPLEXES

Compound	Colour	m.f.	Yield (%)	Elemental analysis % found (calculated)				m.p. (°C)
				C	H	N	M	
ClBepScB	Yellow	$ClC_{24}H_{19}N_5O_2$	77	66.60 (66.90)	4.02 (4.45)	12.87 (13.01)	-	100
CuClBepScB	Dark blue	$CuCl \cdot C_{48}H_{36}N_{10}O_4$	73	62.97 (62.44)	4.14 (3.93)	12.88 (12.14)	6.98 (6.88)	146
CoClBepScB	Orange	$CoCl \cdot C_{48}H_{36}N_{10}O_4$	68	62.89 (62.75)	4.47 (3.95)	12.30 (12.20)	6.54 (6.42)	186
NiClBepScB	Green	$Ni Cl \cdot C_{48}H_{36}N_{10}O_4$	65	63.14 (62.76)	4.10 (3.95)	11.90 (12.20)	7.10 (6.42)	184
HepScB	Whitish	$C_{17}H_{23}N_3OS$	80	58.50 (59.13)	6.79 (6.67)	20.07 (20.29)	-	176
CuHepScB	Dark brown	$CuC_{34}H_{44}N_{10}O_2S_2$	68	54.44 (54.27)	6.69 (5.89)	18.39 (18.62)	8.01 (8.45)	186
NiHepScB	Green	$NiC_{34}H_{44}N_{10}O_2S_2$	65	55.10 (54.62)	6.15 (5.93)	18.88 (18.74)	7.20 (7.85)	290
CoHepScB	Brown	$CoC_{34}H_{44}N_{10}O_2S_2$	66	55.10 (54.60)	6.64 (5.93)	19.06 (18.73)	8.10 (7.88)	280
BupScB	Yellow	$C_{21}H_{22}N_4O_2$	70	69.20 (69.59)	5.89 (6.12)	15.20 (15.46)	-	230
CuBupScB	Brown	$CuC_{42}H_{42}N_8O_4$	65	64.88 (64.14)	5.89 (5.38)	13.77 (14.25)	7.89 (8.08)	278
CoBupScB	Dark yellow	$CoC_{42}H_{42}N_8O_4$	67	64.78 (64.52)	5.11 (5.42)	14.87 (14.34)	1.10 (7.54)	280
NiBupScB	Green	$NiC_{42}H_{42}N_8O_4$	68	64.96 (64.54)	4.88 (5.42)	13.88 (14.35)	7.98 (7.51)	285

TABLE-2
 RELEVANT IR ABSORPTION BANDS ASSIGNMENT FOR THE IMINES AND METAL COMPLEXES (cm⁻¹, KBr)

Compound	$\nu(\text{N-H})$	$\nu(\text{C=O})^a$	$\nu(\text{C=O})^b$	$\nu(\text{C=N})$	$\nu(\text{N-N})$	$\nu(\text{C-O})$	$\nu(\text{C=S})$	$\nu(\text{M-O})$	$\nu(\text{M-N})$	$\nu(\text{M-S})$
ClBepScB	3284	1643	1596	-	1015	-	-	-	-	-
CuClBepScB	3385	1612	-	1595	1088	1437	-	515	411	-
NiClBepScB	3382	1602	-	1574	1053	1437	-	510	430	-
CoClBepScB	3375	1602	-	1566	1053	1450	-	511	421	-
HepScB	3285	-	1592	-	1046	-	843	-	-	-
CuHepScB	3285	-	-	1591	1038	1479	811	509	418	695
NiHepScB	3100	-	-	1594	1079	1455	853	509	450	689
CoHepScB	3054	-	-	1595	1065	1455	801	508	459	689
BupScB	3129	1646	1595	-	1029	-	-	-	-	-
CuBupScB	3089	1621	-	1597	1053	1437	-	514	421	-
NiBupScB	3376	1603	-	1566	1055	1437	-	512	422	-
CoBupScB	3375	1601	-	1566	1075	1437	-	510	421	-

^ahydrazide moiety, ^b pyrazolone ring

complexes, which is an indication that the oxygen atoms are involved in coordination²⁴⁻²⁶. Bands in the region of 1595-1566 cm⁻¹ have been assigned to imino $\nu(\text{C=N})$ in all the metal complexes. The bands in the region of 1479-1430 cm⁻¹ in the metal complexes have been assigned to $\nu(\text{C-O})$ ^{21,27}. The bands around 3390-3050 cm⁻¹ have been assigned to $\nu(\text{N-H})$. In the spectra of metal complexes low frequency bands in the range 459-411 cm⁻¹ were assigned to $\nu(\text{M-N})$, the bands in the range 515-508 cm⁻¹ were assigned to $\nu(\text{M-O})$ ²⁸⁻³¹ while the bands in the region 695-689 cm⁻¹ were assigned to $\nu(\text{M-S})$. In the spectra of HepScB and its metal complexes the bands in the region 853-801 cm⁻¹ were assigned $\nu(\text{C=S})$ ³², the shift to either lower or higher frequencies in the metal complexes, $\Delta\nu$ about 10-40 cm⁻¹, suggest that there is coordination to the metals *via* (C=S). The ligands exist in the keto-amine form (I) in the solid state, but they reacted in the enol-imine form (III) (Fig. 1) when coordinated to metal ions in solution. The Schiff bases are tridentate, coordinating *via* pyrazolone ring enolic (C-O), azomethine (C=N), hydrazide side chain (C=O) or the thiosemicarbazide (C=S).

¹H NMR spectra: Table-3 lists the ¹H NMR data of the Schiff bases. The main features of interest observed in the ¹H NMR spectra include the signals of the 3-methyl substituents at δ (ppm) values upfield in the range 2.35-2.50. The 4-acyl protons in HepScB and BupScB which are basically made up of the terminal -CH₃ and the methylene protons. The signals of the methyl protons appeared as triplets, while the signals of the methylene protons appeared as either triplets or multiplets depending on the number of hydrogen atoms vicinal to the methylene hydrogens³³. Relatively high frequency proton

chemical shifts ranging from 6.98-10.04 ppm were assigned to phenyl hydrogens and -NH-. Assignments done on related studies^{1,34-36} are consistent with the present report.

¹³C NMR spectra: The chemical shift and carbon assignments are displayed in Tables 4 and 5. Assignments were done based on the structures shown in Fig. 2. The signals downfield have been assigned to carbon atom depending on the extent of deshielding of the carbons, while the signals upfield have been assigned to shielded carbons and also taking into consideration the relative shielding effect on the carbons. The relatively high frequency chemical shifts were assigned to -CO, azomethine carbons, Cl-C carbon and CNN carbons in the 4-acylpyrazol-5-one Schiff bases while the relatively lower frequency chemical shifts were assigned to -CH₃ of the 3-methyl, the -CH₃ and methylene of the 4-acyl moieties. Generally for phenyl carbons in rings, the nitrogen atom attached to the phenyl group shields the *ortho* carbon more strongly than the *para* carbon while the *meta* carbon is the least shielded^{1,35}, assignments were therefore done bearing this fact in mind. The ¹³NMR spectrum of ClBepScB exhibited 18 carbons signals comprising 17 *sp*² and 1 *sp*³ carbons, HepScB exhibited 15 carbons signals comprising 10 *sp*² and 5 *sp*³ carbons while BupScB exhibited 17 carbons signals comprising 14 *sp*² and 3 *sp*³ carbons. The C2 and C5 pyrazolone ring carbon atoms resonated at δ 147.86 and 165.86 ppm (ClBepScB), δ 165.57 and 170.11 ppm (HepScB) and δ 165.55 and 167.60 ppm (BupScB), respectively. Other high frequency chemical shifts were assigned to C11 carbons, C7 of the R1 side chains (ClBepScB and BupScB) and C1 carbon (HepScB). The *sp*³ 3-methyl C1 carbons and 4-acyl side chain carbons

 TABLE-3
¹H NMR SPECTRA DATA OF 4-ACYLPYRAZOLOIMINES IN CDCl₃ (CHEMICAL SHIFTS IN δ ppm RELATIVE TO TMS)

Schiff base	3-Methyl protons	4-Acyl protons		Phenyl protons
		Methyl	Methylene	
ClBepScB	2.50 (s, 3H, -CH ₃)	-	-	6.98-8.20 (m, 14H, 3ph), NH
HepScB	2.50 (s, 3H, -CH ₃)	0.90 (t, 3H, -CH ₂ CH ₃)	2.61 (t, 2H, N=C-CH ₂ -) 1.30-1.61 (m, 6H, (-CH ₂) ₃)	7.15-10.04 (m, 10H, 2ph), NH
BupScB	2.35 (s, 3H, -CH ₃)	0.83 (t, 3H, -CH ₂ CH ₃)	2.84 (t, 2H, N=C-CH ₂ -) 1.37-1.84 (m, 2H, (-CH ₂) ₂)	7.20-9.85 (m, 15H, 3ph), NH

TABLE-4
¹³C NMR CHEMICAL SHIFTS OF THE 4-ACYLPYRAZOLONE-5 SCHIFF BASE (δ ppm RELATIVE TO TMS)

Schiff base	Carbon										
	1	2	3	4	5	6	7	8	9	10	11
ClBepScB	16.13	147.86	128.88	135.82	165.86	118.46	127.48	124.60	127.48	118.46	139.26
HepScB	14.19	165.57	125.70	139.30	170.11	118.89	128.89	124.19	128.89	118.89	147.02
BupScB	14.09	165.55	125.15	163.22	167.60	125.24	128.64	127.66	128.64	125.24	163.67

 TABLE-5
¹³C NMR CHEMICAL SHIFTS OF R AND R1 SIDE CHAINS (δ ppm RELATIVE TO TMS)

Schiff base		Carbon						
		1	2	3	4	5	6	7
ClBepScB	R	163.23	129.32	132.00	130.39	132.00	129.32	-
	R1	130.39	127.58	129.10	127.74	129.10	127.58	166.80
HepScB	R	16.93	22.91	27.99	31.94	40.30	-	-
	R1	183.42	-	125.21	126.64	125.21	126.64	147.17
BupScB	R	16.83	22.02	35.18	-	-	-	-
	R1	130.71	128.70	127.48	130.99	127.48	128.70	171.62

Fig. 2. ¹³C NMR numbering schemes for 4-acylpyrazolone-5 Schiff base

in HepScB and BupScB resonated at δ in the range about 14-40 ppm.

Electronic spectra and magnetic measurements: The significant electronic absorption bands in the spectra of the ligands and their metal complexes recorded in DMSO solution are presented in Table-6. High frequency bands in the region 42,000-25,000 cm⁻¹ have been assigned to π → π* and n → π* transitions³⁷⁻³⁹. The spectra of ClBepScB and BupScB Cu(II) complexes show bands in the region 11,000-13,000 cm⁻¹, 14,000-16,000 cm⁻¹ and 20,000-21,000 cm⁻¹, assignable to ²B_{1g} → ²A_{1g}, ²B_{1g} → ²B_{2g} and ²B_{1g} → ²E_g transitions respectively⁴⁰⁻⁴³, while in the spectra of HepScB Cu(II) complex *d-d* transition bands assignable to ²B_{1g} → ²B_{2g} and ²B_{1g} → ²E_g transitions, respectively were observed at 15,479 and 20,101 cm⁻¹. The observed magnetic moments in the range 1.95-2.09 BM suggest octahedral geometry for all the complexes⁴⁰. Copper(II) octahedral ²E_g ground state has an extra electron in the e_g set of *d* orbitals that is strongly anti-bonding with ligands, which results in a symmetry lowering Jahn-Teller distortion of the metal environment⁴³. The Ni(II) complexes were found

to be paramagnetic species with magnetic moments values in the range 2.95-2.97 BM, which are consistent with octahedral geometry. The Ni(II) complexes display bands in the region 11,000-13,000, 15,000 cm⁻¹ and 23,000-24,000 cm⁻¹ that are assignable to ³A_{2g} → ³T_{2g}(F), ³A_{2g} → ³T_{1g}(F) and ³A_{2g} → ³T_{1g}(P) transitions, respectively⁴⁴. The three bands in the region 10,000, 18,000 and 23,000 cm⁻¹ observed for Co(II) complexes have been assigned to ⁴T_{1g}(F) → ⁴T_{2g}(F), ⁴T_{1g}(F) → ⁴A_{2g} and ⁴T_{1g} → ⁴T_{1g}(P) transitions, respectively⁴⁰. The magnetic moment values in the range 4.70-4.82 BM and the observed electronic transitions indicate high spin octahedral geometry of the complexes.

Antimicrobial activity: The *in vitro* antibacterial activity of the Schiff bases and their metal complexes against Gram-negative bacterial strains *Escherichia coli* (EC), *Pseudomonas aeruginosa* (PA), *Klebsiella pneumonia* (KP) and *Salmonella gallinarum* (SG), Gram-positive bacterial strains *Staphylococcus aureus* (SA) and *Bacillus subtilis* (BS) were studied. The antibacterial results are shown in Table-7. All the Schiff bases and their metal complexes exhibited varying degrees of

TABLE-6
 ELECTRONIC SPECTRA, MAGNETIC MOMENTS AND CONDUCTIVITY DATA

Compound	Bands (cm ⁻¹)(ϵ , Lmol ⁻¹ cm ⁻¹)	Assigned transition	μ_{eff} (B.M) ^a	λ_M ^b ($\Omega^1\text{cm}^2\text{mol}^{-1}$)
ClBepScB	38,135(4270) 27,667(6174),25,667(3220)	$n \rightarrow \pi^*$ $\pi \rightarrow \pi^*$, $\pi \rightarrow \pi^*$	-	-
CuClBepScB	12,724(144) 15,139(72) 21,267(157)	$^2B_{1g} \rightarrow ^2A_{1g}$ $^2B_{1g} \rightarrow ^2B_{2g}$ $^2B_{1g} \rightarrow ^2E_g$	1.95	7.70
NiClBepScB	12,936(172) 14,484(202) 24,391(454)	$^3A_{2g} \rightarrow ^3T_{2g}(\text{F})$ $^3A_{2g} \rightarrow ^3T_{1g}(\text{F})$ $^3A_{2g} \rightarrow ^3T_{1g}(\text{P})$	2.97	8.77
CoClBepScB	10,308(220) 18,212(104), 23,310(155)	$^4T_{1g}(\text{F}) \rightarrow ^4T_{2g}(\text{F})$ $^4T_{1g}(\text{F}) \rightarrow ^4A_{2g}(\text{F})$ $^4T_{1g}(\text{F}) \rightarrow ^4T_{1g}(\text{P})$	4.70	7.10
HepScB	41,494(3240), 38,095(3210) 27,435(4370)	$n \rightarrow \pi^*$, $n \rightarrow \pi^*$ $\pi \rightarrow \pi^*$	-	-
CuHepScB	15,479(52.4) 20,101(56.8)	$^2B_{1g} \rightarrow ^2B_{2g}$ $^2B_{1g} \rightarrow ^2E_g$	2.09	10.32
CoHepScB	10,264(164) 18,425(124) 23,095(155)	$^4T_{1g}(\text{F}) \rightarrow ^4T_{2g}(\text{F})$ $^4T_{1g}(\text{F}) \rightarrow ^4A_{2g}(\text{F})$ $^4T_{1g}(\text{F}) \rightarrow ^4T_{1g}(\text{P})$	4.89	12.56
NiHepScB	11,234(145) 14,666(176) 23,310(145)	$^3A_{2g} \rightarrow ^3T_{2g}(\text{F})$ $^3A_{2g} \rightarrow ^3T_{1g}(\text{F})$ $^3A_{2g} \rightarrow ^3T_{1g}(\text{P})$	2.90	9.30
BupScB	39,840.64(3670) 33,670(4230) 30,864.20(3780)	$n \rightarrow \pi^*$ $n \rightarrow \pi^*$ $\pi \rightarrow \pi^*$	-	-
CuBupScB	11,216(212) 14,121(115) 21,174(167)	$^2B_{1g} \rightarrow ^2A_{1g}$ $^2B_{1g} \rightarrow ^2B_{2g}$ $^2B_{1g} \rightarrow ^2E_g$	2.05	13.67
CoBupScB	10,121(154) 18,244(114) 23,174(202)	$^4T_{1g}(\text{F}) \rightarrow ^4T_{2g}(\text{F})$ $^4T_{1g}(\text{F}) \rightarrow ^4A_{2g}(\text{F})$ $^4T_{1g}(\text{F}) \rightarrow ^4T_{1g}(\text{P})$	4.85	10.32
NiBupScB	11,234(154) 14,113(145) 23,817(230)	$^3A_{2g} \rightarrow ^3T_{2g}(\text{F})$ $^3A_{2g} \rightarrow ^3T_{1g}(\text{F})$ $^3A_{2g} \rightarrow ^3T_{1g}(\text{P})$	2.97	12.86

^a μ_{eff} : Magnetic moment; ^b λ_M : Molar conductivity

 TABLE-7
 ANTIMICROBIAL DATA OF SYNTHESIZED COMPOUNDS (ZONE OF INHIBITION IN mm)

Compound	<i>Escherichia coli</i>	<i>Pseudomonas aeruginosa</i>	<i>Salmonella gallinarum</i>	<i>Klebsiella pneumonia</i>	<i>Bacillus subtilis</i>	<i>Staphylococcus aureus</i>
ClBepScB	+	+	+	+	++	++
CuClBepScB	+++	+++	+++	+++	+++	+++
NiClBepScB	++	++	++	++	++	++
CoClBepScB	+++	+++	+++	+++	+++	+++
HepScB	-	++	++	++	+++	+++
CuHepScB	-	+++	++++	+++	+++	+++
NiHepScB	-	+++	++	+++	++++	+++
CoHepScB	-	+++	+++	+++	++++	+++
BupScB	+++	++	-	-	-	-
CuBupScB	++++	+++	++	++	++	+
NiBupScB	++++	+++	++	++	+	+
CoBupScB	++++	+++	+	+	+	+

-(no appreciable activity), + (inhibition zone < 10 mm), ++ (inhibition zone 10-13 mm), +++ (inhibition zone 14-20 mm), ++++ (inhibition zone > 20 mm)

inhibitory effect on the growth of the tested bacterial strains, however the metal complexes showed better antibacterial activity when compared to the Schiff bases, with only slight exception in few cases. For instance HePScB and its metal complexes did not show any appreciable activity against

Escherichia coli (EC). Considering the fact that the ultimate action of antimicrobial agents is the denaturation of proteins of the cell, which results in inhibiting normal cellular processes⁴⁵, it follows that any condition that enhances the penetration of the cell walls by antimicrobial agents is bound

to increase their activity. The lipid membrane that surrounds the cell favours the passage of only lipid soluble materials, thus lipophilicity is also an important factor for antimicrobial activity⁴⁶. The metal complexes are more lipophilic than the Schiff bases, consequently they are able to penetrate the lipid membranes better than the Schiff bases and thereby effect better activity⁴⁷⁻⁴⁹.

On the basis of microanalytical data, magnetic moments, conductivity measurements and spectral analysis the following structure has been proposed for the metal complexes (Figs. 3 and 4).

R2=ClC₆H₄-. R3=C₆H₅-(ClBepScB), R2=CH₃CH₂CH₂-, R3=C₆H₅-(BupScB); M: Ni(II), Cu(II) and Co(II)

Fig. 3. Structure of metal complexes of ClBepScB and BupScB; M: Ni(II), Cu(II) and Co(II)

Fig. 4. Structure of metal complexes of HepScB; M: Ni(II), Cu(II) and Co(II)

Conclusion

The results of this study show that the pyrazol-5-one Schiff base ligands exist in the solid state in the keto-amine form and coordinated in the enol-imine form as tridentate mono-anionic

species. The analytical data show 1:2 complexes of the ligands with Co(II), Cu(II) and Ni(II). The electronic data and magnetic moments results suggest octahedral geometry around the metal (II) ions. The metal complexes exhibit enhanced antibacterial activities compared to their parent ligands.

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