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Mononuclear Transition Metal Complexes Containing Quadridentate Schiff Bases as N_2O_2 Donors: Synthesis, Spectral Characterization Properties and Antibacterial Activity

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A qudridendate Schiff base ligand is synthesized by the condensation of active primary amine 2-amino-4-*tert*-butylphenol with β-diketone. It is found to be an N_2O_2 donor chelate. Quadridentate Schiff bases with an N_2O_2 donor have been widely studied for their ability to coordinate metal ions. Its complexes with Fe(III), Co(II), Ni(II), Cu(II) and Zn(II), have been synthesized and characterized by micro analysis, molar conductivity, magnetic susceptibility studies, UV, IR, NMR, Mass spectral studies, cyclic voltammetry, ESR spectral studies, thermal behaviour and Powder X-ray diffraction studies have also been carried out. The DNA cleavage activities of the Schiff base and its complexes were monitored by agarose gel electrophoresis method in the presence of hydrogen peroxide and antibacterial activities have also been studied.

Keywords: Schiff base complexes, Transition metals, Quadridentate, DNA cleavage, Antibacterial activity.

INTRODUCTION

A new potentially quadridentate Schiff base ligand and its mononuclear metal complexes have been prepared by the condensation of 2-amino-4-*tert*-butylphenol and β-diketone in 2:1 molar ratio. The Schiff base ligand is formed to be dibasic with N_2O_2 quadridentate donor sites. It coordinates with metal ions to form mononuclear complexes after the removal of the hydrogen atoms of the phenolic groups in all the complexes. The ^{1}H NMR, ^{13}C NMR and Mass spectra confirm the formation of N_2O_2 quadridentate Schiff base chelate ligand. Schiff bases of 2-amino-4-*tert*-butylphenol and its complexes have a variety of applications including medical, surgical, clinical and analytical, or other patient oriented applications, or combined with any food product or ingested in any forms [1-3]. All the metal complexes have been fully characterized with the help of elemental analysis, molar conductance, magnetic susceptibility studies and spectral studies. The analytical data helped to elucidate the structure of the metal complexes. All the complexes exhibit electrolytic behaviour in ethanol. The IR spectral data suggest the involvement of azomethine nitrogen in coordination to the central metal ion. The electronic, ESR and magnetic data suggests an octahedral geometry for the Fe(III), Co(II) and Ni(II) metal complexes and a square planar geometry for Cu(II) and Zn(II) complexes [4-6]. The cyclic voltammetry and controlled electrolysis studies of Fe(III) and Cu(II) complexes indicate that the metal ion in the mononuclear complexes undergo quasi reversible one electron reduction and oxidation. The thermogravimetric analysis shows that Fe(III), Co(II) and Ni(II) metal complexes possess two aqua molecules coordinated with octahedral environment, Cu(II) and Zn(II) complexes have square planar geometry as there are no coordinated aqua molecules. The powder XRD patterns were recorded in PAN-analytical diffractometer with CuK_α radiation of wavelength 1.54060 Å operating at a voltage of 30 kV and a current of 40 mA. The nucleolytic cleavage activities of the complexes were assayed on pUC19 plasmid DNA using gel electrophoresis in the presence of H_2O_2 and the complexes show promising nuclease activity [7-9]. The complexes show significant growth inhibitory activity against the bacteria Gram-positive and Gram-negative like *Bacillus cereus*, *Streptococcus pyogenes, Listeria monocytogens, Escherichia coli* and *Salmonella typhi* than the free ligands. The compounds were subjected to antimicrobial activity screening using serial broth dilution method and minimum inhibitory concentration (MIC) is determined. All the complexes show considerable antibacterial activity. The MIC of 31.25 µg/mL of Cu(II) complex is noticeable.

EXPERIMENTAL

All the reagents were of AR grade and the solvents were purified by standard methods. IR spectra (4000-400 cm^{-1}) taken on KBr disc using a Perkin Elmer spectrum ONE-N017-1159 spectrophotometer. Micro analysis of carbon, hydrogen and nitrogen were obtained using elemental analyzer, magnetic moments were measured at room temperature on vibrating sample magneto meter EG & G Model: 155 using $Hg[Co(CN)_4]$ as standard. Electrical conductances of the complexes were made on a systronic conductivity meter type 304 in DMSO with a dip type cell having platinum electrode. The UV-visible spectra were run on a Hitachi U-2800 spectrophotometer (200-1100 nm) in nujol mull. TGA-DTA analyses were obtained by using NETZCH STA-409C/CD thermal analyzer. The electrochemical properties of the complexes have been studied by cyclic voltammetry obtained on a CHI-600A electrochemical analyzer under oxygen free condition using a three electrode cell in which glassy carbon acts as working electrode, Calomel acts as reference electrode and platinum wire as an auxiliary electrode and sodium perchlorate as back ground electrolyte. The ^1H NMR, ^{13}C NMR spectra were recorded on JKM-ECS 400 in DMSO-d_6 solvent. The mass spectrum was recorded using WATERS-Q-T of premier-HAB213, electro spray ionization-MS. ESR spectra of the copper complex were recorded at 300 K on a Bruker Biospin GmbH spectrometer at Indian Institute of Technology, Kanpur.

Antibacterial activity and MIC values: The antibacterial screening of the compounds was carried out against the Gram-positive bacteria (*Bacillus cereus*, *Streptococcus pyogenes* and *Listeria monocytogens)* and Gram-negative bacteria (*Escherichia coli* and *Salmonella typhi)* on the free ligand and metal complexes by cup plate method using the nutrient agar as medium. In a typical procedure, molten nutrient agar kept at 115-120 °C was poured into a petri dish and allowed to solidify. The small wells (10 mm diameter with 1cm distance) were made in the agar medium by carefully using a sterile cork and these were completely filled with test solutions. The plates were incubated for 24 h at 37 °C. The diameters of the zones of inhibition for all the test compounds were measured and the results were compared with that of standard tetracycline at the same condition. The antibacterial activities were done at 15.62, 31.25, 62.5 and 125 µg/mL concentration in DMSO solvent by using three Gram-positive and two Gram-negative bacteria by the minimum inhibitory concentration (MIC) method.

DNA cleavage studies: The pUC19 DNA at pH 7.5 in Tris-HCl buffered solution was used to form agarose electrophoresis. Oxidative cleavage of DNA was examined by keeping the concentration of the 30 µM of complex and 2 µL of pUC19 DNA and made up the volume to 16 µL with 5 mM tris-HCl/5 mM NaCl buffer solution. The resulting solution was incubated at 37 °C for 2 h and electrophoresed for 2 h at 50 V in Tris-acetate-EDTA (TAE) buffer using 1 % agarose gel containing 1 µg/mL ethidium bromide and photographed under UV light. All the experiments were performed at room temperature.

Synthesis of Schiff base: A solution of 2-amino-4-*tert*-butylphenol (0.02 mol) and acetyl acetate (0.01 mol) in 2:1 molar ratio in ethanol was mixed with constant stirring. The resulting mixture was refluxed for 6 h in a water bath. The concentrated solution was filtered out, washed with ethanol and recrystallized using a solution of chloroform and ethanol mixture, its purity was checked by TLC (Fig. 1).

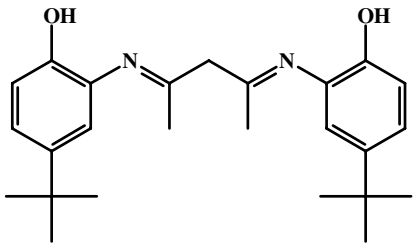

Fig. 1. Schiff base free ligand

Synthesis of Fe(III), Co(II), Ni(II), Cu(II) and Zn(II) complexes: A 1 mmol hot ethanolic solution of (35 mL) of Schiff base was mixed with 1 mmol ethanolic solution (15 mL) of $FeCl_3 \cdot 6H_2O$, $Co(CHCOO) \cdot 4H_2O$, $Ni(CHCOO) \cdot 4H_2O$, $Cu(CH_3COO)_2$ and $ZnSO_4$ and refluxed on water bath for 2-4 h. The concentrated solution was filtered out, washed with ethanol and recrystallized using a solution of chloroform and ethanol mixture, its purity was checked by TLC.

RESULTS AND DISCUSSION

Micro analysis: The elemental analyses C, H and N analyses were carried out using an Elementar Vario EL III elemental analyzer for the Schiff base and its complexes. The obtained elemental analyses data were [10] in good agreement with the calculated values and display the formation of 1:1 [M:L] ratio (Table-1).

Molar conductivity and magnetic susceptibility measurements: The molar conductance values of the complexes fall in the range 10-81 S cm^2 mol^{-1} (Table-1) in DMF suggesting that the complexes of Co(II), Ni(II), Cu(II) Zn(II) behave as non-electrolytes and those of Fe(III) behave as (1:1) electrolytes.

TABLE-1
ELEMENTAL ANALYSES OF SCHIFF BASE AND ITS COMPLEXES

Compound	m.w.	Elemental analysis (%): Calcd. (Found)				μ_{eff} (BM)	Λ_m (S cm^2 mol^{-1})
		M	C	H	N		
$C_{25}H_{34}N_2O_2$	394	–	76.10 (76.08)	8.68 (8.66)	7.10 (7.08)	–	–
$[FeC_{25}H_{34}N_2O_2(H_2O)_2]Cl$	592	9.42 (9.40)	50.65 (60.63)	6.12 (6.09)	4.72 (4.70)	5.72	81.6
$[CoC_{25}H_{34}N_2O_2(H_2O)_2]$	607	9.69 (9.65)	49.41 (49.39)	5.97 (5.95)	4.61 (4.59)	4.61	17.5
$[NiC_{25}H_{34}N_2O_2(H_2O)_2]$	607	9.66 (9.62)	49.43 (49.40)	5.97 (5.95)	4.61 (4.59)	2.92	14.6
$[CuC_{25}H_{32}N_2O_2]$	574	11.06 (11.04)	52.29 (52.25)	5.61 (5.59)	4.87 (4.85)	1.86	18.9
$[ZnC_{25}H_{32}N_2O_2]$	555	11.78 (11.75)	54.10 (54.06)	5.81 (5.79)	5.04 (5.01)	Dia.	10.4

The room temperature magnetic moment (μ_{eff}) values exhibit paramagnetic nature for Fe(III), Co(II), Ni(II) and Cu(II) complexes and diamagnetism for Zn(II) complex (Table-1). The Fe(III), Co(II) and Ni(II) complexes exhibit a magnetic moment of 5.72 BM, 4.61 BM and 2.92 BM respectively suggesting octahedral geometry. The observed magnetic moments for the Cu(II) complex is 1.86 BM suggesting an square geometry [11-13].

Electronic spectra: The electronic absorption spectra of free Schiff base ligand (L) and its metal(II) complexes were recorded in ethanol solution (10^{-3} M) in the range 200-1100 nm at room temperature (Table-2). Schiff base ligand shows two bands at 32,051 and 40,160 cm^{-1} corresponding to $\pi \rightarrow \pi^*$ transition of aromatic benzene moiety and $n \rightarrow \pi^*$ transition of azomethine C=N bond. Iron(III) complex shows three bands at 13600, 16100 and 19379 cm^{-1} which corresponds to $^6A_{1g} \rightarrow {}^1T_{1g}$, $^6A_{1g} \rightarrow {}^1T_{1g}(G)$ and $^6A_{1g} \rightarrow {}^1T_{2g}(D)$ transition and its magnetic moment value (5.72 BM) is very close to the theoretically calculated (5.92 BM) value. This indicates an octahedral environment around the Fe(III) ion. The ligand field parameter Dq and LFSE value for this complex are 1937.9 cm^{-1} and 55.41 Kcal mol^{-1} respectively. Cobalt(II) complex exhibits three bands at 11,507, 13,477 and 17,985 cm^{-1} which corresponds to $^4T_{1g}(F) \rightarrow {}^4T_{2g}(F)$, $^4T_{1g}(F) \rightarrow {}^4A_{2g}(F)$ and $^4T_{1g}(F) \rightarrow {}^4T_{1g}(P)$, respectively and the observed magnetic moment value (4.61 BM) indicates that it has an octahedral environment. The ligand field parameter Dq and LFSE value for this complex are1150.7 cm^{-1} and 32.90 Kcal mol^{-1}, respectively The nickel(II) complex shows three bands at 10,400, 13,927 and 19,230 cm^{-1} which are assigned to $^3A_{2g}(F) \rightarrow {}^3T_{2g}(F)$, $^3A_{2g}(F) \rightarrow {}^3T_{1g}(F)$ and $^3A_{2g}(F) \rightarrow {}^3T_{1g}(P)$ respectively and the observed magnetic moment (2.92 BM) which confirms the octahedral geometry. The ligand field parameter Dq and LFSE value for this complex are 1300.0 cm^{-1} and 37.17 Kcal mol^{-1}, respectively. Copper(II) complex shows two bands, one at 23,696 cm^{-1} corresponding to the LMCT band and another broad band, centered at 14,164 cm^{-1} due to *d-d* electronic transition. These bands confirm its square planner geometry. The observed magnetic moment (1.86 BM) supports its monomeric nature and geometry of the complex. The ligand field parameter Dq and LFSE value for this complex are1416.4 cm^{-1} and 40.50 Kcal mol^{-1} respectively. Zn(II) complex shows only one broad band centered at 18,796 cm^{-1} in the UV region which is due to $L \rightarrow M$ charge transfer. From its analytical and spectral data, by analogy a square geometry is also assigned to the Zn(II) complex. The ligand field parameter Dq and LFSE value for this complex are 1879.6 cm^{-1} and 53.74 Kcal mol^{-1} respectively [14,15].

Infrared spectra: The IR spectra of the free ligand were shifted upon complex formation. A shift to lower frequency, relative to the free Schiff base ligands, of about 5-22 cm^{-1} for the (-C=N-) stretching vibration in the complexes showed that coordination occurs through the nitrogen atoms of the azomethine groups (Table-3). The IR spectra of ligand showed a band at 3368 cm^{-1} assigned to ν(OH) group. The disappearance of this band in its complexes indicates the deprotanation [16,17] of the hydroxyl group and coordination through oxygen. The band observed at 1652 cm^{-1} region in the ligand is assigned to the azomethine group ν(-C=N-). The band at 1273 cm^{-1} due to ν(C-O) of phenolic moiety shifted to higher frequencies region in metal complexes, indicating coordination of phenolic oxygen atom to the metal ion. Two new bands at lower frequencies region 520-585 cm^{-1} and 486-456 cm^{-1} are assigned to ν(M-O) and ν(M-N) respectively. The appearance of bands at 3418, 3459 and 3466 cm^{-1} in the Fe(III), Co(II) and Ni(II) complexes

TABLE-2
UV-VISIBLE SPECTRA OF SCHIFF BASE AND ITS COMPLEXES

Compound	Transition	λ_{max} (cm^{-1})	D_q	LFSE (KJ mol^{-1})
Schiff base	$\pi \rightarrow \pi^*$	32051	–	–
	$n \rightarrow \pi^*$	40160		
$[FeC_{25}H_{34}N_2O_2(H_2O)_2]Cl$	$^6A_{1g} \rightarrow {}^1T_{1g}$	13600	1360.0	681.35
	$^6A_{1g} \rightarrow {}^1T_{1g}(G)$	16100		
	$^6A_{1g} \rightarrow {}^1T_{2g}(D)$	19379		
$[CoC_{25}H_{34}N_2O_2(H_2O)_2]$	$^4T_{1g}(F) \rightarrow {}^4T_{2g}(F)$	11507	1150.7	137.71
	$^4T_{1g}(F) \rightarrow {}^4A_{2g}(F)$	13477		
	$^4T_{1g}(F) \rightarrow {}^4T_{1g}(P)$	17985		
$[NiC_{25}H_{34}N_2O_2(H_2O)_2]$	$^3A_{2g}(F) \rightarrow {}^3T_{2g}(F)$	10400	1300.0	155.60
	$^3A_{2g}(F) \rightarrow {}^3T_{1g}(F)$	13927		
	$^3A_{2g}(F) \rightarrow {}^3T_{1g}(P)$	19230		
$[Cu\ C_{25}H_{32}N_2O_2]$	$^2B_{1g} \rightarrow {}^2B_{2g}$	14164	1416.4	169.53
	d-d	23696		
$[Zn\ C_{25}H_{32}N_2O_2]$	LMCT	18796	1879.6	225.00

TABLE-3
INFRARED SPECTRA OF SCHIFF BASE AND ITS COMPLEXES

Compound	ν(O-H_2)	ν(OH) (phenolic)	ν(C=N)	ν(C-O) (phenolic)	ν(M-N)	ν(M-O)
Schiff base	-	3368.29	1652.05	1273.02	-	-
$[FeC_{25}H_{34}N_2O_2(H_2O)_2]Cl_3$	3418.62	-	1635.46	1263.58	456.80	520.28
$[CoC_{25}H_{34}N_2O_2(H_2O)_2](CH_3COO)_2$	3459.64	-	1639.09	1260.88	460.95	518.18
$[NiC_{25}H_{34}N_2O_2(H_2O)_2](CH_3COO)_2$	3466.10	-	1641.57	1219.62	486.27	584.78
$[CuC_{25}H_{32}N_2O_2](CH_3COO)_2$	-	-	1647.54	1267.06	468.34	-
$[ZnC_{25}H_{32}N_2O_2](SO_4)_2$	-	-	1630.65	1257.64	475.97	-

respectively due to O-H stretching vibration indicate the presence of coordinated water molecules.

^{1}H NMR spectrum of Schiff base: ^{1}H NMR spectra of the ligand was taken in DMSO-d_6 solvent (Fig. 2). The aromatic region was a set of multiples in the range 6.7-7.4 ppm for the Schiff base ligand, while the phenolic group protons were observed in the range 9.7-9.9 ppm. The methyl group proton show peak at 1.3-1.9 ppm. The total number of protons present in the Schiff base exhibited signals of the protons in their expected regions [18]. This confirms the formation of the Schiff base ligand. It was also observed that DMSO did not show any coordinating effect on the ligand.

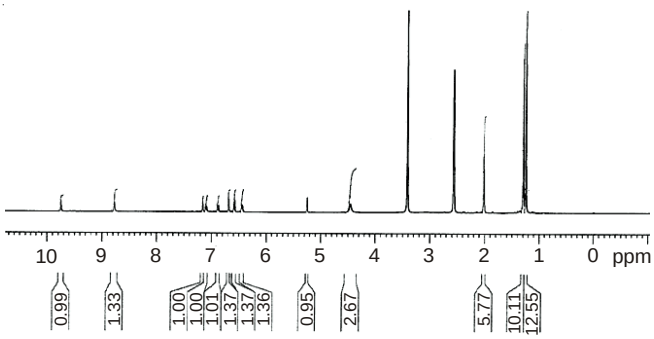

Fig. 2. ^{1}H NMR spectrum of the free Schiff base

^{13}C NMR spectrum of Schiff base: ^{13}C NMR spectra of the ligand were taken in $CDCl_3$ solvent. The aromatic region was a set of multiples in the range 115.281-164.422 ppm for the Schiff base ligand, while the azomethine carbons were observed in the range 164.422 ppm. The methyl group carbons lines show at 23.810-31.263 ppm. The total number of carbons present in the Schiff base exhibited signals of the carbons in their expected regions [19]. It was also observed that $CDCl_3$ did not show any coordinating effect on the ligand (Fig. 3).

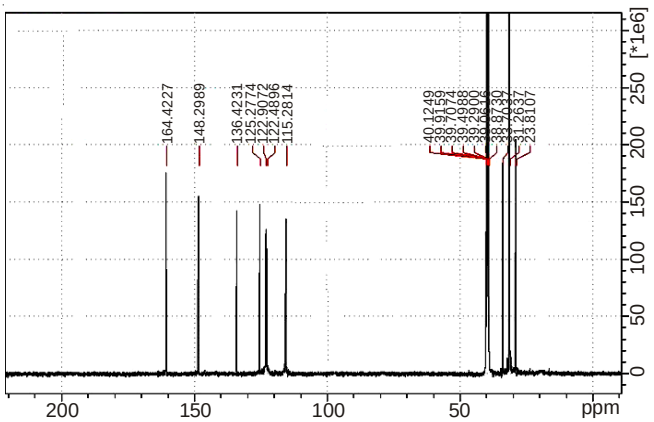

Fig. 3. ^{13}C NMR spectrum of the free Schiff base

Mass spectral fragmentation of the Schiff base: The mass spectra of the ligand recorded at room temperature were used to ascertain the stoichiometric [20] composition. The ligand [L] shows a molecular ion peak at *m/z* 395, which corresponds to [L+H] peak as the calculated *m/z* being 394 (L = $C_{25}H_{34}N_2O_2$).

Thermal studies: The TGA and DTA curves of the Fe(III) complex show an endothermic band at 100-135 °C with a loss of mass corresponding to two coordinated water molecules in this complex. Similarly the Co(II) and Ni(II) complexes also shows an endothermic band at 120-140 °C. This indicates the presence of two coordinated water molecules in this complex [21].

ESR studies of Cu(II) complex: The ESR spectra of paramagnetic transition metal(II) complex give information about the distribution of the unpaired electrons and hence about the nature of the bonding between the metal ion and its ligand. The synthesized Cu(II) complex exhibits an isotropic signal without any hyperfine splitting with $g_{iso} = 2.031$ is shown (Fig. 4). The g values obtained in the present study when compared to the g value of a free electron, 2.0023 indicates an increase of the covalent nature of the bonding between the metal ion and the ligand molecule. Isotropic lines are usually the results due to occupancy of the unpaired electron in a degenerate orbital in square planner geometry [22,23].

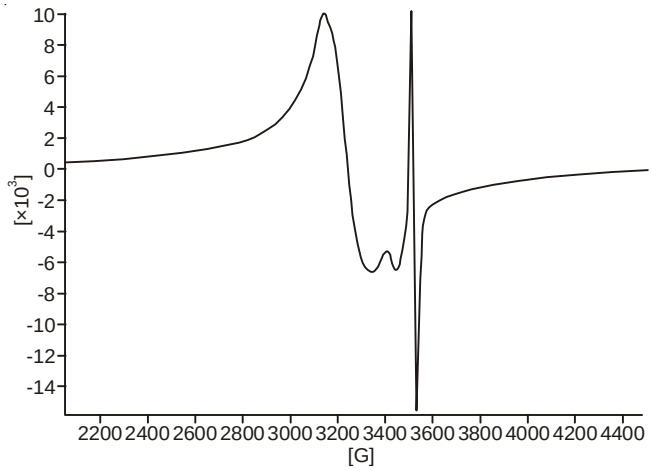

Fig. 4. ESR for Cu(II) complex

Electrochemical studies: The electrochemical properties of the complexes were studied by cyclic voltammetry in the potential range 0 to -2.0 V. The complexes show a quasi reversible reduction wave at negative potential (Table-4). ΔE increases with increase in the scan rate and is always greater than 60 mV. The Fe(III) complex shows a well-defined quasi reversible reduction peak at 1.06 to -1.01V which corresponds to Fe(III) → Fe(II) redox process. The Cu(II) complex shows [24] a well-defined quasi reversible reduction peak at -0.97 to -1.29 V which corresponds to Cu(II) → Cu(I) redox process (Figs. 5 and 6).

Powder X-ray diffraction studies: The synthesized Fe(III), Co(II), Ni(II), Cu(II) and Zn(II) complexes of Schiff base ligand were soluble in all organic solvents. The crystals that are suitable for single crystal studies are not obtained. In order to test the degree of crystalline of the synthesized metal complexes, we obtained the powder X-ray diffraction pattern of the above complexes. The X-ray diffraction of Fe(III), Co(II), Ni(II), Cu(II) and Zn(II) complexes was scanned in the range 30-80° (θ) at wave length 1.54 Å. In all the complexes the trend of the curves decreases from maximum to minimum intensity indicating the amorphous nature of the complexes in the present metal-ligand formation [25]. The X-ray diffraction pattern of Cu(II) complex records three reflections between

TABLE-4
ELECTRO CHEMICAL DATA OF THE METAL COMPLEXES

Compound	E^1_{pc} (V)	E^1_{pa} (V)	$E^1_{1/2}$ (V)	ΔE (V)	E^2_{pc} (V)	E^2_{pa} (V)	$E^2_{1/2}$ (V)	ΔE (V)
Fe(III) complex	1.06	-1.01	1.035	2.07				
Cu(II) complex	0.97	-1.29	1.13	2.26	0.16	-0.09		.169

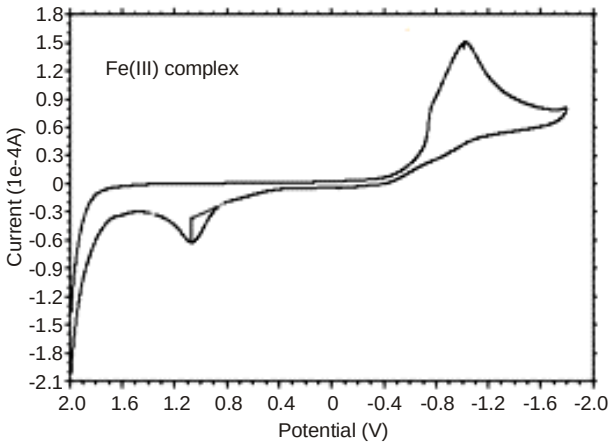

Fig. 5. Cyclic voltammetry for Fe(III) complex

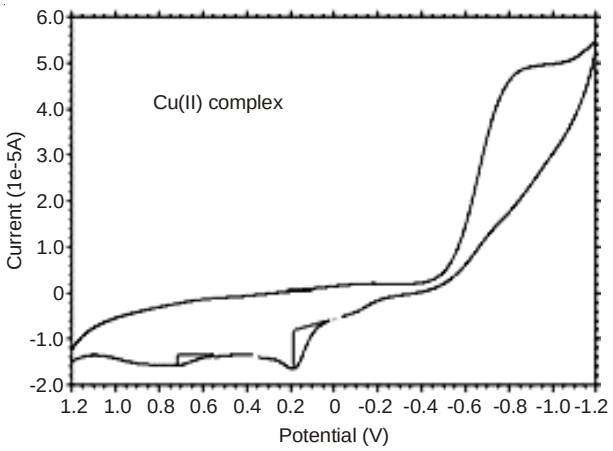

Fig. 6. Cyclic voltammetry for Cu(II) complex

the range 30-80° (2θ), which arise from diffraction of X-ray by the plane of the complex (Fig. 7).The inter planar spacing (d-values) has been calculated by using Bragg's equation: nλ = 2d sin θ. The unit cell calculations have been done for cubic symmetry from the all-important peaks and the methods yielded *h k l* (Miller indices) unit cell parameter values and depicted in (Tables 5 and 6). The observed inter planar d-spacing values have been compared with the calculated ones and found to be in good agreement. The $h^2 + k^2 + l^2$ values are 33, 45 and 75. The Cu(II) complex may belong to FCC system. Three peaks at 2θ values of 33.90, 45.13 and 75.95° corresponding to (110), (111) and (211). Planes of copper have been observed and compared with the JCPDS copper file No.

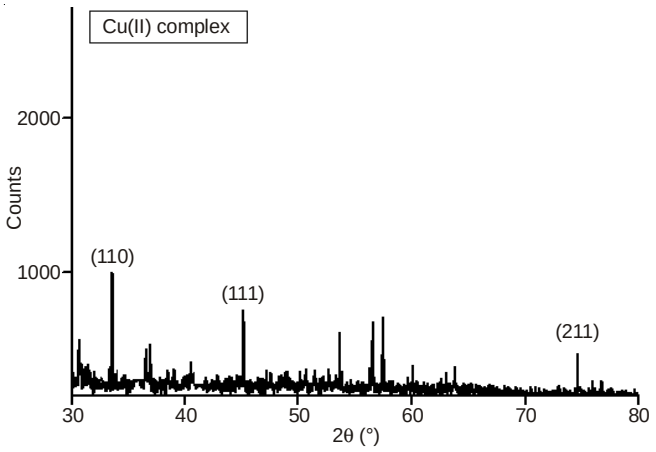

Fig. 7. Powder XRD spectra of Cu(II) complex

TABLE-5
SIMPLE PEAK INDEXING FOR Cu(II) COMPLEX

Peak position (2θ)	1000 × $\sin^2\theta$	1000 × $\sin^2\theta$/62.27	Reflection	Remarks
33.90	85.03	2	(1 1 0)	$1^2 + 1^2 + 0$
45.139	147.30	3	(1 1 1)	$1^2 + 1^2 + 1^2$
75.954	378.65	6	(2 1 1)	$2^2 + 1^2 + l^2$

TABLE-6
PEAK INDEXING FROM *d*-SPACING FOR Cu(II) COMPLEX

2θ	*d*	$1000/d^2$	$(1000/d^2)/104.89$	h k l
33.900	2.641	143.37	1.360	110
45.139	2.007	248.26	2.367	111
75.954	1.251	638.16	6.084	211

04-0836. The strong and broad peak confirms the complex formation and the appearance of large feeble peaks indicates that the complex is nano crystalline. The grain size of the complexes is calculated using Scherer's formula (Tables 7 and 8). The results confirm Cu(II) complex having uniformed size less than 30 nm.

TABLE-7
EXPERIMENTAL AND STANDARD
DIFFRACTION ANGLES OF Cu SPECIMEN

Experimental diffraction angle [2θ in degrees]	Standard diffraction angle [2θ in degrees] JCPDS Copper: 04-0836
33.907	33.564
45.139	44.796
75.954	75.611

TABLE-8
GRAIN SIZE OF COPPER(II) COMPLEX POWER

2θ of intense peak (°)	h k l	Θ of intense peak (°)	FWHM of intense peak (β) radians	Size of particle (D)	*d*-spacing (nm)
33.900	(1 1 0)	16.953	0.0046	28.820	0.0264
45.139	(1 1 1)	22.569	0.0060	25.016	0.0200
75.954	(2 1 1)	37.977	0.0071	24.760	0.0125

DNA cleavage studies: DNA cleavage is controlled by relaxation of supercoiled circular conformation of pUC19 DNA to nicked circular conformation and linear conformation. When circular plasmid DNA is conducted by electrophoresis, the fastest migration will be observed for the supercoiled form (Form I). If one strand is cleaved, the supercoils will relax to produce a slower-moving open circular form (Form II). If both strands are cleaved (Fig. 8) illustrates the gel electrophoresis [26] experiments showing the cleavage of plasmid pUC19 DNA induced by the five mononuclear complexes. The control experiments did not show any apparent cleavage of DNA (lane 1 and 2). Fe(III) mononuclear complex in the presence of H_2O_2 (lane 1) at higher concentration (50 µM) shows more cleavage activity compared to mononuclear Co(II), Ni(II), Cu(II) and Zn(II) complexes. The supercoiled plasmid DNA was completely degraded. This shows that a slight increase in the concentration over the optimal value led to extensive degradations, resulting in the disappearance [27] of bands on agarose gel. Fe(III) mononuclear complex in the presence of H_2O_2 resulting the conversion of supercoiled form (Form-I) into linear form (Form-II). Co(II), Ni(II), Cu(II) and Zn(II) complexes are the presence of H_2O_2 at higher concentration (50 µM) shows cleavage activity in which supercoiled DNA (Form-I) cleaved and supercoiled form converted to open circular form (Form-II).

$$[DNA+ Fe(III) + H_2O_2] > [DNA+ Cu(II) + H_2O_2] > [DNA+ Co(II) + H_2O_2] > [DNA+ Zn(II) + H_2O_2] > [DNA+ Ni(II) + H_2O_2] > [DNA + H_2O_2]$$

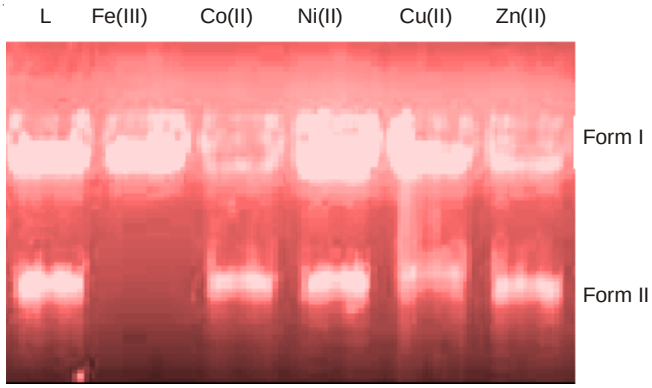

Fig. 8. DNA-cleavage

Antimicrobial activity: The synthesized Fe(III), Co(II), Ni(II), Cu(II) and Zn(II) Schiff base complexes were screened for *in vitro* antibacterial activity against three Gram-positive and two Gram-negative bacterial strains. The results of the antibacterial activity studies for the complexes and standard compound tetracycline, evaluated by Muller Hinton agar diffusion method and serial dilution sensitivity test against both Gram-positive and Gram-negative bacteria. DMSO solvent was also used as control. As it could be seen from these tables, both Gram-positive and Gram-negative bacteria were affected by these antibacterial agents and *L. monocytogens* was the most sensitive microorganism to the studied complexes. On the other hand, *E. coli*, *S. typhi*, *B. cereus* and *S. pyogenes* were, to some extent, more resistant to those compounds [28,29]. It is previously reported that the presence of electronegative and electron donating groups on the acetyl acetate part of the Schiff bases increases the antibacterial activity of their metal complexes (Fig. 9).

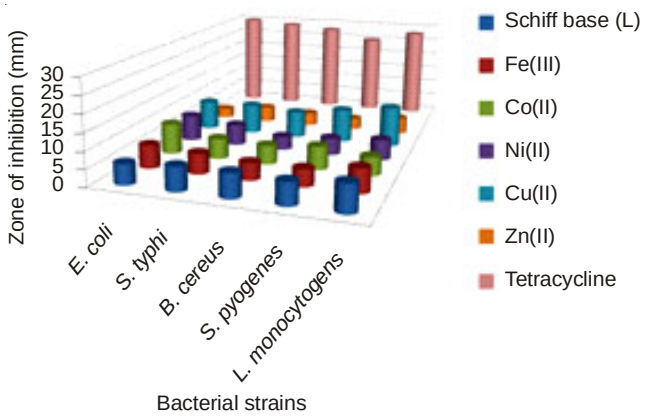

Fig. 9. Antimicrobial activity

The minimum inhibitory concentration (MIC) was calculated as the highest dilution showing complete inhibition of the tested strains and reported in (Tables 9 and 10). These Schiff base and complexes also disturb the respiration process of the cell and thus block the synthesis of proteins, which further restricts the growth of the organisms [30]. The Cu(II) complex has good activity when compared to Schiff base and other metal complexes.

TABLE-9
DETERMINATION OF MINIMUM INHIBITORY CONCENTRATION FOR ANTIBACTERIAL ACTIVITIES

Micro organisms	Schiff base (µg/mL)				Fe(III) (µg/mL)				Co(II) (µg/mL)			
	125	62.5	31.25	15.62	125	62.5	31.25	15.62	125	62.5	31.25	15.62
E. coli	–	–	+	+	–	–	–	+	–	–	+	+
S. typhi	–	–	+	+	–	–	+	+	–	–	+	+
B. cereus	–	+	+	+	–	–	+	+	–	–	+	+
S. pyogenes	–	–	+	+	–	–	–	+	–	–	–	+
L. monocytogens	–	–	+	+	–	–	–	+	–	–	–	+
Micro organisms	Ni(II) (µg/mL)				Cu(II) (µg/mL)				Zn(II) (µg/mL)			
	125	62.5	31.25	15.62	125	62.5	31.25	15.62	125	62.5	31.25	15.62
E. coli	–	–	+	+	–	–	–	+	–	–	+	+
S. typhi	–	–	+	+	–	–	+	+	–	–	+	+
B. cereus	–	+	+	+	–	–	+	+	–	–	+	+
S. pyogenes	–	–	+	+	–	–	–	+	–	–	–	+
L. monocytogens	–	–	+	+	–	–	–	+	–	–	–	+

TABLE-10
ANTIBACTERIAL ACTIVITIES MINIMUM INHIBITORY CONCENTRATION VALUES

Micro organisms	Minimum inhibitory concentration values (μg/mL)					
	Schiff base	Fe(III)	Co(II)	Ni(II)	Cu(II)	Zn(II)
E. coli	62.5	31.25	62.50	62.5	31.25	62.50
S. typhi	62.5	62.50	62.50	62.5	62.50	62.50
B. cereus	125.0	62.50	62.50	125.0	62.50	62.50
S. pyogenes	62.5	31.25	31.25	62.5	31.25	31.25
L. monocytogens	62.5	31.25	31.25	62.5	31.25	31.25

Conclusion

The novel qudridendate mononuclear Fe(III), Co(II), Ni(II), Cu(II) and Zn(II) complexes were synthesized from 2-amino-4-*tert*-butylphenol with β-diketone containing N_2O_2 donors set in different environments. The ligand and complexes were characterized by spectral and analytical data. All the complexes are paramagnetic except Zn(II) which is diamagnetic. Based on spectral data and magnetic moments Fe(III), Co(II) and Ni(II) are assigned octahedral geometry while Cu(II) and Zn(II) complexes are to square geometry. XRD analysis suggests the crystalline structural studies of the complexes. The DNA cleaving activity of Schiff base and complexes with pUC19 DNA shows more pronounced activity in presence of the oxidant. The antibacterial studies carried out with the complexes confirm that they are good antibacterial agents with their MIC values being 15.62, 31.25, 62.5 and 125 μg/mL.

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