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Syntheses, Physico-Chemical Studies and Antioxidant Activities of Transition Metal Complexes with a Perimidine Ligand

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Keywords: Pyrimidene ligand; Physico-chemical studies; Antioxidant activity; Copper; Cobalt; Zinc

Abstract. A series of mononuclear complexes of the type, [MLCl$_2$] [M = Co^{II}, Ni^{II}, Cu^{II}, and Zn^{II}] with a pyrimidene-type ligand, which was synthesized by the reaction of 2-furaldehyde and 1,8-diaminonaphthalene, was obtained. The ligand and its complexes were characterized by elemental analysis, IR, NMR, EPR, and UV/Vis spectroscopy, ESI-mass spectrometry, magnetic susceptibility, molar conductivity, and thermogravimetric analyses. On the basis of UV/Vis spectroscopic and magnetic susceptibility data, an octahedral arrangement was assigned around all metal ions. The low molar conductivity data for all the complexes show their non-electrolytic nature. The thermal behavior of the complexes was studied by TGA analyses. The electrochemical study carried out on the Cu^{II} complex exhibits a quasi reversible redox process. The ligand and its complexes showed potential antioxidant and antimicrobial activities.

1 Introduction

Pyrimidines have high physiological importance as components of nucleic acids,[1] they have been found to be associated with various biological activities viz., antibacterial, antifungal, antitubercular, anticonvulsant, antiviral, anticancer, and antioxidant etc.[2–7] Moreover, there is considerable interest in the coordination chemistry of transition metal complexes of pyrimidine-derived ligands because of their diverse biological applications, which have often been related to their chelating ability with trace metal ions.[7] Oxygen is vital to life as a diatomic molecule and is the substrate for the generation of a variety of superoxide anions ($O^{2-\cdot}$), a reactive oxygen species (ROS). These compounds, when present in a sufficient concentration, are able to damage cellular proteins and lipids or form DNA adducts that may lead to the development of many serious diseases e.g. cancer, astherosclerosis, asthma, and neurodegenerative disorders etc.[8–11] The lethal effects of ROS are counterbalanced by antioxidant enzymes such as superoxide dismutase (SOD), catalase, and glutathione peroxidase as well as by small molecular antioxidants. SOD, in particular, is the antioxidant enzyme that is able to convert the superoxide anion to less reactive forms, hydrogen peroxide and dioxygen, to keep the free radical density in the body at normal level and therefore, to lead to potentially effective pharmaceuticals.[13] However, SOD is easily excreted through kidneys in vivo and is not able to enter the cells because of its high molecular weight.[14] Many metal complexes were investigated as effective scavengers of ROS, acting as antioxidants.[13,15,16] Therefore, in search of new bioactive compounds, which are able to act as effective scavengers of ROS, the synthesis, physico-chemical studies, and antimicrobial as well as antioxidant activities of the ligand L, which was derived from 2-furaldehyde and 1,8-diaminonaphthalene and its Co^{II}, Ni^{II}, Cu^{II}, and Zn^{II} complexes were investigated.

2 Experimental Section

2.1 Materials and Methods

All the reagents used were of analytical grade and were purchased from Sigma–Aldrich (St. Louis, MO) and used as received.

2.2 Synthesis of 2-(2-Furyl)-2,3-dihydro-1H-perimidine (L)

A methanol solution of 2-furaldehyde (1 mmol) was added dropwise to a methanol solution of 1,8-diaminonaphthalene (1 mmol). The reaction mixture was heated to reflux for 2 h resulting in a clear brown colored solution. The resulting solution was concentrated to 1 mL and subsequently *n*-hexane (10 mL) was added, which caused precipitation. The precipitate was collected and recrystallized from dichloromethane/*n*-hexane and obtained in analytically pure form. Yield 65%, brown color, m.p. 128 °C. Calcd. C 76.25; H 5.11; N 11.85; O 6.77%; found: C 76.21; H 5.04; N 11.81; O 6.72% **IR** (KBr): $\tilde{\nu}$ = 3350 (ν_{NH}), 1590 (ν_{CO}) cm^{-1}. **^{1}H NMR** ([D$_6$]DMSO): δ = 3.35 (NH), 5.51 (–CH),

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6.26–7.61 (m, 9 H, Ar–H) ppm. **^{13}C NMR** ($CDCl_3$): δ = 60.02 (–CH), 155.80 (O–C) ppm.

2.3 Synthesis of [$MLCl_2$] [M = Co^{II}, Ni^{II}, Cu^{II}, and Zn^{II}]

A solution of the metal salt (0.50 mmol) in methanol (15 mL) was added to a methanol solution (10 mL) of the ligand (0.50 mmol). The resulting mixture was stirred for 30 min and afterwards concentrated to 1 mL followed by addition of *n*-hexane (10 mL) to cause precipitation. The resulting colored precipitate was collected, washed with methanol, dried in vacuo, and obtained in analytically pure form.

[$CoLCl_2$]: Yield 68 %, black color, m.p. 245 °C. Calcd. C 49.21; H 3.30; N 7.65; O 4.37; Co 16.09 %; found: C 49.17; H 3.15; N 7.58; O 4.26; Co 16.04 %. **IR** (KBr): $\tilde{\nu}$ = 3340 cm^{-1} (ν_{NH}), 1580 (ν_{CO}) cm^{-1}. Molar conductivity ($\acute{e}^{-1}$·cm^2·mol^{-1}): 15.

[$NiLCl_2$]: Yield 62 %, brown color; m.p. 280 °C. Calcd. C 49.24; H 3.30; N 7.65; O 4.37; Ni 16.04 %; found: C 49.17; H 3.18; N 7.54; O 4.31; Ni 15.99 %. **IR** (KBr): $\tilde{\nu}$ = 3335 (ν_{NH}), 1585 (ν_{CO}) cm^{-1}. Molar conductivity ($\acute{e}^{-1}$·cm^2·mol^{-1}): 14.

[$CuLCl_2$]: Yield 70 %, dark brown color, m.p. 220 °C. Calcd. C 48.59; H 3.26; N 7.55; O 4.31; Cu 17.14 %; found: C 48.50, H 3.17, N 7.45, O 4.25, Cu 17.08 %. **IR** (KBr): $\tilde{\nu}$ = 3347 (ν_{NH}), 1587 (ν_{CO}) cm^{-1}. Molar conductivity ($\acute{e}^{-1}$·cm^2·mol^{-1}): 17.

[$ZnLCl_2$]: Yield 68 %, brown color, m.p. 215 °C. Calcd. C 48.36; H 3.24; N 7.51; O 4.29; Zn 17.55; found: C 48.24; H 3.17; N 7.45; O 4.21; Zn 17.48 %. **IR** (KBr): $\tilde{\nu}$ = 3338 (ν_{NH}), 1582 (ν_{CO}) cm^{-1}. **^{1}H NMR** ([D_6]DMSO): δ = 3.46 (NH), 5.75 (–CH), 6.72–7.21 (m, 9 H, Ar–H) ppm. **^{13}C NMR** ($CDCl_3$): δ = 66.5 (–CH), 160.02 (O–C) ppm. Molar conductivity ($\acute{e}^{-1}$·cm^2·mol^{-1}): 12.5.

2.4 Physical Measurements

Elemental analyses were recorded with an Elementar Varrio EL analyzer. The FT-IR spectra (4000–200 cm^{-1}) were obtained from KBr discs with a Perkin–Elmer 621 spectrophotometer. ^{1}H and ^{13}C NMR spectra were recorded in [D_6]DMSO with a Jeol 400 NMR spectrometer. Electronic spectra were recorded in DMSO with a Pye-Unicam 8800 spectrophotometer. Magnetic susceptibility measurements were carried out with a Faraday balance at 25 °C. EPR spectrum of Cu^{II} complex was recorded with a Varian-4 spectrometer (X-band) using diphenylpicrylhydrazide (DPPH) (g = 2.0036) as a calibrant. Mass spectrometry was performed with a Micromass Quattro Premier tandem MS fitted with an ESI interface and controlled by MassLynx 4.1 software. MS/MS detection was performed with electrospray positive ionization mode. The molar conductance was measured (10^{-3} M solutions in DMSO) using a Systronic type 302 conductivity bridge thermostatted at 25 ± 0.01 °C. Electrochemical measurements (CV) were carried out with a LK2005A electrochemical analyzer in a nitrogen atmosphere at room temperature. Thermal analyses were carried out with TA instrument SDT-Q600 in a helium atmosphere.

2.5 Antioxidant Assays

Antioxidant properties of the synthesized compounds were analyzed by DPPH and FRAP methods.

2.5.1 DPPH Radical Scavenging Assay

The free radical scavenging activity of the different compounds was evaluated according to a method described in literature.[17] In brief, a solution of the tested compound (50 μL) in methanol (containing 6.25 μM to 400 μM of the compounds, respectively) in each reaction set was mixed with a solution of DPPH (1 mL, 0.1 mM) in methanol and Tris-HCl buffer (450 μL, 50 mM) (pH 7.4). Methanol (50 μL) was used as negative control while L-ascorbic acid and BHT were used as positive controls. After 30 min of incubation at room temperature, the reduction of the DPPH free radical was measured spectrophotometrically at 517 nm. The percent inhibition was calculated from the following equation:

% Inhibition = [Absorbance of control–Absorbance of test sample / Absorbance of control] × 100

2.5.2 FRAP (Fe^{3+} Reducing Power Assay)

The reducing power was measured by the direct reduction of $Fe^{3+}(CN^-)_6$ to $Fe^{2+}(CN^-)_6$, and was determined by measuring the absorbance resulting from the formation of the Perl's Prussian Blue complex following the addition of excess ferric ions (Fe^{3+}). Hence, the ferric reducing antioxidant power (FRAP) method[18] with little modification was adopted to measure the reducing capacity of compounds. This method is based on the reduction of (Fe^{3+}) ferricyanide in stoichiometric excess relative to the antioxidants.[19,20] Different concentrations of the complexes (6.25 μM to 400 μM) in distilled water (0.75 mL) were mixed with sodium phosphate buffer (1.25 mL of 0.2 M, pH 6.6) and potassium ferricyanide [$K_3Fe(CN_6)$] (1.25 mL, 1 %). The mixtures were incubated at 50 °C for 20 min. After 20 min of incubation, the reaction mixtures were acidified with trichloroacetic acid (1.25 mL, 10 %). Finally, $FeCl_3$ (0.5 mL, 0.1 %) were added to these solutions, and the absorbances were measured at 700 nm in a spectrophotometer. The increased absorbances of the reaction mixtures indicate greater reduction capability.[21]

2.6 Antimicrobial Assays

The antimicrobial activity of the ligand and its complexes was done by Agar well diffusion method as reported in literature.[22,23] Briefly, 0.1 mL of the diluted inoculum (10^5 CFU·ml^{-1}) of a test organism was spread on nutrient agar (NA)/SD agar plates. Wells of 6 mm diameter were punched into the agar medium and filled with 100 μL of the tested compound (1 mg·mL^{-1}). The plates were incubated for 18 h at 37 °C for test bacteria and *candida albicans* and the *Aspergillus niger* plates were incubated for 48–72 h at 28 °C. Zone of inhibition around the well was reported. The antibiotics, chloramphenicol and nystatin at 100 μg·mL^{-1} concentration were used in the test system as positive controls.

Supporting Information (see footnote on the first page of this article): ^{13}C NMR spectrum of the ligand L and [$ZnLCl_2$]; EPR spectrum of the Cu^{II} complex.

3 Results and Discussion

The pyrimidene ligand L was synthesized by the reaction of 2-furaldehyde with 1,8-diaminonaphthalene in 1:1 molar ratio in methanol (Scheme 1). Its complexes of the type, [$MLCl_2$] [M = Co^{II}, Ni^{II}, Cu^{II}, and Zn^{II}] were synthesized by the reaction of L and the respective metal salts in 1:1 molar ratio in methanol. All possible efforts to get crystals suitable for single-crystal X-ray diffraction failed. The Ligand L and its complexes were stable at room temperature, and were soluble in all organic solvents. The low molar conductivity data of all

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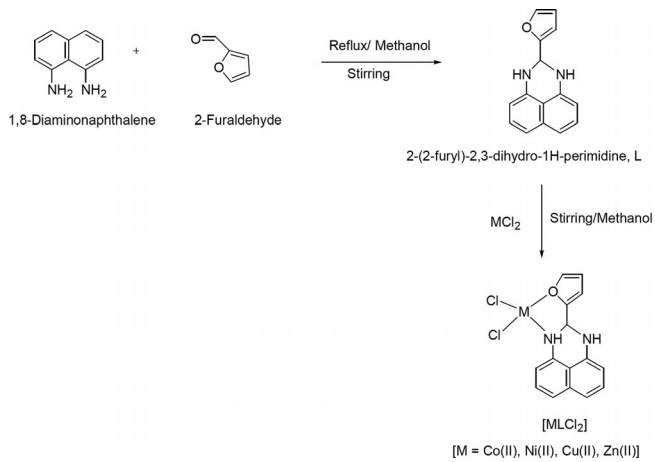
complexes suggest their non-ionic nature.[24] The analytical data are in good agreement with the proposed composition of ligand and its complexes. The formation of ligand and its complexes were confirmed on the basis of results of elemental analyses, molecular ion peak in mass spectra, characteristic bands in the FT-IR spectra, and resonance signals in the ^{1}H and ^{13}C NMR spectra. The arrangement around the Co^{II}, Ni^{II}, and Cu^{II} ions in the complexes was inferred from the positions of absorption bands observed in UV/Vis spectra and magnetic moment values. The EPR spectrum of the Cu^{II} complex shows a distorted octahedral arrangement.



Scheme 1. Schematic representation of the synthesis of the ligand L and its metal complexes.

3.1 IR Spectrococoscopy

In order to obtain information on the bonding mode of the ligand to the metal ion, IR spectra were recorded (Figure 1). The IR spectrum of the ligand shows a sharp band at 3350 cm^{-1} assigned to –NH group, which undergoes a negative shift ca. 15 cm^{-1} indicating the involvement of –NH group in complexation.[25] The medium intensity bands observed at 1590 cm^{-1} in the free ligand assigned to $\nu_{C–O}$ stretching vibration of furan moiety is shifted to lower values ca. 10 cm^{-1} in complexes, suggesting the involvement of the oxygen atom to the metal ion,[26] which is further confirmed by the appearance of a new medium intensity band in the region 515–520 cm^{-1} indicating participation of the oxygen atom of the furan ring in coordination.[27,28] A band appearing in the region 285–295 cm^{-1} may reasonable be assigned to $\nu_{(M–Cl)}$ vibration,[29] whereas the other bands were found at their expected position.

3.2 NMR Spectroscopy

The ^{1}H NMR spectra of ligand and its Zn^{II} complex were recorded in [D_6]DMSO to ascertain the coordination of the ligand, L to the Zn^{II} ion (Figure 2). The ^{1}H NMR spectrum of ligand shows a broad singlet signal at δ = 3.35 ppm due to the –NH proton, which undergoes downfield shift in the Zn^{II} complex indicating its coordination to Zn^{II} ion.[30] The aromatic protons (m, Ar–H, 9 H) of free ligand exhibit multiplet

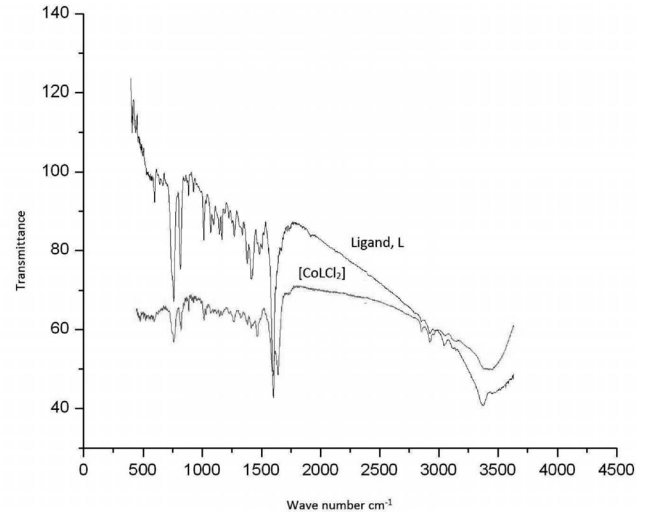


Figure 1. IR Spectra of the ligand L and its [$CoLCl_2$] complex.

signals and appear in 6.26–7.61 ppm region.[31] The signal for the –CH proton (s, 1 H) appeared at δ = 5.63 ppm. These values were found to undergo a little change in Zn^{II} complex (Figure 2).

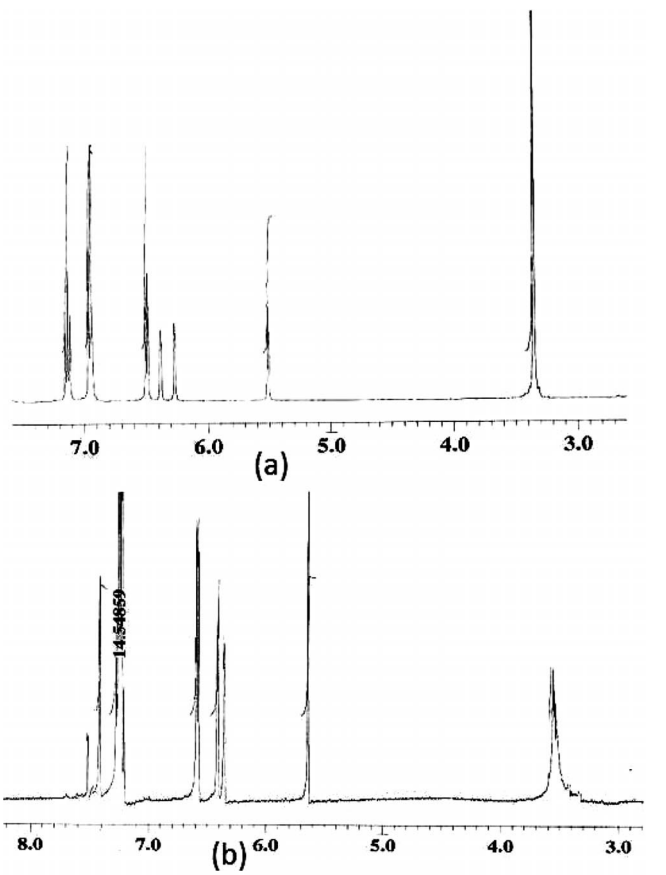


Figure 2. (a) ^{1}H NMR spectrum of the ligand L; (b) ^{1}H NMR spectrum of [$ZnLCl_2$].

The ^{13}C NMR spectral findings recorded in [D_6]DMSO further confirm the ^{1}H NMR spectroscopic data. The ^{13}CNMR

spectrum of ligand (Figures S1, S2, Supporting Information) shows characteristic sets of signals belonging to various aliphatic and aromatic carbons. These values were found to be downfield shifted on coordination to the Zn^{II} ion.

3.3 Mass Studies

Mass spectra of the pyrimidene ligand L and its complexes exhibited molecular ion peak $[M + H]^+$, *m/z* at 237.26, 367.11, 366.87, 371.72, and 373.57 corresponding to their molecular formulae, $[C_{15}H_{12}N_2O]$, $[CoLCl_2]$, $[NiLCl_2]$, $[CuLCl_2]$, and $[ZnLCl_2]$, respectively, as their calculated *m/z* being 236.26, 366.11, 365.87, 370.72, and 372.57 for their corresponding compounds, $[C_{15}H_{12}N_2O]$, $[CoLCl_2]$, $[NiLCl_2]$, $[CuLCl_2]$, and $[ZnLCl_2]$, respectively (Figure 3, Figure 4).

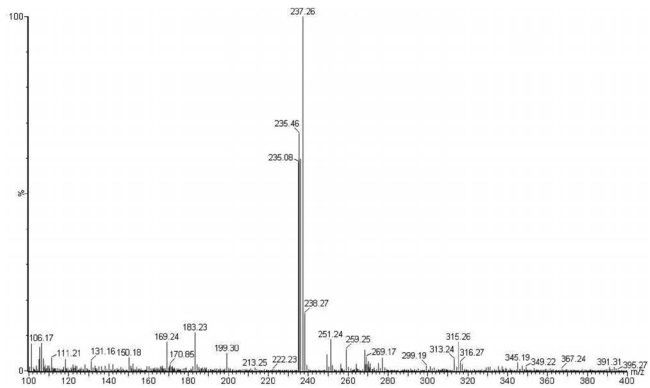


Figure 3. ESI mass spectrum of the ligand L.

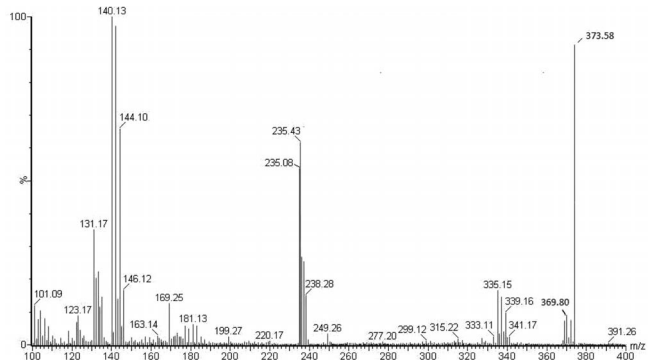


Figure 4. ESI mass spectrum of $[ZnLCl_2]$.

3.4 Electronic Spectra and Magnetic Susceptibility Data

The electronic spectrum of the Co^{II} complex shows two bands at 14100 and 20500 cm^{-1}, which are assigned to $^4T_{1g}(F) \rightarrow {}^4A_{2g}(F)$ and $^4T_{1g}(F) \rightarrow {}^4T_{1g}(P)$ transitions, respectively, corresponding to an octahedral arrangement around the Co^{II} ion. This assignment is further supported by magnetic moment value of 4.52 B.M.[32,33] The Ni^{II} complex shows bands at 27500, 20000, and 11000 cm^{-1}, which are attributed to $^3A_{2g}(F) \rightarrow {}^3T_{1g}(P)$, $^3A_{2g}(F) \rightarrow {}^3T_{1g}(F)$, and $^3A_{2g}(F) \rightarrow {}^3T_{2g}(F)$ transitions, respectively, indicating an octahedral environment around the Ni^{II} ion. The magnetic moment value of 3.07 B.M. further supports the proposed arrangement.[32,33] The electronic spectrum of Cu^{II} complex displays a broad band at 18500 cm^{-1} with a shoulder on the lower energy side at 15300 cm^{-1}, which are ascribed to $^2B_{1g} \rightarrow {}^2E_g$ and $^2B_{1g} \rightarrow {}^2B_{2g}$ transitions, respectively, suggesting a distorted octahedral arrangement for the Cu^{II} complex. The magnetic moment value of 1.73 B.M. further confirms its electronic spectral findings.[32,33]

3.5 EPR Spectroscopy

The EPR spectrum of the polycrystalline Cu^{II} complex was recorded at room temperature. The hyperfine line could not be resolved, which may be attributed to the strong dipolar and exchange interactions between Cu^{II} ions in the unit cell. The calculated $g_\parallel$ and $g_\perp$ values were found to be 2.32 and 2.37, respectively, indicating the unpaired electrons in the $d_{(x^2-y^2)}$ orbital[34] and hence $^2B_1$ is the grand state. The axial spectrum with $g_\parallel > g_\perp > 2.04$ is in agreement with a distorted octahedral arrangement around the Cu^{II} ion.[35] In an axial symmetry, the g values are related by the expression $G = (g_\parallel - 2) / (g_\perp - 2)$,[36] which measures the exchange interaction between copper atoms in the polycrystalline solid. The calculated G values appeared in the range 3.18–3.87, suggesting[37] a considerable exchange interaction between Cu^{II} atoms as ($G < 4$) (Figure S3, Supporting Information).

3.6 Thermal Studies

Theromogravimetric analyses of complexes were studied in a helium atmosphere in a temperature range of 25–800 °C at a heating rate of 30 K·min^{-1}. It was found that all complexes are thermally stable up to temperature 50 °C and decompose in three main steps. The first step includes the loss of hydrated water in the temperature range 50–125 °C, followed by the second step involving the loss of coordinating water and chloride ion up to 333 °C (total loss 18 %). Degradation continues on further elaboration of temperature until a final residue is left at a temperature of 607 °C. At this temperature the whole organic part is decomposed and the metal oxide is formed. The data of thermal analysis was favored by DSC.

3.7 Electrochemical Properties

The electrochemical property of the Cu^{II} complex was studied by cyclic voltammetry (CV) with a platinum electrode in DMSO containing KCl (0.1 M) as an electrolyte at 0.05 V·s^{-1} scan rate at room temperature. The Cu^{II} complex exhibits a pair of cathodic and anodic peaks. The separation between the cathodic and anodic peak potentials (E_{pa}–E_{pc} = 0.36–0.25 = 0.12 V and $E_{1/2}$ = 0.305 V) and the current *I* (*I*pa/*I*pc = 4.5/4.0 = 1.1 A) indicate a quasi reversible redox process assignable to Cu^{II}/Cu^{I} couple.[38]

3.8 Antioxidant Activity

DPPH and FRAP assay methods were used to evaluate the antioxidant activity of the complexes. The DPPH free radical

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scavenging method is based on the reduction of DPPH, a stable free radical and any molecule that can donate an electron or hydrogen to DPPH can react with it and thereby bleach the DPPH absorption. Because of its odd electron, DPPH gives a strong absorption maximum at 517 nm by visible spectroscopy (purple). As the odd electron of the radical becomes paired off in the presence of a hydrogen donor, that is, a free radical scavenging antioxidant, the absorption strength is decreased and the resulting decolorization is stoichiometric with respect to the number of electrons captured.[39,40] Hence, when compounds were evaluated for their antioxidant activity by DPPH radical scavenging assay, the concentration dependent activity (% decolorization) was recorded in all the five compounds at tested concentrations ranging from 6.25 μM to 400 μM. The ligand (L) and its complexes [$CoLCl_2$] and [$NiLCl_2$] demonstrated considerably strong antioxidant activity (≥ 70% decolorization) at 400 μM dose, while [$CuLCl_2$] and [$ZnLCl_2$] exhibited 61.2 and 57.2% decolorization activity (Figure 5) as compared commercial standards ascorbic acid and BHT, which showed 93.0% and 89.7% of decolorization, respectively.

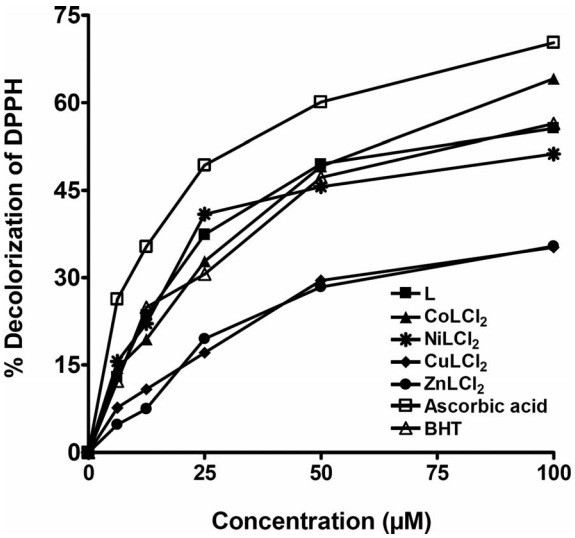

Figure 5. Antioxidant activity of the complexes by DPPH method: the concentration dependent activity (% decolorization) recorded for all compounds in a concentration range of 6.25–100 μM. The ligand L and its complexes [$CoLCl_2$] and [$NiLCl_2$] demonstrated considerable strong antioxidant activity (>50% decolorization) at 100 μM. Ascorbic acid and BHT were included as reference compounds.

The ferric reducing antioxidant power (FRAP) is measured by the direct reduction of Fe^{3+} $(CN^{-})_6$ to Fe^{2+} $(CN)_6$, and can be determined by measuring the absorbance resulted due to the formation of the Perl's Prussian Blue complex. The absorbance can be measured at 700 nm in a spectrophotometer. Increased absorbance of reaction mixture indicates greater reduction capability.[20,21] The ligand and its complexes [$CoLCl_2$], [$NiLCl_2$], [$CuLCl_2$] and [$ZnLCl_2$] demonstrated powerful ferric ions (Fe^{3+}) reducing ability and has electron donor properties for neutralizing free radicals by forming stable products[41] as compared with commercial standards ascorbic acid and BHT. The reducing power of all the compounds was found to increase with increasing concentration of samples (6.25 to 400 μM) as shown in (Figure 6) suggesting that all the above compounds have significant antioxidant potential as revealed by DPPH and FRAP assay similar to that reported for Naringenin Schiff base and its Cu^{II}, Ni^{II}, Zn^{II} complexes, which displayed antioxidant activity better than standard antioxidants like ascorbic acid and mannitol.[42] Our study reflected that these compounds could be further explored for their possible mechanisms in vivo.

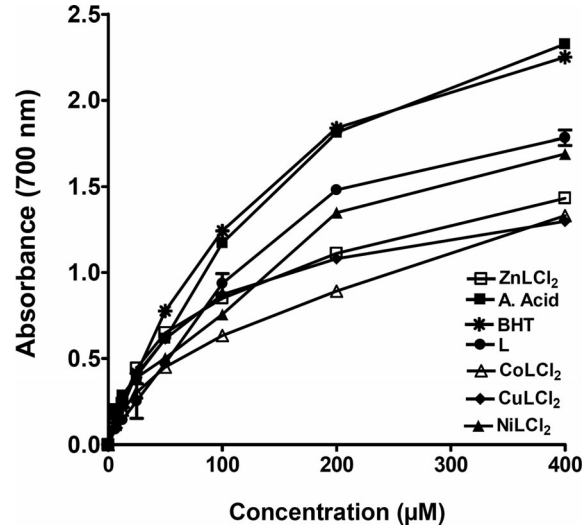

Figure 6. Antioxidant activity of the complexes determined by FRAP method: Increased absorbance of reaction mixture indicated greater reduction capability. The ligand L and its complexes demonstrated powerful ferric ions (Fe^{3+}) reducing ability and electron donor properties for neutralizing free radicals by forming stable products as compared with commercial standards ascorbic acid and BHT. The reducing power of all compounds was found to increase with increasing concentration of samples (6.25–400 μM).

3.9 Antimicrobial Activity

The antimicrobial activity of the compounds was determined against both Gram positive and negative bacterial well as fungal strains as shown in Table 1. Out of the five compounds, two compounds namely L and [$NiLCl_2$] showed broad spectrum antibacterial activity against all the test strains. The remaining compounds [$CoLCl_2$], [$CuLCl_2$], and [$ZnLCl_2$] were found to be active against one or few tested bacteria. These results clearly show the potential of L and [$NiLCl_2$] and other compounds as possible new entities appropriate for further development as antibacterials.

However, when these compounds were tested against fungal strains *C. albicans* and *A. niger*, no activity was recorded. Therefore, these compounds are promising and require further attention for possible mechanisms for the demonstrated antibacterial activity. As similar compounds have shown antifungal potential,[4] more sensitive strains should be tested for the evaluation of antifungal activity.

4 Conclusion

A series of mononuclear complexes derived from 2-(2-furyl)-2,3-dihydro-1H-perimidine were synthesized and charac-

Table 1. Antimicrobial activity of the ligand L and its complexes.

Compounds /100 μg (well)	Antibacterial activity, zone of inhibition /mm				Antifungal activity[a], zone of inhibition /mm	
	Staphylococcus aureus (IOA-SA-22)	*Bacillus subtilis* (MTCC-121)	*Escherichia coli* (K-12)	*Salmonella typhimurium* (MTCC-98)	*Candida albicans* (Clinical isolate)	*Aspergillus niger* (Clinical isolate)
L	13	12	13	14	–	–
$[CoLCl_2]$	–	–	12	13	–	–
$[NiLCl_2]$	13	12	13	14	–	–
$[CuLCl_2]$	–	–	10	11	–	–
$[ZnLCl_2]$	–	–	12	12	–	–

a) (–) represents no zone of inhibition.

terized by various physico-chemical studies viz., elemental analyses, IR, NMR, UV/Vis, and EPR spectroscopy, ESI-mass spectrometry, magnetic susceptibility, thermal analyses, and electrochemical studies. The synthesized compounds showed potential antimicrobial and antioxidant activity.

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