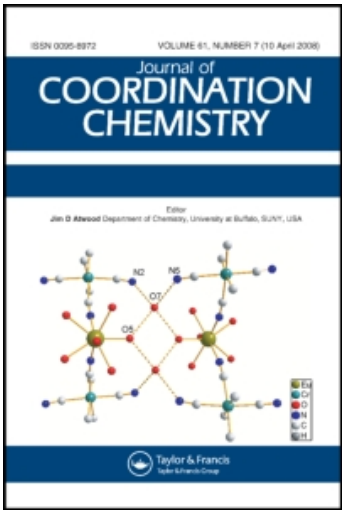

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Synthesis and characterization of metal 2-pyridine carboxaldehyde-*N*-methyl-*N*-2-pyridyl hydrazone complexes and their microbiological activity

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SYNTHESIS AND CHARACTERIZATION OF METAL 2-PYRIDINE CARBOXALDEHYDE-*N*-METHYL-*N*-2-PYRIDYL HYDRAZONE COMPLEXES AND THEIR MICROBIOLOGICAL ACTIVITY

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Complexes of Cu(II), Mn(II), Co(II), Ni(II), Hg(II), Cd(II) and Rh(III) with 2-pyridine carboxaldehyde-*N*-methyl-*N*-2-pyridylhydrazone (*pamph*) have been prepared and characterized. The new complexes have been characterized by elemental analysis, conductivity and magnetic measurements, IR, UV–vis and ^{1}H NMR spectroscopic methods. The microbiological activity of the complexes was investigated against bacteria and fungi. Most of the complexes studied appear to be active against bacteria while all are active against fungi. The Cu, Cd and Hg complexes exhibit the highest activity against both bacteria and fungi.

Keywords: 2-Pyridine carboxaldehyde-*N*-methyl-*N*-2-pyridyl hydrazone; Hydrazone complexes; Microbiological activity

INTRODUCTION

Pyridylhydrazones are organic compounds that have been investigated extensively [1]. They are effective in treating diseases such as tuberculosis, leprosy, leukemia and malignant neoplasms [2]. Moreover, they have received considerable attention because of their important role in analytical and coordination chemistry [3]. They have been used in applications such as chromogenic reagents in the spectrophotometric determination of transition metal ions, metal extracts and biologically active compounds [4]. The sensitivity and selectivity of pyridylhydrazones towards metal ions are important for pharmaceutical samples, biological materials [5] and in pharmacology [6,7].

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Equally, there has been considerable interest in the study of complexes with pyridyl-hydrazone ligands as they exhibit catalytic as well as biological properties [8], and due to their ability to be used in solar energy storage and conversion [9].

Recently, the preparation of *pamph* was reported [2], but no metal complexes containing this ligand have been described. In this paper we report the synthesis and characterization of Mn(II), Rh(III), Ni(II), Co(II), Cu(II), Cd(II) and Hg(II) complexes containing *pamph* ligand and their microbiological activity against bacteria and fungi.

EXPERIMENTAL

Materials

All solvents were analytical grade reagents, used as purchased. The metal salts and starting materials for the ligands were Aldrich, Fluka or Labort products. The ligand was prepared according to the literature method [2].

Physical Measurements

Elemental analyses for the complexes were carried out on a Perkin Elmer % Analyser 2400 series(II) instrument. Metal analyses were performed on a Unicam 929 Atomic Absorption Spectrometer. Conductivity measurements were recorded on Conductivity Meter LF 538 at 25°C for 10^{-3} M solutions in dimethylformamide (DMF), dimethylsulfoxide (DMSO) or water. Magnetic measurements were carried out on a Johnson Matthey Magnetic Susceptibility Balance. The IR spectra (KBr and CsI pellets) were recorded on Nicolet FT-IR and Pye-Unicam SP3-300 Far-IR spectrophotometers. Electronic absorption spectra were measured on a Unicam UV-VIS spectrometer for 10^{-5} M solutions in DMF or DMSO. ^{1}H NMR spectra were determined with a Bruker WP SY 200 MHz instrument in DMSO-d_6 using Me_4Si as internal standard.

Preparation of *pamph*

The ligand was prepared according to the following procedure [2]. A mixture of *N*-methyl-*N*-2-pyridyl hydrazone and 2-pyridyl carboxaldehyde (1 : 1) in ethanol was boiled under reflux for 1 h. Upon cooling the ligand precipitated, was filtered off and dried. The solid was recrystallized from ethanol. m.p. = 102–104°C. Anal. calcd. for $C_{12}H_{12}N_4$(%): C, 67.92; H, 5.66; N, 26.42. Found: C, 68.00; H, 5.74; N, 26.57. ^{1}H NMR spectra were recorded in $CDCl_3$ at 25°C (ppm): (N–CH_3) = 3.68 (3H, s); (HCN) = 7.75 (1H, s); H_4 = 8.05 (1H, m); H_3 = 7.32 (1H, m); H_2 = 6.92 (1H, m); H_1 = 8.57 (1H, m); $H_{4'}$ = 7.85 (1H, m); $H_{3'}$ = 7.28 (1H, m); $H_{2'}$ = 6.8 (1H, m); $H_{1'}$ = 8.24 (1H, m). ^{13}C-NMR spectra in $CDCl_3$ show the characteristic peak for the methyl carbon at 29.1 ppm and for the aromatic as well as the imine C=N carbons at 157.4, 155.3, 149.2, 147.0, 137.5, 136.3, 134.6, 122.4, 119.3, 116.1 and 110.1 ppm, a total of twelve different types; the mass spectrum shows $[M^+] = 212$.

Preparation of the Complexes

Complexes were all dried under vacuum at 25°C and prepared using the following general procedures:

[M(pamph)Cl_3]Cl · xH_2O · yEtOH; [M=Cu(II), x = 1, y = 0; Co(II), x = 1, y = 0.5; Mn(II), x = 0, y = 0.5; Hg(II), x = 0, y = 0]

To a stirred solution of 1.0 mmol of the ligand *pamph* in EtOH was added a solution of the corresponding metal chloride. The reaction mixture was stirred at room temperature, resulting in a color change and solid formation. The solid was filtered and thoroughly washed with EtOH.

[Cd(pamph)Br_2]MeOH

To an EtOH solution of the *pamph* ligand (1.0 mmol), a methanolic solution of cadmium acetate (1.0 mmol) was added, followed by excess of an aqueous solution of KBr. The mixture was refluxed for 20 min, allowed to cool and filtered. The product was washed with hot H_2O and EtOH.

[Rh(pamph)Cl_3]H_2O · 0.5EtOH

To a stirred hot aqueous solution of $RhCl_3 \cdot 3H_2O$ (1.0 mmol) was added an EtOH solution of *pamph* (1.0 mmol). The mixture was refluxed for 30 min, allowed to cool and filtered. The product was washed with a small amount of H_2O, EtOH and then with Et_2O.

[Cu(pamph)$_2$](ClO_4)$_2$ · 0.5H_2O

An EtOH solution of hydrated copper sulfate (1.0 mmol) was added to an ethanolic solution of *pamph* (2.0 mmol). The reaction mixture was stirred for a few minutes and treated with an excess of $NaClO_4$ as an aqueous solution. The product formed was filtered off, and washed with hot H_2O and then EtOH.

[Ni_2(pamph)$_2SO_4$](ClO_4)$_2$ · H_2O

An EtOH solution of hydrated nickel sulfate (1.0 mmol) was added to an ethanolic solution of *pamph* (1.0 mmol). The reaction mixture was then treated with excess of an aqueous solution of $NaClO_4$. The formed product was filtered and washed with hot H_2O and then EtOH.

Microbiological Screening

An inoculum of each bacteria strain was suspended in 5 cm^3 of Muller–Hinton broth (oxoid) and incubated overnight at 37°C. The overnight cultures were diluted 1/10 with Muller–Hinton broth (oxoid) before use. An inoculum of *Candida albicans* was prepared by picking five colonies from a 24-hour-old culture and the colonies were suspended in 5 cm^3 of potato dextrose broth (oxoid). Disc-diffusion assay [10] was

used to screen for antibiotic and antifungal activity. The impregnated discs (AA disc Whatman) were then placed on the plates and incubated for 15 min to allow diffusion. Ten μ dm^3 of the diluted culture was spread on sterile Muller–Hinton agar (oxoid) plates (for bacteria) or sterile potato dextrose agar (oxoid) plates (for *Candida albicans*). The plates were incubated for 18 h at 35–37°C before the resulting zones of inhibition were observed and recorded. Tests were repeated twice to ensure reliability of the results.

RESULTS AND DISCUSSION

The hydrazone derivative, 2-pyridine carboxaldehyde-*N*-methyl-*N*-2-pyridyl hydrazone (*pamph;* Fig. 1) was treated at room temperature with the corresponding metal salt using 1 : 1 mole ratios in EtOH to give mononuclear complexes [Cu(*pamph*)Cl]$Cl \cdot H_2O$, [Mn(*pamph*)Cl_2]0.5EtOH, [Hg(*pamph*)Cl_2] and [Co(*pamph*)Cl_2]$H_2O \cdot 0.5EtOH$. Under the same conditions a 1 : 1 mole ratio gave the dinuclear complex [Ni_2(*pamph*)$_2SO_4$]$(ClO_4)_2 \cdot H_2O$ as the chlorate salt by adding $NaClO_4$ to the reaction mixture. Reaction at a 1 : 2 metal-to-ligand mole ratio gave [Cu(*pamph*)$_2$]$^{2+}$, which was isolated as the chlorate salt on addition of excess $NaClO_4$. The complex [Rh(*pamph*)Cl_3]$H_2O \cdot 0.5EtOH$ was prepared by boiling an aqueous ethanolic solution of $RhCl_3 \cdot 3H_2O$ and *pamph*. The cadmium–bromo complex [Cd(*pamph*)Br_2]MeOH was prepared by boiling a methanolic solution of cadmium acetate with an ethanolic solution of *pamph* in 1 : 1 mole ratio, with an excess of KBr.

All complexes are colored solids, stable in air, and were isolated in good yields. The analytical and physical data are listed in Table I.

Conductivity

The molar conductances for these complexes (Table I) are in good agreement with those reported for similar complexes [11]. The complexes [Mn(*pamph*)Cl_2]0.5EtOH, [Hg(*pamph*)Cl_2], [Co(*pamph*)Cl_2]$H_2O \cdot 0.5EtOH$, [Cd(*pamph*)Br_2]MeOH and [Rh(*pamph*)Cl_3]$H_2O \cdot 0.5EtOH$ behave as neutral nonelectrolytes in DMF. The complexes [Cu(*pamph*)$_2$]$(ClO_4)_2 \cdot 0.5H_2O$ and [Ni_2(*pamph*)$_2SO_4$]$(ClO_4)_2 \cdot H_2O$ behave as 1 : 2 electrolytes. The complex [Cu(*pamph*)Cl]$Cl \cdot H_2O$ which was insoluble in DMF, dissolved in H_2O and gave an unexpected result, behaving as a 1 : 2 electrolyte

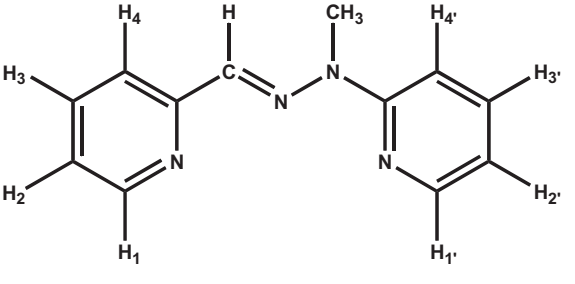


FIGURE 1 Structure of the *pamph* ligand.

TABLE I Analytical and physical data for the complexes

Complex	*Color*	*M.p.* (°C)	*Found (Calcd), (%)*				μ_{eff} (BM)	Λ_M[a]
			C	*H*	*N*	*M*		
[Cu(*pamph*)Cl]Cl · H_2O	green	293	39.72 (39.50)	3.78 (3.84)	14.97 (15.36)	17.45 (17.43)	1.97	232[b]
[Cu(*pamph*)$_2$](ClO_4)$_2$ · 0.5H_2O	green-yellow	282–285	41.61 (41.40)	3.49 (3.59)	15.62 (16.10)	9.03 (9.25)	1.98	129
[Mn(*pamph*)Cl_2]0.5EtOH	orange	357–359	42.57 (43.23)	3.63 (4.15)	15.57 (15.52)	13.88 (15.22)	6.34	29.8
[Hg(*pamph*)Cl_2]	pale-yellow	260–262	29.86 (29.78)	2.49 (2.48)	10.82 (11.58)	–	diam.	4
[Co(*pamph*)Cl_2]H_2O · 0.5EtOH	green-yellow	385	40.0 (40.73)	3.65 (4.43)	14.48 (14.62)	–	4.55	14.8
[Ni_2(*pamph*)$_2SO_4$](ClO_4)$_2$ · H_2O	sandy-yellow	372–375	33.75 (33.70)	2.95 (3.04)	12.32 (13.10)	6.65 (6.87)	3.70	158
[Cd(*pamph*)Br_2]MeOH	yellow	350	29.71 (30.21)	2.43 (3.09)	10.06 (10.8)	21.74 (21.70)	diam.	7.5
[Rh(*pamph*)Cl_3]H_2O · 0.5EtOH	orange-yellow	348–360	33.94 (33.73)	2.98 (3.67)	11.99 (12.11)	–	diam.	2

[a]Molar conductance ($\Omega\,cm^2\,mol^{-1}$) for 10^{-3} M solutions at 25°C in DMF; [b]in H_2O.

TABLE II Important IR frequencies for the ligand and complexes (KBr pellets, cm^{-1})

Compound	ν(C=N)	ν(N–N)	γ(Py)	ν(M–N)[a]	ν(M–X)[a]
pamph	1595 vs	985 vs	777 vs	–	–
[Cu(*pamph*)Cl]Cl · H_2O	1608 s	1017 m	789 m	520 m	389 m
[Cu(*pamph*)$_2$](ClO_4)$_2$ · 0.5H_2O	1595 s	1004 m	769 m	508 w	–
[Mn(*pamph*)Cl_2] · 0.5EtOH	1602 vs	976 m	776 m	445 m	334 s
[Hg(*pamph*)Cl_2]	1595 s	997 m	782 m	515 m	330 s
[Co(*pamph*)Cl_2]H_2O · 0.5EtOH	1602 vs	992 w	777 m	517 w	381 m
[Ni_2(*pamph*)$_2SO_4$](ClO_4)$_2$ · H_2O	1602 s	984 m	776 s	528 m	–
[Cd(*pamph*)Br_2]MeOH	1595 vs	1004 m	789 m	508 m	334 w
[Rh(*pamph*)Cl_3]H_2O · 0.5EtOH	1607 vs	1004 s	783 vs	426 w	383 m

vs, very strong; s, strong; m, medium; w, weak.
[a]CsI pellets.

instead of a 1 : 1 electrolyte. This indicates the replacement of coordinated Cl by water to give the isomer [Cu(*pamph*)H_2O]Cl_2 which acts as 1 : 2 electrolyte [11].

IR Spectra

The characteristic IR bands for the free ligand and the complexes are shown in Table II. The main points are given below.

(i) Upon complexation the characteristic free ligand bands of isomethine ν(C=N) at 1595 cm^{-1}, as well as the band at 985 cm^{-1} which is assigned to the ν(N–N) are reduced in intensity and shifted to slightly higher wavenumbers (Table II). Such results are in good agreement with what has been reported for such complexes [8].

(ii) The pyridine out-of-plane ring deformation γ(py) of the free ligand which appears at 777 cm^{-1} shifts to higher wavenumbers in the complexes [Cu(*pamph*)Cl]Cl · H_2O, [Hg(*pamph*)Cl_2], [Cd(*pamph*)Br_2]MeOH and [Rh(*pamph*)Cl_3]

$H_2O \cdot 0.5EtOH$, while in the complexes [Mn(*pamph*)Cl_2] 0.5EtOH, [Co(*pamph*)Cl_2] $H_2O \cdot 0.5EtOH$, [Cu(*pamph*)$_2$]$(ClO_4)_2 \cdot 0.5H_2O$ and [Ni_2(*pamph*)$_2SO_4$] $(ClO_4)_2 \cdot H_2O$ it shifts to lower wavenumbers.

(iii) The strong absorption bands appearing in the range 1092–1125 cm^{-1} in the IR spectra of [Cu(*pamph*)$_2$]$(ClO_4)_2 \cdot 0.5H2O$ and [Ni_2(*pamph*)$_2SO_4$]$(ClO_4)_2 \cdot H_2O$, which are assigned to ν(Cl–O) vibrations, indicate the presence of ClO_4^- [12]. The bridging SO_4^{2-} group in [Ni_2(*pamph*)$_2SO_4$]$(ClO_4)_2 \cdot H_2O$ was characterized by the medium band at 683 cm^{-1}. However, the other characteristic bands of bridging SO_4^{2-} could not be detected, perhaps obscured by bands of the ClO_4^- group and the ligand [12,14].

(iv) The appearance of a medium, broad absorption in the range 3400–3500 cm^{-1}, together with other bands in the range 1615–1635 cm^{-1}, supports the presence of water molecules in the hydrated complexes [13], as well as ethanol and methanol molecules.

(v) The far-IR spectra of the complexes exhibit a new band in the range 426–528 cm^{-1} characteristic of metal–nitrogen stretching vibration [8,14]. The coordinated halogen in the complexes shows a far IR absorption peak in the range 330–389 cm^{-1}, which may be attributed to ν(M–Cl), while the complex [Cd(*pamph*)Br_2]MeOH shows a weak band at 334 cm^{-1}, which may be assigned to ν(M–Br) [14].

Electronic Absorption Spectra

The electronic spectrum of the uncoordinated pyridylhydrazone ligand exhibits three bands (LC) in the 256, 272 and 340 nm ranges from $n \rightarrow \pi^*$, $n \rightarrow \sigma^*$ and $\pi \rightarrow \pi^*$ (Table III). Upon complexation the LC bands undergo an intensity increase with a slight shift relative to the ligand [15,16]. The spectra exhibit, in addition to LC bands, broad bands which are assigned to metal–ligand charge-transfer (MLCT) transitions and d–d transitions, which are responsible for the characteristic colors of these complexes [17,18] (Table III). The broadness of the peaks at ca. 250–340 nm may indicate the presence of MLCT bands underlying the LC bands. These results are in good agreement with reports for complexes containing other hydrazones [15–18].

The complex [Cu(*pamph*)Cl]$Cl \cdot H_2O$ exhibits a d–d band at 376 nm, suggesting square-planar geometry. This is comparable to that reported for analogous complexes containing four-coordinate Cu(II) centers in a square-planar environment [19–22]. The complex [Cu(*pamph*)$_2$]$(ClO_4)_2 \cdot 0.5H_2O$ is characterized by the presence of a d–d band at 384 nm indicating an octahedral environment, in good agreement with similar complexes containing six-coordinate Cu(II). The strong bands at 300 and 348 nm may be assigned to MLCT transitions [23].

The electronic spectrum of [Rh(*pamph*)Cl_3]$H_2O \cdot 0.5EtOH$ shows MLCT bands at 304 and 322 nm along with another broad band at 436 nm that may be assigned to a d–d transition, in agreement with what has been reported for Rh(III) complexes [13,17,18,24].

The complex [Co(*pamph*)Cl_2]$H_2O \cdot 0.5EtOH$ exhibits three d–d transitions at 565, 585 and 635 nm, consistent with Co(II) five-coordinate stereochemistry, along with the bands at 292 and 483 nm that may be assigned to MLCT transitions [25,26]. Moreover, the electronic spectrum of the five-coordinate complex [Mn(*pamph*)Cl_2] 0.5EtOH

TABLE III Electronic absorption spectra (in DMF) of the ligand and its complexes

Compound (1×10^{-5} M solution)	λ_{max} *(nm)*	$\varepsilon \times 10^{-3}$ *($dm^3 mol^{-1} cm^{-1}$)*	*Band assignment*
pamph	256	9.6	LC
	278	7.7	LC
	340	6.8	LC
[Cu(*pamph*)Cl]Cl · H_2O[a]	292	16.7	MLCT
	300	33.2	MLCT
	376 br	0.0063	d–d
[Cu(*pamph*)$_2$](ClO_4)$_2$ · 0.5H_2O	300	28.9	MLCT
	348	41.1	MLCT
	384 br,sh	0.0035	d–d
[Mn(*pamph*)Cl_2] · 0.5EtOH	300	8.6	MLCT
	475	0.00578	d–d
	525	0.00777	d–d
	545	0.011	d–d
[Hg(*pamph*)Cl_2]	292	35.4	MLCT
[Co(*pamph*)Cl_2]H_2O · 0.5EtOH	292	14.7	MLCT
	483 sh	12.5	MLCT
	565 sh	0.0022	d–d
	585	0.0098	d–d
	635	0.013	d–d
[Ni_2(*pamph*)$_2SO_4$](ClO_4)$_2$ · H_2O	296	42.2	MLCT
	483	0.0057	d–d
	530 sh	0.0066	d–d
	567	0.0032	d–d
[Cd(*pamph*)Br_2]MeOH	284	34.7	MLCT
	312	39.9	MLCT
[Rh(*pamph*)Cl_3]H_2O · 0.5EtOH	304	19.4	MLCT
	322	27.1	MLCT
	436 br,sh	0.0045	d–d

[a]In H_2O; br, broad; sh, shoulder.

shows bands at 475, 525 and 545 nm that are assignable to d–d transitions [27], together with the MLCT band at 300 nm. The observed bands at 483, 530 and 567 nm for [Ni_2(*pamph*)$_2SO_4$](ClO_4)$_2$ · H_2O may be assigned to d–d transitions, indicating four-coordinate Ni(II) [28].

The complexes [Hg(*pamph*)Cl_2] and [Cd(*pamph*)Br_2]MeOH exhibit a different type of electronic spectra with LC bands within the expected regions; however, other bands appear that may be assigned to MLCT transitions [29].

Magnetic Measurements

The room temperature magnetic moment of the complexes [Mn(*pamph*)Cl_2]0.5EtOH and [Co(*pamph*)Cl_2]H_2O · 0.5EtOH (Table I) indicate behavior consistent with a square pyramidal environment [25,27]. For the nickel(II) complex, the magnetic moment value is in good agreement with that for Ni(II) in a distorted tetrahedral stereochemistry [18]. The measured value for the Cu(II) complex [Cu(*pamph*)Cl]Cl · H_2O is consistent with the spin-only value of 1.73 BM, indicating little or no interaction between the Cu(II) centers in the monomeric square-planar geometry [8,19,30]. For [Cu(*pamph*)$_2$](ClO_4)$_2$ · 0.5H_2O, the magnetic moment is consistent with d^9 octahedral stereochemistry [31]. Moreover, the magnetic moments for Cd(II)

TABLE IV ^{1}H NMR data (in DMSO, 200 MHz) for the ligand and some of the complexes

Compound	*Band shift (ppm)*
pamph	(N–CH_3) = 3.68 (3H, s); (HCN) = 7.75 (1H, s); H_4 = 8.05 (1H, m); H_3 = 7.32 (1H, m); H_2 = 6.92 (1H, m); H_1 = 8.57 (1H, m); $H_{4'}$ = 7.85 (1H, m); $H_{3'}$ = 7.28 (1H, m); $H_{2'}$ = 6.8 (1H, m); $H_{1'}$ = 8.24 (1H, m)
[Mn(*pamph*)Cl_2] · 0.5EtOH	(N–CH_3) = 3.6 (3H, s); (HCN) = 7.70 (1H, s); H_4 = 8.02 (1H, m); H_3 = 7.3 (1H, m); H_2 = 6.9 (1H, m); H_1 = 8.55 (1H, m); $H_{4'}$ = 8.02 (1H, m); $H_{3'}$ = 7.3 (1H, m); $H_{2'}$ = 6.9 (1H, m); $H_{1'}$ = 8.22 (1H, m)
[Hg(*pamph*)Cl_2]	(N–CH_3) = 3.65 (3H, s); (HCN) = 8.0 (1H, s); H_4 = 7.88 (1H, m); H_3 = 7.72 (1H, m); H_2 = 7.45 (1H, m); H_1 = 8.58 (1H, m); $H_{4'}$ = 7.82 (1H, m); $H_{3'}$ = 7.69 (1H, m); $H_{2'}$ = 7.05 (1H, m); $H_{1'}$ = 8.25 (1H, m)
[Rh(*pamph*)Cl_3]H_2O · 0.5EtOH	(N–CH_3) = 3.86 (3H, s); (HCN) = 8.55 (1H, s); H_4 = 8.25 (1H, m); H_3 = 7.75 (1H, m); H_2 = 7.45 (1H, m); H_1 = 8.9 (1H, m); $H_{4'}$ = 8.0 (1H, m); $H_{3'}$ = 7.5 (1H, m); $H_{2'}$ = 7.35 (1H, m); $H_{1'}$ = 8.6 (1H, m)

s, singlet; m, multiplet.

TABLE V Microbiological screening

Compound	*Bacteria*			*Fungi Candida albicans*
	E. coli	*S. aureus*	*P. aeruginosa*	
pamph	+	−	−	+++
[Cu(*pamph*)Cl]Cl · H_2O	++	+	++	+
[Cu(*pamph*)$_2$]$(ClO_4)_2$ · 0.5H_2O	++	+	++	+++
[Mn(*pamph*)Cl_2] · 0.5EtOH	−	−	−	+++
[Hg(*pamph*)Cl_2]	+++	++	++	+++
[Co(*pamph*)Cl_2]H_2O · 0.5EtOH	−	−	−	+
[Ni_2(*pamph*)$_2SO_4$]$(ClO_4)_2$ · H_2O	−	−	−	+
[Cd(*pamph*)Br_2]MeOH	++	++	++	++
[Rh(*pamph*)Cl_3]H_2O · 0.5EtOH	−	−	−	+

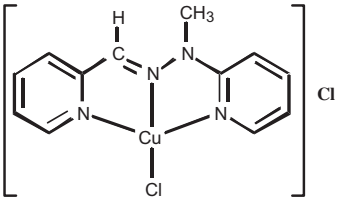
Samples were dissolved in DMSO (30 μg/disk).
Diameter of zone of inhibition in mm: − (0–5); + (5–10); ++ (10–20); +++ (20–30).

and Hg(II) complexes are in good agreement with the expected diamagnetism for completely filled d orbitals.

^{1}H NMR Spectra

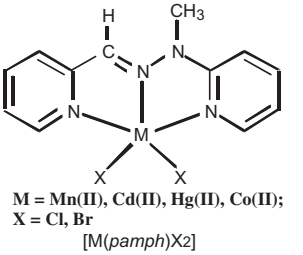
The ^{1}H NMR spectra for the ligand and some of the isolated complexes were recorded and the results are presented in Table IV. Coordination of the ligand nitrogens to the metal can be assumed by the general chemical shift differences of the protons in the ^{1}H NMR spectra of the complexes as compared to the free ligand (Table IV; Fig. 1). The chemical shift changes on coordination for H_1, H_2, and H_3 are similar to those observed for $H_{1'}$ $H_{2'}$ and $H_{3'}$, respectively. Thus both pyridyl nitrogen atoms interact with the metal center [32]. The downfield shift of the proton (HCN) confirms that the imino nitrogen coordinates to the metal. The peaks due to aliphatic protons of the ligand N–CH_3 appear in the 3.60–3.86 ppm range, as expected [33–35].

For [Rh(*pamph*)Cl_3]$H_2O \cdot 0.5$EtOH protons (H_1, $H_{1'}$) are directed towards the chloride ion and thus experience a different environment. These protons are expected to be highly deshielded and their presence may be used as evidence for the assumed structure **4**; therefore the peaks at 8.9 and 8.6 ppm may be assigned to the protons (H_1, $H_{1'}$). Based on the physical measurements and upon similar results found for previously reported compounds [25,32,36,27], we conclude that the complexes have the configurations shown in structures **1**, **2**, **3**, **4** and **5**.



[Cu(*pamph*)Cl]Cl

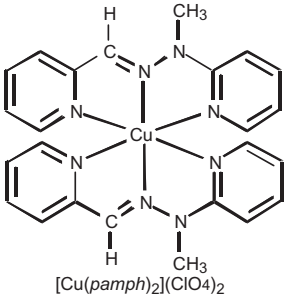
1



M = Mn(II), Cd(II), Hg(II), Co(II); X = Cl, Br

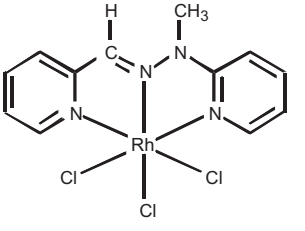
[M(*pamph*)X2]

2



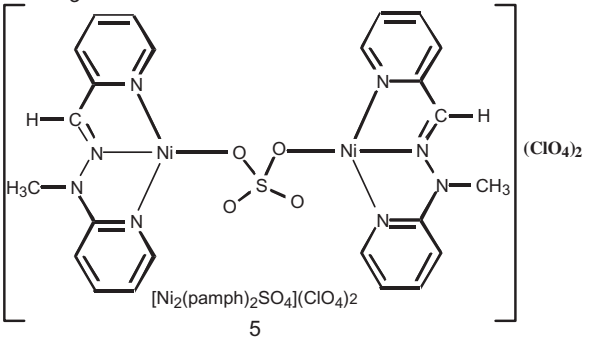
[Cu(*pamph*)$_2$](ClO4)$_2$

3



[Rh(*pamph*)Cl_3]

4



[Ni_2(pamph)$_2SO_4$](ClO4)2

5

Microbiological Screening

Screening tests were carried out to investigate the bactericidal and fungicidal activity of the complexes. The tested bacteria were *E. coli, S. aureus* and *P. aeruginosa* while the fungus was *Candida albicans*. The culture media were Muller–Hinton agar (MHA) supplemented with 1 g yeast 1. The antibacterial and antifungal activity of each compound was evaluated by the classical disk diffusion agar plates technique. It is evident from the biological screening data for the complexes (Table V) that the complexes exhibit activity

against bacteria and fungi. The primary conclusions are that (i) some complexes show greater activity against bacteria than does the ligand; (ii) the activity of most of the complexes was greater against *Candida albicans* than against bacteria. This might be attributed to the difference in the chemical composition of the cell walls of *Candida albicans* and bacteria. A potential explanation for the trend in activity exhibited by these compounds could reside in their low lipophilicity. In the penicillin family of antibiotics potency is directly related to lipophilic character, particularly with Gram-positive organisms [38]. The hydrazone aromatic nucleus is highly electron-rich and it is possible that the aromatic rings found in such compounds do not sufficiently enhance the log *P* value of the complexes to allow for effective penetration of the bacterial cell membrane. Moreover, it might be indicative of the need for a hydrophilic interaction (as opposed to charge transfer or van der Waals type interaction) at the receptor surface for effective inhibition of fungal growth [38]. (iii) The complexes of Rh, Ni, Mn and Co are inactive against bacteria but show activity against *Candida albicans*. (iv) The Cu complexes are found to be active against both *Candida albicans* and bacteria. (v) Cd and Hg complexes show greater activity against *Candida albicans* and bacteria than do the other complexes.

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