

Original Article



Synthesis, Spectral and Biological Studies of Co(II), Fe(II), Ni(II), Cu(II), Pd(II), Mn(II), Hg(II), Cd(II), and Zn(II) Complexes Derived from Benzohydrazide Schiff Base

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ABSTRACT

Electronic absorption spectra, infrared spectroscopy, nuclear magnetic resonance, molar conductance, and elemental analysis are some of the physicochemical methods used to characterize the 4-chloro-*N'*-[(*E*)-(2,6-dihydroxy phenyl) methylidene] benzohydrazide (HBHDH) molecule that has been synthesized. The results of the analysis show that the metal and ligand formed a 1:2 ratio. According to the spectra, the ligand HBHDH forms tridentate coordination spheres with metal ions using an ONO bond. Complexes with Fe(II), Co(II), Ni(II), Cu(II), and Mn(II) have an octahedral shape because of this. In contrast to the tetrahedral structure of the complexes created with Zn(II), Cd(II), and Hg(II), the Pd(II) complex takes on a square planar layout. According to the molar conductance values in DMF, the complexes do not undergo electrolysis. It has been determined that the metal complexes and Schiff's base HBHDH ligand have antibacterial action. The antibacterial efficiency of each combination and ligand against *E. coli* bacteria is higher than that of regular *streptomycin*. *Candida albicans* (MCC 1439) and *Saccharomyces cerevisiae* (MCC 1033) have significant antifungal effectiveness, with their growth being inhibited by over 92% in the presence of Mn(II) and Fe(II) complexes, respectively.

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Introduction

In particular, hydrazones -NH-N=CRR' (where R and R' = H, alkyl, aryl) have attracted a lot of attention as a family of ligands due to their ability to create stable complexes with most metal ions through novel coordination mechanisms [1-4]. Catalytic processes and simulations of biological systems have made use of hydrazone Schiff base complexes. Schiff base metal complexes with nitrogen and other donors have recently been the subject of a great deal of chemical investigation. Their biological activity and stability, like their anti-convulsant and anti-tumor properties, may be related to osteoporosis. Oxidation catalysis and electrochemistry are two of the many possible uses for hydrazones [5,6]. Hydrazones have multiple uses, including as growth regulators, nematocides, rodenticides, and herbicides [7]. According to literature [8-10], much of the research has focused on hydrazone complexes of transition metal ions.

Hydrazine Schiff base metal complexes prepared from 4-chlorobenzohydrazide and 2, 4-dihydroxybenzaldehyde have not yet been documented in any study. The objective of this study is to create and characterize complexes of 4-chloro-*N'*-[(*E*)-(2,6-dihydroxyphenyl)methylidene]benzohydrazide (HBHDH) with several metals. Spectroscopic methods (electronic absorption, infrared, ^1H nuclear magnetic resonance) and magnetic moments are used to investigate the complexes' shape, bond types, and probable chelation mechanism. Antimicrobial and antifungal activity testing was performed on all of the synthesized compounds.

Experimental

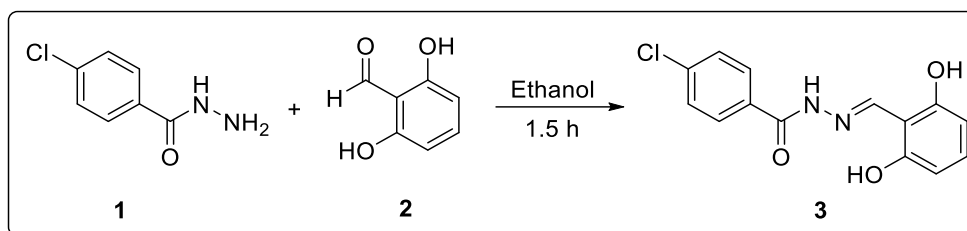
The analytical grade (AR) chemicals and solvents used to synthesize the HBHDH ligand and its related metal complexes were supplied by S.D. Fine. To prepare metal complexes, certain metal salts are required, such as FeSO_4 ,

$\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$, $\text{NiCl}_2 \cdot 7\text{H}_2\text{O}$, PdCl_2 , $\text{CuCl}_2 \cdot 5\text{H}_2\text{O}$, $\text{ZnCl}_2 \cdot 7\text{H}_2\text{O}$, CdCl_2 , HgCl_2 , and $\text{MnCl}_2 \cdot 2\text{H}_2\text{O}$. You can buy them and use them just the way they are. The production of 4-chlorobenzohydrazide [11] followed the steps outlined in the published literature. We found the amounts of metals and chlorides using Vogel's approach [12]. The ligand and its metal complexes were studied by measuring their infrared spectra with KBr pellets using a Bruker infrared spectrophotometer. A JASCO UV-Visible spectrophotometer (V-650) was used to detect the electronic absorption spectra of the metal complexes within the 1000 to 200 nm wavelength range. Researchers recorded the ^1H -NMR spectra of the ligand and its metal complexes in DMSO- d_6 using a Bruker 400 MHz spectrophotometer, with TMS acting as an internal reference. The method developed by Rast was used to determine molecular weights [13-17].

At room temperature, the metal complexes' magnetic susceptibilities were measured using Gouy's method, calibrated with $\text{Hg}[\text{Co}(\text{SCN})_4]$, which stands for mercury (II) tetra thiocyanate cobalt (II). A solution of nitrobenzene (10^{-3} M) was used to determine the molar conductivity at room temperature.

Preparation of HBHDH ligand

In **Scheme 1**, a hot 4-chlorobenzohydrazide (**1**) was mixed with a hot ethanolic solution of 2, 6-dihydroxybenzaldehyde (**2**) dropwise while being constantly agitated. An oil bath could heat the reaction mixture for three to four hours. We filtered the yellow PPT, washed it with ethanol, and dried it under vacuum after it cooled to room temperature. Colour; yellow. M.W.; 290.70 g/mol. % yield; 69.07. M.P.; 183. % composition: C, 57.84; H, 3.81; N, 9.64; O, 16.51; S, 12.20. UV-vis (λ_{nm}); 335, 295, and 335. FT(IR) (cm^{-1}); 3257, 2926, 3190, 2937, 1629, 1605, and 1295. ^1H -NMR (δ); 12.01 (-OH, C2), 11.46 (-OH, C6), 10.02 (-NH), 8.55 (-CH=), and 6.36-7.99 (Ar. protons).



Scheme 1. Preparation of HBBDH ligand

Preparation of metal complexes

The appropriate metal salt (0.05 mol) was slowly added to a 15 mL container of hot ethanolic HBBDH ligand (0.1 mol) solution while stirring continuously. Hot ethanol was used to carry out the reaction. The inclusion of 0.1 N NaOH brought the reaction mixture's pH up to 7. The mixture was heated in an oil bath and refluxed for five to eight hours. Cooling the solution after digestion reduced its volume by half and allowed it to solidify. Following a period of drying at room temperature, the product was rinsed with ethanol. Results should range from 69 to 73%.

[Fe(BHDDH)₂]

Colour: Blue. M.W.: 635.24 g/mol. % yield: 73.46. M.P.: 200. % composition: C, 52.89; H, 3.75; N, 8.82; O, 15.11; S, 11.20; Fe, 8.79. UV-Vis (λ_{nm}): 613 and 503. FT(IR) (cm^{-1}): 2926, 3152, 2840, 1584, 1525, 1233, 631, 550, and 520.

[Co(BHDDH)₂]

Color: brown. M.W: 640.39 g/mol. % yield: 76.44. M.P.: 203. % composition: C, 52.47; H, 3.12; N, 8.75; O, 15.00; S, 11.10; Co, 9.12. UV-Vis (λ_{nm}): 900 and 675. FT(IR) (cm^{-1}): 2919, 3448, 2849, 1596, 1542, 1217, 653, 590, and 511.

[Ni(BHDDH)₂]

Colour: light green. M.W.: 640.09 g/mol. % yield: 79.13. M.P.: 204. % composition: C, 52.49; H, 3.12; N, 8.75; O, 15.00; S, 11.10; Ni, 9.17. UV-Vis (λ_{nm}): 995 and 667. FT(IR) (cm^{-1}): 2924, 3408, 2848, 1593, 1549, 1217, 639, 618, and 532.

[Pd(BHDDH)₂]

Colour: Green. M.W.: 687.40 g/mol. % yield: 83.87. M.P.: 209. % composition: C, 48.48; H, 2.91; N, 8.15; O, 14.00; S, 10.33; Pd, 15.42. UV-Vis (λ_{nm}): 396, 331, and 285. FT(IR) (cm^{-1}): 2923, 3288, 2851, 1552, 1518, 1218, 535, and 525. ¹H-NMR (δ); 11.51 (-OH, C6), 9.74 (-NH), 8.65 (-CH=), 6.41-8.04 (Ar. protons).

[Cu(BHDDH)₂]

Colour: Green. M.W.: 644.95 g/mol. % yield: 81.61. M.P.: 206. % composition: C, 52.10; H, 3.10; N, 8.68; O, 14.90; S, 11.00; Cu, 9.85. UV-Vis (λ_{nm}): 638. FT(IR) (cm^{-1}): 2923, 3152, 2852, 1581, 1513, 1219, 595, 521, and 515.

[Zn(BHDDH)₂]

Colour: Yellow. M.W.: 646.76 g/mol. % yield: 77.40. M.P.: 206. % composition: C, 52.10; H, 3.10; N, 8.68; O, 14.90; S, 11.00; Zn, 9.85. UV-Vis (λ_{nm}): 332, 310, and 230. FT(IR) (cm^{-1}): 2922, 3341, 2851, 1592, 1547, 1215, 595, and 528. ¹H-NMR (δ); 11.28 (-OH, C6), 9.61 (-NH), 8.48 (-CH=), 7.11-7.55 (Ar. protons).

[Cd(BHDDH)₂]

Colour: Yellow. M.W.: 693.81 g/mol. % yield: 81.55. M.P.: 210. % composition: C, 48.43; H, 2.88; N, 8.07; O, 13.80; S, 10.20; Cd, 16.20. UV-Vis (λ_{nm}); 340, 253. FT(IR) (cm^{-1}): 2979, 3197, 2835, 1579, 1548, 1226, 602, and 552. ¹H-NMR (δ); 11.27 (-OH, C6), 10.04 (-NH), 8.65 (-CH=), 6.41-8.67 (Ar. protons).

[Hg(BHDH)₂]

Colour: Yellow. M.W.: 781.40 g/mol. % yield; 69.77. M.P.: 206. % composition: C, 43.00; H, 2.56; N, 7.17; O, 12.29; S, 9.09; Hg, 25.67. UV-Vis (λ_{nm}); 340, 310, 230. FT(IR) (cm^{-1}); 2922, 3321, 2852, 1604, 1540, 1241, 529, and 510. ¹H-NMR (δ); 11.56 (-OH, C6), 9.89 (-NH), 8.55 (-CH=), 6.36-7.99 (Ar. protons).

[Mn(BHDH)₂]

Colour: Brown. M.W.: 634.34 g/mol. % yield; 69.88. M.P.: 202. % composition: C, 52.97; H, 3.15; N, 8.83; O, 15.10; S, 11.20; mn, 8.66. UV-Vis (λ_{nm}); 561 and 398. FT(IR) (cm^{-1}); 2925, 3257, 2836, 1552, 1515, 1218, 618, 571, and 534.

Biological evaluation

To investigate the chemicals' efficacy against various microorganisms, including *Staphylococcus aureus* (MCC 2408), *B. subtilis* (MCC 2010), *Escherichia coli* (MCC 2412), *Pseudomonas aeruginosa* (MCC 2080), fungi (*C. albicans* (MCC 1439), and *S. cerevisiae* (MCC 1033) [16], the conventional disc-agar diffusion technique was employed. *Fluconazole* was considered the best treatment for Gram-negative bacteria.

This is in contrast to the usage of cycloheximide against fungi and cephalothin against Gram-positive bacteria. A 2 and 1 mg/mL solution of

the compounds was prepared before testing using DMF, which did not have any inhibitory effect. The experimental medium used was PDA, which stands for potato dextrose agar and is composed of 200 g of potato infusion, 6 g of dextrose, and 15 g to measure.

Before being delicately put on incubated agar surfaces, discs of filter paper were soaked with 10 mL of a solution containing a controllable concentration of test compounds. Following incubation for 36 hours at 27 °C for bacteria and 48 hours at 24 °C for fungus, the distance between each disc and the surrounding clear zone was measured. The mean inhibition zones were then calculated.

Results and discussion

The HBHDH ligand and its complexes exhibit resistance to the negative impacts of oxygen and moisture when stored at room temperature. The complexes exhibit limited solubility in water, although they are partially soluble in ethanol and methanol and completely soluble in DMF, nitrobenzene, and DMSO solvents. Table 1 presents the analytical data for both the ligand and the complexes. The results corroborate the chemical formula of the ligand, C₁₄H₁₁ClN₂O₃, and the 1:2 metal-to-ligand stoichiometry in the complexes.

Table 1. Analytical and physicochemical data of metal complexes with the HBHDH ligand

Compound	Colour	MW	% Yield	MP/DP	Element Content						Cond	MM
					M	C	H	N	O	S		
HBHDH	Yellow	290.70	69.07	183	-	57.84	3.81	9.64	16.51	12.20	-	-
Fe(BHDH) ₂	Blue	635.24	73.46	200	8.79	52.89	3.15	8.82	15.11	11.20	1.49	5.12
Co(BHDH) ₂	Brown	640.39	76.44	203	9.21	52.47	3.12	8.75	15.00	11.10	1.56	4.45
Ni(BHDH) ₂	L. Green	640.09	79.13	204	9.17	52.49	3.12	8.75	15.00	11.10	0.76	3.14
Pd(BHDH) ₂	Green	687.40	83.78	209	15.42	48.88	2.91	8.15	14.00	10.33	2.25	-
Cu(BHDH) ₂	Green	644.95	81.61	206	9.85	52.10	3.10	8.68	14.90	11.00	2.10	2.10
Zn(BHDH) ₂	Yellow	646.76	77.40	203	10.11	51.94	3.09	8.66	14.80	10.97	2.40	-
Cd(BHDH) ₂	Yellow	693.81	81.55	210	16.20	48.43	2.88	8.07	13.80	10.20	3.02	-
Hg(BHDH) ₂	Yellow	781.40	69.77	206	25.67	43.00	2.56	7.17	12.29	9.09	0.73	-
Mn(BHDH) ₂	Brown	634.34	69.88	202	8.66	52.97	3.15	8.83	15.10	11.20	2.25	5.27

The molar conductance values of the complexes in DMF at a concentration of 10^{-3} M, ranging from 9.8 to 20 $\text{ohm}^{-1}\text{cm}^2\text{mol}^{-1}$, suggest that the complexes lack electrolytic properties [18].

¹H-NMR study of HBHDH ligand

Table 2 lists the pertinent data for determining the structure of the HBHDH ligand from the ¹H NMR spectra that were acquired in CDCl₃ (supplementary file). At 12.02 ppm, the HBHDH ligand's ¹H-NMR spectra revealed a singlet (S, 1H, -OH C2). The C2 position's phenolic -OH group was designated as the site of this singlet. This peak is absent in all prepared metal complexes, indicating the deprotonation of the hydroxyl group during complexation. At 11.46 ppm, there was another singlet that was identified as the proton of the C6 position's phenolic -OH group (S, 1H, -OH C6) [19-20]. The singlet was observed at 10.02 ppm, assigned as the proton of the imino-NH group. The -CH= group of the prepared ligand and its metal complexes was observed at 8.55 ppm. The multiplets seen in the range from 6.38 to 7.99 ppm are assigned by aromatic protons.

Absorption and magnetic moment spectra

The HBHDH ligand and its complexes were subjected to electronic spectra measurements in DMF (supplementary file). The projected structure of synthesized transition complexes and data on magnetic moments are displayed in Table 3, which is based on recorded electronic absorption spectra. The aromatic ring $\pi \rightarrow \pi^*$ transition, the $>C=O$ transition, and the $n \rightarrow \pi^*$ transitions of the $C=N$ groups were identified in

the ligand's electronic absorption spectra, which showed high-energy bands at 235, 295, and 335 nm, respectively. It was considered that intra-ligand and LMCT transitions of coordinated ligands caused these bands to be moved to 230-340, 253-378, and 331-480 nm in complexes. The ${}^5T_{2g} \rightarrow {}^5E_g$ transition, identified as occurring at 613 nm and assigned to one atom, validated the complex's octahedral geometry, and a magnetic moment value of 5.12 B.M. was determined for the Fe (II) complex. The magnetic moment values of Fe(II) complexes were 3.14 B.M. and 4.45 B.M., respectively, in the literature [21,22]. The Co(II) complex's electronic spectra display three transitions at 900 and 621 nm, which can be attributed to ${}^4T_{1g}(F) \rightarrow {}^4T_{1g}(F)$ and ${}^4T_{2g}(F) \rightarrow {}^4T_{1g}(P)$ transitions, respectively.

In contrast, the Ni(II) complex exhibits three transitions at 995, 667, and 545 nm, which can be attributed to ${}^3T_{2g} \rightarrow {}^3T_{2g}$, ${}^3T_{2g} \rightarrow {}^3T_{1g}(F)$, and ${}^3T_{2g} \rightarrow {}^3T_{1g}(P)$ transitions, each of which suggests an octahedral geometry. The electronic spectra of the Cu(II) compound showed a wideband with low intensity at around 638 nm in the visible region [23], which is caused by the $d-d$ (${}^2B_{1g} \rightarrow {}^2E_g$) transition. All signs led to a distorted octahedral arrangement.

In the Mn(II) complex, the octahedral structure was brought about via the $d-d$ (${}^6A_{1g} \rightarrow {}^5E_g$, 4D , and ${}^6A_{1g} \rightarrow {}^5T_{1g}$) transition, which was seen as the lowest-energy band at 561 and 398 nm, respectively. The electronic spectra of the Pd(II) complex showed transitions at 396, 331, and 285 nm [25]. These alterations were given a square, flat form. Because their d^{10} transition is complete, complexes containing Zn(II), Cd(II), and Hg(II) do not display a $d-d$ band.

Table 2. ¹H-NMR spectroscopic data of the HBHDH ligand and its metal complexes

Compound	-OH (C2)	-OH (C6)	-NH-	-CH=	Aromatic Protons
HBHDH	12.02	11.46	10.02	8.55	6.38-7.99
Pd(BHDH) ₂	-	11.51	9.74	8.65	6.41-8.04
Zn(BHDH) ₂	-	11.28	9.61	8.48	7.11-7.55
Cd(BHDH) ₂	-	11.27	10.04	8.65	6.41-8.67
Hg(BHDH) ₂	-	11.56	9.89	8.55	6.36-7.99

Table 3. HBHDH ligand electronic spectral data and metal complexes

Compound	λ_{nm}	Transition
HBHDH	335	$n \rightarrow \pi^*$
	295	$n \rightarrow \pi^*$
	235	$n \rightarrow \pi^*$
Mn(BHDH) ₂	561	${}^6A_{1g} \rightarrow {}^4T_{1g}({}^4P)$
	398	${}^6A_{1g} \rightarrow {}^4E_g(4D)$
Fe(BHDH) ₂	613	${}^5T_{2g} \rightarrow {}^5E_g$
	503	L → M charge transfer
Co(BHDH) ₂	900	${}^4T_{1g(F)} \rightarrow {}^4T_{2g(F)} (v_1)$
	675	${}^4T_{1g(F)} \rightarrow {}^4T_{2g(P)} (v_2)$
Ni(BHDH) ₂	995	${}^3A_{2g(F)} \rightarrow {}^3T_{2g(F)} (v_1)$
	667	${}^3A_{2g(F)} \rightarrow {}^3T_{1g(F)} (v_2)$
Pd(BHDH) ₂	396, 331, 285	L → M charge transfer
Cu(BHDH) ₂	638	${}^2B_{1g} \rightarrow {}^2A_{1g}(v_1)$
Zn(BHDH) ₂	332, 257, 288	L → M charge transfer
Cd(BHDH) ₂	340, 253	L → M charge transfer
Hg(BHDH) ₂	340, 310, 230	L → M charge transfer

FT(IR) spectral studies

As a result of comparing the IR spectra indicated in Table 4 with those of free HBHDH ligands, we can see the different kinds of bonds that form in complexes (supplementary file). At 3190, 1629, 1605, and 1295 cm^{-1} , respectively, the infrared bands for $\nu(\text{N-H})$, $\nu(\text{C=O})$, $\nu(\text{C=N})$, and phenolic (C-O) are visible in the free HBHDH ligand. The wavelengths that were measured are these. At 3295 cm^{-1} , however, a medium broad band was observed due to the o-hydroxy group's intramolecular solid hydrogen bonding. The breadth of this band was approximately 3295 cm^{-1} . When this band vanished in complexes, it meant that phenolic oxygen had deprotonated and was coordinating with metal ions. The phenolic (C-O) frequency decreased from 1295 cm^{-1} to 1215-1233 cm^{-1} , in contrast to the ligand's frequency of 1350 cm^{-1} , lending credence to this theory. It is worth noting that this band vanished in complexes, suggesting that metal ions coordinate with phenolic oxygen by deprotonation. The stretching frequency of (C=N), which is present in free ligands, changes to a value of 63-90 cm^{-1} lower [24] when complexes are present. In this case, the coordination of the metal ion with the

nitrogen of the azomethine molecule is seen. The (C=O) vibrations moved to the lower side of the spectrum in all transition metal complexes, indicating that this group was involved in the complexation process [26-27].

That HBHDH ligands in metal complexes are monobasic tridentate was thus proven by this finding. A band in the vicinity of 3152-3448 cm^{-1} is allocated to the 6-position hydroxy group of the aromatic ring by the HBHDH ligand and its complexes. It appears from this band that the complexation mechanism does not involve the 6-position hydroxyl group [28-30]. The bands observed in the 535-653, 521-618, and 510-534 cm^{-1} far-infrared regions can be ascribed to the $\nu(\text{M-O})$, $\nu(\text{M})$, and $\nu(\text{M-N})$ vibrations, respectively. The structures of complexes are allocated based on spectral investigations.

Antimicrobial study

Testing the HBHDH ligand and its compounds for antibacterial properties is shown in Table 5. The standard and its metal complexes had higher activity against all microorganisms, but the ligand HBHDH had lesser activity. The chelation that took place is the reason behind this, according to Tweedy's hypothesis of chelation.

Antibacterial activity

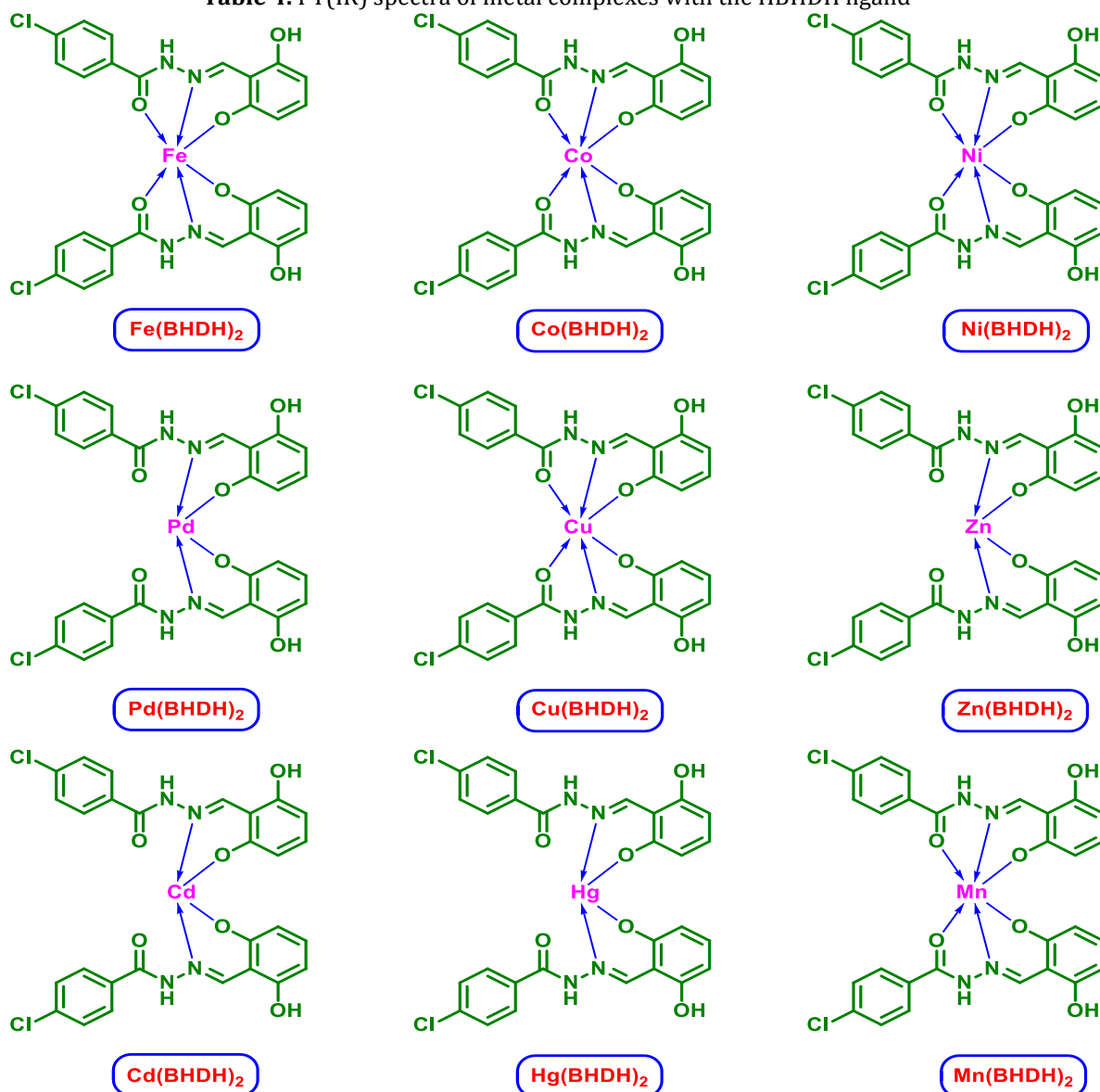
The antibacterial efficacy associated with each metal complex is nearly uniform against all bacterial strains.

The average *B. subtilis* has an inhibition zone of 13mm, but Cu(II), Zn(II), and Co(II) all have far larger inhibition zones of 14 mm, 13 mm, and 13 mm, respectively, against *E. coli*. The Hg(II) molecule had no impact on *S. aureus* (Figure 1).

Antifungal activity

The Ni(II) complex exhibits potent antifungal activity, as demonstrated by its efficacy against *C. albicans*. *S. cerevisiae* demonstrates a growth rate reduction of over 90% in the presence of the Mn(II) complex (Table 6). The Co(II) complex inhibits the development of all fungal strains (Figure 2).

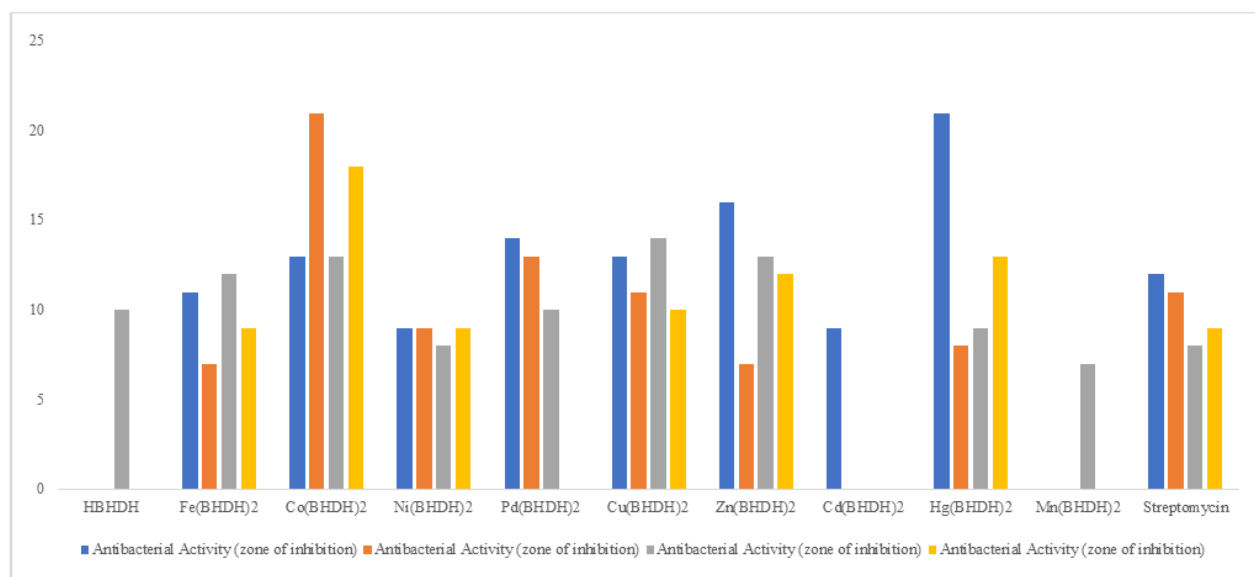
Table 4. FT(IR) spectra of metal complexes with the HBBDH ligand



Compound	-OH (C2)	-OH (C6)	-NH-	-C-H=	>C=O	>C=N-	Phenolic C-O	N→M	O→M	O-M
HBBDH	3257	2926	3190	2937	1629	1605	1295	-	-	-
Fe(BHBDH) ₂	-	2926	3152	2840	1584	1525	1233	631	550	520
Co(BHBDH) ₂	-	2919	3448	2849	1596	1542	1217	653	590	511
Ni(BHBDH) ₂	-	2924	3408	2848	1593	1549	1217	639	618	532
Pd(BHBDH) ₂	-	2923	3258	2851	1552	1518	1218	535	-	535
Cu(BHBDH) ₂	-	2923	3152	2852	1581	1513	1219	595	521	515
Zn(BHBDH) ₂	-	2922	3341	2851	1592	1547	1215	595	-	528
Cd(BHBDH) ₂	-	2979	3197	2835	1579	1548	1226	602	-	552
Hg(BHBDH) ₂	-	2922	3321	2851	1604	1540	1241	529	-	510
Mn(BHBDH) ₂	-	2925	3257	2836	1552	1515	1218	618	571	534

Table 5. HBBDH ligand and its metal complexes have been studied for their antibacterial properties

Compound	Antibacterial Activity (zone of inhibition)			
	<i>S. aureus</i>	<i>B. subtilis</i>	<i>E. coli</i>	<i>P. aeruginosa</i>
HBBDH	0	0	10	0
Fe(BBDH) ₂	11	7	12	9
Co(BBDH) ₂	13	21	13	18
Ni(BBDH) ₂	9	9	8	9
Pd(BBDH) ₂	14	13	10	0
Cu(BBDH) ₂	13	11	14	10
Zn(BBDH) ₂	16	7	13	12
Cd(BBDH) ₂	9	0	0	0
Hg(BBDH) ₂	21	8	9	13
Mn(BBDH) ₂	0	0	7	0
Streptomycin	12	11	8	9

**Figure 1.** Antibacterial activity of HBBDH ligand and its metal complexes**Table 6.** Antifungal investigation on the HBBDH ligand and its metal complexes

Compound	Antibacterial Activity (zone of inhibition)	
	<i>C. albican</i>	<i>S. C.</i>
HBBDH	8	8
Fe(BBDH) ₂	14	13
Co(BBDH) ₂	15	9
Ni(BBDH) ₂	25	21
Pd(BBDH) ₂	8	14
Cu(BBDH) ₂	9	8
Zn(BBDH) ₂	14	8
Cd(BBDH) ₂	8	12
Hg(BBDH) ₂	14	8
Mn(BBDH) ₂	12	19
Fluconazole	10	7

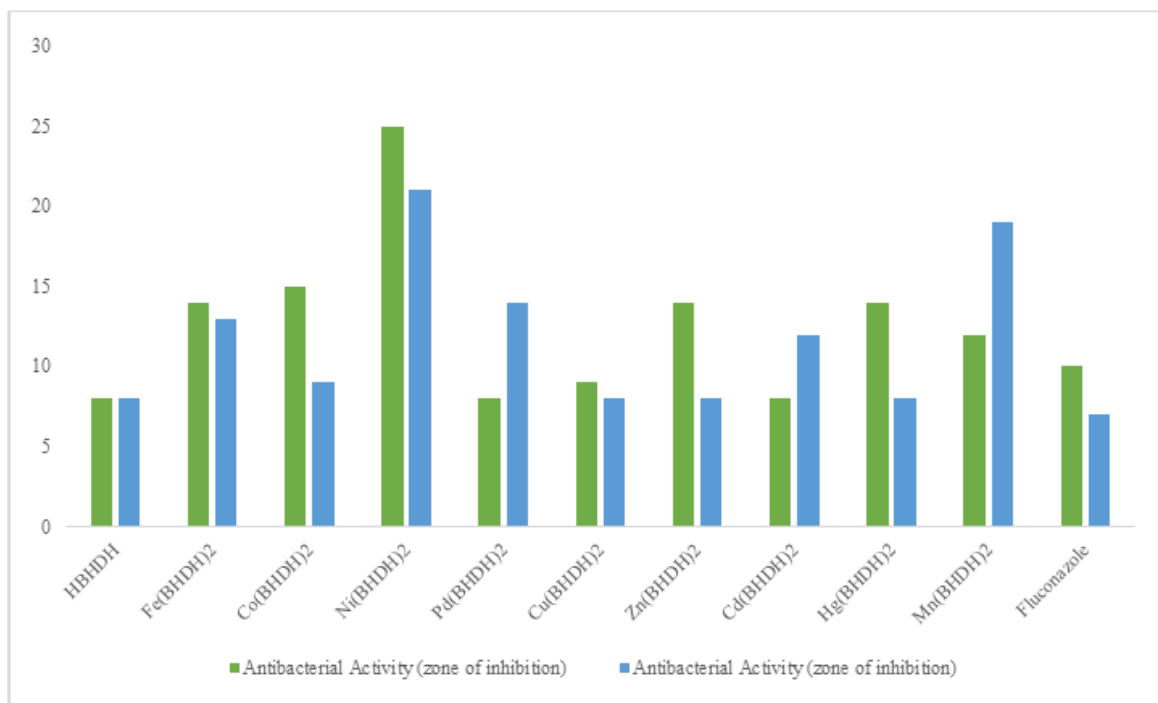


Figure 2. HBHDH ligand and its metal complexes have antifungal behavior

Conclusion

Various spectroscopy techniques, including analytical, infrared (IR), electrical, magnetic, and electronic absorption spectra, were used to validate the binding of ligands to metal. The research revealed that the HBHDH ligand exhibited a monobasic tridentate structure with transition metal ions. The Mn(II), Fe(II), Ni(II), Cu(II), and Co(II) complexes were determined to have octahedral geometry, whereas the Zn(II), Mn(II), Hg(II), and Cd(II) complexes were found to have square planar and tetrahedral geometry for Pd(II) complex. These conclusions were drawn from the findings of analytical and physicochemical examinations. The metal complexes exhibit a considerably greater antibacterial activity compared to the ligand. Typically, the ligand and its complexes have significantly greater efficacy against *E. coli* bacteria compared to normal Penicillin.

Conflict of interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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