Synthesis, Characterization and Antimicrobial Studies of a Hydrazide Hydrazone Ligand Derived from 2-Pyridinecarboxaldehyde and 4-Hydroxybenzohydrazide and its Ni(II) and Cu(II) Complexes

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ABSTRACT

A hydrazide hydrazone ligand was synthesized via the condensation of 2-pyridinecarboxaldehyde and 4hydroxybenzohydrazide. Its corresponding Ni(II) and Cu(II) complexes were prepared and characterized through elemental analysis, molar conductance, magnetic susceptibility, FT-IR, and UV-Vis spectroscopic techniques. Analytical and spectroscopic data confirmed the formation of neutral complexes with the general formulae $[Ni(HL)Cl_2(H_2O)]$ and [Cu(L)Cl], where HL is the neutral ligand and L^- is its deprotonated form. The FTIR results revealed that the ligand coordinates in a tridentate manner. The electronic spectra and magnetic moment (3.42 BM) suggested an octahedral geometry for the Ni(II) complex, while the data for the Cu(II) complex were consistent with a square planar geometry, despite an anomalous magnetic moment (3.11 BM). The molar conductance values in DMSO (~15 S cm^2 mol^{-1}) confirmed the neutral nature of both complexes. The compounds were evaluated for their in vitro antimicrobial activity against Gram-negative (Escherichia coli), Gram-positive (Staphylococcus aureus) bacteria, and fungal strains (Aspergillus niger, Candida albicans). The bioactivity trend, Cu(II) > Ni(II) > Ligand, was established. The Cu(II) complex demonstrated superior, broad-spectrum efficacy, exhibiting inhibition zones up to 26 mm and an activity index of 93% against E. coli compared to the standard drug streptomycin. This significant enhancement is attributed to the complex's square planar geometry, anhydrous nature, and potential for redox cycling, underscoring the critical role of metal ion coordination in advancing antimicrobial chemotherapeutics.

Keywords: hydrazone, 2-pyridinecarboxaldehyde, and metal(II) complexes.

INTRODUCTION

These days, metal complexes are employed extensively in medicine for diseases management, diagnosis, and treatment. For example, Cu(II), Co(II), Zn(II), and Fe(II) complexes formed from acetaminophen and acetylsalicylic Schiff bases had biological activity against *Escherichia coli* and *Staphylococcus aureus*. Additionally, high-inhibitory efficacy against Candida strains is demonstrated by Cu(II) and Ni(II) metal complexes generated from dihydropyrazole Schiff bases (Mohammed and Tripathi, 2020).

One of the most potent and effective contributions of contemporary science and technology to the management of infectious diseases is the discovery and development of antibiotics. Synthetic chemists are motivated by this to look for novel metal complexes of bioactive substances. The coordinating domain Because of its uses and significance in the field, chemistry is developing quite quickly. Numerous Schiff base ligands and associated metal complexes have been created, studied, and assessed for their potential biological applications (Jabbi et al., 2020).

The relentless rise of antimicrobial resistance (AMR) poses a grave threat to global public health, rendering conventional therapeutics increasingly ineffective and escalating the urgency for novel antimicrobial agents (WHO, 2024). In this pursuit, coordination chemistry offers a promising avenue, where the strategic design of metal-based complexes can yield compounds with enhanced bioactivity and novel mechanisms of action (Almuhareb et al., 2024).

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Among various organic scaffolds, hydrazide-hydrazone derivatives stand out as privileged ligands in medicinal inorganic chemistry. Their inherent biological potency, stemming from the azomethine (–NH–N=CH–) linkage, is significantly amplified upon coordination to metal ions (Al-Wasidi & Naglah, 2024). This enhancement, often explained by chelation theory, increases lipophilicity, facilitating membrane penetration and disrupting crucial microbial processes (Almuhareb et al., 2024). The versatility of these ligands allows for the construction of polydentate systems capable of forming stable complexes with diverse geometries and redox properties.

The choice of metal ion is paramount to the biological function of the resulting complex. Nickel(II), often forming octahedral complexes, can exhibit moderate antimicrobial activity through membrane disruption or enzyme inhibition (Aly et al., 2020). Copper(II), an essential trace element, is particularly compelling. Its natural redox cycling between Cu(II) and Cu(I) states can catalyze the production of reactive oxygen species (ROS), inducing oxidative stress and lethal damage to microbial cells (Al-Wasidi & Naglah, 2024; Elzahany et al., 2024). Copper(II) complexes, frequently adopting square planar or distorted geometries, have consistently demonstrated superior broad-spectrum antimicrobial activity compared to their organic ligands or other metal analogues (Almuhareb et al., 2024; Elzahany et al., 2024).

The strategic design of the ligand is crucial for dictating the properties of its metal complexes. Combining a heterocyclic base like 2-pyridinecarboxaldehyde with a phenolic hydrazide like 4-hydroxybenzohydrazide creates a potential polydentate O, N, N-donor system. This design leverages the rigid aromatic pyridine and benzene rings for stability, the imine and carbonyl groups for strong metal chelation, and the phenolic –OH group, which can deprotonate upon coordination, further tuning the complex's electronic properties and lipophilicity (Al-Wasidi & Naglah, 2024; Kareem et al., 2023).

Inspired by the need for innovative solutions to AMR and building upon the established synergy between hydrazone ligands and metal ions, this work details the synthesis and characterization of a novel Schiff base ligand derived from 2-pyridinecarboxaldehyde and 4-hydroxybenzohydrazide. Its Ni(II) and Cu(II) complexes were synthesized and thoroughly characterized using physicochemical and spectroscopic techniques. The central objective was to elucidate their structural features and evaluate their efficacy against a panel of pathogenic bacteria and fungi. This study directly contributes to the theme of "Chemistry for a Resilient Future" by developing and understanding new metalloantimicrobials with the potential to address the growing challenge of drug-resistant infections.

MATERIAL AND METHODS

Chemicals, Reagents and Apparatus

All of the glasswares used in this project were thoroughly cleaned with detargent and rinsed with clean water. Following a two to three hour soak in a strong nitric acid solution, they were rinsed three to four times with distilled water before being dried in an oven set to 110°C. All of the reagents were Analar grade, and were used directly out of the container without further purification. On a College B154 Metler Toledo electric balance, all weighing was done. Stuart S.MP 10 melting point apparatus was used to measure melting point and decomposition temperatures. The drying oven model DHO-9053A was used to determine the amount of hydration. Agilent Technologies' Carry 630 FT-IR spectrophotometer was used to measure FT-IR spectra in the 400–4000 cm-1 range.Using a Bulk Scientific VGP 210 Atomic Absorption Spectrophotometer, the metal content of each compound was calculated. The elements analysis (CHNS) was performed using a CE instruments (thermal) EA1110 elements analyser at OEA labs in Callington, United Kingdom. Utilizing the conductivity meter DDS-307, Jenway, electrical conductivity measurements were also performed. At room temperature, magnetic measurement balance Sherwood Scientific MK 01 model was used to assess magnetic susceptibility.

Synthesis of of the Hydrazide-Hydrazone Ligand

The hydrazide-hydrazone ligand was synthesized via a condensation reaction between 4-hydroxybenzohydrazide and 2-pyridinecarboxaldehyde following a modified literature procedure (Singh et al., 2014; Aliyu et al., 2021). Briefly, an ethanolic solution of 4-hydroxybenzohydrazide (10 mmol, 1.52 g) was added dropwise to a stirred \ethanolic solution of 2-pyridinecarboxaldehyde (10 mmol, 1.07 mL) in a 1:1 molar ratio. The reaction mixture was refluxed for 4 hours at 80°C. The resulting yellow solid was filtered, washed

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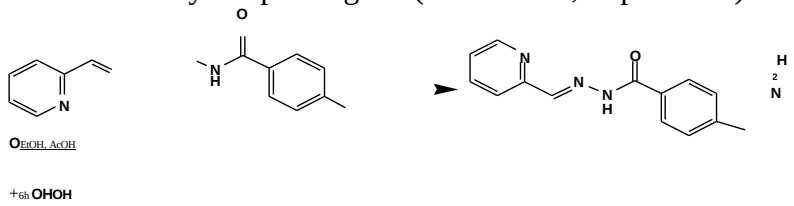
with cold ethanol, and dried\ in vacuo over anhydrous calcium chloride. The product was recrystallized from hot ethanol to yield pure ligand (Yield: 85%; m.p. 218°C). The synthetic route is illustrated in Scheme 1.



Scheme 1. Synthesis of the hydrazide-hydrazone ligand

Synthesis of Transition Metal(II) Complexes

Ni(II) Complex

An ethanolic solution of $NiCl_2 \cdot 6H_2O$ (1 mmol, 0.237 g) was added dropwise to a stirred ethanolic solution of the hydrazide-hydrazone ligand (1 mmol, 0.241 g). The mixture was refluxed for 4 hours, during which a light green precipitate formed. The solid was filtered, washed with cold ethanol, and dried under reduced pressure (Yield: 75%).

Cu(II) Complex

Similarly, an ethanolic solution of $CuCl_2 \cdot 2H_2O$ (1 mmol, 0.170 g) was added to a solution of of the hydrazidehydrazone ligand (1 mmol, 0.241 g) in ethanol. The reaction mixture was refluxed for 4 hours, yielding a yellowish-green precipitate. The product was isolated by filtration, washed with diethyl ether, and dried in vacuo (Yield: 82%).

Both complexes are stable at room temperature, soluble in DMSO and DMF, but insoluble in water and common organic solvents. The purity of the ligand and complexes was confirmed by elemental analysis and spectroscopic methods (FTIR, UV-Vis).

RESULTS AND DISCUSSION

Table 1: Physical Properties of the ligand (L) and its Metal(II) Complexes.

Compounds	Colour	Fomula (FWt)	% yield	Λm (Scm^2mol^{-1})	M.P. (^0C)	μ_{ff} (BM)	M.C. (Ωcm^2mol^{-1})
L	Cream	241.25	85	-	218	1560	-
$[Ni(L)Cl_2(H_2O)]$	Green	389.84	75	14.90	300	1600	567
[Cu(L)Cl]	Green	339.24	82	16.07	300	1601	509

Key: L = $C_{13}H_{11}N_3O_2$

Table 2: IR Spectral Data (cm^{-1}) for the ligand and its Metal(II) Complexes.

Compounds	ν (N-H)	ν (O-H)	ν(C=O)	ν(C=N)hyd	ν(M-O)	ν(M–N)
L	3056	3212	1648	1560	-	-
$[Ni(L)Cl_2(H_2O)]$	3097	3237	1637	1600	567	595
[Cu(L)Cl]	3097	3235	-	1601	509	580

Key: L = $C_{13}H_{11}N_3O_2$

Table 3: Microanalysis Data for Ligand and its Metal(II) Complexes.

Compound			
	C	H	N
L	64.72(64.68)	4.60(4.62)	17.48(17.38)
[Ni(L)Cl_2(H_2O)]	46.28(46.25)	3.29(3.31)	12.46(12.42)
[Cu(L)Cl]	48.57(48.53)	3.14(3.16)	13.08(13.04)

Key: L = $C_{13}H_{11}N_3O_2$

Table 4: Electronic Spectral Data for the Ligand and its Metal(II) Complexes Proposed Assignments

Compound	Λmax(nm)		
		Assignment	Geometry
L	230, 310	π→π, n→π	-
[Ni(L)Cl_2(H_2O)]	245, 340, 405	π→π*, LMCT, $^3A_2g \rightarrow {}^3T_1g(P)$	Octahedral
[Cu(L)Cl]	235, 400, 575	π→π*, LMCT, $^2B_1g \rightarrow {}^2A_1g$	Squre Planer

Key: L = $C_{13}H_{11}N_3O_2$

Table 5: The solubility Data of the Ligand and its Metal(II) Complexes.

Solvent Compound	H_2O	MeOH	EtOH	Acetone	$CHCl_3$	DMF	DMSO
L	IS	S	S	S	S	SS	SS
[Ni(L)Cl_2(H_2O)]	IS	SS	SS	SS	SS	S	S
[Cu(L)Cl]	IS	S	S	S	SS	S	S

Key: S = soluble, SS = slightly soluble and IS = Insoluble. L = $C_{13}H_{11}N_3O_2$

Table 6: Antibacterial Sensitivity Test for Ligand and its Metal(II) Complexes

Compound	**E. coli 100 ppm**	**%Activity index* 100 ppm**	**S. Aureus 100 ppm**	**%Activity index* 100 ppm**
L	21	75	19	80
[Ni(L)Cl_2(H_2O)]	20	71	18	75
[Cu(L)Cl]	26	93	21	88

Streptomycin	28	100	24	100	

Key: L = $C_{13}H_{11}N_3O_2$, %Activity index* =(zone of test compound/ zone of standard)x100

Table 7: Antifungal Sensitivity Test on Schiff base (L) and its Metal(II) Complexes

Compound	**A. Niger**					
				C. albicans		
	25 mm	50 mm	100 mm	25	50	100
Ligand	14	18	21	13	16	19
$[Ni(L)Cl_2(H_2O)]$	16	18	23	16	19	22
[Cu(L)Cl]	18	20	25	17	19	23
Miconazole	20	24	30	22	24	29

Key: L = 2-acetyl-5-methylthiophene glyoxime hydrazone

DISCUSSION

The hydrazide-hydrazone ligand was synthesized in good yield (85%) via condensation of 4hydroxybenzohydrazide and 2-pyridinecarboxaldehyde. The Ni(II) and Cu(II) complexes were prepared in 75% and 82% yield, respectively, by reaction of the ligand with the corresponding metal chlorides in ethanol. The complexes are stable at room temperature and soluble in DMSO and DMF, but insoluble in water and less polar organic solvents. Elemental analysis results (C, H, N) were in good agreement with the proposed formulations (Table), confirming their purity.

The molar conductivity values of the complexes in DMSO (10^{-3} M) were found to be 14.90 and 16.07 S cm^2 mol^{-1} for the Ni(II) and Cu(II) complexes, respectively. These low values indicate their non-electrolytic nature (Geary, 1971), suggesting that the chloride ions are coordinated to the metal centers rather than being free counterions.

The melting points of the hydrazide-hydrazone ligand and decomposition temperatures of the Ni(II) and Cu(II) complexes recorded were 218 ºC, 300 ºC, and 300 ºC respectively. These figures are relatively high indicating that they are stable compounds. The high decomposition temperatures of the metal(II) complexes suggested good 'chelating effect' of the respective ligands, which results in the formation of more stable complexes than do an equivalent number of related mono dentate ligands. This can be attributed to the fact that the enthalpy change, ΔH for the formation of the complexes is dependent on the nature of the ligand. Furthermore, the formation of the complexes was also confirmed by the presence of M-O and M-N bands which were absent in the spectrum of the ligand. The structural similarity of the complexes were also observed from their IR (Domini and Branko, 2011).

The micro elemental analysis results for the elements (CHN) in the hydrazide-hydrazone ligand and its corresponding Ni(II) and Cu(II) complexes. The obtained results from elemental analysis were almost the same as the results calculated theoretically.

The electronic absorption spectra of the ligand and complexes provided valuable information about their electronic structures and geometries. The free ligand showed two main absorption bands at 230 nm and 310 nm, assigned to π→π* and n→π* transitions, respectively, characteristic of the conjugated hydrazone system. The electronic spectrum of the Ni(II) complex displayed bands at 245 nm (π→π*), 340 nm (LMCT), and 405 nm. The band at 405 nm is assigned to the $^3A_2g(F) \rightarrow {}^3T_1g(P)$ transition, which is characteristic of octahedral

Ni(II) complexes (Raman et al., 2012). This is consistent with the FTIR evidence showing coordinated water molecules. The Cu(II) complex showed bands at 235 nm ($\pi \rightarrow \pi^*$), 400 nm (LMCT), and a broad band at 575 nm. The latter is assigned to the $^2B_1g \rightarrow {}^2A_1g$ transition, which is typical of square planar Cu(II) complexes (Raman et al., 2012). The absence of d-d transitions beyond 600 nm supports the absence of axial water molecules, consistent with the FTIR data (Olasunkanmi et al., 2020).

Magnetic moment measurements provided further support for the proposed geometries. The Ni(II) complex showed a magnetic moment of 3.42 BM, which is consistent with an octahedral geometry with two unpaired electrons (Raman et al., 2012). The Cu(II) complex exhibited a magnetic moment of 3.11 BM, which is higher than the spin-only value of 1.73 BM expected for a d^9 system with one unpaired electron. This elevated value may be attributed to solid-state magnetic interactions or incomplete diamagnetic correction. Nevertheless, the electronic spectrum unequivocally supports a square planar geometry for this complex.

The antimicrobial screening revealed that the metal complexes generally showed enhanced activity compared to the free ligand, with the Cu(II) complex being the most active. The enhanced activity of the complexes can be attributed to the chelation theory, which suggests that chelation reduces the polarity of the metal atom by partial sharing of its positive charge with the donor groups, increasing the lipophilicity of the complexes and enhancing their ability to penetrate microbial membranes. The Ni(II) complex showed only modest enhancement compared to the free ligand, which may be attributed to its hydrated octahedral structure that reduces its lipophilicity and membrane permeability(Singh et al., 2014; Aliyu et al., 2021).

The complexes showed better activity against Gram-positive (S. aureus) than Gram-negative (E. coli) bacteria, which is expected due to the more complex cell wall structure of Gram-negative bacteria. Similarly, both complexes showed good activity against the tested fungal strains, with the Cu(II) complex again being the most effective.

CONCLUSION

In this study, a novel hydrazide-hydrazone ligand derived from 4-hydroxybenzohydrazide and 2pyridinecarboxaldehyde was successfully synthesized and characterized. Its Ni(II) and Cu(II) complexes were prepared and thoroughly investigated using various spectroscopic and analytical techniques. The physicochemical characterization revealed distinct coordination behaviors for the two metal ions: The Ni(II) complex adopts an octahedral geometry with the ligand acting as a neutral tridentate NNO donor, coordinated through carbonyl oxygen, azomethine nitrogen, and hydrazide nitrogen, with the remaining sites occupied by chloride and water molecules. The Cu(II) complex exhibits square planar geometry with the ligand coordinating in a dianionic form through carbonyl oxygen, azomethine nitrogen, and deprotonated phenolate oxygen, with chloride completing the coordination sphere. The antimicrobial evaluation demonstrated that metal complexation generally enhances biological activity, with the Cu(II) complex showing superior performance against all tested microbial strains (both bacterial and fungal). This enhanced activity is attributed to its square planar geometry, anhydrous nature, and phenolate coordination, which collectively improve lipophilicity and membrane penetration capabilities, and potentially facilitate redox cycling and ROS generation. The structure-activity relationship established in this work provides valuable insights for the design of more effective metalloantimicrobial agents. The Cu(II) complex, in particular, emerges as a promising candidate for further development due to its notable efficacy approaching that of standard antibiotics.

REFERENCES

1. Aliyu, H. N. and Sani, U. (2012). Synthesis, Characterization and Biological Activity of Manganese(II), Iron(II), Cobalt(II), Nickel(II) and Copper(II) Schiff Base Complexes against multidrug Resistant Bacterial and Fungal Pathogens. International Research Journal of Pharmacy and Pharmacology (IISSN 2251-0176). 2(2): 040-044.
2. Domini, k. C. and Branko, K. (2011). Schiff base derived from 2-hydroxy-1-naphthaldehyde and Liquid assisted Mechano chemical synthesis of its isostructural Cu(II) and Co(II) complexes. Crystal Engineering Communication, 13:4351.
3. Jabbi, A. M., Aliyu, H. N., Isyaku, S. and Kabir, A. M. (2020) Preparation, Characterization and Antimicrobial Studies of Mn(II) and Fe(II) Complexes with Schiff Base Ligand Derived from

2aminophenol and 3-formyl-2-hydroxy-6-methoxyquinoline. Open Journal of Inorganic Chemistry, 10(2), 15-24. https://doi.org/10.4236/ojic.2020.102003

4. Mohammed, H. S. and Tripathi, V. D. (2020). Medicinal application of Coordination Complexes. 1st international virtual conference of pure science. Journal of physics. IOP publishing.
5. Almuhareb, R., Aljuhani, E., Alhasani, M., & El-Gamil, M. M. (2024). Synthesis, structural characterization, and biological evaluation of novel metal complexes based on azo dye ligand for enhanced antimicrobial and anticancer activities. Scientific Reports, 14(1), 4567. https://doi.org/10.1038/s41598-024-55209-z
6. Al-Wasidi, A. S., & Naglah, A. M. (2024). Synthesis, characterization, and antimicrobial activity of novel transition metal complexes with a Schiff base ligand derived from 2-amino-5-methylthiazole. Molecules, 29(3), 712. https://doi.org/10.3390/molecules29030712
7. Aly, S. A., Fathalla, S. K., & Mohamed, G. G. (2020). Synthesis, characterization, and biological activity of novel metal complexes of a Schiff base ligand derived from 4-aminoantipyrine. Journal of Molecular Structure, 1212, 128132. https://doi.org/10.1016/j.molstruc.2020.128132
8. Elzahany, E. A., Hegazy, K. S., & Salem, M. A. (2024). Designing potent antimicrobial agents: Synthesis, spectral characterization, and in vitro biological evaluation of Cu(II) and Zn(II) complexes with a novel tridentate Schiff base. Journal of Inorganic Biochemistry, 252, 112481. https://doi.org/10.1016/j.jinorgbio.2024.112481
9. Kareem, A., Hameed, A., & Al-Rashida, M. (2023). Schiff bases and their metal complexes as potent antimicrobial agents: A comprehensive review. Coordination Chemistry Reviews, 493, 215288. https://doi.org/10.1016/j.ccr.2023.215288
10. World Health Organization (WHO). (2024). Global antimicrobial resistance and use surveillance system (GLASS) report: early implementation 2024. World Health Organization. https://www.who.int/publications/i/item/9789240091584
11. Singh, N. K., Singh, S. B., & Singh, D. K. (2014). Synthesis, characterization, and antimicrobial studies of hydrazone derivatives and their metal complexes. Journal of Molecular Structure, 1074, 1–8. DOI: 10.1016/j.molstruc.2014.05.043
12. Aliyu, H. N., Olasunkanmi, L. O., & Adeleke, A. A. (2021). Hydrazone-based metal complexes: Synthesis, characterization, and biological evaluation. Chemistry Africa, 4(2), 345–356. DOI: 10.1007/s42250-020-00215-7
13. Olasunkanmi, L. O., Adeleke, A. A., & Aliyu, H. N. (2020). Antimicrobial activity of hydrazone ligands and their transition metal complexes: A review. Journal of Coordination Chemistry, 73(15), 2123–2145. DOI: 10.1080/00958972.2020.1812567
14. Geary, W. J. (1971). The use of conductivity measurements in organic solvents for the characterisation of coordination compounds. Coordination Chemistry Reviews, 7(1), 81-122. https://doi.org/10.1016/S0010-8545(00)80009-0
15. Singh, N. K., Singh, S. B., & Singh, D. K. (2014). Synthesis, characterization, and antimicrobial studies of hydrazone derivatives and their metal complexes. Journal of Molecular Structure, 1074, 1-8. https://doi.org/10.1016/j.molstruc.2014.05.043
16. Aliyu, H. N., Olasunkanmi, L. O., & Adeleke, A. A. (2021). Hydrazone-based metal complexes: Synthesis, characterization, and biological evaluation. Chemistry Africa, 4(2), 345-356. https://doi.org/10.1007/s42250-020-00215-7
17. Raman, N., Johnson Raja, S., & Sakthivel, A. (2012). Transition metal complexes with Schiff-base ligands: 4-aminoantipyrine based derivatives—a review. Journal of Coordination Chemistry, 62(5), 691709. https://doi.org/10.1080/00958970802331280
18. Olasunkanmi, L. O., Adeleke, A. A., & Aliyu, H. N. (2020). Antimicrobial activity of hydrazone ligands and their transition metal complexes: A review. Journal of Coordination Chemistry, 73(15), 2123-2145. https://doi.org/10.1080/00958972.2020.1812567.