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Antibacterial Activity of Pyridine Nucleus-Containing Schiff Bases and their Copper and Cobalt Complexes

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Abstract: *Pyridine is a valuable nitrogen-containing heterocyclic compound widely present in numerous naturally occurring bioactive molecules and extensively utilized in pharmaceutical drug design and development. In this study, three pyridine-based Schiff bases, namely 2-((pyridine-4-ylimino)methyl)phenol (L1), 4-nitro-2-((pyridine-4-ylimino)methyl)phenol (L2) and 4-bromo-2-((pyridine-4-ylimino)methyl)phenol (L3). Their corresponding copper and cobalt complexes were synthesized and characterized using melting point determination, FTIR spectroscopy, NMR spectroscopy, and elemental analysis. The Schiff bases acted as bidentate ligands, coordinating through the imine nitrogen and phenolic oxygen atoms. The in vitro antibacterial activity of the synthesized compounds was evaluated against Staphylococcus aureus, Enterococcus faecalis, Escherichia coli,* and *Pseudomonas aeruginosa. Results revealed that antibacterial activity increased with concentration. Notably, the cobalt complexes demonstrated pronounced antibacterial efficacy, particularly against* S. aureus*, suggesting their potential as promising candidates for further development as antibacterial agents. However, additional toxicological and formulation studies would be required before considering practical applications such as hospital antiseptic formulations.*

Keywords: *Schiff bases, pyridine-nucleus, Copper complex, cobalt complex, antibacterial*

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1.0 Introduction

The rapid emergence and spread of antimicrobial resistance has become a major global health concern, significantly reducing the effectiveness of existing antibiotics. In response, scientists have remained actively engaged in the discovery and development of novel antibacterial agents with improved efficacy and new mechanisms of action. Particular attention has been given to heterocyclic compounds, especially those containing the pyridine nucleus, due to their wide range of biological activities. Pyridine, which is a nitrogen-containing heterocyclic compound that occurs in various analogues, holds great importance in the arena of medicinal chemistry as an extremely valuable source of pharmacologically active molecules (Marinescu & Popa, 2022; Kumar *et al*., 2023). The nitrogen-containing heterocyclic compound pyridine and its various derivatives have frequently been included in drugs approved by the FDA (De *et al*., 2022; Yousef *et al*., 2023). Pyridine and its derivatives have

been extensively reported in recent literature to exhibit diverse pharmacological properties, including antibacterial (Islam *et al*., 2023; Rani & Reddy, 2018), antifungal (Balaes *et al*., 2025; Elsayed, Elsayed & Sroor, 2024) anti-inflammatory (Sroor *et al*., 2025) and anticancer activities (Yousef *et al*., 2023; Nasif, & Sayin, 2025). This has made the pyridine scaffold a valuable pharmacophore in modern drug design and medicinal chemistry. Its structural versatility allows for chemical modification that can enhance binding interactions with biological targets, thereby improving therapeutic potential. Building on these findings, Schiff base derivatives of pyridine have attracted increasing attention due to their structural versatility and enhanced biological activity arising from the azomethine linkage (Joshi, 2023).

Schiff bases are a class of organic compounds characterized by the presence of an azomethine (-C=N-) functional group formed through the condensation of primary amines with aldehydes or ketones. The azomethine moiety serves as an important pharmacophore and metal-binding site, contributing significantly to the biological and coordination properties of these compounds (Raczuk *et al*., 2022). Owing to their structural resemblance to naturally occurring biomolecules, Schiff bases exhibit diverse biological activities and have attracted considerable attention in medicinal chemistry (Hamdan, Hamdan & Aljabawi, 2024; Obeid *et al*., 2025). Schiff bases constitute an important class of compounds with diverse pharmacological and biological activities, including antitumoral, antimicrobial, antimalarial, antioxidant, neuroprotective, antidiabetic, antidepressant, and anti-inflammatory effects (Alyamani, 2023; Dueke-Eze *et al*., 2022, 2024; Dueke-Eze & Fasina, 2023; Yuldasheva *et al*., 2022; Hamid & Salih, 2022).

Reports of Schiff bases with much greater antimicrobial effects when complexed with metal ions than as free ligands are well documented (Thakur *et al*., 2024). The type of metal that is incorporated in the complex and type of Schiff base have great impact on their activity profile (Zhang *et al*., 2011; John, Joseyphus & Joe, 2020; Meeran *et al*., 2022; Abu-Yamin, *et al*., 2022; Lacopetta *et al*., 2023; Guo *et al*., 2024; Mannaa *et al*., 2025) . Despite the growing body of literature on pyridine-derived Schiff bases and their metal complexes, limited information is available regarding the antibacterial properties of substituted N-(2-hydroxybenzylidene)pyridine-4-amine derivatives containing electron-withdrawing substituents such as nitro and bromo groups. Furthermore, comparative studies evaluating the influence of Cu(II) and Co(II) coordination on the antibacterial activity of these ligands against both Gram-positive and Gram-negative bacteria remain scarce. Consequently, the structure-activity relationships associated with ligand substitution and metal complexation in this class of compounds are not yet fully understood.

Our group has previously synthesized derivatives of N-(2-hydroxybenzylidene)pyridine-4-amine (L1–L3), which exhibited significant in vitro inhibitory activity against Mycobacterium tuberculosis H37Rv. Their Cu(II), Co(II), and Ni(II) complexes also demonstrated enhanced antitubercular activity relative to the free ligands (Dueke-Eze & Fasina, 2023a). . These promising findings suggest that coordination of pyridine-based Schiff bases with transition metal ions may enhance biological activity through increased lipophilicity, improved membrane permeability, and altered modes of interaction with microbial targets. However, their antibacterial activities against clinically relevant bacterial pathogens have not yet been investigated. Therefore, this study aimed to synthesize and characterize a series of substituted pyridine-based Schiff bases and their Cu(II) and Co(II) complexes and to evaluate their antibacterial activities against selected Gram-positive and Gram-negative

bacterial strains. Particular emphasis was placed on determining the effects of ligand substitution and metal coordination on antibacterial efficacy. The findings of this study are expected to contribute to the development of new metal-based antibacterial agents and provide insights into the structure-activity relationships of pyridine-derived Schiff base complexes.

2.0 Materials and Methods

All reagents and solvents used in this study were of analytical grade and were obtained from Sigma-Aldrich and other commercial suppliers. The chemicals were used without further purification unless otherwise stated. Melting points were determined using a Stuart SMP3 melting point apparatus and are uncorrected. Fourier-transform infrared (FTIR) spectra were recorded on a Digilab FTS 7000 spectrometer equipped with an attenuated total reflectance (ATR) diamond-selenium accessory over the range 4000–400 cm−1. The 1H and 13C NMR spectra were recorded on a Varian 300 MHz spectrometer using CDCl3 as solvent and tetramethylsilane (TMS) as the internal standard. Elemental analyses (CHN) were carried out using a Perkin-Elmer 2400 CHNS/O elemental analyzer. Antibacterial studies were conducted at the Nigeria Institute of Medical Research (NIMR), Yaba, Lagos, Nigeria.

2.1 Standard procedure for the preparation of Schiff bases(L1-L3)

The degassed solution containing 4-aminopyridine (0.80 mmol), aldehyde (0.80 mmol), and p-toluene sulfonic acid monohydrate (10 mg) in toluene (100 ml) was refluxed for 24 h under a nitrogen atmosphere in a Dean-Stark apparatus. After removal of the solvent under reduced pressure, the crude product was purified by recrystallization from toluene to obtain the Schiff base **(**Dueke-Eze & Fasina, 2023 [a])

2.1.1. 2-((pyridine-4-ylimino)methyl)phenol (L1)

Deep yellow solid,yield: 12.80 mg (81%); mp: 77–78^{0}C; R_f : 0.55. IR (cm^{-1}): 3324, 1587, 1557, 1398, 1339, 1271, 1214, 1148, 1121, 1056, 930, 845, 801, 730, 679; ^{1}H NMR (300 MHz, $CDCl_3$) δ_H: 6.95–7.05 (m, 2H), 7.14 (d, *J* 6.6 Hz, 2H), 7.46 (t, *J* 15.6 Hz, 2H), 8.61 (s, 1H), 8.65 (d, *J* 5.4 Hz, 2H), 12.57 (s, 1H). ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 116.10, 151.15, 155.46, 117.50, 118.64, 119.45, 132.92, 134.37, 161.29, 165.68. Anal. calcd.: $C_{12}H_{10}N_2O$: C, 72.71, H, 5.08, N, 14.10. Found: C, 72.62, H, 5.02, N, 13.96.

2.1.2. 4-nitro-2-((pyridine-4-ylimino)methyl) phenol (L2)

Yellow solid, yield: 14.60 mg (75%); mp: 193–194^{0}C; R_f : 0.32. IR (cm^{-1}): 1652, 1584, 1524, 1471, 1354, 1280, 1228, 1173, 1081, 947, 888, 820, 751, 718, 639; ^{1}HNMR (300 MHz, $CDCl_3$) δ_H: 7.09–7.22 (m, 3H), 8.30–8.44 (m, 2H), 8.56 (s, 1H), 8.717 (t, *J* 8.4Hz, 2H), 10.01; ^{13}CNMR (75 MHz, $CDCl_3$) δ_C: 115.94, 118.58, 119.04, 128.95, 129.30, 129.67, 131.63, 151.44, 164.14, 166.39. Anal. calcd.: $C_{12}H_9N_3O_3$: C, 59.26, H, 3.77, N, 17.28. Found: C, 58.96, H, 3.63, N, 17.06.

2.1.3. 4-bromo-2-((pyridine-4-ylimino)methyl)phenol (L3)

Orange crystals. Yield: 18.60 mg (84%); mp: 139–141^{0}C; R_f : 0.42. IR (cm^{-1}): 1615, 1582, 1550, 1472, 1411, 1354, 1328, 274, 1183, 1078, 985, 916, 867, 804, 781, 738, 689; ^{1}H NMR (300 MHz, $CDCl_3$) δ_H: 6.96 (d, *J* 8.7 Hz, 2H), 7.13 (d, *J* 5.4Hz, 2H), 7.48–7.54 (m, 2H), 8.54 (s, 1H), 8.66 (s, 2H), 12.57 (s, 1H); ^{13}C NMR (75 MHz, $CDCl_3$) δ_C: 110.88, 116.05, 119.53, 119.97, 134.80, 136.93, 151.26, 154.93, 160.27, 164.38. Anal. calcd.: $C_{12}H_9BrN_2O$: C, 52.01, H, 3.27, N, 10.11. Found: C, 52.16, H, 3.18, N, 9.82.

2.2. Procedure for the synthesis of metal complexes

A stirred ethanolic solution (10 ml) of the ligands (1.1 mmol) was gradually mixed with a solution of each chloride metal salt (0.5 mmol)

dissolved in either ethanol or water. The mixture was refluxed for four to six hours, and after cooling, the solid result was filtered and repeatedly cleaned with a 1:1 ethanol to water mixture. In a desiccator, the substance was dried on silica gel.

2.2.1. Cu-2-((pyridine-4-ylimino)methyl) phenol (Cu-L1)

Yield: 2.07 mg (60 %); mp: 244 ºC (dec.). IR (cm^{-1}): 3464, 1594, 1581, 1527, 1438, 1372, 1147, 1058, 1027, 902, 869, 748, 655, 528, 489. Anal. calcd.: $C_{12}H_{11}ClCuN_2O_2$: C, 45.87, H, 3.53, N, 8.92, Cu, 20.22. Found: C, 46.32, H, 3.00, N, 8.40, Cu, 20.74.

2.2.2. Cu-4-nitro-2-((pyridine-4-ylimino) methyl)phenol (Cu-L2)

Yield: 1.67 mg (39%); mp: >349 ºC. IR (cm^{-1}): 3212, 1597, 1508, 1424, 1373, 1246, 1101, 1087, 1003, 850, 826, 720, 622, 508, 482, 444. Anal. calcd.: $C_{12}H_{10}ClCuN_3O_4$: C, 40.12, H, 2.81, N, 11.70, Cu, 17.69. Found: C, 40.07, H, 2.61, N, 10.78, Cu, 18.19.

2.2.3. Cu-4-bromo-(2-((pyridine-4-ylimino) methyl)phenol (Cu-L3)

Yield: 2.33 mg (59%); mp: 248 ºC (dec.). IR (cm^{-1}): 2359, 1739, 1598, 1517, 1452, 1391, 1333, 1316, 1279, 1168, 1028, 933, 874, 700, 626, 563, 464, 439. Anal. Calcd: $C_{12}H_{10}BrClCuN_2O_2$: C, 36.66, H, 2.56, N, 7.13, Cu, 16.16. Found: C, 38.49, H, 2.17, N, 6.63, Cu, 16.00.

Cobalt (II) complexes of the Schiff bases

2.2.4. Co-(2-((pyridine-4-ylimino)methyl) phenol (Co-L1)

Yield: 3.33 mg (54 %); mp: 298-303 ºC. IR (cm^{-1}): 1590, 1524, 1491, 1462, 1444, 1387, 1351, 1319, 1174, 1124, 1056, 1027, 980, 866, 834, 753, 735, 445, 414.Anal. calcd.: $C_{24}H_{22}CoN_4O_4$: C, 58.90, H, 4.53, N, 11.45, Co, 12.04. Found: C, 60.64, H, 4.02, N, 10.81, Co, 13.17.

2.2.5. Co-4-nitro-(2-((pyridine-4-ylimino)methyl)phenol (Co-L2)

Yield: 4.93 mg (58%); mp: 248-251 ºC. IR (cm^{-1}): 3421, 1597, 1574, 1507, 1456, 1395, 1369, 1335, 1216, 1196, 1160, 1084, 1055, 922, 855, 804, 696, 490, 428. Anal. Calcd: $C_{24}H_{20}CoN_6O_8$: C, 49.75, H, 3.48, N, 14.51, Co, 10.17. Found: C, 50.26, H, 3.02, N, 15.8,5 Co, 9.71.

2.2.6. Cu-4-bromo-2-((pyridine-4-ylimino)methyl)phenol (Cu-L3)

Yield: 4.78 mg (66 %); mp: >349 ºC. IR (cm^{-1}): 3060, 1597, 1554, 1470, 1334, 1279, 1211, 1170, 1081, 987, 913, 870, 848, 818, 781, 628, 529, 523, 429. Anal. calcd.: $C_{24}H_{24}Br_2CoN_4O_6$: C, 42.19, H, 3.54, N, 8.20, Co, 8.63. Found: C, 41.54, H, 2.79, N, 7.56, Co, 8.51.

2.3 Antitbacterial Activity

The antibacterial activity of the synthesized Schiff bases and their metal complexes was evaluated against *Staphylococcus aureus, Enterococcus faecalis, Escherichia coli* and *Pseudomonas aeruginosa* using the agar diffusion method according to the standard protocols of the Nigeria Institute of Medical Research, Yaba, Lagos. Fresh bacterial cultures were prepared and standardized prior to inoculation. Sterile nutrient agar plates were seeded with the test organisms and wells were aseptically bored into the agar medium. Solutions of the test compounds were prepared in dimethyl sulfoxide (DMSO) at concentrations of 40, 20, 10 and 5 mg mL−1 and introduced into the wells. The plates were incubated at 37 °C for 24 h and antibacterial activity was assessed by measuring the zones of inhibition around the wells. Appropriate positive and negative controls were included and all experiments were carried out in triplicate (Dueke-Eze & Fasina, 2023[b])

3.0. Results and Discussion

3.1. Synthesis

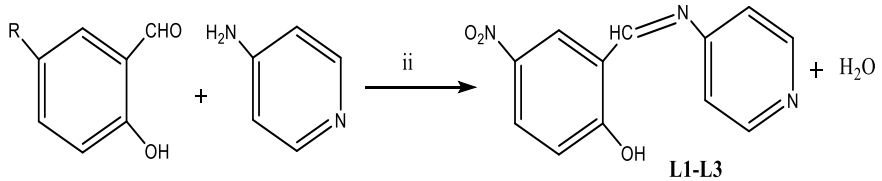
The Schiff bases were obtained in good yields (75–84%), indicating that the condensation reactions proceeded efficiently under the

reaction conditions employed. Complexation with Cu(II) and Co(II) ions resulted in compounds with significantly higher melting or decomposition temperatures than the corresponding ligands, suggesting increased thermal stability arising from metal–ligand coordination. The elemental analysis data were generally consistent with the proposed molecular formulae.

The ligands L1, L2 and L3 were synthesized by direct condensation reaction of 4-aminopyridine with 2-hydroxybenzaldehyde (L1), 5-nitro-2-hydroxybenzaldehyde (L2) and 5-bromo-2-hydroxybenzaldehyde (L3) (Scheme 1).

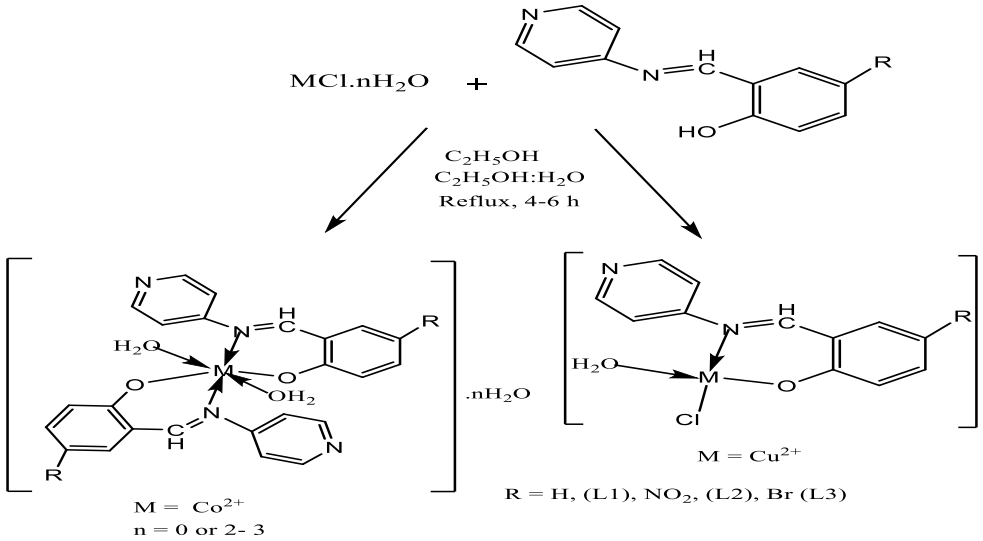
Scheme 1: Synthetic route to the Schiff base formation

The compounds' analytical and physical properties are displayed in Table 1. The synthesis of these compounds was successful as evidenced by the fact that they formed in reasonable yields, and the elemental analyses confirmed the molecular formulae. The significant difference from the melting points of the metal complexes and their corresponding ligand suggest that the metal complexes were synthesized. Each metal complex's elemental analysis supported the proposed molecular formula.



Reagents and conditions: (ii) $C_6H_8O_4S$, toluene, $N_{2(g)}$, heat , 24 h

R = H, (L1), NO_2, (L2), Br, (L3)



Scheme 2: Synthetic route to Schiff base metal formation

Table 1: Physical and analytical data of L1-L3

Ligand code	Molecular Wt. (M.wt. (g/mol))	mp:(°C)	Yield(%)	Microanalysis: %Calculated (Found)			
				C	H	N	M
	$C_{12}H_{10}N_2O$	77-78	81	72.71	5.08	14.10	
L1	(198)			(72.62)	(5.02)	(13.96)	
Cu(L1)	$C_{12}H_{11}ClCuN_2O_2$	244	60	45.87	3.53	8.92	20.22
	(314)	(dec.)		(46.32)	(3.00)	(8.40)	(20.74)
Co(L1)	$C_{24}H_{22}CoN_4O_4$	298-303	54	58.90	4.53	11.45	12.04
	(489)			(60.64)	(4.02)	(10.81)	(13.17)
	$C_{12}H_9N_3O_3$	193-194	75	59.26	3.77	17.28	
L2	(243)			(58.96)	(3.63)	(17.06)	
Cu(L2)	$C_{12}H_{10}ClCuN_3O_4$	>349	39	40.12	2.81	11.70	17.69
	(359)			(40.07)	(2.61)	(10.78)	(18.19)
Co(L2)	$C_{24}H_{20}CoN_6O_8$	248-251	58	49.75	3.48	14.51	10.17
	(579)			(50.26)	(3.02)	(15.15)	(9.71)
	$C_{12}H_9BrN_2O$ (277)	139-141	84	52.01	3.27	10.11	
L3				(52.16)	(3.18)	(9.82)	
Cu(L3)	$C_{12}H_{10}BrClCuN_2O_2$	248 (dec)	59	36.66	2.56	7.13	16.16
	(393)			(38.49)	(2.17)	(6.63)	(16.00)
Co(L3)	$C_{24}H_{24}Br_2CoN_4O_6$	>349	66	42.19	3.54	8.20	8.63
	(683)			(41.54)	(2.79)	(7.56)	(8.51)

3.2 Spectroscopic Analysis of L1-L3

3.2.1. Nuclear Magnetic Resonance (NMR)

The imine (HC=N) and hydroxyl (OH) protons are responsible for the singlet δH 8.61 and 12.57 ppm (L1), δ_H 8.56 and 10.01 ppm and δH 8.54 and 12.57 ppm (L3) resonances in the ligands' 1H NMR spectra. The 13C NMR spectrum included all of the carbon atom signals. Therefore, the ligand's structure is supported by the NMR data. The appearance of singlet signals at δH 8.54–8.61 ppm corresponding to the azomethine proton confirms successful condensation of the aldehydes with 4-aminopyridine. The phenolic OH resonances observed between δH 10.01 and 12.57 ppm are characteristic of intramolecular hydrogen bonding commonly observed in salicylaldehyde-derived Schiff bases.

Table 2: Characteristic ^{1}H and ^{13}C NMR bands of L1-L3

Ligand code	Chemical shift (ppm)			
	HC=N		C-OH	
	δ_H	δ_C	δ_H	δ_C
L1	8.61	161.29	12.57	165.68
L2	8.56	164.14	10.01	166.39
L3	8.54	160.27	12.57	164.38

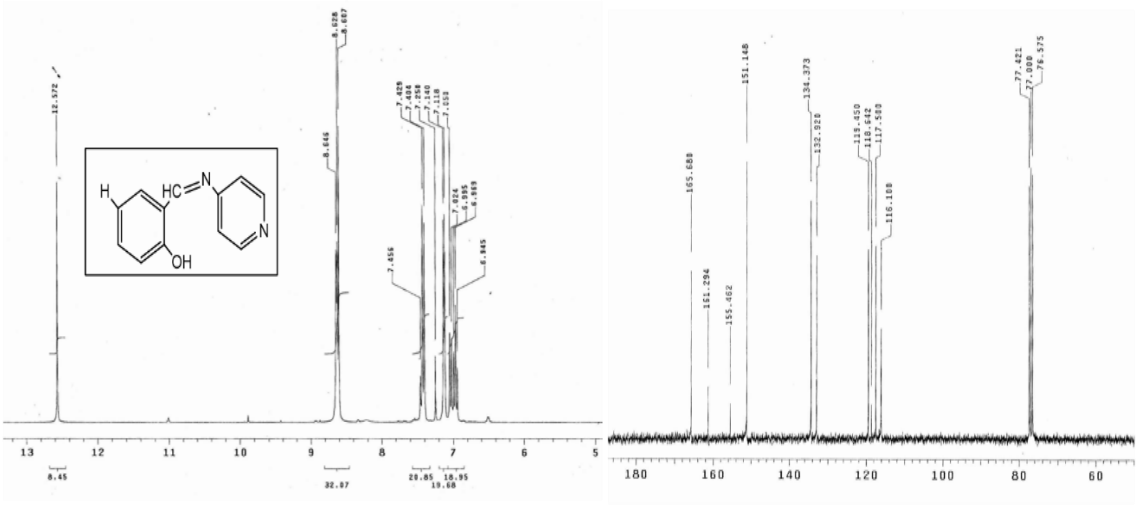


Fig. 1a: NMR Spectra of (2-((pyridine-4-ylimino)methyl)phenol (L1)

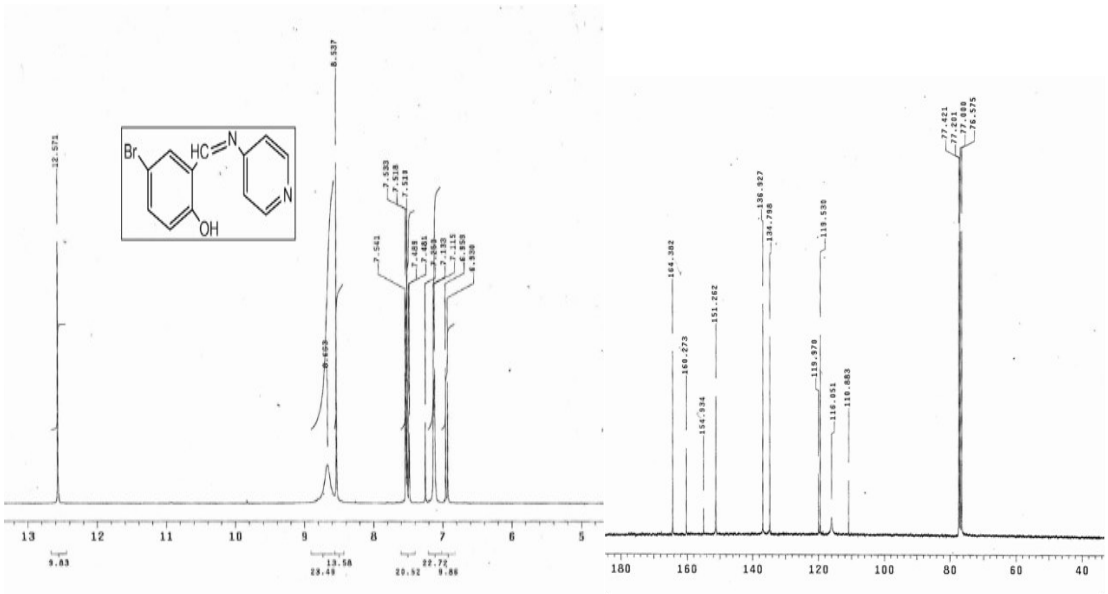


Fig. 1b: NMR spectra of 4-bromo-(2-((pyridine-4-ylimino)methyl)phenol (L3)

3.1.2. IR Spectra

The binding mode of the Schiff bases to the metal ions in the complexes was determined by comparing the IR spectra of the complexes and the free ligands. Following complexation, the ligands' characteristic absorption bands with frequencies of 1587, 1650, and 1615 cm-1 shifted by about 3-6 cm-1, indicating azomethine nitrogen's involvement in coordination. After complexation, the C-O band appeared at higher frequencies at 1271, 1280, and 1274 cm-1 due to the coordination of the ligand's phenolic oxygen to the metal ion. Coordinating through azomethine nitrogen and phenolic oxygen suggests that the Schiff bases are bidentate in nature (Aggoun *et al*., 2020). The coordination of the ligand to the metal ion via azomethine nitrogen and phenolic oxygen is further supported by the development of two

additional bands at 414-489 (M-N) and 445-529 (M-O) (Rani *et al*., 2020).

3.1.3. Antibacterial Activity

The synthesized compounds exhibited concentration-dependent antibacterial activity, with metal complexes generally showing enhanced activity compared with the free ligands and greater efficacy against Gram-positive bacteria than Gram-negative bacteria.

Table 3: Characteristic IR (cm^{-1}) bands of L1-Co-L3

Code	Formula	νOH	νC=N	νC–O	νPy	νH_2O	νM–O	νM–N
L_1	$C_{12}H_{10}N_2O$	3324	1587	1271	1056	–	–	–
Cu–L1	$[CuDL1 \cdot Cl \cdot H_2O]$	–	1581	1372	1058	869	528	489
Co–L1	$[Co(DL1)_2 \cdot 2H_2O]$	–	1590	1319	1056	866	445	414
L2	$C_{12}H_9N_3O_3$	–	1650	1280	1081	–	–	–
Cu–L2	$[CuDL2 \cdot Cl \cdot H_2O]$	–	1597	1373	1087	850	482	444
Co–L2	$[Co(DL2)_2 \cdot 2H_2O]$	–	1597	1335	1084	855	490	428
L3	$C_{12}H_9BrN_2O$	–	1615	1274	1078	–	–	–
Cu–L3	$[CuL3 \cdot Cl \cdot H_2O]$	–	1598	1279	1080	874	464	439
Co–L3	$[Co(L3)_2 \cdot 2H_2O] \cdot 2H_2O$	–	1597	1279	1081	870	523	429

Abbreviations: νOH = O–H stretching vibration; νC=N = azomethine C=N stretching; νC–O = C–O stretching; νPy = pyridine ring C=N stretching; νH_2O = coordinated water vibration; νM–O = metal–oxygen vibration; νM–N = metal–nitrogen vibration. All values are in cm^{-1}.

Among all compounds investigated, Co-L1 exhibited the highest antibacterial activity against S. aureus, maintaining strong activity even at lower concentrations. In contrast, Cu-L3 displayed comparatively weaker activity. The enhanced performance of cobalt complexes relative to the corresponding copper complexes suggests a favorable role of cobalt coordination in promoting antibacterial activity.

Activity was more pronounced against Gram-positive bacteria (*S. aureus* and *E. faecalis*) than Gram-negative bacteria (*E. coli* and *P. aeruginosa*). The greater susceptibility of Gram-positive bacteria may be associated with the absence of an outer lipopolysaccharide membrane, allowing easier penetration and interaction of the compounds with cellular components, unlike Gram-negative bacteria which possess an additional permeability barrier.

This trend was evident in the activity against *S. aureus*, where all compounds showed inhibitory effects at varying concentrations, while incorporation of metal ions further enhanced activity, particularly among the cobalt complexes. The enhanced antibacterial activity observed upon incorporation of metal ions, particularly in the cobalt complexes, may be attributed to the chelation effect, which reduces the polarity of the ligand and increases the lipophilic character of the complexes

Table 4: Antibacterial Activity of L1-Co-L3

	Gram Positive					**Gram negative**				
	S.auerus				***E.Feacalis***	*E. coli*				*p. aeruginosa*
Conc. Mg/ml	40	20	10	5	40-5	40	20	10	5	40-5
L1	2+	2+	1+	0	0-0	1+	1+	0	0	0-0
Cu-L1	3+	3+	1+	1+	0-0	1+	0	0	0	0-0
Co-L1	3+	3+	3+	0	0-0	2+	1+	1+	0	0-0
L2	3+	2+	2+	2+	0-0	1+	0	0	0	0-0
Cu-L2	3+	2+	2+	2+	0-0	2+	1+	1+	0	0-0
Co-L2	3+	3+	2+	1+	0-0	3+	1+	1+	1+	0-0
L3	2+	2+	1+	1+	0-0	1+	0	0	0	0-0
Cu-L3	2+	1+	1+	0	0-0	2+	1+	0	0	0-0
Co-L3	3+	3+	1+	1+	0-0	3+	0	0	0	0-0
Control	0	0	0	0	0-0	0	0	0	0	0-0

Inhibition values = 1 - 5 m m = 1+ (less active); 6 - 11 m m = 2+ (moderate active); >12 m m = 3+ (highly active) , 0 = not detected

This facilitates better penetration through the bacterial cell membrane, resulting in improved interaction with intracellular targets and enhanced antibacterial efficacy. Additionally, metal coordination may alter the electronic properties of the ligand and promote stronger binding to microbial biomolecules, thereby increasing biological activity. The observed trend in antibacterial activity followed the order CoL1 > CoL2 = CoL3 = CuL1> Cu-L2> L2>L1=L3>Cu-L3.

4.0. Conclusion

A series of pyridine-based Schiff bases and their copper and cobalt complexes were successfully synthesized and structurally characterized. The coordination behavior of the Schiff bases through the imine nitrogen and phenolic oxygen atoms contributed to the formation of stable metal complexes with improved antibacterial performance. The observed concentration-dependent antibacterial activity, particularly the pronounced efficacy of the cobalt complexes against *Staphylococcus aureus*, highlights the influence of metal coordination on enhancing biological potency. These findings demonstrate the potential of pyridine-containing Schiff base metal complexes as promising antibacterial scaffolds and provide a basis for further studies aimed at developing novel antiseptic agents, supported by future toxicological and biological investigations.

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Cordelia U. Dueke-Eze and Tolulope M. Fasina and Oluwole B. Familoni designed, synthesized and characterized the compounds. Cordelia U. Dueke-Eze and Tolulope M. Fasina and Oluwole B. Familoni interpreted the results. Cordelia U. Dueke-Eze wrote the manuscript.