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Synthesis, Characterization and Antimicrobial Studies of Schiff Base Derived From 2-Hydroxy Acetophenone and P-Anisidine and its Metal (II) Complexes

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ABSTRACT
Microbial infections remain a major global health challenge due to the rapid emergence and spread of antimicrobial-resistant pathogens. The misuse and overuse of conventional antimicrobial agents have accelerated multidrug resistance, highlighting the need for new therapeutic candidates with improved biological activity. In this study, Mn(II), Co(II), and Ni(II) complexes of a Schiff base derived from p-anisidine and 2-hydroxyacetophenone were synthesized, characterized, and evaluated for antimicrobial activity. The ligand and its complexes were obtained in good yields and characterized using physicochemical and spectroscopic techniques. The ligand exhibited a melting point of 197°C, while the complexes decomposed at 242–263°C, indicating enhanced thermal stability upon complexation. Molar conductivity values (6.23 – 31.40 $\Omega^{-1}cm^2mol^{-1}$) confirmed their non-electrolytic nature. Magnetic susceptibility measurements and effective magnetic moments of 5.5, 4.3, and 3.2 BM for the Mn(II), Co(II), and Ni(II) complexes, respectively, suggested tetrahedral geometry and paramagnetic behavior. Electronic spectra showed characteristic $\pi \rightarrow \pi^*$ (230 – 265 nm) and $n \rightarrow \pi^*$ (305 – 335 nm) transitions, while FTIR spectra revealed a shift of the azomethine C=N band from 1607 cm^{-1} to 1585 – 1592 cm^{-1} and disappearance of the phenolic O–H band at 3387 cm^{-1}, confirming coordination through azomethine nitrogen and phenolic oxygen atoms. Job's method established a 1:2 metal-to-ligand ratio. The ligand and complexes exhibited concentration-dependent antimicrobial activity against *Staphylococcus aureus, Escherichia coli, Salmonella typhi, Candida albicans, Tinea capitis,* and *Aspergillus flavus*. The complexes showed enhanced activity relative to the free ligand but remained less active than the standard drugs amoxicillin and griseofulvin.

Keywords:
Antimicrobial,
Conductivity,
2-Hydroxyacetophenone,
P-anisidine and
Paramagnetic

INTRODUCTION

Coordination chemistry remains one of the most dynamic and rapidly advancing branches of inorganic chemistry owing to the remarkable structural diversity and functional versatility of metal complexes. Coordination compounds are formed through the interaction of metal ions with ligands possessing donor atoms such as nitrogen, oxygen, sulfur, or phosphorus, resulting in stable molecular architectures with unique physicochemical and biological properties (Marinova & Tamahkyarova, 2025). Recent advances in coordination chemistry have expanded the scope of metal complexes beyond traditional applications to include catalysis, molecular sensing, energy conversion, nanotechnology, environmental remediation, and medicinal chemistry. The integration of computational chemistry, crystal engineering, green synthetic strategies, and nanotechnology has further accelerated the rational design of coordination compounds with enhanced selectivity, stability, and biological relevance (Malav & Ray, 2025; Marinova & Tamahkyarova, 2025).

One of the most significant developments in recent years is the design of biologically active transition metal complexes capable of overcoming limitations associated with conventional therapeutic agents. The coordination of biologically relevant ligands to transition metals frequently results in synergistic effects that improve lipophilicity, membrane permeability, redox properties, and target specificity. Consequently, transition metal complexes have attracted considerable attention as

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potential antimicrobial, anticancer, antioxidant, antiviral, anti-inflammatory, and enzyme-inhibitory agents. Advances in spectroscopic characterization, computational modeling, and structure–activity relationship studies have significantly improved the understanding of how the coordination environment influences biological activity, thereby facilitating the development of more effective metal-based therapeutics (Marinova & Tamahkyarova, 2025; Abd-El-Aziz *et al*., 2025).

Among the numerous classes of ligands employed in coordination chemistry, Schiff bases occupy a prominent position because of their straightforward synthesis, structural flexibility, and exceptional coordinating ability (Aldullahi *et al*., 2025; Abd-El-Aziz *et al*., 2025). Their electronic and steric properties can be conveniently tailored through ligand modification, making them versatile platforms for the synthesis of coordination compounds with desirable chemical and biological characteristics (Al-Maqtari *et al*., 2023; Abd-El-Aziz *et al*., 2025).

Recent investigations have demonstrated that Schiff base complexes exhibited superior physicochemical and biological properties compared with the corresponding free ligands. Chelation reduces the polarity of the metal ion through electron sharing between the donor atoms and the metal center, thereby enhancing lipophilicity and facilitating penetration through microbial cell membranes. This phenomenon often leads to improved antimicrobial potency, increased stability, enhanced catalytic efficiency, and better pharmacological applications. Modern research has also explored environmentally friendly synthetic methods, including microwave-assisted synthesis, ultrasonic irradiation, mechanochemical techniques, ionic liquids, and deep eutectic solvents, which offer higher reaction efficiencies while minimizing environmental impact (Abd-El-Aziz *et al*., 2025; Nandini & Amutha Selvi, 2025).

Transition metal(II) ions such as copper(II), cobalt(II), nickel(II), manganese(II), iron(II), and zinc(II) are particularly attractive in medicinal inorganic chemistry because of their variable coordination geometries, accessible oxidation states, and biological relevance. Such structural diversity enables fine-tuning of electronic properties that govern interactions with biomolecules including proteins, enzymes, and nucleic acids. Recent studies have shown that these complexes exert biological activities through multiple mechanisms, including disruption of microbial membranes, inhibition of essential enzymes, DNA interaction, induction of oxidative stress, and generation of reactive oxygen species, making them promising candidates for combating drug-resistant pathogens (Marinova & Tamahkyarova, 2025; Malav & Ray, 2025).

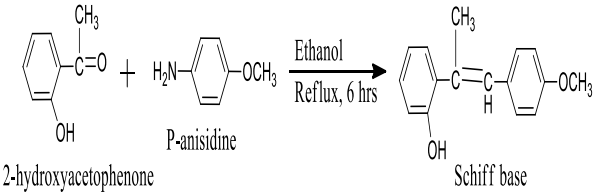
The rapid emergence of antimicrobial resistance (AMR) has become one of the most pressing global public health challenges. The increasing prevalence of multidrug-resistant bacteria has substantially reduced the effectiveness of many existing antibiotics, emphasizing the urgent need for alternative antimicrobial agents possessing novel mechanisms of action. Metal-based drugs have emerged as attractive alternatives because microorganisms are less likely to develop resistance against compounds that simultaneously target multiple cellular processes. Schiff base transition metal complexes have therefore gained increasing attention due to their remarkable antibacterial and antifungal activities against both Gram-positive and Gram-negative microorganisms. Their enhanced biological efficacy has been attributed to improved cellular uptake, favorable redox properties, and synergistic interactions between the metal center and the coordinated ligand (Jorge *et al*., 2024; Nandini & Amutha Selvi, 2025).

MATERIALS AND METHODS

The Schiff base and its Metal(II) complexes were synthesized by adopting standard published procedure.

Synthesis of Schiff base ligand

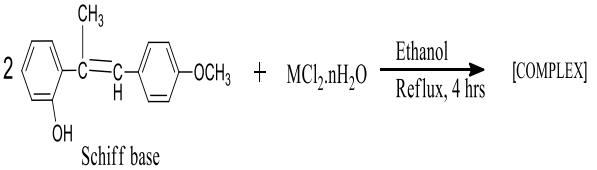
The Schiff base was synthesized by dissolution of (0.01 mol, 1.236 g) p-anisidine in 20cm^3 absolute ethanol and added drop wise to 20cm^3 ethanolic solution of (0.01mol, 1.361 g) 2-hydroxyacetophenone and reflux for 6 hours at 78°C. A dark green solution was formed, the solution was concentrated, on cooling crystals were formed. which were washed and recrystallized from ethanol, filtered and dry in a desiccator Muhammad, (2024).



Scheme 1: Synthesis of Schiff base ligand

Synthesis of Metal (II) Complexes

The metal complexes were synthesized by the dissolution of 0.02 mol of the Schiff base ligand in 15cm^3 of ethanol which was added to 0.01mol of the respective metal(II) chloride in 15 cm^3 of ethanol. The mixture was refluxed for 4 hours, the resulting reaction mixture was concentrated and allowed to cool in an ice bath. The crystals formed were recrystallized from hot ethanol, washed with diethyl ether and dried over P_2O_5 Muhammad (2024).



Scheme **2:** Synthesis of metal(II) complexes.
Where M = Mn(II), Co(II) and Ni(II)

Determination of Metal to Ligand Ratio

The number of ligands that coordinated to each metal ion in the complexes were determined by Job's method of continuous variation. About 3.0 mmol of DMSO solution of the ligand and the metal salt, were prepared in the following ratios 15:1, 13.3, 11:5, 9:7, 5:11, 3:13 and 1:15 were taken from the ligand solution and the metal salt solution respectively. A total volume of 16cm^3 was maintained throughout the method. The blank solution of each metal salt was scanned based on its wavelength of maximum absorbance (λ_{max}). The λ_{max} of each metal was fixed in the machine before taking the absorbance values. The number of coordinated ligands was determined using the formula from graph of absorbance against the mole fraction of the ligand (Prajapati, 2026).

$\bar{n}= \frac{x_i}{1- x_i}$, where $\bar{n}$ = number of coordinated ligands, x_i = mole fraction at maximum absorbance

Antimicrobial Assay

The bacterial and fungal species were clinically isolated according to published standard procedure. Antibacterial and antifungal activity test of the synthesized Schiff base and its respective complexes were carried out against three pathogenic bacterial isolates, *Staphylococcus aureus, Escherichia coli and Salmonella typhi* and three deleterious fungal species, *Candida albicans, Tinea capitis* and *Aspergillus flavus,* using well diffusion method by adopting the method reported by Laxman *et al.,* (2024). The activities of the compounds were determined by measuring the diameter of inhibition zone (in mm) using vernia-caliper and comparing the values with that of standard (positive control) and blank DMSO was used as negative control. The results were shown in Table 1 and 2 respectively.

RESULTS AND DISCUSSION

The results obtained from the physico-chemical analyses, spectral characterizations, *in-vitro* antibacterial and antifungal activities of the Schiff base and its respective metal(II) complexes are presented in the tables 1 – 7.

Table 1: Show the percentage yield and some properties of the Schiff base and its corresponding metal(II) complexes

Compounds	Colour	Melting Point (ºC)	Decomposition Temperature (ºC)	Percentage Yield (%)
L	*Greenish-yellow*	*197*	___	*80*
[MnL_2]	*Ash*	___	*263*	*58*
[CoL_2]	*Blue*	___	*243*	*64*
[NiL_2]	*Green*	___	*242*	*73*

L = $C_{15}H_{15}NO_2$

Table 2: Result for Solubility Test of the Schiff Base and its Metal(II) Complexes

Compounds	Solvents									
	Ether	Benzene	CCl_4	DMF	DMSO	Ethanol	Methanol	n-Hexane	Water	
L	IS	IS	IS	S	S	SS	S	IS	IS	
[MnL_2]	IS	IS	IS	S	S	SS	SS	IS	IS	
[CoL_2]	IS	IS	IS	S	S	SS	SS	IS	IS	
[NiL_2]	IS	IS	IS	S	S	SS	SS	IS	IS	

Key: S = Soluble; SS = Slightly Soluble and IS = Insoluble, L = $C_{15}H_{15}NO_2$

Table 3: Results for Molar Conductivity Measurement of the Complexes in 10^{-3} M DMSO

Compounds	Specific Conductance ($\Omega^{-1}cm^{-1}$)	Molar Conductance ($\Omega^{-1}cm^2mol^{-1}$)
[MnL_2]	23.7 x 10^{-6}	23.7
[CoL_2]	31.4 x10^{-6}	31.4
[NiL_2]	20.6x10^{-6}	20.6

L = $C_{15}H_{15}NO_2$

Table 4: Magnetic Susceptibility Data of Metal(II) Complexes

Compounds	X_g (erg.$G^{-2}g^{-1}$)	X_m(erg.$G^{-2}mol^{-1}$)	μeff (BM)	Magnetic property
[MnL_2]	2.4095 x 10^{-5}	1.382 x 10^{-2}	5.5	Paramagnetic
[CoL_2]	1.4403 x 10^{-5}	7.770 x 10^{-3}	4.3	Paramagnetic
[NiL_2].	7.781 x 10^{-6}	4.196 x 10^{-3}	3.2	Paramagnetic

L = $C_{15}H_{15}NO_2$

Table 5: IR Spectral Data of the Schiff Base and its Metal(II) Complexes

Compounds	υ(C=N) cm^{-1}	υ(M-N) cm^{-1}	υ(M-O) cm^{-1}	υ(OH) cm^{-1}	υ(C-O) cm^{-1}	υ(OCH_3) cm^{-1}
L	1607	___	___	3387	1242	2836
[MnL_2]	1592	599	444	___	1235	2836
[CoL_2]	1585	584	477	___	1220	2836
[NiL_2]	1585	581	469	___	1235	2836

L = $C_{15}H_{15}NO_2$

Table 6: UV – Visible Spectral Data of the Schiff base and its Metal(II) Complexes

Compounds	π → π* (nm)	n → π*(nm)
L	230	335
[MnL_2]	265	325
[CoL_2]	260	310
[NiL_2]	235	310

L = $C_{15}H_{15}NO_2$

Table 7: Establishing Metal to Ligand ratio using Job's Method of Continuous Variation

Compound	Mole fraction at maximum absorbance (Xi)	Number of coordinated ligand n = $\frac{Xi}{1-Xi}$	M: L Ratio
[MnL_2]	0.61	1.56	1:2
[CoL_2]	0.60	1.50	1:2
[NiL_2]	0.70	2.33	1:2

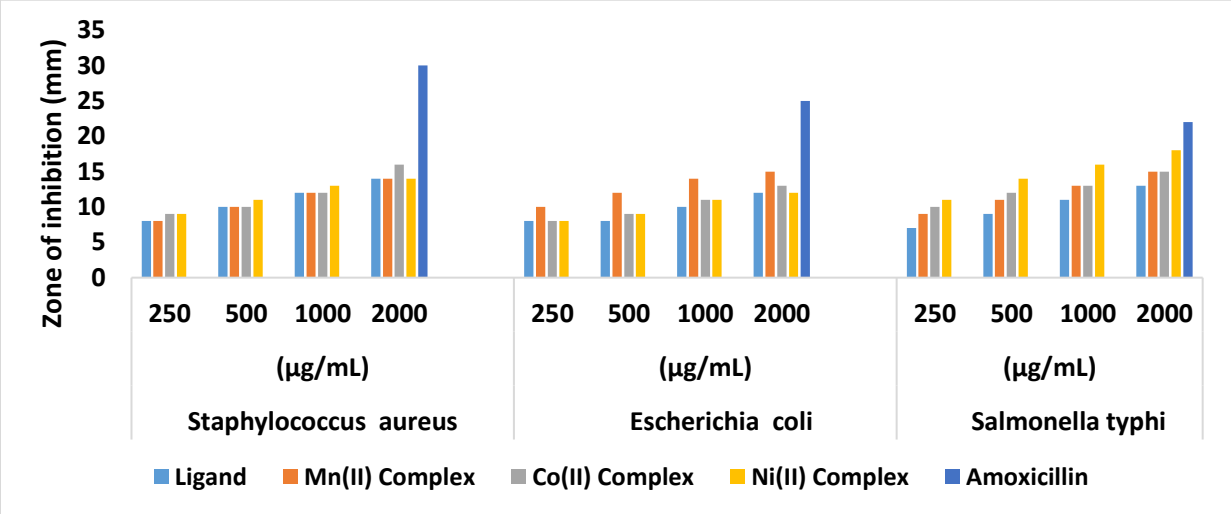


Fig. 1: Bar Chart showing the antibacterial activity of the Schiff base and its metal(II) complexes

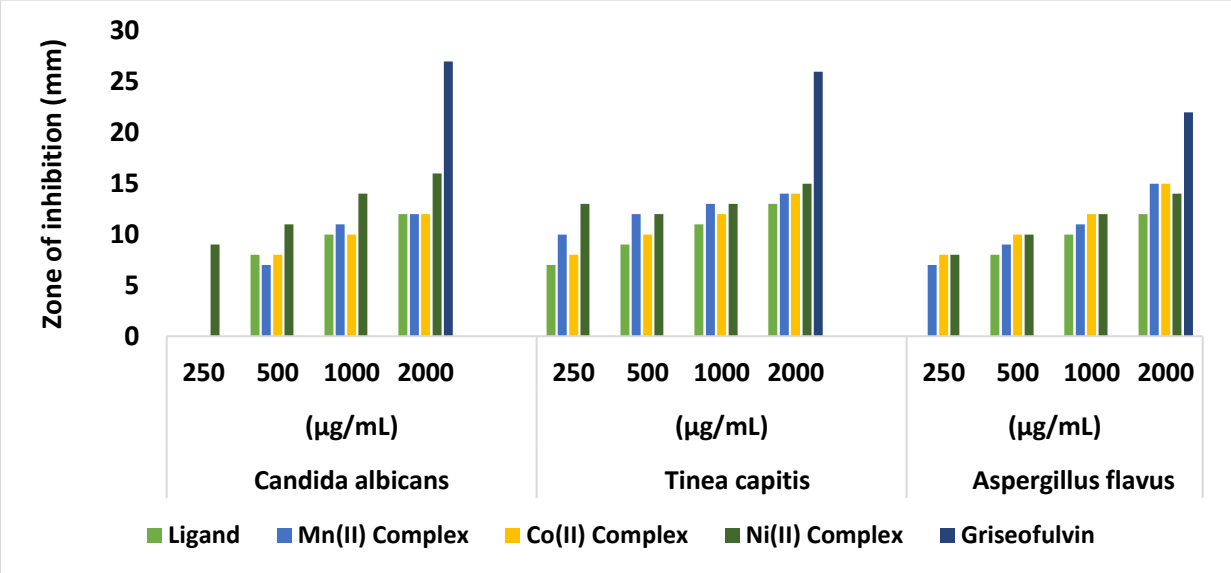


Fig. 2: Bar Chart showing the antifungal activity of the Schiff base and its metal(II) complexes

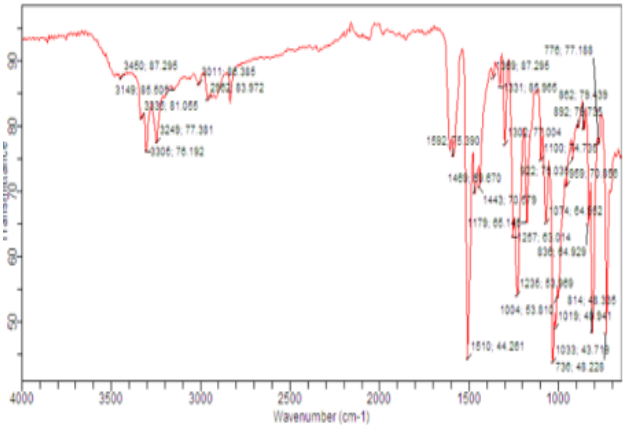


Fig. 3: FTIR Spectrum of $[Mn(L)_2]$

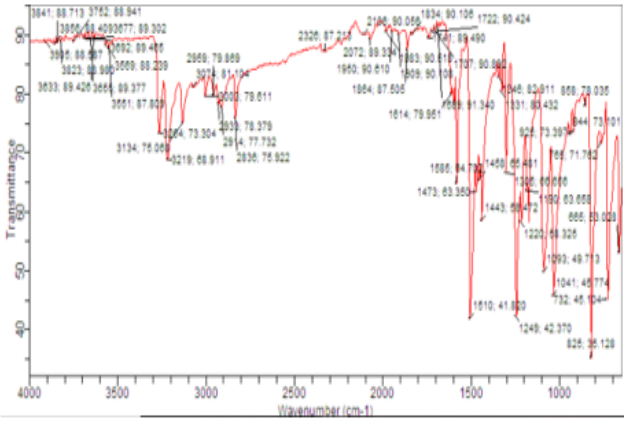


Fig. 4: FTIR Spectrum of $[Co(L)_2]$

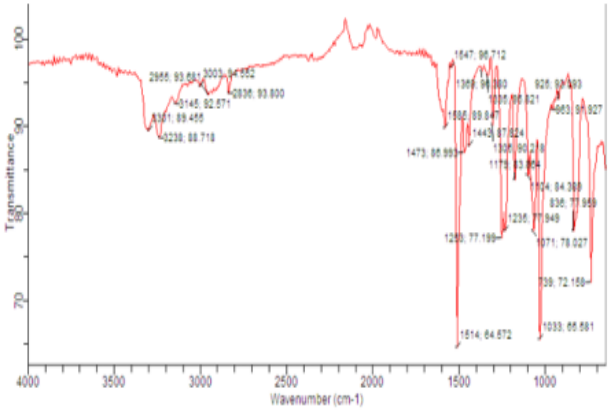


Fig. 5: FTIR Spectrum of $[Ni(L)_2]$

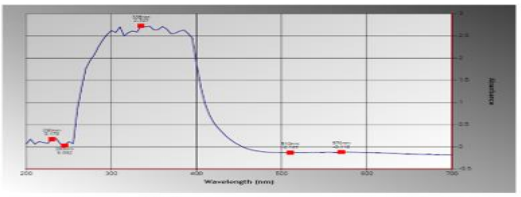


Fig. 6: UV-Visible Spectrum of Schiff base Ligand

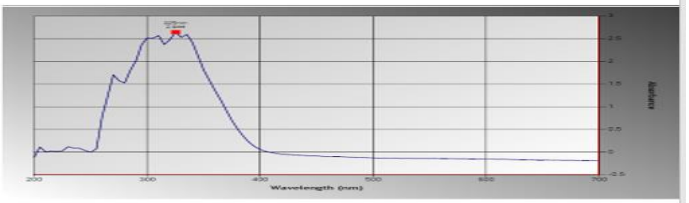


Fig. 7: UV-Visible Spectrum of $[Mn(L)_2]$

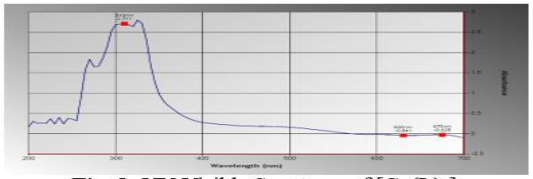


Fig. 8: UV-Visible Spectrum of $[Co(L)_2]$

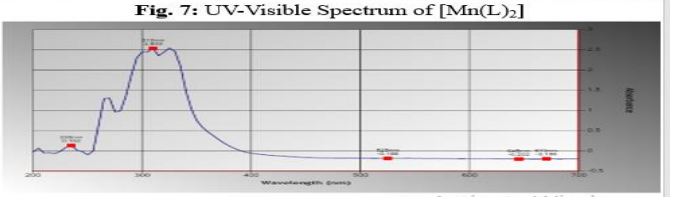


Fig. 9: UV-Visible Spectrum of $[Ni(L)_2]$

The synthesized Schiff base ligand and its transition metal(II) complexes were successfully synthesized and characterized using spectroscopic and physiochemical techniques. The results obtained provided strong evidence for coordination of the ligand to the metal ions and formation of stable complexes. The Schiff base was obtained as a greenish-yellow shiny crystal with a yield of 80 %, while the metal complexes showed varying colors, ash, blue and green, for Mn(II), Co(II) and Ni(II) complexes respectively, the differences in color suggested varying wavelength at which each complex absorb light in the visible region. The percentage yields of the complexes ranged from 58 -75 %, as shown, in Table 1. The results were comparable with those reported by Muhammad (2024) and Abdullahi *et al*., (2026)

The solubility data of the ligands and its complexes (Table 2) showed all the complexes were slightly soluble in ethanol and methanol, insoluble in water and non-polar solvents (n-hexane, benzene, diethyl ether, and carbon tetrachloride), but, soluble in strongly polar aprotic solvents (DMSO and DMF) likely, due to exceptional dielectric constants and high polarity index of the solvents.

The result of conductivity measurement of the synthesized complexes carried out in DMSO solution at room temperature (Table 3) were in the range of 20.6 – 31.4 $Ohm^{-1}cm^2\,mol^{-1}$ revealing the non-electrolytic nature of the complexes which were in agreement with the values reported by Mehta and More (2007).

Table 4 showed The result of magnetic susceptibility of the complexes. The values of effective magnetic moment of Mn(II) complex was 5.5 BM, this indicated the presence of five (5) unpaired electrons (high spin eg^2, t_2g^3) in tetrahedral environment. Effective magnetic moment of Co(II) complex was found to be 4.3 BM, which was consistent with high spin eg^2, t_2g^5 tetrahedral geometry and is comparable to the results reported by Laxman *et al.,* (2024). The magnetic moment value of Ni(II) complex was 3.2 BM which indicated two unpaired electrons in tetrahedral environment (eg^2, t_2g^6), suggesting that all the complexes were paramagnetic, these were similar to the results reported by Alomari *et al*., (2016).

The FTIR spectrum of the Schiff base (Table 5) showed a sharp band at $1607cm^{-1}$ assigned to ν(C=N) stretching, this band was absent in the starting materials, confirming successful condensation. The broad band observed at 3387 cm^{-1} in the ligand was attributed to phenolic ν(O-H). On complexation, the ν(C=N) band shifted from 1607 cm^{-1} in the free ligand to (1592, 1585, and 1581) cm^{-1} in the complexes, suggesting coordination through azomethine nitrogen. Also, the disappearance of the phenolic ν(O-H) indicated deprotonation of the phenolic -OH and coordination through phenolic oxygen confirming bidentate N O-donor behavior of the ligand. This result was in agreement with the report by Alomari *et al*., (2016). The absorption band observed at approximately 2836 cm^{-1} in the ligand was also present in the spectra of the corresponding metal complexes (Figure 3 – 5), the band was assigned to the C-H stretching vibration of the methoxy ν(-OCH_3) group. The retention of this band without any significant shift upon complexation indicated that the methoxy group did not participate in co-ordination with the metal ions, this was in agreement with similar report by Abdullahi and Na'aliya, (2018). The Band observed at $1242cm^{-1}$ was assigned to ν(C-O) stretching in the ligand, which shifted to lower absorption bands for all the five complexes also indicates bonding of phenolic oxygen to the metal ion this is in agreement with the result reported by Sravanthi *et al.,* (2019) and Oluseyije and Olalekan, (2026).

The UV–visible spectra of the Schiff base ligand and its metal(II) complexes (Table 6 and Figure 6 -9), showed the electronic transitions and coordination behavior. The free ligand exhibited two absorption bands at 230 nm and 335 nm, which were attributed to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions, respectively. The band at 230 nm is associated with the aromatic system of the ligand, while the band at 335 nm is due to the non-bonding electrons of the azomethine (–C=N–) group. Upon complexation with Mn(II), Co(II) and Ni(II) ions, noticeable shifts in these bands were observed. The $\pi \rightarrow \pi^*$ transitions in the complexes appeared in the range of 235–265 nm, this

indicated some degree of interaction between the metal ions and the ligand π-system. More importantly, the n → π* transition band of the ligand (335 nm) shifted to lower wavelengths (310 – 325 nm) in the metal complexes. This shift suggested the involvement of the azomethine nitrogen in coordination with the metal ions, which reduced the availability of the lone pair electrons as reported by Alomari *et al*., (2016).

Jobs method of continuous variation was employed to determine the stoichiometric ratio between the metal(II) ions and the ligand (Table 7). The mole fractions at maximum absorbance was found in the range 0.61 to 0.70 which established a 1:2 metal – ligand stoichiometry, there were in good agreement with the results reported by Abdullahi and Na'aliya, (2018). Based on physicochemical and spectral studies which were supported by existing literatures, confirmed that, the Schiff base (ligand, L) coordinated to the metal ions in a bidentate manner (through N-atom of azomethine and phenolic O-atom) resulting in tetrahedral geometries for all the complexes.

Figure 1 and 2 showed the antimicrobial activity of the Schiff base and its metal(II) complexes against selected bacterial isolates (*Staphylococcus aureus, Escherichia coli* and *Salmonella typhi*) and fungal strains (*Candida albicans, Trichophyton capitis* and *Aspergillus flavus*) Standard drugs (Amoxicillin for bacteria and Griseofulvin for fungi) were used as positive controls and dimethylsulphoxide (DMSO) as negative control. The results revealed that all compounds exhibited concentration-dependent antimicrobial activity, with zones of inhibition increasing with increase in concentration. The metal(II) complexes demonstrated enhanced antimicrobial activity compared to the free ligand, however their activities remained lower than that of the standard drugs, this result resembled the one reported by Al-Resayes *et al*., (2023) and Saulawa *et al*., (2024).

On chelation, due to the overlap of the ligand orbital and partial sharing of the positive charge of the metal ion with donor groups, it increases the delocalization π-electrons over the whole chelate ring and enhances the lipophilicity of complex compounds. This increased in lipophilicity enhances the penetration of complexes into lipid membrane and restricts further multiplication of the microorganisms as reported by Obaleye *et al.,* (2021). A variation in effectiveness of different compounds against different organisms depends either on the permeability of microbial cells or on differences in ribosome of microbial cells. That is the reason why some compounds are more potent against microbes than others (Karthika *et al.,* 2024).

CONCLUSION

The Schiff base and its corresponding bio-active complexes were successfully synthesized and characterized by different physicochemical techniques and spectral analysis. All the synthesized compounds were obtained in appreciable yield with significant thermal stability. The complexes are non-electrolytic due to low values of molar conductance. The values of effective magnetic moment indicated the paramagnetic nature of the complexes. Infrared spectra show all the prominent absorption bands at the desired wave number. Electronic spectra show π - π* and n - π* transitions at the expected wavelength values. Additionally, Job's method of continuous variation showed 1:2 metal to ligand ratio which are in good agreement with the proposed structures. The Schiff base and all the complexes displayed appreciable activities against pathogenic bacterial and fungal isolates, as such the compounds are potent antimicrobial agents.

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Conflicts of Interest

All the authors declared that, they have no conflicts of interest regarding the publication of this article.

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