International Journal of Chemical Science
www.chemicaljournals.com
Online ISSN: 2523-2843
Received: 20-05-2026, Accepted: 21-06-2026, Published: 06-07-2026
Volume 10, Issue 3, 2026, Page No. 1-10

Halogen-substituted schiff base and its Co(II), Ni(II), Cu(II), and Zn(II) complexes: Synthesis, structural elucidation, and anti- tubercular and anticancer studies

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DOI: https://doi.org/10.66856/chemical.2026.10.2.10039

Abstract

Here in we prepared, a Schiff base ligand synthesis from 2-hydroxybenzaldehyde and 3-choloro-4-fluoroaniline which was complexed with cobalt(II), Ni(II), Cu(II), Zn(II).The obtained compound were characterized using a several spectroscopic and physicochemical technique such as 1HNMR, HRMS,FTIR, UV, magnetic susceptibility, TGA. The co-ordination of the ligand through azomethine nitrogen and phenolic oxygen atoms was validated by FTIR measurements, which were corroborated by the emergence of new M-N and M-O bands, the shift in the (HC=N) band and the disappearance of the phenolic-OH proton upon complexation. Uv-visible spectra and magnetic data showed suitable geometries surrounding the metal centers. The thermogravimetric analysis show that the complexes are thermally stable up to 200 °C followed by multi-step decomposition process that finally yields the corresponding metal oxides. The biological studies showed that the all compound possess anti-tubercular activity against mycobacterium tuberculosis with inhibition increases as the concentration increases, among them the Ni(II) complex exhibit comparatively higher activity. In addition the anticancer study on the K562 cell line revealed a moderate to strong cytotoxic response, the ligand itself performed better than most of the complexes, although the Cu(II) complex also showed a meaningful level of activity. The enhanced biological activity may be related to increased lipophilicity after chelation which can enhance interaction with biological systems. Overall the results indicate that the synthesized Schiff base and its metal complexes could serve as potential candidates for further investigation as anti-tubercular and anticancer agents.

Keywords: Schiff base, metal complexes, anti-tubercular activity, anticancer activity, mycobacterium tuberculosis

Introduction

The search for new biologically active compounds has gained significant importance in recent years due to the increasing prevalence of infectious diseases and cancer [1]. In particular Mycobacterium tuberculosis continues to pose a serious global health challenges especially with the rise of drug-resistant strains [2]. At the same time cancer including leukemia remain one of the leading causes of mortality worldwide. Although several drugs are available for treatment issues such as toxicity resistance and limited efficacy highlight the need for the development of new therapeutic against with improved performance [3, 4]. In this context Schiff base compounds have attracted considerable attention because of their promising biological properties [5]. These compounds contain an azomethine (H-C=N) linkage and are generally abstained through simple condensation reaction between amines and carbonyl compounds [6]. Their structural flexibility and ease of modification make them suitable candidate for designing biologically active molecules. In addition the presence of donor atom such as N-O allows them to interact effectively with metal ions [7]. It has been widely observed that the biological properties of Schiff base can be significantly altered upon coordination with transition metals [8]. The formation of metal complexes often leads to changes in electronics distribution and lipophilicity which may enhance the ability of these compounds explained by the chelation effect where coordination reduces the polarity of the metal ion and facilitates its penetration though cell membranes [9, 10]. Another important factor influence biological activity is the presence of substituent on the ligand framework [11, 12]. In particular halogen atom such as chlorine and fluorine are know to affect electronic properties and increase lipophilicity which can improve interaction with biological targets [13]. Furthermore the nature of metal ion also plays a key role in determining the overall behavior of the complex including its geometry and reactivity [14]. Transition metals such as Co(II),Ni(II), Cu(II),and Zn(II) are often selected due to their diverse coordination characteristics and biological relevance [15].

Based on these considerations the present work focused on the synthesis of a halogen substituted Schiff base ligand derived from 2-hydroxybenzaldehyde and 3-chloro-4 fluor aniline along with its corresponding Co(II), Ni(II), Cu(II), and Zn(II) complexes. The prepared compounds were analyzed using various techniques including FT-IR, UV-Visible spectroscopy, magnetic susceptibility [1], HNMR, HRMS, and TGA, to establish their structural features. In addition their biological potential was investigated through anti-tubercular studies against Mycobacterium tuberculosis and *in vitro* anticancer evaluation using the K562 cell line. The study aims to understand how metal coordination and ligand modification influence both structural characteristics and biological performance.

Experimental

1. Material

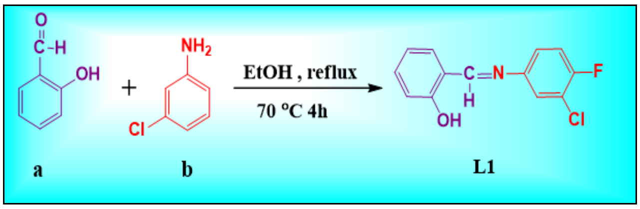
All chemicals and reagents were of analytical grade and used without further purification. 2-Hydroxybenzaldehyde and 3-chloro-4-fluoroaniline were procured from standard commercial suppliers. Metal salts, namely cobalt(II) chloride hexahydrate ($CoCl_2 \cdot 6H_2O$), nickel(II) chloride hexahydrate ($NiCl_2 \cdot 6H_2O$), copper(II) chloride dihydrate ($CuCl_2 \cdot 2H_2O$), and zinc(II) chloride ($ZnCl_2$), were used as received. Ethanol (absolute) was used as solvent for synthesis and recrystallization. Potassium hydroxide (KOH) was used to facilitate deprotonation during complex formation.

2. Material characterization

FT-IR spectra were recorded in the range 4000–400 cm^{-} [1] using KBr pellets. UV–Visible spectra were obtained in ethanol solution in the range 200–800 nm [1].H NMR spectra were recorded in $CDCl_3$ using tetramethyl silane (TMS) as an internal standard. High-resolution mass spectra (HRMS) were recorded using electrospray ionization (ESI) technique. Powd. Thermogravimetric analysis (TGA) was carried out under a nitrogen atmosphere at a heating rate of 10°C min^{-} [1]. Magnetic susceptibility measurements were performed at room temperature using the Gouy method

3. Synthesis of Schiff Base Ligand (L1)

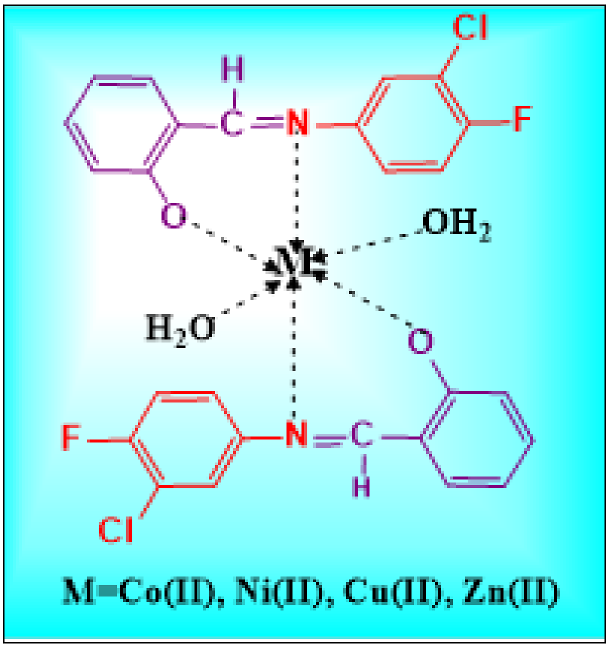
The Schiff base ligand was synthesized via a condensation reaction between 2-hydroxybenzaldehyde (1 mmol) and 3-chloro-4-fluoroaniline (1 mmol) in ethanol (20 mL). The reaction mixture was refluxed for 3–4 h at 70°C with continuous stirring. A few drops of glacial acetic acid were added to catalyze the reaction. Upon completion, the mixture was cooled to room temperature, resulting in the formation of a colored precipitate. The product was filtered, washed with cold ethanol, and dried under vacuum. The purified ligand was recrystallized from ethanol and stored in a desiccator (scheme1) [16, 17].



(Scheme1) Synthesized of Schiff base ligand

4. Synthesis of Metal Complexes

The metal complexes were synthesized by reacting the prepared Schiff base ligand with corresponding metal salts in a 2:1 ligand-to-metal molar ratio. Typically, the ligand (2 mmol) was dissolved in hot ethanol (20 mL), while the metal salt (1 mmol) was dissolved separately in ethanol (10 mL). The metal solution was added dropwise to the ligand solution under constant stirring. The reaction mixture was refluxed for 12h, during which a colored precipitate was formed. The resulting solid was filtered, washed thoroughly with ethanol to remove unreacted materials, and dried under vacuum. The complexes were stored in a desiccator for further characterization(scheme2) [18, 19].



(Scheme2) Synthesized of Schiff base ligand metal complexes

5. Biological evaluation

5.1 Anti-Cancer activity

The K562 cells at a concentration of 1×10 [4] cells/mL were maintained in culture medium and incubated for 24 h at 37 °C under 5% CO_2. K562 cell were seeded into tissue culture grade 96-well microplate at a density of 1×104 cell /well in 100 mL of culture medium followed by treatment with the test samples at concentration of 20,40,60,80, and 100 µg/mL. Control well containing the cell line with 0.2% DMSO in PBS were maintained under identical condition. All experimental samples were analyzed in triplicate while untreated control wells were used to evaluate cell viability and percentage cell survival after incubation. The cell culture were incubated for 24 h at 37 °C in a CO_2 incubator maintained under 5% CO_2 atmosphere. Subsequently the medium was removed completely from the well and 20mL of MTT solution (5 µg/mL in PBS) was introduced into each well. Following the addition of MTT reagent the cell were further incubated for 4 h at 37 °C in a CO_2 incubator. The wells were examined under a microscope for the formation of formazan crystals. Viable cells reduced the yellow colored MTT reagent into dark formazan crystals. After complete removal of the medium 200mL of DMSO was added to each well and kept for 10min to dissolve the formed crystal followed by incubation at 37 °C with the plates wrapped in aluminum foil. The absorbance of each triplicate sample was measured at 550 nm with the help of a microplate reader for further analysis [20].

5.2 Mycobacterium Tuberculosis activity

The *Mycobacterium tuberculosis* culture was grown until the mid-logarithmic phase and reached an optical density of 0.6 at 600nm corresponding approximately to 5×10^7 CFU/ML. Each well of the 96 well plate was loaded with 100mL of bacterial inoculum (5×10^4 CFUs) after which the synthesized compound was introduced at a final concentration of 10mM. Dimethyl sulfoxide (DMSO) served as the negative control where as rifampicin (RIF) was employed as the positive control. The microplate were sealed properly and incubated at 37 °C for a period of six days. A 10%(v/v) Alamar blue solution was subsequently introduced into each well. The anti-Mycobacterium tuberculosis activity of the tested compound was assessed on the basis of the observed color variation. The transition in color from blue to pink indicated antimycobacterial activity against *M tuberculosis.* Thereafter absorbance measurement were carried out at 600nm with the help of a microplate reader [21].

Result and discussion

1. Chemistry

The Schiff base ligand and its transition metal complexes were synthesized through a simple and efficient condensation route followed by complexation with Co (II), Ni(II), Cu(II) and Zn(II) metal ions. The synthetic procedure produced good yields within comparatively shorter reaction time and the obtained compounds were isolated as stable colored solids. Formation of the azomethine linkage and subsequent coordination with metal ions were confirmed through various physicochemical and spectroscopic techniques. The synthesized complexes remained stable under normal laboratory conditions and showed decomposition only at higher temperatures, indicating appreciable thermal stability of the coordinated framework. All the prepared compounds were found to be sparingly soluble in common organic solvents, while they dissolved readily in DMSO and DMF, which facilitated their spectral and biological investigations. The coordination behavior of the ligand toward transition metal ions was established using FT-IR, UV-Visible spectroscopy, magnetic susceptibility measurements, HRMS ^{1}H NMR, and TGA studies. Spectral observations suggested that the Schiff base acts as a bidentate donor ligand through the azomethine nitrogen and phenolic oxygen atoms, forming stable chelate complexes around the metal center. while thermal analysis demonstrated their stepwise decomposition pattern with formation of corresponding metal oxide residues at higher temperatures. Electronic spectral studies together with magnetic susceptibility values supported octahedral geometry around the metal ions for Co (II), Ni (II), and Cu(II) complexes, whereas the Zn(II) complex exhibited diamagnetic behavior due to its completely filled d [10] electronic configuration. Overall, the combination of structural stability, coordination ability, and promising biological response highlights the importance of these Schiff base metal complexes as potential candidates for further medicinal and coordination chemistry investigations.

2. ^{1}HNMR study

The HNMR spectrum of the synthesized Schiff base ligand provides useful insight into its structural features(fig.1). A distinct singlet is observed in the downfield region at around 8.5 ppm which can be assigned to the proton of the azomethine (HC=N) group. The appearance of this signal confirm the formation of the imine linkage after condensation. And the signals corresponding to aromatic proton appear as multiplets in the range of 6.7-7.7ppm which is due to the substituted phenyl ring present in the structure. In addition to these a strongly deshielded signal is observed near 12ppm attributable to the phenolic O-H proton. The position of this peak suggests that its involved in intramolecular hydrogen bonding which is commonly seen in such systems. Overall the distribution and nature of the signal are consistent with the expected structure of the ligand.

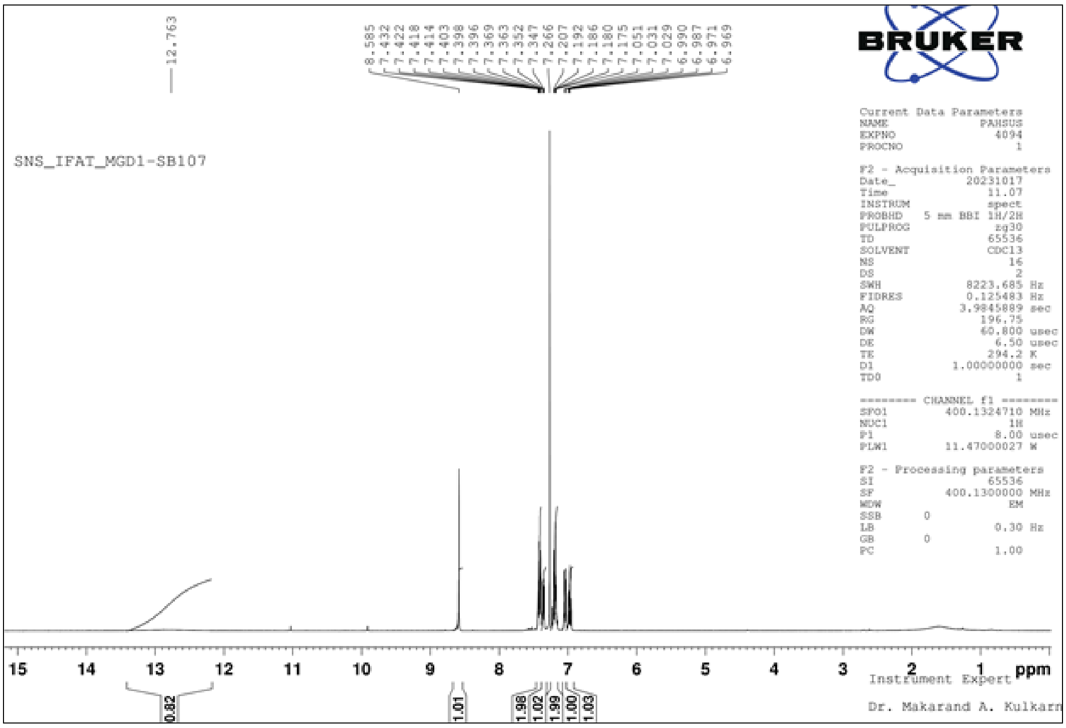


Fig 1: 1HNMR spectra of the synthesized Schiff base ligand (L1) recorded in $CDCl_3$ Solvent

3. HRMS study

High-resolution mass spectrometry was used to verify the molecular composition of the ligand (fig.2). The spectrum shows a peak at m/z =250 which matches well with the expected [M+H] value of the compound. This agreement between observed and calculated mass confirm the successful formation of the ligand.

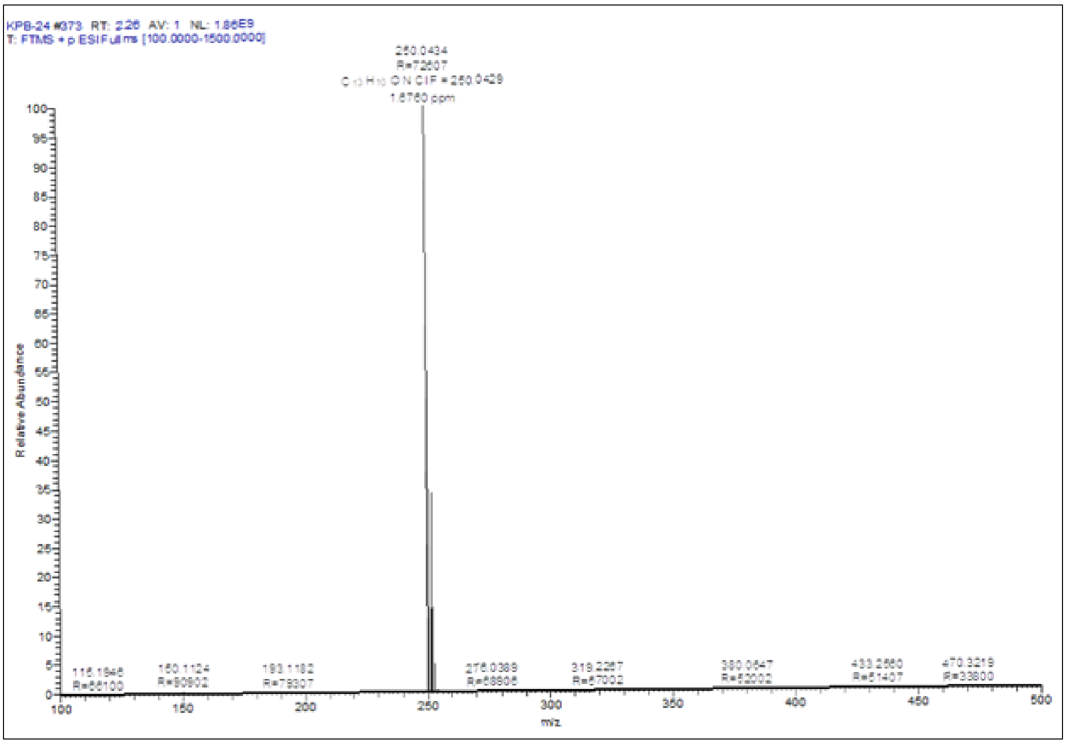


Fig 2: HRMS spectrum of the Schiff base ligand (L1) showing the molecular ion peak corresponding to the proposed structure.

4. FTIR spectral studies

The FTIR spectra of the ligand and its metal complexes were examined to understand how co-ordination takes place(fig.3a-e). In the spectrum of the free ligand a broad absorption band is seen around 3417 cm^{-1} which can be related to the starching of the phenolic O-H group[22]. The position and broad nature of this band suggest the presence of intermolecular hydrogen bonding. Another prominent feature appears at 1625cm^{-1} corresponding to the azomethine (H-C=N) group confirming that the condensation reaction has successfully taken place. Additional band observed near 1150cm^{-1} and 740cm^{-1} are assigned to C-F and C-Cl vibration respectively which remain largely unchanged and indicate that these groups do not participate in coordination [23]. After complex formation noticeable differences can be see in the spectra. One of the important changes in the shift of the azomethine band toward lower wavenumber (around 1610-1615cm^{-1}) which suggests that the nitrogen atom of the (H-C=N) is involved in binding with the metal ions [24]. At the same time the phenolic O-H band present in the free ligand is disappear in the complexes indicating that deprotonation of hydroxyl group and coordination through phenolic oxygen atom. Although the phenolic O-H band of the ligand disappears, a broad absorption band still observed in the region 3380-3410cm $^{[-1]}$ in all the complexes like Co(II), Ni(II), Cu(II), Zn(II)[25]. This broad band may arise from contribution of coordinated water molecule. In the region near 1600-1650 cm $^{[-1]}$ no clearly separate band for water bending is observed which may be due to overlap with the azomethine vibration [26]. Further evidence of coordination is obtained from the low frequency region. New bands appear between 550-576cm^{-1} which can be assigned to metal-oxygen(M-O) vibration while band around 430-448cm^{-1} are associated with metal-Nitrogen(M-N) stretching [27, 28]. Overall, these spectral changes clearly indicated that the ligand coordinates to the metal ions through the azomethine nitrogen and phenolic oxygen atom (Table.1).

Table 1: FTIR spectral bands (cm-1) of the Schiff base ligand and its Co(II), Ni(II), Cu(II),and Zn(II) metal complexes.

sr	Ligand/complexes	O-H	HC=N	M-O	M-N
1	L1	3417	1625	-	-
2	Co(II)	3382	1613	550	448
3	Ni(II)	3411	1610	570	442
4	Cu(II)	3386	1610	576	448
5	Zn(II)	3383	1615	540	430

5. Electronic Spectral and Magnetic Studie

The UV-Visible spectra of the ligand and its metal complexes were studied in order to understand the electronic transitions and possible geometry around the metal centers (fig.4.a-e). The first one can be linked to $\pi \rightarrow \pi^*$ transitions within the aromatic rings the band appear at 272nm, while the second band is associated with the $n \rightarrow \pi^*$ transition of the azomethine group the band appear at 343nm, indicating the presence of the -C=N- linkage. Once the ligand coordinates with metal ions, changes in the spectral pattern become noticeable. For the Co (II) complex, bands appear at 262nm and 318nm, which are similar to ligand-based transitions. In addition, a band near 400nm is observed, which can be related to d-d transition. The magnetic moment value reported for this complex (around 4.1691BM) suggests the presence of three unpaired electrons, supporting a high- spin octahedral arrangement [29]. In the case of the Ni (II) complex, absorption bands are seen at 259nm, 300nm, and 414nm. The higher energy bands correspond to ligand-centered of a d-d transition in octahedral Ni (II) systems. This interpretation is consistent with the observe magnetic moment (3.15BM), which indicates two unpaired electrons. The Cu (II) complex shows bands at 260nm and 360nm, again related to ligand-based transitions. A broader band is observed around 562nm, which is typical for Cu (II) complexes and can be assigned to d-d transition. The magnetic moment (1.81BM) confirms the presence of a single unpaired electron, and the overall data point toward a distorted octahedral geometry, likely influenced by John-Teller distortion [30]. For Zn (II) complex, bands are observed at 256nm, 360nm, and 442nm. Since Zn (II) has a d^{10} electronic configuration, d-d transitions are not expected. Therefore, the observed bands are mainly due to ligand-centered and charge transfer transitions. The diamagnetic nature of this complex further supports the absence of unpaired electrons (Table.2).

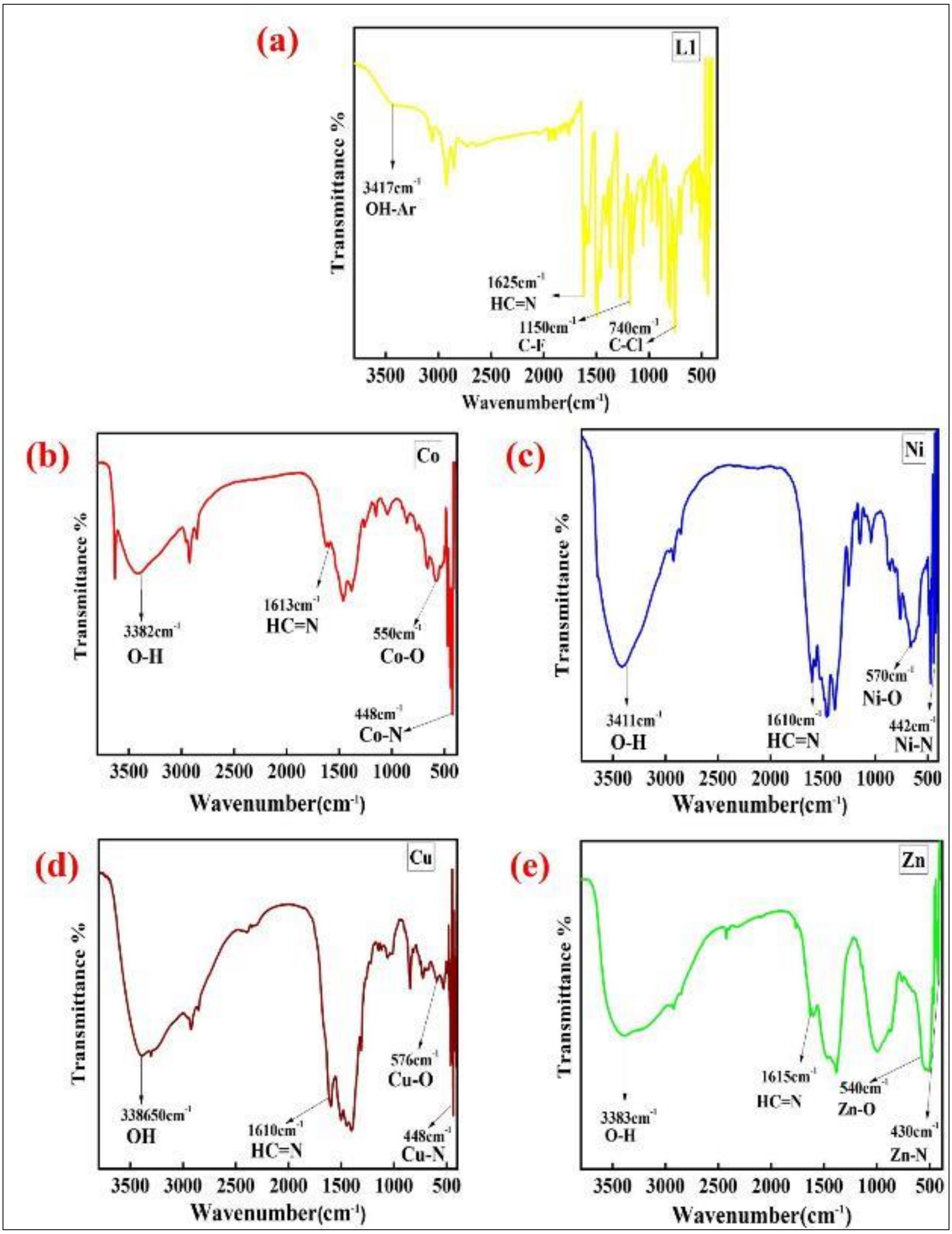


Fig 3: (a-e) FT-IR spectra of Schiff Base ligand(a) L1, (b) Co(II), Ni(II),(d) Cu(II) and (e)Zn(II).

Table 2: Electronic spectral data and magnetic susceptibility values of the Schiff base ligand (L1) and its transition metal complexes
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Sr. No	Ligand/Metal complexes	Electronic Transition(nm)	Magnetic momentum μeff(B.M)
1	L1	272,343	-
2	Co(II)	262,318,400	4.1691
3	Ni(II)	259,300,414	3.1574
4	Cu(II)	260,360,562	1.81
5	Zn(II)	256,360,422	diamagnetic

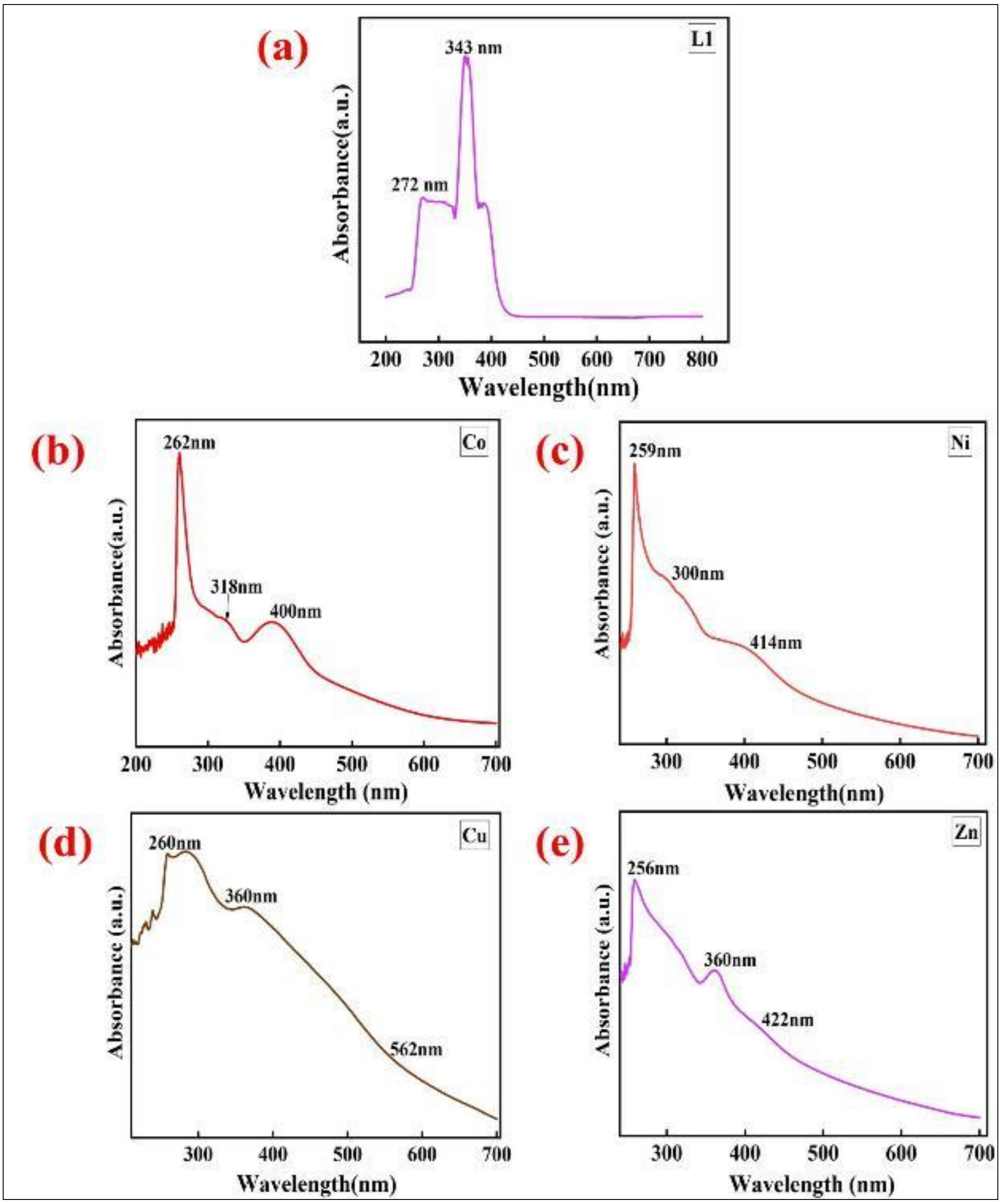

Fig 4: (a-e) UV-Visible spectra of the Schiff base ligand and its metal complexes(a) L1 (b) Co(II), (c) Ni(II), (d) Cu(II) and (e) Zn(II) complexes.

6. TGA studies

The thermal decomposition behavior of the synthesized metal complexes was investigated using thermogravimetric analysis in order to understand their stability and decomposition pattern. All the complexes exhibits a similar trend showing stepwise weight loss as the temperature increases which indicates a multi-stage decomposition process rather then a single step breakdown (fig.5.a-d). In the initial stage a small weight loss is observed below 250 °C which can be associated with the removal of coordinated water molecules. As the temperature increases further a more significant weight loss occurs in the range of 250-600 °C. This stage corresponds to the gradual decomposition of the organic ligand framwork [31]. During this process the aromatic portion of the schiff base ligand begain to breakdown. The decomposition in this region is not instantaneous but occure over a wide temperature range indicating that different parts of the ligand degrade at slightly different temperatures. At higher temperature tipically above 600 °C the remaining organic moiety undergos further decomposition leading to the formation of stable inorganic residues. This final stage continues up to around 700-900 °C after which no major weight change is observed [32]. The residue obtained at the end of the analysis can be attributed to the formation of the corresponding metal oxides such as CoO, NiO, CuO, ZnO. Overall the TGA analysis suggest that the complexes are stable upto around 200 °C after which Controlled decomposition takes place in multiple step [33]. The stepwise nature of the weight loss along with the final residue supports the proposed composition of the complexes and confirm the presence of coordinated ligand and water molecule (Table.3).

Table 3: Thermodynamic analysis data of the synthesized schiff base metal complexes showing decomposition stage and residual metal oxide formation

Sr	Complexes	stage	Temperature	Mass loss %	Calculated %	Decomposition products
1	Co(II)	I	50-250	6.67	6.09	Water molecule
		II	250-700	35.59	42.13	Organic moiety
		III	700-950	44.79	39.10	Organic moiety
			>950	12.95	12.67	Residue
2	Ni(II)	I	50-250	6.35	6.10	Water molecule
		II	250-690	36.20	42.20	Organic moiety
		III	700-920	44.59	39.05	Organic moiety
			>920	12.86	12.65	Residue
3	Cu(II)	I	50-250	6.22	6.05	Water molecule
		II	250-685	37.40	41.85	Organic moiety
		III	685-910	43.03	38.74	Organic moiety
			>910	13.80	13.36	Residue
4	Zn(II)	I	50-250	6.04	6.04	Water molecule
		II	250-710	38.50	41.78	Organic moiety
		III	710-1090	41.77	38.53	Organic moiety
			>1090	13.69	13.65	Residue

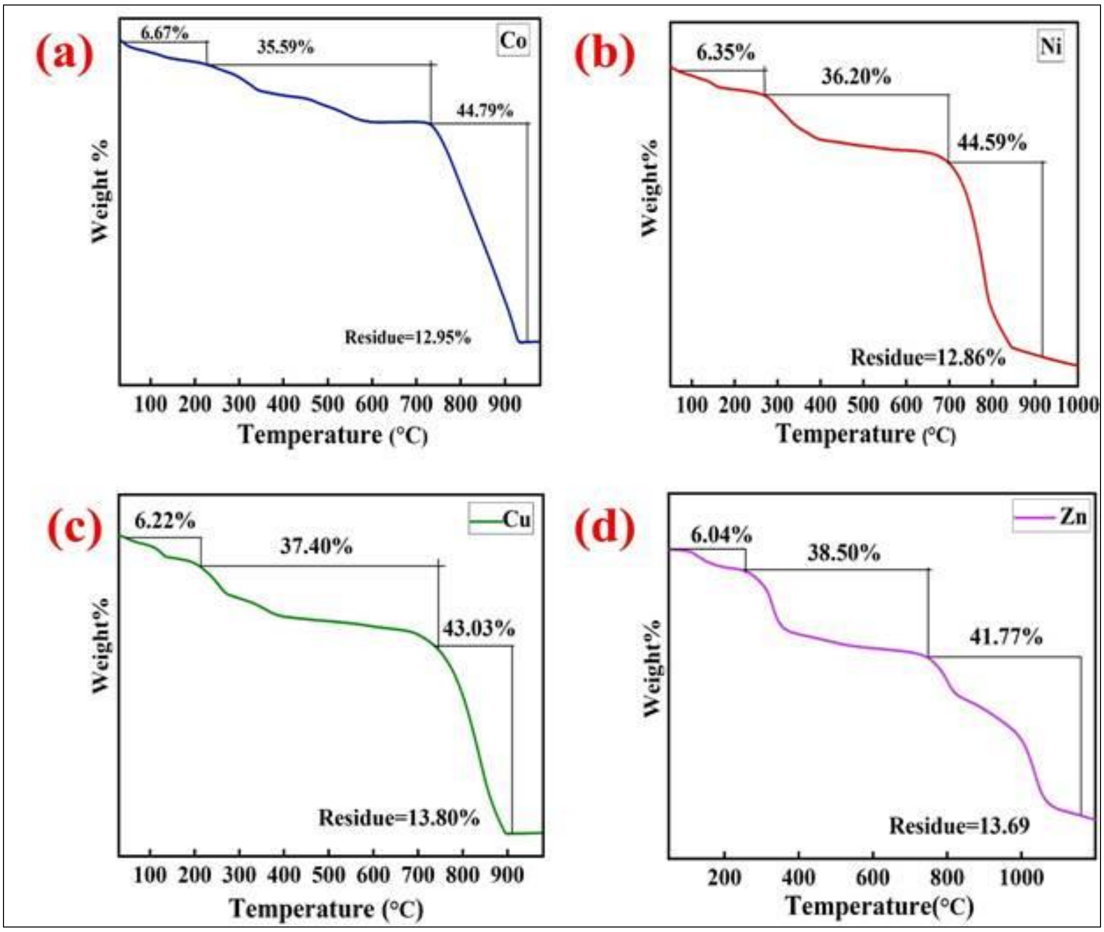

Fig 5: TGA curves of the Co(II), Ni(II), Cu(II) and Zn(II) schiff base complexes showing stepwise thermal decomposition behavior.

7. Anti-Cancer activity

The cytotoxic potential of the the synthesized Schiff ligand (L1) and its metal complexes was evaluated against the K562(human leukemia) cell line using different concentration (20-100µg/mL) (Table.4). The obtained results indicate that the response of the cells dependent strongly on the concentration of the compound with a gradual decrease in cell viability observed as the dose increases. A closer look at the data shows that the behavior of the compound is not uniform. The Cu(II) complex exhibits comparatively stronger cytotoxic effects among the metal complexes which becomes more evident at higher concentration. Its IC50 value (78.62µg/mL) suggests a moderate level of activity. The free Schiff base ligand also demonstrates noticeable cytotoxicity with an IC50 value of around 58.26 µg/mL indicating that the ligand itself contributing significantly to the observed biological effect. On the other hand, the Co(II), Ni(II), and Zn(II) complexes do not show comparable activity within the tested concentration range. Although some reduction in cell viability is observed at higher doses their overall effect remains limited and IC50 values could not be clearly determine in these cases. This suggests that coordination with these particular metal ion dose not necessarily enhance anticancer activity in this system. The microscopic image of the tested cell further supports these observations. Compared to the control treated cell show visible morphological changes such as shrinkages and loss of normal structure especially at higher concentrations. These changes are more pronounced in the case of the Cu(II) complex and the ligand indicating stronger interaction with the cancer cells. Overall the study suggests that while metal complexation can influence biological activity its effect depends on the nature of the metal ion. In the present case the ligand and Cu(II) complex show relatively better anticancer potential possibly due to more effective interaction with cellular components or improved cellular uptake [34, 35].

Table 4: In-*vitro* anticancer activity of Schiff base ligand and its metal complexes against the K562 cell line at different concentrations.

Sr No	sample	100µg/mL	80µg/mL	60µg/mL	40µg/mL	20µg/mL	IC50
1	MGD1S.B	36.51%	43.36%	48.64%	65.06%	92.31%	58.26
2	MGD1Co	65.06%	72.04%	77.84%	82.40%	98.83	NE
3	MGD1Ni	41.92%	47.92%	83.45%	98.83%	NE	78.62
4	MGD1Cu	64.02%	65.26%	66.69%	92.31	NE	NE
5	MGD1Zn	64.61%	76.15%	81.56%	83.45%	95.38	NE
6	5,flurour-acil	16.04	25.3	33.84	48.64	63.69	38.12

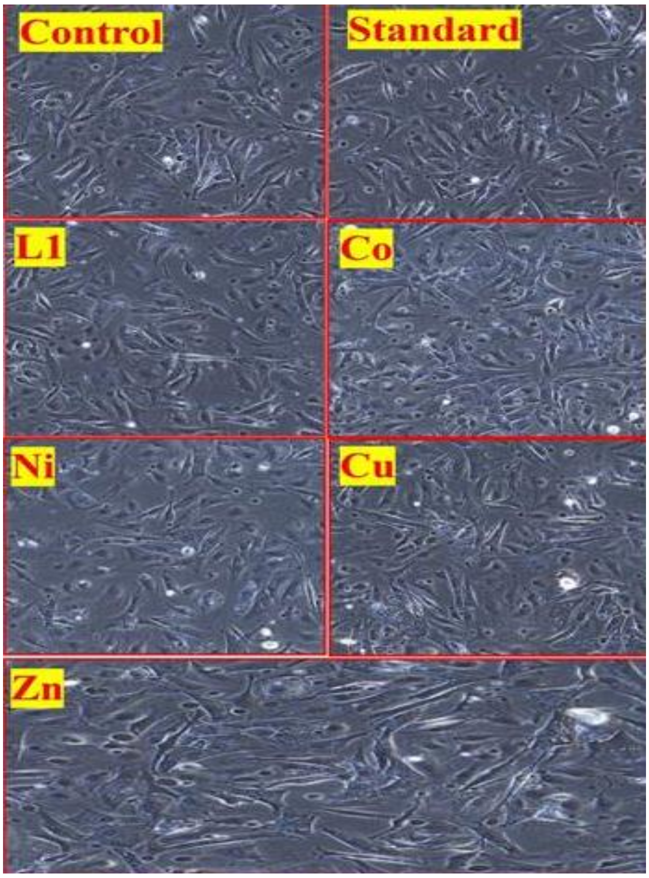

Fig 6: microscopic image showing the cytotoxic effect of the schiff base ligand and its Co(II), Ni(II),Cu(II), and Zn(II) complexes on K562 leukemia cells compared with control and standerd drug-treated cells.

8. Anti-TB activity

The anti-tubercular potential of the ligand (L1) and its corresponding metal complexes [M=Co, Ni, Cu, Zn] was examined against Mycobacterium tuberculosis at different concentration ranging from 20-100µg/mL (Table.5). The results clearly indicates that all the compound are capable of inhibiting bacterial growth and the effect becomes more pronounced as the concentration increases. Among the tested sample the Ni(II) complex showed comparatively better activity giving about 61.88% inhibition at 100µg/mL. The Co(II) and Zn(II) complexes also demonstrated noticeable activity with inhibition value of 56.39% and 43.02% respectively at the same concentration. In contrast the Cu(II) complex and the free ligand exhibited relatively lower inhibition under similar condition. A consistent decrease in activity was observed at lower concentration for all the compound which reflects a typical dose-dependent behavior. As expected the standard drug rifampicin showed higher inhibition across all concentrations confirming the validity of the experimental method. The improved activity of the metal complexes compared to the ligand can be linked to changes that occur after coordination such as increased lipophilicity which may help the bacterial cell membrane. The comparatively better performance of the Ni(II) complex suggests that its structural and electronic features may favor stronger interaction with biological targets. (fig.7) The microplates observations further support these finding where a visible change in color indicates reduced bacterial growth with increasing concentration [36, 37].

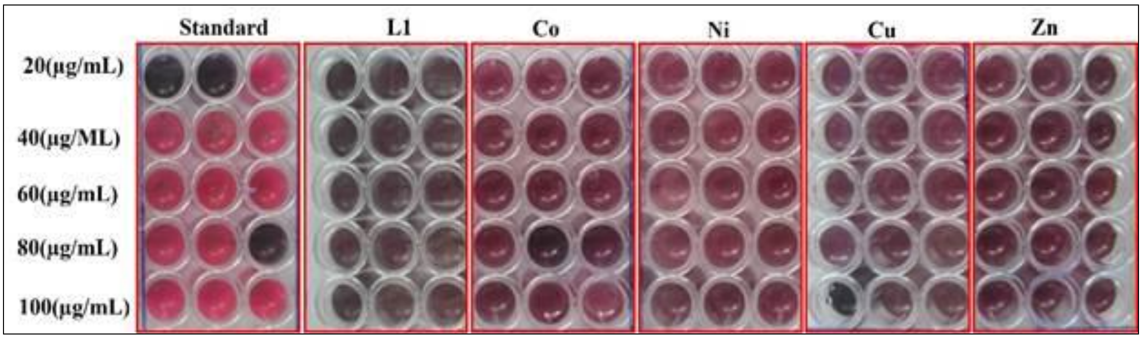

Fig 7: Microplate images showing the anti-tubercular activity of the Schiff base ligand (L1) and its metal complexes against Mycobacterium tuberculosis in comparison with rifampicin.

Table 5: Anti-tubercular activity of the Schiff base ligand (L1) and its metal complexes against Mycobacterium tuberculosis at different concentrations.

Sr No	sample	100µg/mL	80µg/mL	60µg/mL	40µg/mL	20µg/mL
1	L1	44.79%	42.35%	35.87%	12.53%	5.55%
2	Co(II)	56.39%	30.23%	16.27%	12.20%	-
3	Ni(II)	61.88%	47.97%	12.85%	11.35%	-
4	Cu(II)	28.13%	23.51%	13.66%	-	-
5	Zn(II)	43.02%	29.65%	16.27%	12.20%	-
6	Rifampicin	81.47%	80.22%	73.61%	49.53%	16.21%

Conclusion

In this work a halogen-substituted Schiff base ligand was successfully prepared and further used to synthesized its Co(II), Ni(II), Cu(II) and Zn complexes. The formation of the ligand and its coordination with metal ions was supported by different characterization techniques including FT-IR, UV-Visible spectroscopy, HNMR, HRMS, TGA, and magnetic measurements. The spectral changes, especially in the IR and UV-Visible data clearly indicate the involvement of azomethine nitrogen and phenolic oxygen in coordination leading to the formation of stable metal complexes. The thermal analysis shows that the complexes remain stable up to a moderate temperature and decompose gradually in multiple step finally giving the corresponding metal oxides. From the biological studies it is evident that all the compounds exhibits some level of anti-tubercular activity with the Ni(II) complex showing comparatively better performance among the series. In contrast the anticancer results suggest that the free ligand and the Cu(II) complex are more effective against the K562 cell line while the other complexes show limited activity within the tested range. Overall the study highlights that both ligand design and the choice of metal ion play an important role in determining biological behavior. While coordination can improve activity in some cases the effect is not the same for all metals. The present results suggest that these types of Schiff base systems can be further explored for developing new biologically active compounds.

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