Trop J Nat Prod Res, June 2025; 9(6): 2721 - 2727 **ISSN 2616-0684 (Print)**
ISSN 2616-0692 (Electronic)

Tropical Journal of Natural Product Research

Available online at https://www.tjnpr.org

Original Research Article

Synthesis, Characterisation, and Cytotoxic Activity of New Schiff Base Prepared Using 3,3`-Diamino Benzidine and its Complexes with Cu (II), Co (II), and Ni (II) Against Oesophageal Cancer Cell Line (SK-GT-4)

Zahraa T. M. Al-bahrany, Jasim M.S. Alshawi*

Department of Chemistry, College of Education of Pure Sciences, University of Basrah, Basrah, Iraq

ARTICLE INFO

Article history:
Received 15 March 2025
Revised 24 April 2025
Accepted 05 May 2025
Published online 01 July 2025

ABSTRACT

The chemistry of condensed Schiff base compounds, including their potential for drug development and other biological properties, has been the subject of numerous experiments. Amines are important to medicinal chemistry since they are available as natural compounds and are the building blocks of several currently marketed drugs. This study used the condensation reaction between 3,3'-diaminobenzidine and 2-hydroxy-1-naphthaldehyde to synthesise a new chemical compound (Schiff base). Transition metal complexes containing copper(II) (Cu(II)), cobalt(II) (Co(II)), and nickel(II) (Ni(II)) were then created by reacting the ligand with the respective metal chlorides in a molar ratio of 2:1. A range of spectroscopic and characterisation tests were conducted on the ligand and its metal complexes to confirm their structural geometry. Nuclear magnetic resonance (NMR) tests were performed on the novel ligand as a product using proton NMR (^{1}H-NMR), carbon NMR (^{13}C-NMR), mass spectrometer, ultraviolet-visible (UV-Vis) absorption, infrared (IR) and molecular weight determination, molar conductance, and magnetic measurement techniques. The cytotoxicity of the Schiff base ligand and its complexes against the SK-GT-4 cell line, a model for oesophageal cancer, was evaluated using the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay. The results showed that the Co(II) combination was highly active against the SK-GT-4 cells. Additionally, this substance was evaluated biologically and toxicologically on healthy cells. The complex was notable for its remarkable selectivity, allowing it to efficiently target and eradicate cancer cells while causing the least damage to healthy cells.

Keywords: Cancer cell, Cytotoxic Activity, Schiff base, 2-Hydroxy-1-naphthaldehyde, 3,3`-Diaminobenzidine.

Introduction

The creation of flexible ligand-based compounds is a popular topic in coordination chemistry due to their erratic framework connection and possible uses in magnetic, ion exchange, porous, luminescence, and optical devices. Furthermore, because complexes with a metal-organic framework can be activated against diseased cells, particularly cancer cells, without harming healthy cells, they may be valuable in biomedicine. The field of coordination chemistry is a subfield of inorganic chemistry. One strategy of coordination chemistry is the rational design of organic blocking ligands and the use of organic/inorganic bridging ligands to create species with a metal-organic framework.[1,2] The structurally significant role of Schiff bases in inorganic chemistry can be seen by their ability to form stable complexes with most transition metal ions in the periodic table, their various biological uses, ease of production, chelating qualities, and extraordinary stability.[3] Schiff bases are derivatives of aldehydes or ketones where an azomethine or imine group (>C=N-) takes the place of the carbonyl group (C=O). Schiff bases, which are generated by condensing carbonyl compounds with primary amines,[4] have displayed a range of pharmacological benefits, such as antioxidant qualities,[5] antibacterial effects,[6] anticancer potential,[7,8] and antifungal efficacy.[9] Their applications, including molecular docking studies, antibacterial research, and thermodynamic studies of the formation of complexes with metal ions, have been the focus of multiple inquiries.[10,11] This study used ethanol as a solvent to create a new ligand by reacting 3,3'-diaminobenzidine with 2-hydroxy-1-naphthaldehyde. Specific metal ions were then used to generate metal complexes. Tetra-coordination with binuclear metal centres was present in all the resultant complexes. It was discovered that the di-nuclear nickel (Ni_2L) complex was diamagnetic, but the di-nuclear cobalt (Co_2L) and di-nuclear copper (Cu_2L) complexes both displayed paramagnetic characteristics. According to the hybridisation studies, the Cu and Co complexes showed sp^3 conformation, while the nickel complex showed dsp^2 hybridisation. The 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyltetrazolium bromide (MTT) assay was used to test the cytotoxicity of the Schiff base ligand and its complexes against the SK-GT-4 cell line, a model for oesophageal cancer. The results showed that the cobalt(II) (Co(II)) complex was highly active against the SK-GT-4 cells. Additionally, at IC50 = 462.5, the compound was tested biologically and toxicologically on normal cells, and the complex showed remarkable selectivity by efficiently identifying and killing the cancer cells while causing the least damage to the healthy cells.

Materials and Methods

Cell line sources and cell culture maintenance

An oesophageal cancer model, the SK-GT-4 cell line, was acquired from the IRAQ Biotechnology Cell Banking Centre in Basrah and cultured in an RPMI-1640 medium supplemented with 10% foetal bovine serum, 100 units/mL of the antibiotic penicillin, and 100 g/mL

---

*Corresponding author. Email: jasim.salih@uobasrah.edu.iq
Tel: +9647705638532

Citation: Al-bahrany ZTM, Alshawi JMS. Synthesis, Characterisation, and Cytotoxic Activity of New Schiff Base Prepared Using 3,3`-Diamino Benzidine and its Complexes With Cu (II), Co (II), and Ni (II) Against Oesophageal Cancer Cell Line (SK-GT-4). Trop. J. Nat. Prod. Res., 2025 9(6): 2721 - 2727 https://doi.org/10.26538/tjnpr/v9i6.49

Official Journal of Natural Product Research Group, Faculty of Pharmacy, University of Benin, Benin City, Nigeria

of minocycline. The cells were cultivated at 37°C in 5% carbon dioxide (CO_2), reseeded twice or three times a week at 70% viability, and passed with trypsin-ethylenediaminetetraacetic acid (trypsin-EDTA).[12]

Spectral analyses

All the compounds were used without additional purification after being purchased from Ark Pharm, Inc., TGI Group, BDH Pharma, LLC; Scharlab S.L., and Honeywell International Inc. Trypsin-EDTA was obtained from Capricorn Therapeutics, Inc., dimethylformamide (DMF) from Santa Cruz Biotechnology, the RPMI-1640 medium from Gibco™, MTT stain from Sigma Pharmaceuticals, LLC, foetal bovine serum from Gibco™, and a CO_2 incubator from Cypress Diagnostics. For the other materials used for the toxicity investigations, micropipettes were purchased from Cypress Diagnostics, cell culture plates from Thermo Fisher Scientific, a laminar flow hood from K.K. Scientific Co., Ltd., and a microtiter reader from Thermo Fisher Scientific. All the instruments in this study were from the Department of Chemistry, University of Basrah. The melting points of the produced compounds were measured in capillary tubes using a Griffin apparatus. The reaction was examined using thin-layer chromatography plates made of silica gel. A Bruker® ARX-400 spectrometer, proton nuclear magnetic resonance (^{1}H-NMR) at 400 MHz, and carbon NMR (^{13}C-NMR) at 100 MHz were employed. Tetramethyl silane served as the internal standard, and deuterated dimethyl sulfoxide served as the internal solvent (^{1}H-NMR: DMSO-d_6: δ 2.5 ppm and water at 3.35 ppm; ^{13}C-NMR: DMSO-d_6: δ 39.52 ppm). A Shimadzu® 1700 double-beam spectrophotometer was used to measure the wavelength in a Shimadzu® 8400 Fourier transform infrared (FTIR) spectrometer. Molar conductivity was measured using a Wissenschaftlich-Technische Werkstätten GmbH (WTW®) D-82362 machine. Magnetic susceptibility was measured using a Sherwood Scientific® auto magnetic susceptibility balance machine in the Chemistry Department of Al-Mustansiriya University in Baghdad. The electrospray ionisation mass spectra (ESI-MS) were recorded with methyl cyanide using the Waters Alliance® high-performance liquid chromatography (HPLC) system and the Quattro® micro API mass spectrometer in Tehran, Iran.

Synthesis of the Schiff base

Four to five drops of glacial acetic acid and 0.04 mol of 2-hydroxy-naphthaldehyde were dissolved in 15 mL of ethanol to complete the synthesis depicted in Figure 1. 3,3′-diaminobenzidine (0.01 mol) was dissolved in 10 mL of ethanol in multiple stages. The aldehyde solution was then progressively mixed with the amine solution during reflux. The refluxing process continued for 18 hours. The mixture was filtered once the refluxing was completed, and methanol was used to recrystallise the resultant product.[7]

Preparing the metal complexes

To establish the 1:2 chelate complexes between the ligand and the metal, a Schiff base solution (0.01 mol) was created at a molar ratio of 2 DMF: 4 Ethanol: 4 Methanol. This mixture was mixed with a hydrated metal chloride salt solution dissolved in 10 mL of ethanol. A total of 5 hours was spent refluxing the resultant mixture. Following the reaction's completion and the solvent's evaporation, the complexes were separated, repeatedly cleaned with dry diethyl ether, and vacuum-dried. A comprehensive summary of the physical characteristics and analytical information of these complexes is presented in Table 1.[13]

Biological processes

The cytotoxic effects of the complexes were assessed in 96-well plates in the MTT cell viability experiment. The seeding density was 1×10^4 cells per well.[14] The test chemicals (ligand and its complexes) were added at different concentrations (62.5-1000 µg/mL for each component) to the cells after 24 hours or when they reached a confluent monolayer. The viability of the cells was evaluated 72 hours after the treatment. In the experiment, the medium was removed, and 28 µL of a 2-mg/mL MTT solution was added, after which the cells were incubated for 2 hours at 37°C. Then, 100 µL of dimethyl sulphide (DMSO) was used to dissolve the resultant crystals following the disposal of the MTT after the incubation period.

Table 1: Characteristic of ligands and their complexes

Comp. No.	M.P	Yield %	M.F	Colour	M.Wt
L	288-290	79	$C_{46}H_{38}N_4O_4$	Red	**830.94**
Cu_2L	>300	78	$[Cu_2\ (C_{46}H_{38}N_4O_4\ )]$	Red-Brown	**952**
Co_2L	>300	75	$[Co_2\ (C_{46}H_{38}N_4O_4\ )]$	Bright black	**944**
Ni_2L	>300	71	$[NI_2\ (C_{46}H_{38}N_4O_4\ )]$	Black	**945**

The plates were shaken and incubated at 37°C for >15 minutes to achieve full solubilisation.[15] A microplate reader was used to detect absorbance at the test wavelength of 620 nm. Every experiment was carried out in triplicate. Using the following formulae, the percentage of cytotoxicity, or the inhibition rate of cell growth, was determined:

$$\text{Proliferation rate (PR)} = (B / A) \times 100,$$

Where: A and B represent the mean optical densities of the untreated and treated wells, respectively.

The inhibition rate (IR) formula was $IR = 100 - PR$.[16]

Biological activity

After 72 hours of incubation, the Schiff base ligand and its complexes were tested for cytotoxicity against the SK-GT-4 cell line, a model for oesophageal cancer, using the MTT assay. The findings demonstrated notable activity of the Co(II) complex against the SK-GT-4 cells. Moreover, this compound was subjected to biological and toxicological assessments with normal cells. Notably, the complex displayed exceptional selectivity by effectively targeting and eliminating cancer cells while minimising harm to healthy cells.[17]

Characteristics of the synthesised compounds

Schiff base ligand

It was red and yielded 79% at M.P of 288-290°C. The mass-to-charge ratio (m/z) was 831.40 [M+1], 389.05 (base peak), ^{1}H-NMR (DMSO-d_6, 400MHz, □ppm), H4 (4H□=10.8ppm) (CH=N), H5(4H □=15.3ppm) (OH), H6(4H □=8.5ppm), H7(4H □=8.12ppm), H9 (4H □=7.6ppm), H1 (2H □=6.5ppm), ^{13}C-NMR (DMSO-d_6), C1(□=193ppm), C3-C8 (□=120-130ppm), C11(□=164ppm), and C10 (□=138ppm). The FTIR (νcm^{-1}) was 2980 C=H(Alipha), 3034 C=H(Ar), 1620 C=N, 1562 C=C(Ar), 3431 OH, and 1483 C-N. The UV-Vis (nm) transition was 322.5(($\pi \rightarrow \pi^*$) and 362.5(($\pi \rightarrow \pi^*$) (Figures 1, 5, 6, 7, and 11).[18]

Schiff base complexes

The di-nuclear cobalt (Co_2L) complex was bright black and yielded 75% at M.P >300°C. The m/z was 472.15 (base peak), 943 [M]. The FTIR (νcm^{-1}) was 2922 C=H(Alipha), 3041 C=H(Ar), 1642 C=N, 1524 C=C (Ar), 3440 O-H, 1430 C-N, and 819 M-N. The UV-Vis (nm) transition was 374 (n-π*), 446 (d-d), and 496 (d-d) (Figures 4, 10, and 13). The di-nuclear nickel (Ni_2L) complex was black and yielded 71% at M.P >300°C. The m/z was 340.9 (base peak), 943.8 [M]. The FTIR (νcm^{-1}) was 2920 C=H(Alipha), 3037 C=H(Ar), 1614 C=N, 1533 C=C(Ar), 3387 O-H, 1325 C-N, and 814 M-N.

The UV-Vis (nm) transition was 330 (n-π*), 392 (n-π*), 417 (MLCT), 490 (MLCT), 585 (d-d), 593 (d-d), and 621 (d-d) (Figures 3, 8, and 14). The di-nuclear copper (Cu_2L) complex was red-brown and yielded 78% at M.P >300°C. The m/z was 121 (base peak), 957.35 [M]. The FTIR (νcm^{-1}) was 2789 C=H(Alipha), 3039 C=H(Ar), 1602 C=N, 1535 C=C(Ar), 3444 OH, 1454 C-N, and 810 M-N. The UV-Vis (nm) transition was 275 (π→π*), 340 (n-π*), 437 MLCT, and 775 d-d (Figures 2, 9, and 12).

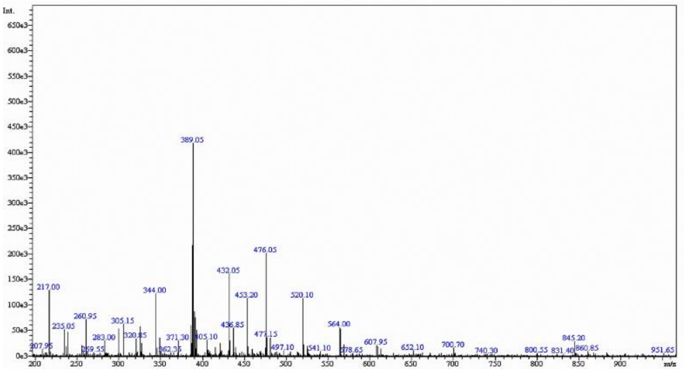
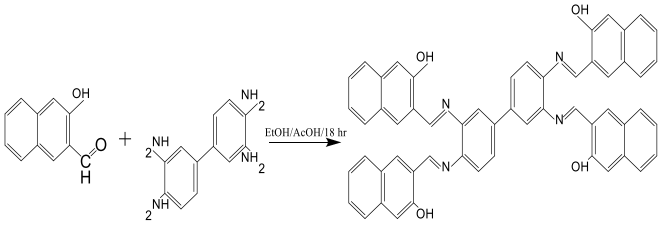


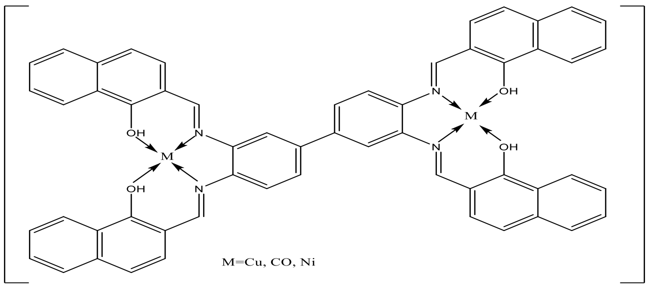
Figure 1. Mass spectra of ligand

Results and Discussions

The importance of Schiff base compounds in contemporary medicine is growing, especially in treating cancer. First, a good yield was obtained by evaluating the simplicity of the one-pot multicomponent reaction utilising 2-hydroxy-naphthaldehyde in the presence of glacial acetic acid in ethanol at reflux for 18 hours with 3,3′-diaminobenzidine (Scheme 1). The successful synthesis of the Schiff base ligand and its structures was confirmed using mass spectrometry and NMR spectroscopy. In the ^{1}H-NMR spectra, a singlet was found at 10.82 ppm, which was attributed to the azomethine proton (CH=N), while several singlets were detected between 8-7 ppm, suggesting the presence of aromatic protons.[19] Additionally, the ^{13}C-NMR spectra for the compound showed multiple lines between 120-140 ppm for the C=C aromatic rings of naphthaldehyde, a line at 40 ppm attributed to carbon atoms (C-N), and a line at 193 ppm belonging to carbon atoms in C=N.[20] The mass spectrum analysis of the Schiff base ligand identified many fragments with different relative abundances and m/z. Its chemical structure was represented by a noticeable peak at 831.40 m/z.



Scheme (1): The process of synthesising the Schiff base ligand



Scheme (2): The process of synthesising the metal complexes

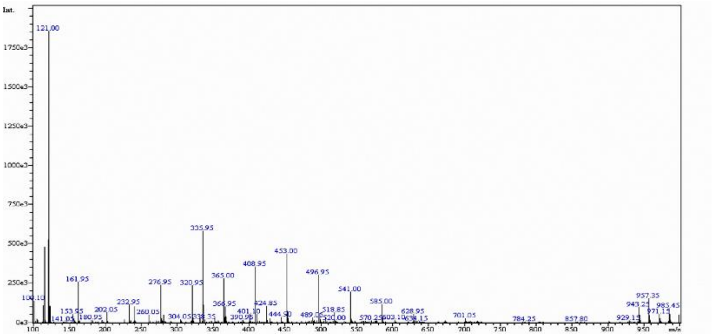


Figure 2. Mass spectra of Cu_2L

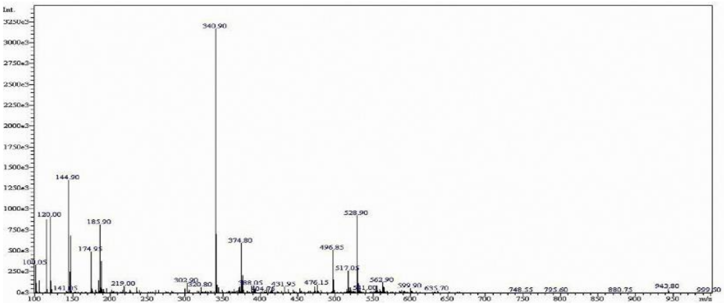


Figure 3. Mass spectra of Ni_2L

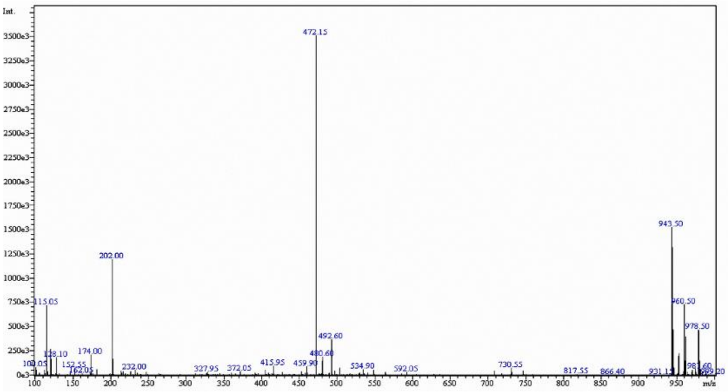


Figure 4. Mass spectra of Co_2L

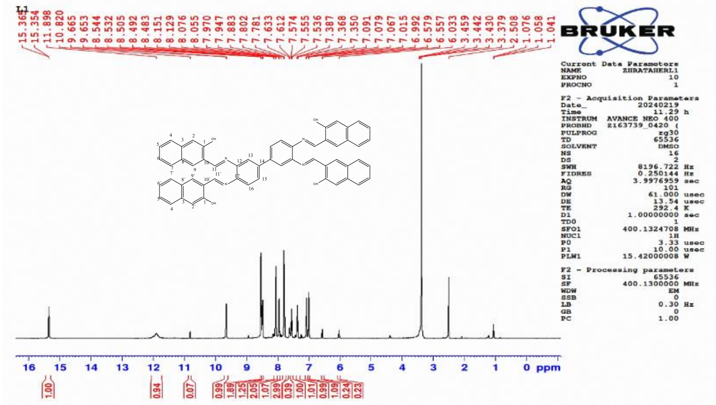


Figure 5. ^{1}H-NMR spectra of ligand

A ligand-to-metal ratio of 1:2 was used to create the synthetic complexes. The results obtained from several analytical techniques by refluxing the Schiff base ligand with metal chlorides for the Co(II), Ni(II), and Cu(II) ions in a mixture of solvents containing 2 DMF: 4

ethanol: 4 methanol showed that the generic formula [M_2L] could be used to characterise the metal complexes. Numerous fragments with varying relative abundances and m/z were found using an ESI-mass spectrum analysis. Prominent peaks were observed at 943, 943.8, and 957.35 m/z in the Co_2L, Ni_2L, and Cu_2L complexes, respectively.[18] A list of the conductivity ($\Lambda\mu$) of the synthetic complexes measured at room temperature after being dissolved in the DMF solvent at a concentration of 10^{-3} M is presented in Table 3. According to the molar conductance values, which varied between 14-22 $S{\cdot}cm^2{\cdot}mol^{-1}$, these substances did not exhibit electrolyte behaviour.[21] The magnetic properties of the synthesised complexes, summarised in Table 3 and derived from referenced data and measured using advice type,[22] revealed that both the Cu(II) and Co(II) complexes exhibited paramagnetic behaviour, while the Ni(II) complex was diamagnetic. The effective magnetic moment (μeff) of the complexes was calculated using the following formulae:

$$Xm = Xg \times M.wt \quad \ldots\ldots\ldots\ldots 1$$

$$XA = Xm + D \quad \ldots\ldots\ldots\ldots\ldots 2$$

$$\mu eff = 2.828\sqrt{(XA \times T)}\, B.M \quad \ldots\ldots\ldots 3$$

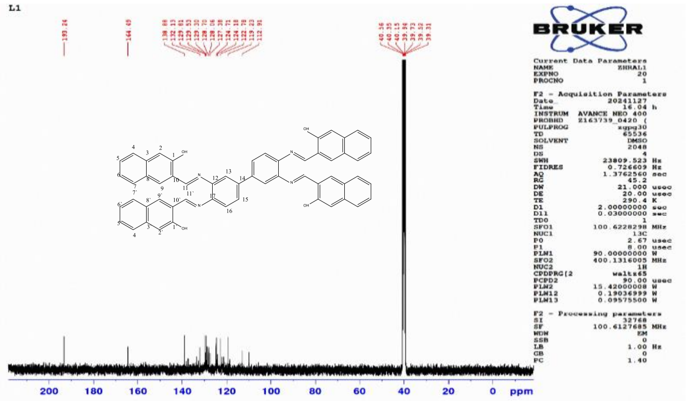


Figure 6. ^{13}C-NMR spectra of ligand

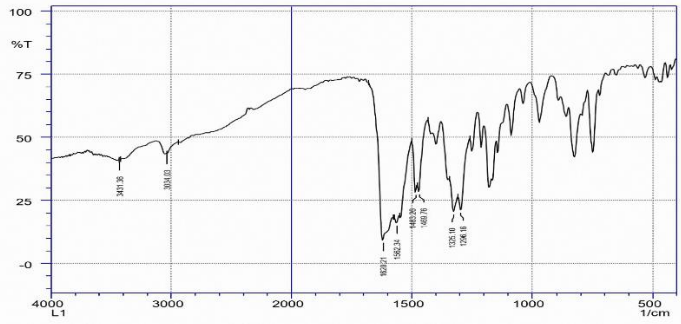


Figure 7. IR spectra of ligand

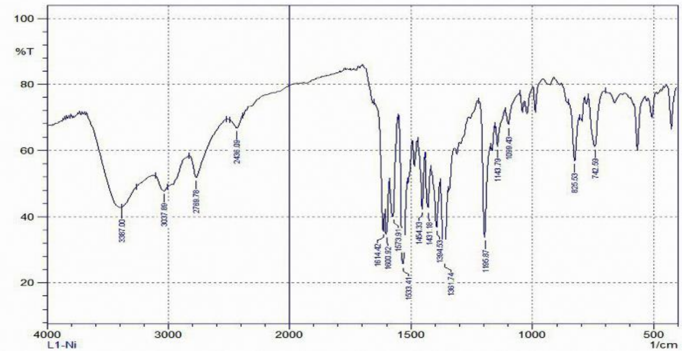


Figure 8. IR spectra of Ni_2L.

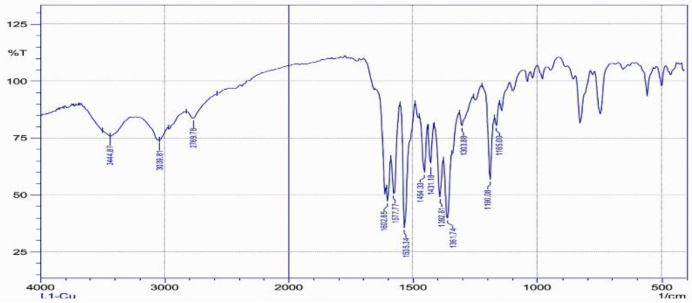


Figure 9. IR spectra of Co_2L

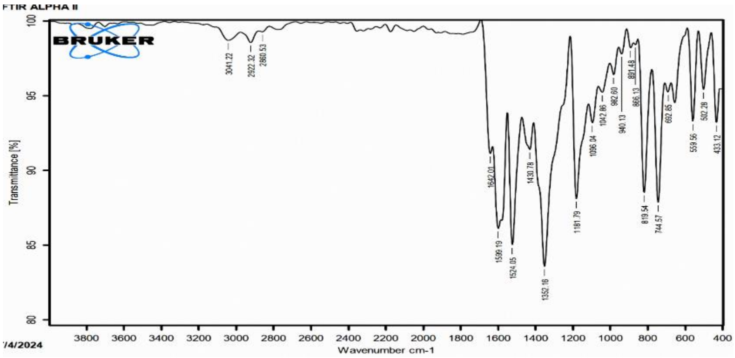
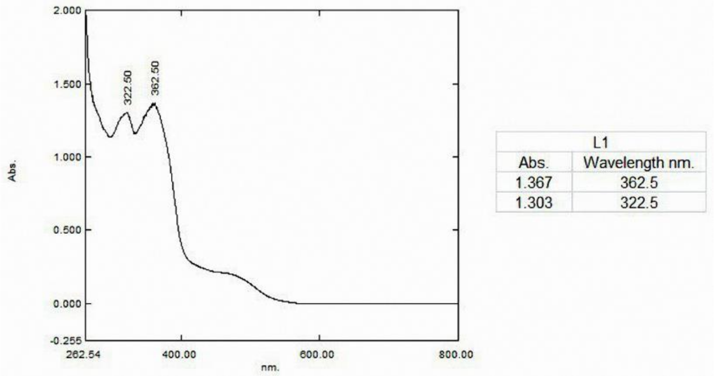


Figure 10. IR spectra of Cu_2L.



L1	
Abs.	Wavelength nm.
1.367	362.5
1.303	322.5

Figure 11. UV-visible spectrum of the ligand.

Details of the UV-Vis spectra for the free ligand and its metal complexes are also highlighted in Table 3. There were two peaks in the UV-Vis spectra of the free ligand,[23] as displayed in Figure 12: one at 322 nm, corresponding to $\pi\rightarrow\pi^*$ electronic transitions, and another at 362 nm, corresponding to $n\rightarrow\pi^*$ transitions. Charge transfer was responsible for the observed absorption peak at 437 nm for the Cu_2L complex (Figure 13), which supported a square planar geometry surrounding the Cu ion. The Co_2L complex, depicted in Figure 14, had a square planar geometry around the Co ion, as evidenced by the two absorption peaks at 496 and 446 nm caused by d-d electronic transitions. In Figure 15, the Ni_2L complex exhibited three extra peaks originating from d-d transitions and absorption peaks at 417 and 490 nm, which are attributed to the charge transfer. These studies supported the square pyramidal shape surrounding the Ni ion well. A thermal analysis technique was employed to study the interaction between the ligand and metals and assess the thermal behaviour and decomposition of the transition metal complexes. The complexes were subjected to a thermogravimetric analysis using a Rheometric Scientific® simultaneous thermal analysis (STA) 1500 in a controlled nitrogen atmosphere. The analysis began at room temperature and progressed to 600 °C, with a heating rate of 10 °C/m.[24] The Co_2L complex: The thermal analysis was conducted in three stages.

Table 2: The FT-IR spectral data (cm^{-1}) for the Schiff base ligand and its complexes

Sym.	C=H (Alipha)	C=H(Ar)	C=N)	C=C-(Ar)	O-H	C-N-	M-N-
L	2980	3034	1620	1562	3431	1483	---
Cu_2L	2789	3039	1602	1535	3444	1454	**810**
Co_2L	2922	3041	1642	1524	3440	1430	**819**
Ni_2L	2920	3037	1614	1533	3387	1325	**814**

Table 3: Conductivity, Magnetic moment, and electronic spectra for ligand and its complexes

Compound	Absorption bands(nm)	Transition	Conductivity S.cm^2.mol^{-1}	μeff
Ligand	322.5	($\pi\rightarrow\pi^*$)	------	-----
	362.5	($\pi\rightarrow\pi^*$)		
Cu_2L	275	($\pi\rightarrow\pi^*$)	15	**1.95**
	340	(n-π^*)		
	437	MLCT		
	775	d-d		
Co_2L	374	(n-π^*)	22	**2.55**
	446	d-d		
	496	d-d		
Ni_2L	330	(n-π^*)	14	-----
	392	(n-π^*)		
	417	MLCT		
	490	MLCT		
	585	d-d		
	593	d-d		
	621	d-d		

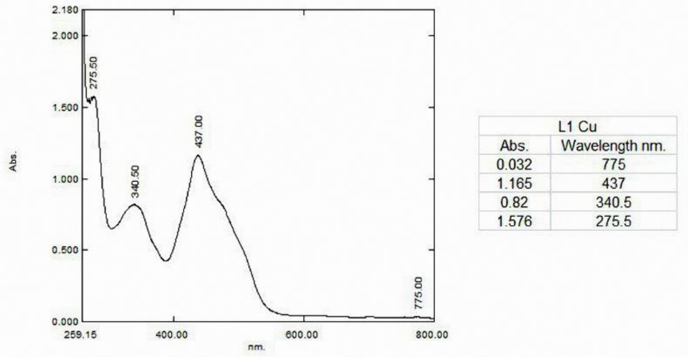


Figure 12. UV-visible spectrum of Cu_2L.

The mass did not change when the temperature was <170°C. In the first stage, when the temperature was between 171-231°C, 5.45% of the weight was lost. In the second stage, when the temperature was between 342-408°C, 4.6% of the weight was lost. In the last stage, when the temperature was between 415-572°C, 8.37% of the weight was lost (Figure 15). The Ni_2L complex: The complex disintegrated in stages. A change in mass was observed when the temperature was between 58-147°C, indicating that crystallisation had occurred.

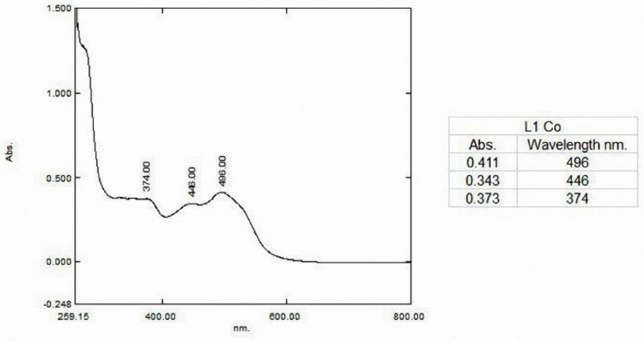


Figure 13. UV-visible spectrum of Co_2L

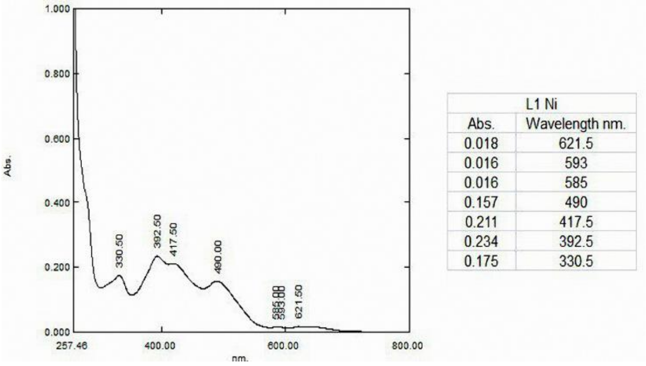


Figure 14. UV-visible spectrum of Ni_2L.

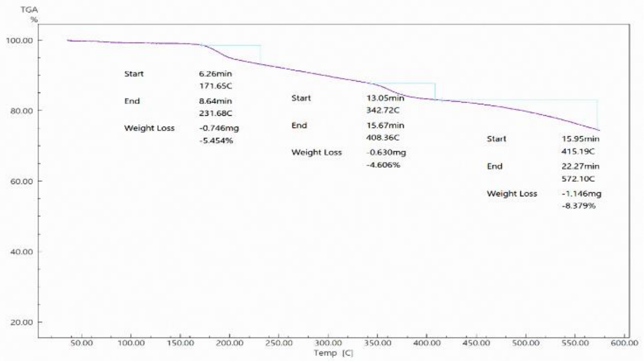


Figure 15. TG curve of Co_2L.

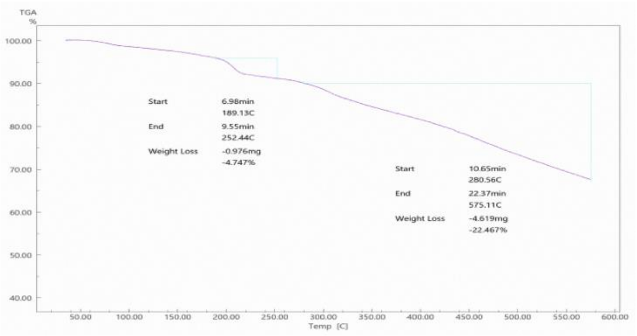


Figure 16. TG curve of Cu_2L.

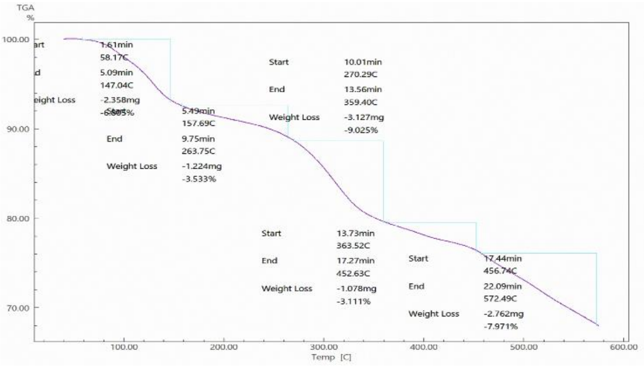


Figure 17. TG curve of Ni_2L.

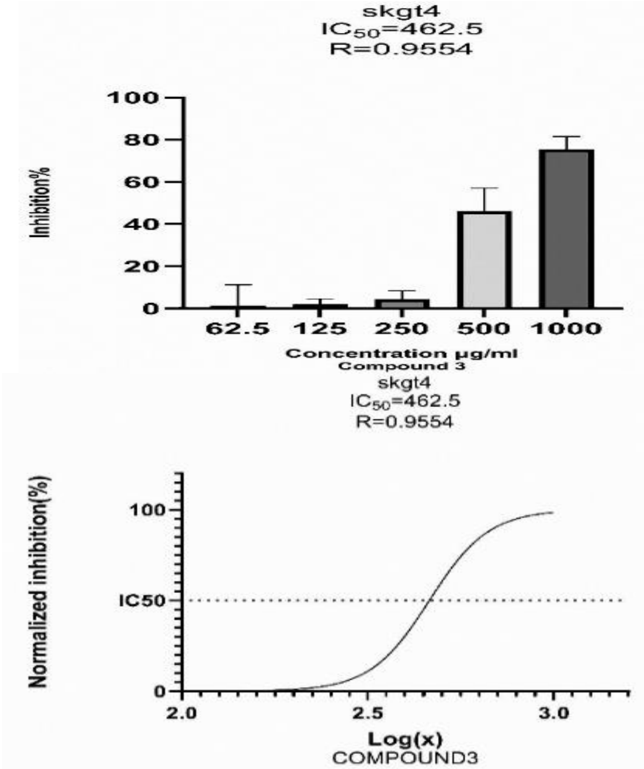


Figure 18. Rate inhibition of SK-GT-4 cell line treated with five replicates of concentrations(µg/ml) from Co (II) complex with IC_{50} in µg/ml.

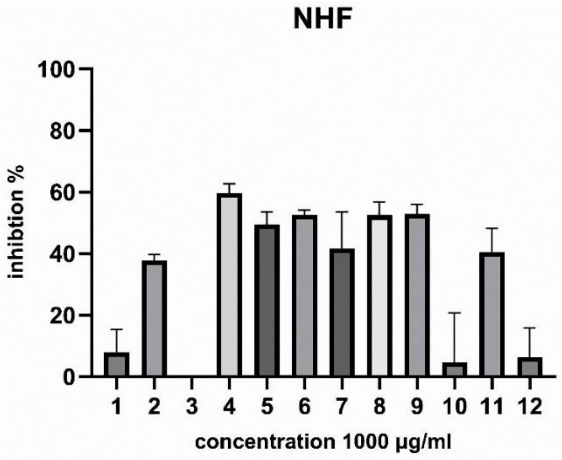


Figure 19. Rate inhibition of normal cell line (NHF) with concentration (1000 µg/ml) from L-Co (compound 3)

More specifically, it represented the loss of a molecule due to the crystallisation of water, with 6.8% of the weight lost. In the second stage, the temperature was between 157-263°C, resulting in a 3.5% reduction in weight, indicating the loss of two molecules of H_2O. In the third stage, when the temperature was between 270-359°C, 9.02% of the weight was lost. In the fourth stage, the temperature was between 363-452°C, and 3.1% of the weight was lost. In the last stage, the temperature was between 456-572°C, resulting in a 7.9% reduction in weight (Figure 17). The Cu_2L complex: The thermal analysis was conducted in two stages. The mass did not change when the temperature was <180°C, indicating the high thermal stability of the complex. In the first stage, the temperature was between 189-252°C, and 4.47% of the weight was lost. In the second stage, the temperature was between 280-575°C, resulting in a 22.4% reduction in weight (Figure 16).

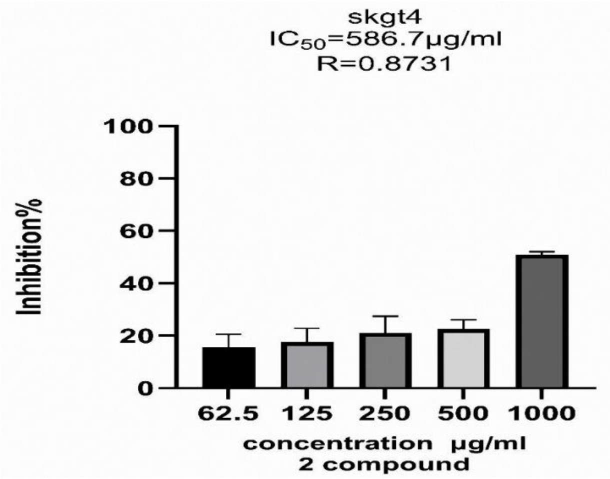


Figure 20. Rate inhibition of cancer cell line (SK-GT-4) with concentration (1000 µg/ml) from [Cu_2L] (compound 2).

Conclusion

Three novel metal complexes were produced using a tetra nucleation ligand, and these were subjected to various in-depth characterisation methods, such as analytical and physicochemical techniques. The supposed composition was verified by FTIR, ^{1}H-NMR, ^{13}C-NMR, mass, and electronic changes. Electric conductivity and magnetic susceptibility measurements provided additional evidence, indicating that the Cu(II) and Co(II) complexes had a square planar geometry while the Ni(II) complex had a square pyramidal geometry. Based on the cytotoxicity of the Schiff base ligand and its complexes (Figure 18-

20), the Co(II) complex was found to be highly active against SK-GT-4 cells and is thus a promising candidate for further development as an anticancer agent due to its potent anti-tumour activity, and promising pharmacokinetic properties, opening up avenues for the design of novel metal-based therapeutics.

Conflict of Interest

The authors declare no conflicts of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

Acknowledgements

The authors would also like to thank Dr Ali Abdul Lateef from the Faculty of Biology, College of Education for Pure Sciences, University of Basrah, Iraq, for his support in determining the toxicity of compounds.

References

1. Xu-Sheng L, Yu-Jie H, Jiao C, Quan-Quan L, Ping L, Jian-Li Li. Recent advances in rational design, synthesis, and application of metal-organic frameworks as visible-light-driven photocatalysts. Inorg. Chem. Front. 2024;11: 6794-6852.
2. Abdel-Aziz A Y, Maisa S., Sultan A M S, Naif A G. Synthesis, Characterization and Biological Activities of New Schiff Base Compound and Its Lanthanide Complexes. Pharmaceuticals. 2022; 15: 454.
3. Mohammed A A, Mohamed S, Ali H S. Synthesis, characterization and antibacterial activity of ruthenium complex bearing 3,3’-dicarboxy-2,2’-bipyridine ligand. Pharmacia. 2023; 70(2): 405–410.
4. Johana Z M, Rebeca G P, Saskya E C P, Cristina R P, Carlos B O, Antonio M, Linda P G, Christian D A L, Jorge H M, Experimental and computational studies of Schiff bases derived from 4 aminoantipyrine as potential antibacterial and anticancer agents. Discover Applied Sciences. 2025; 7:115.
5. Kadhem B J, Alshawi J, Alsalim T A, Abdalla M. Novel Schiff bases ligands and their complexes: Thermal analysis, antibacterial activity, and molecular docking. Egypt. J. Chem. 2022; 65: 107–119.
6. Dana A, Sarhang H. Synthesis, characterization, and antimicrobial evaluation of Schiff base derived from sulfonamides and vanillin. Zanco J Med Sci. 2024; 28:(1).
7. Al-Husseini Z N O. Alshawi J. Synthesis, characterization and cytotoxic activity study of Mn (II), Co (II), and metal complexes with new Schiff base against the hepatocellular carcinoma (SK-GT-4) cancer cell. Onkol. I Radioter. 2023;17 (11) 2023: 001-011.
8. Tüzün B. Investigation of pyrazoly derivatives Schiff base ligands and their metal complexes used as anticancer drug. Spectrochim. Acta Part A Mol. Biomol. Spectrosc.2020; 227: 117663.
9. Seitzhan T, Sabina K, Ardak J, Alexandr I, Dana A, Amir A, Asse K. Synthesis, physicochemical properties and antimicrobial activity of a diaminopropionic acid hydrogen tri-iodide coordination compound. BMC Research Notes. 2024; 17:384.
10. Adam M S S, Abdel-Rahman L H, Abu-Dief A M. Hashem N A. Synthesis, catalysis, antimicrobial activity, and DNA interactions of new Cu (II)-Schiff base complexes. Inorg. Nano-Metal Chem. 2020; 50: 136–150.
11. Mahmoud W H, Deghadi R G. Mohamed G G. Metal complexes of ferrocenyl-substituted Schiff base: Preparation, characterization, molecular structure, molecular docking studies, and biological investigation. J. Organomet. Chem. 2020; 917, 121113.
12. Al-Ali A A A, Alsalami K A S. Athbi A M. Cytotoxic effects of CeO2 NPs and β-Carotene and their ability to induce apoptosis in human breast normal and cancer cell lines. Iraqi J. Sci. 2022; 923–937.
13. Yassin S K, ALshawi J M S. Mohammedsalih Z A. Novel N2O2 Schiff Base Derived from 1, 2-Hydrazinedicarboximidamide and its Complexes with Cu (II), Co (II), Ni (II), Mn (II) and Cr (III): Synthesis and Characterization. Orient. J. Chem. 2020; 36: 940.
14. Falih S M J, Al-Saray S T, Alfaris A A. Al-Ali A A A. The synergistic effect of eucalyptus oil and retinoic acid on human esophagus cancer cell line SK-GT-4. Egypt. J. Med. Hum. Genet. 2022; 23: 70.
15. Fatema FYA, Ali AAA. Evaluation of The Anticancer Efficiency of Lavender Oil and Newcastle Disease Virus (NDV) Through Induction of Apoptosis. J Popul Ther Clin Pharmacol. 2023; 30(5): e391–e406; 04.
16. Amanda CD, Freshney R I. Freshney's Culture of Animal Cells: A Manual of Basic Technique and Specialized Applications. (8th ed). Wiley-Blackwell; 2021.
17. Fatimah AA. Biological Applications of Thiourea Derivatives: Detailed Review. Chemistry. 2024; 6: 435–468.
18. Niklas G. Modern Electrospry Ionization Mass Spectrometry Techniques for the Characterization of Supramolecules and Coordination Compounds. Anal. Chem. 2024; 96: 7332−7341.
19. Nabaz A M S. Synthesis, Characterization, and Bioactivity Studies of the Schiff Base Ligand and its Zinc(II) Complex. Aro-The Scientific Journal of Koya University, 2024; 12(1):108-114.
20. Mustafa B, Aysegül K. Schiff bases containing 1,2,3-triazole group and phenanthroline: Synthesis, characterization, and investigation of DNA binding properties. J. Photochem. Photobiol. A: Chem. 2024; 448: 115320.
21. Hadi MA, Kareem IK. Synthesis, Characterization, and Spectral Studies of a new Azo-Schiff base Ligand Derived from 3, 4-diamino benzophenone and its Complexes with Selected Metal Ions. Res. J. Adv. Sci. 2020; 1: 54–73.
22. Despina D, Angeliki P, Michael P, Yiannis S, Vassilis P, Catherine P R. Synthesis, Crystal Structures and Magnetic Properties of Trinuclear {Ni2Ln} (LnIII = Dy, Ho) and {Ni2Y} Complexes with Schiff Base Ligands. Crystals. 2022; 12: 95.
23. Abass S K, A-Hilfi J A, Abbas S K. Ahmed L M. Preparation, characterization and study biological activity of some new metal chelate complexes derived from ligand azo–Schiff for hetrocyclicthiazole. Indones. J. Chem. 2020; 20: 404–412.
24. Chebout O, Trifa C, Bouacida S, Boudraa M, Merzougui M, Mazouz W, Ouari K, oudaren C, Merazig C, Two new copper (II) complexes with sulfanilamide as ligand: Synthesis, structural, thermal analysis, electrochemical studies, and antibacterial activity. J. Mol. Struct. 2022; 1248: 131446.