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Synthesis, Analysis and Biological assessment of a Novel Coumarin Azo-Dye Ligand and Its 3d Metal Complexes for Photocatalytic investigation of MB dye

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Abstract

A novel azo dye ligand, 7-hydroxy-4-methyl-8-[(*E*)-(6-nitro-1,3-benzothiazol-2-yl)diazenyl]-2*H*-chromen-2-one ligand (MNB) was synthesized, and has been used to synthesise Co(II), Ni(II), Cu(II) complexes. The synthesized compounds were characterized using various physicochemical and spectroscopic techniques. The biological investigation of the synthesized Schiff base ligand and its metal complexes have been determined against the bacteria (*Staphylococcus aureus* and *Escherichia coli*), fungal (*A. flavus* and *P. anomala*) and antioxidant activity using Iron chelating assay by using standard assay method. Analysis of the absorbance data revealed degradation percentages of 83%, 64% and 61% for Co(II), Ni(II) and Cu(II) complexes, respectively. These results indicate that Co(II) complex exhibit superior photodegradation efficiency compared to the Ni(II) and Cu(II) complexes for methylene blue dye.

Keywords: Azo-dye, Metal complexes, Photocatalytic activity, Antimicrobial, Molecular docking.

1. Introduction

Azo-dye molecules having (-N=N-) group that can serve as ligand in coordination chemistry and their metal complexes have gained significant attention in coordination chemistry [1-4]. The study of coordination chemistry of azo dye metal complexes involves interesting bonding interactions, spectroscopic properties and their reactivity which contributes for the development of new materials and technologies [3-4]. The presence of hetero atom moieties in azo dyes has led to the discovery of numerous azo compounds and their metal complexes with remarkable medicinal properties. These compounds have found applications in various industries, including textiles, toys, leather, plastics and cosmetics [5-8]. Their low toxicity and lack of adverse effects on hyperactivity or allergic reactions make them suitable for use in paints, polymers, food, pharmaceuticals and other everyday items. Furthermore, 4-hydroxycoumarine compounds exhibit a wide range of therapeutic properties including anticoagulant [9], antibacterial [10], antifungal [11], antiviral [12], anticancer and anti-inflammatory activities [13-14]. Recent advancements have also seen the development of azo dye derivatives as HIV protease inhibitors and tyrosine kinase inhibitors. Furthermore, metal complexes of azo dyes play a significant role in the medical field as pharmaceuticals due to their potential applications in imaging, drug delivery and diagnostics. These complexes exhibit unique characteristics that make them suitable for various biomedical purposes. Consequently, the development of novel synthetic compounds with biological potency has become imperative in the global medical arena [15-16].

In the past few years, our laboratory has made significant progress in the synthesis of azo dye derivatives, their metal complexes, the electrochemical, photocatalytic detection of bio-vital molecules and the biological investigation of synthesized molecules. In highlight of these works, we are pleased to report the synthesis of a novel azo dye ligand, 7-hydroxy-4-methyl-8-[(*E*)-(6-nitro-1,3-benzothiazol-2-yl)diazonyl]-2*H*-chromen-2-one ligand (MNB) and its 3d metal complexes. Furthermore, we have successfully demonstrated the photocatalytic degradation of MB dyes using the synthesized metal complexes. Recent studies have described the synthesis and biological investigations of novel metal complexes derived from coumarin derivatives. Transition metals such as Co, Cu and Ni found in biological system.

2. Experimental Section

2.1 Materials and methods

In this synthesis, all chemicals and solvents used were of analytical grade and obtained from Sigma Aldrich and Hi-Media. The melting points of the ligand and its metal complexes were determined using DTC-967 digital melting point analyser. The carbon, hydrogen and nitrogen elemental analysis were found by using Perkin-Elmer 2400 series II CNS analyser. IR spectra were determined by FTIR spectroscopy, IR Spirit Shimadzu serial no; A224159 (Made in Japan) at Sahyadri Science College, Shivamogga, Karnataka, India. KBr pellets made by using hydrolic press and spectra were recorded in the range $350\text{-}4500\text{ cm}^{-1}$. Electronic spectra were recorded in DMSO solvent using a systronics UV-Vis spectrometer 119 at Sahyadri Science College, Shivamogga. Using TMS as the internal standard, the ^1H NMR spectrum was measured using Jeolanalyzer operating at 400 MHz in DMSO- d_6 at Mangalore University, Mangalore. The XRD composition were analysed by using Bruker D8 advance and SEM was measured using Carl Zeiss model-EVO LS 15. The synthesized compounds LC-MS composition were identified MS model Acquity UPLC made in USA at Mysuru.

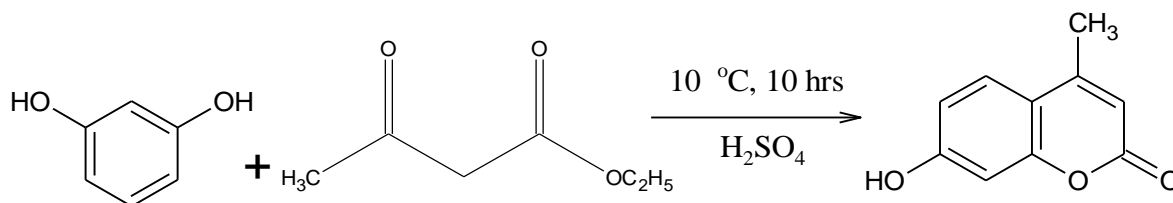
2.2 Synthesis of azo dye ligand (MNB)

A two-step synthesis was employed to produce an azo dye ligand, commencing with the synthesis of 7-hydroxy-4-methyl coumarin. This was through the addition of equimolar amounts of resorcinol (5g) and ethylacetoacetate (5 mL) in the presence of concentrated sulfuric acid (50 mL). The reaction mixture was cooled to $0\text{-}5\text{ }^\circ\text{C}$ using an ice salt bath and allowed to undergo reaction for 10 hrs at room temperature. Subsequently, the reaction mixture was carefully poured into ice-cold water. After the resulting solution was basified with sodium hydroxide, The progress of the reaction was monitored by TLC (Ethyl acetate: Petroleum ether, 1:3). This precipitate was then collected through filtration and washed with distilled water. Confirmation of the obtained compound was determined through melting point, which was found to be 188°C . The synthesis of 7-hydroxy-4-methyl coumarin was effectively carried out.

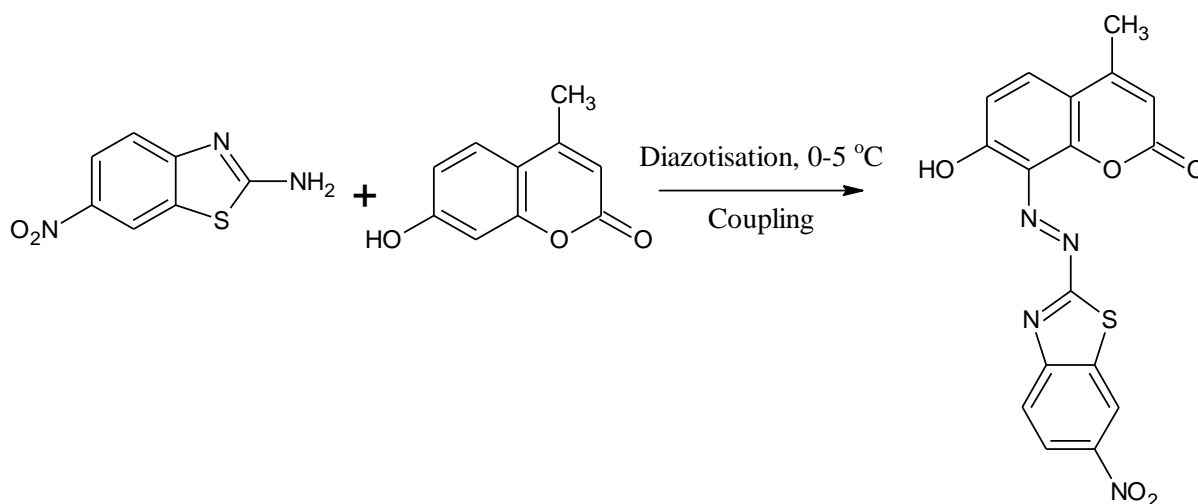
In the second step, a mixture was prepared by combining 20 mL of distilled water, 4 mL of concentrated hydrochloric acid, and 2 mmol of 2-amino-6-nitrobenzothiazole to form a diazonium solution. Subsequently, a cold aqueous solution of sodium nitrite (2 Mmol) dissolved in 3 mL of concentrated sulfuric acid was added dropwise with stirring to the previously mentioned solution, which had been cooled to a temperature range $0\text{-}5^\circ\text{C}$ using an ice bath, following this addition, a cold solution of 7-hydroxy-4-methyl coumarin (2 Mmol) in alkaline media was added, the resulting mixture was stirred approximately two hours at the same

temperature, keeping the pH in the range of 7-8. The progress of the reaction was monitored by TLC (Ethyl acetate : Petroleum ether, 1:3). Then poured into ice cold water, the precipitate was filtered and washed with distilled water and recrystallised with ethanol. Yield 69 %, to get 7-hydroxy-4-methyl-8-[(*E*)-(6-nitro-1,3-benzothiazol-2-yl)diazenyl]-2*H*-chromen-2-one. The reaction pathway of the above procedure is represented in Scheme 1.

Step 1:



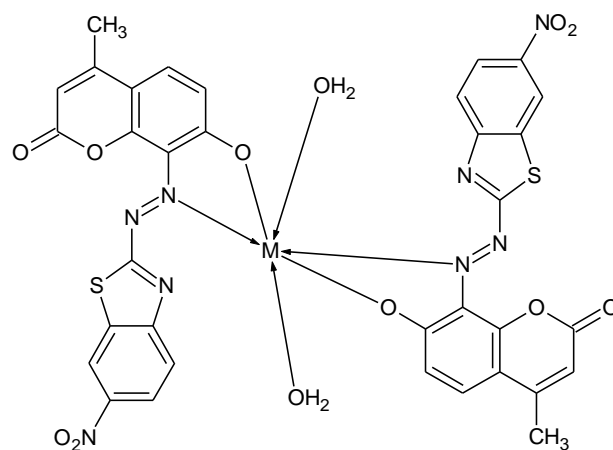
Step 2:



Scheme 1. Synthesis of azo dye 7-hydroxy-4-methyl-8-[(*E*)-(6-nitro-1,3-benzothiazol-2-yl)diazenyl]-2*H*-chromen-2-one ligand (MNB)

2.3 Synthesis of metal [Co(II), Ni(II) and Cu(II)] complexes

To prepare the complexes, a hot ethanolic solution containing 0.002 mol of ligand (MNB) was mixed with hot ethanolic solution of 0.001 mol hydrated metal chlorides (Co, Ni and Cu). The addition of the metal chlorides solution was done slowly dropwise with continuous stirring. The resulting mixture was stirred and refluxed on a water bath for 5-6 hrs at 60-70 °C. After refluxing, the reaction mixture was cooled to room temperature. The coloured precipitate formed was then collected, washed with ethanol to remove impurities. Finally the obtained complexes were dried and stored in a desiccator. Scheme-2 represents the synthetic path of metal complexes and their proposed structure. Yield 65-73%.



Scheme 2. Schematic representation of metal complexes

2.4 Photodegradation study

Photodegradation experiments were performed on metal complexes as photocatalysts for Methylene blue (MB) dye under UV light, utilizing natural sunlight irradiation. Initially, a solution of MB was prepared by dissolving it in 100 mL of deionized water. Subsequently, 50 mg of the metal complexes, serving as the photocatalyst, were added to the solution. The mixture was then allowed to equilibrate in darkness for a duration of 15 minutes to establish a baseline condition. Following the equilibration period, the solution was exposed to natural sunlight. At regular intervals of 15 minutes, aliquot samples were withdrawn from the solution for analysis. The degradation percentage of the dye solution was measured using a UV-Visible spectrometer. This experimental setup enables the assessment of the efficacy of the metal complexes as photocatalysts in degrading the MB dye under natural sunlight exposure. By periodically sampling the solution and analysing the degradation percentage, the kinetics of the photodegradation process can be elucidated. Additionally, the use of natural sunlight as the light source ensures a practical and environmentally friendly approach to assess the photocatalytic activity of the metal complexes [17-18].

2.5 Pharmacology

2.5.1 Antibacterial and antifungal screening

The synthesized compounds were subjected to antibacterial activity testing using a modified version of the agar well diffusion method described by standard procedure [19]. The test panel included two gram-positive bacterial strains (staphylococcus aureus and Escherichia coli) two gram-negative bacterial strains (Acetobacter sp. And Pseudomonas aeeuginosa),

and two fungal species (*A.flavous* and *P.anomala*). A standard drug was also included for comparison.

Inoculums were prepared in sterile saline solution and adjusted to approximately 5×10^8 CFU/mL. All synthesized substances were dissolved in dimethyl sulfoxide (DMSO) to create a stock solution of 10 mg/mL. Varying concentrations ranging from 100 to 500 μg were loaded into five separate wells. The employed media were Czapeks-Doxagar for fungi and nutrient agar for bacteria. As a positive control, conventional antibiotics Rifampicin (5 $\mu\text{g}/\text{Disc}$), Bacitracin (10 $\mu\text{g}/\text{Disc}$), and Fluconazole were utilized for microorganisms, while DMSO as a negative control revealed no inhibition zone (mm) was measured after 24 hours of incubation at 28 °C for fungi and 37 °C for bacteria. The relative percentage inhibition was computed against the standard medication using the formula [20].

2.5.2 Antioxidant activities (DPPH method)

The stable DPPH radical was utilized to assess the radical-scavenging capabilities of compounds with slight modifications to the procedure [21]. A spectrometer (Shimadzu UV-1800, Kyoto, Japan) was used to measure absorbance at 517 nm against a blank (without compound and standard). The results were expressed in IC₅₀ values. In brief, 3 mL of appropriately diluted compounds in methanol and 0.5 mL of DPPH (500 μM) were combined. The reaction mixture was subsequently incubated in darkness for 45 minutes at room temperature. Butylated hydroxytoluene (BHT) was employed as a reference antioxidant.

2.5.3 Molecular docking studies

The molecular docking studies had been carried out using HEX 8.2 software in order to comprehend the binding interaction modes of the synthesized compounds in comparison to the compare cytotoxicity effect [22-23]. Using Chem Sketch and Chem3D Ultra the potential structures for the complexes docking experiments were created. The RCSB Protein Data Bank was searched for the protein Epidermal growth factor receptor (EGFR) tyrosine kinase in PDB format (PDB ID: 1M17). The docking calculation with correlation form, Fourier Transform, FFT steric experiment, FFT final search, and MM refinement had all used the default settings. A stronger binding interaction between the drug and the receptor, which results in the inhibition of receptor activity, is indicated by a higher negative E-total value.

3. Results and discussion

3.1 Chemistry

It has been observed that the ligand and its metal complexes exhibit stability under atmospheric conditions when dissolved in polar solvents such as ethanol, methanol, DMF, DMSO, and chloroform. Table 1 provides analytical and physical data for MNB and its metal complexes, indicating a consistent metal-to-ligand ratio of 1:2 across all complexes. Molar conductivity values for the complexes were determined at room temperature in a 0.001 M concentration of DMF solution. It was noted that the conductivity values for the metal complexes fell within the range of 23 to 27 $\text{cm}^2\text{mol}^{-1}$, suggesting non-electrolytic behaviour.

Table 1. Physical properties and analytical data of the MNB and their complexes

Compounds and color	Mol.wt	Yield (%)	CHN Analysis Found (Calculated %)				Molar conductance ($\text{ohm}^{-1}\text{cm}^2\text{mol}^{-1}$)	M.P. ($^{\circ}\text{C}$)
			M	C	H	N		
Ligand (MNB)	382.35	69	-	53.40 (52.66)	2.64 (2.44)	14.65 (13.67)		170
[Co(MNB) ₂ (OH ₂) ₂]	857.64	70	8.30 (8.10)	47.61 (46.89)	2.59 (2.45)	13.07 (12.88)	23	260
[Ni(MNB) ₂ (OH ₂) ₂]	862.26	67	8.28 (8.40)	47.63 (46.88)	2.59 (2.35)	13.07 (13.22)	25	265
[Cu(MNB) ₂ (OH ₂) ₂]	857.40	73	8.10 (8.35)	47.36 (47.58)	2.57 (2.25)	13.00 (12.75)	27	268

3.2 ¹H and ¹³C NMR spectral studies

The NMR spectra of the azo-dye ligand were obtained using DMSO-d₆ as the solvent at room temperature, and TMS was used as an internal standard. Within the spectra, the ligand MNB exhibited signals a singlet at 10.53 ppm attributed to the -OH protons (s, 1H, OH) of the coumarine ring, peaks ranging from 6.20 to 7.5 ppm representing the aromatic protons of the ligand (m, Ar-6H) and a singlet at 2.5 ppm corresponding to the -CH₃ group (s, 3H, CH₃) of the coumarine ring.

The ¹³C NMR spectrum of the MNB ligand exhibits carbon atoms distributed across a range of chemical shifts from 21.2 to 166.9 ppm. Notably, the C=O group of the ligand resonates as a singular peak at 166.9 ppm, which another distinct signal appears at 160.9 ppm, attributed to the aromatic C=N within the coumarine ring. Additionally, the carbon atom proximal to the diazo group (=C-N) displays resonance at 159.04 ppm. Furthermore, the (C-OH) moiety

of the benzene ring manifests a singular peak at 161.64 ppm. Within the 102.63 to 132.03 ppm region corresponds to resonance of aromatic carbons, while the signal at 21.2 ppm arises from the methyl carbon ($\text{CH}_3\text{-C}$) of the coumarin ring. Figure are given in Fig 2.

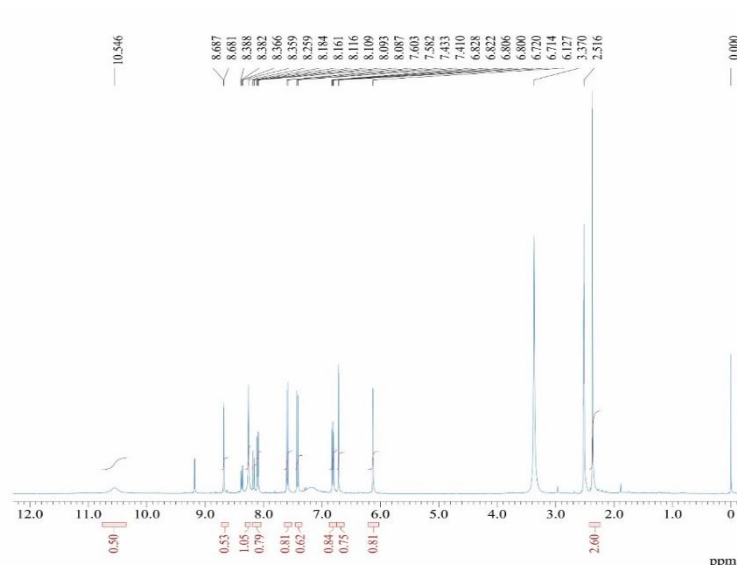


Figure 1. ^1H NMR spectrum of MNB

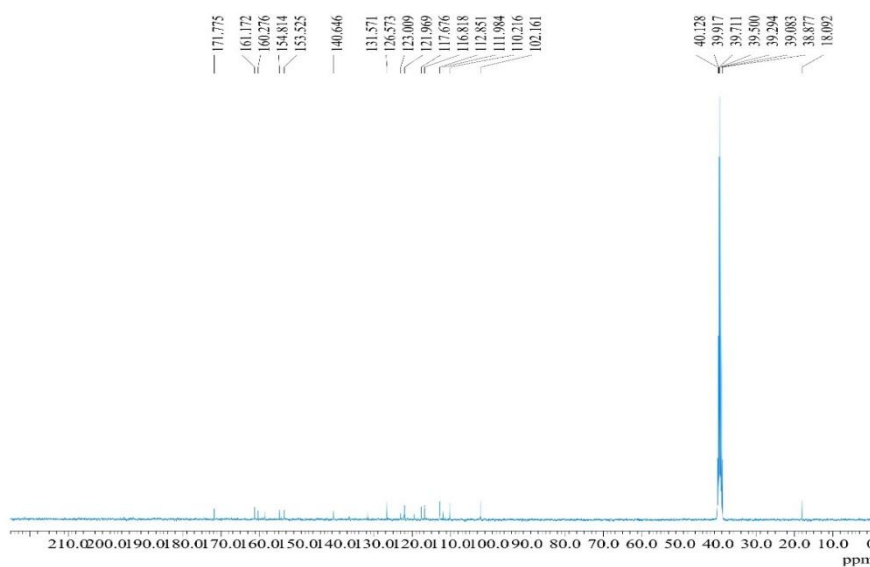


Figure 2. ^{13}C NMR spectrum of MNB

3.3 Mass spectral studies

The mass spectrum of the ligand (MNB) a distinct molecular ion peak at m/z 382.53 (cal 381.40), corresponding to $(M+ 1)$, suggesting the proposed molecular formula weight of the ligand is showed in Fig 2. The molecular ion peaks observed for the Co(II), Ni(II) and Cu(II) complexes are at m/z 857.64 (cal 856.33), 862.26 (cal 861.62) and 857.40 (cal 856.50) respectively, indicating a stoichiometric ratio of 1:2 (M:L). These observed molecular masses align with the proposed molecular structures of the prepared complexes, confirming their consistency. The mass spectra of the metal complexes are given in Figures 4,5 and 6.

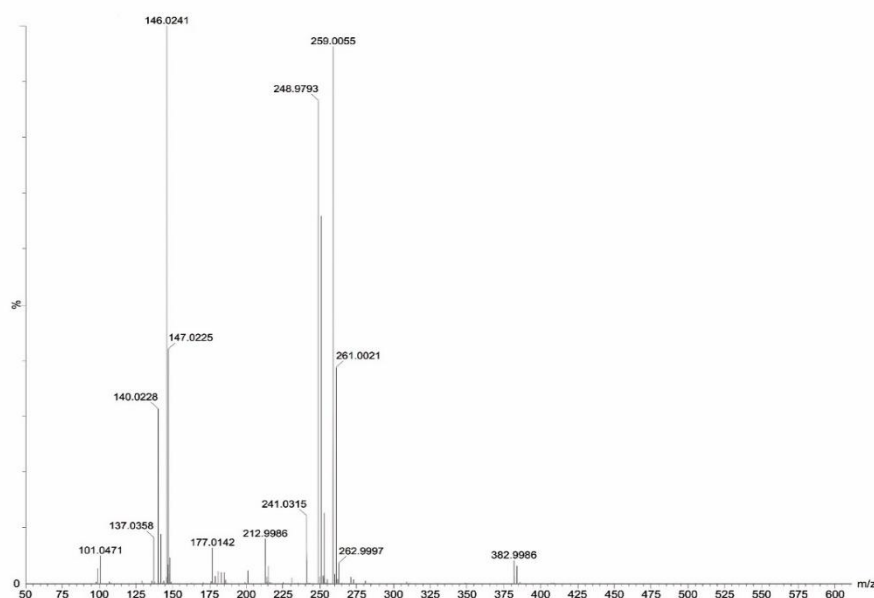


Figure 3. Mass spectrum of MNB

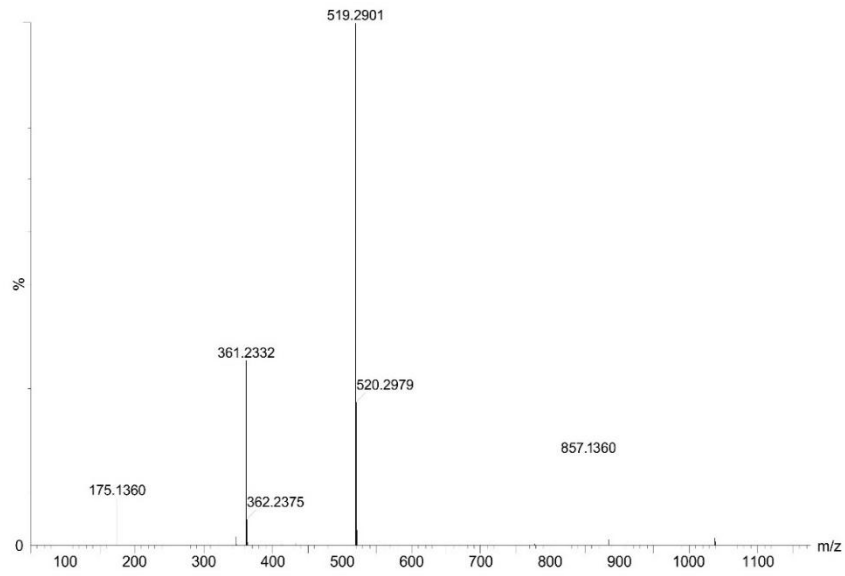


Figure 4. Mass spectrum of [Co(MNB)₂(OH₂)₂]

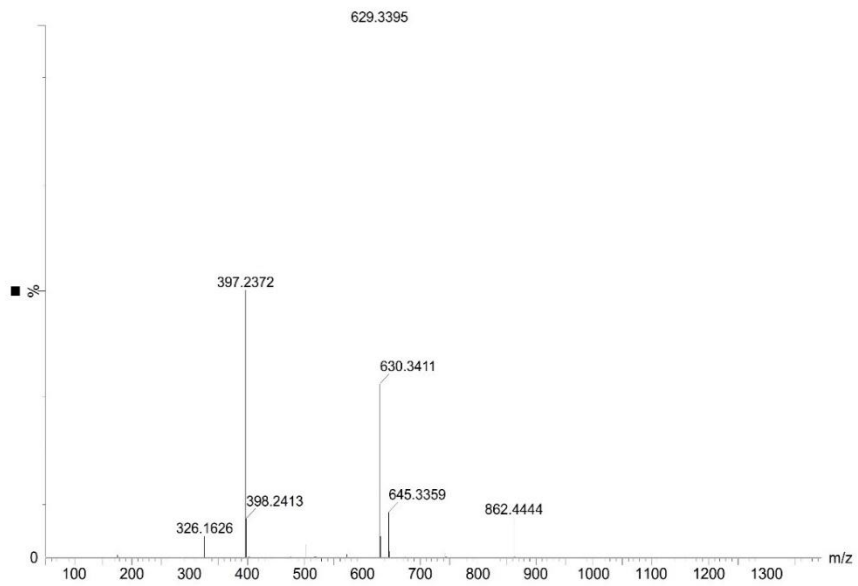


Figure 5. Mass spectrum of [Ni(MNB)₂(OH₂)₂]

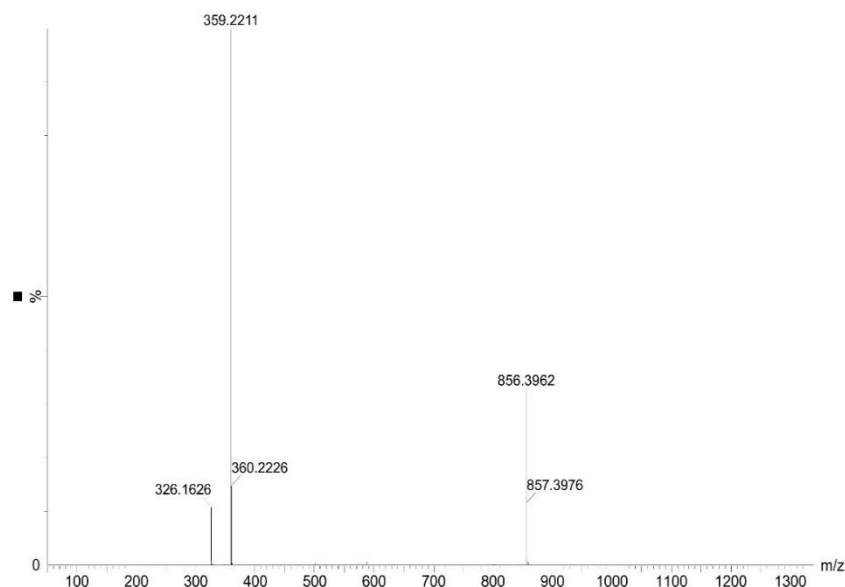


Figure 6. Mass spectrum of $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$

3.4 IR spectral studies

The IR spectra analysis of an azo-dye ligand and its metal complexes, conducted using KBr pellets in the range of 4000-350 cm^{-1} , reveals significant insights into their coordination behaviour. In the ligand spectrum, a distinctive absorption band at 3150 cm^{-1} is attributed to -OH stretching vibration, which notably shifts to higher frequencies in all complexes, indicating the involvement of the hydroxyl group in complexation [24]. Additionally, a sharp band at 1360 cm^{-1} corresponding to the N=N azo group is observed in the ligand spectrum, with a consistent shift to higher frequencies in complexes, suggesting azo group participation in complex formation. Notably, intense sharp peaks at 1130 cm^{-1} and 1690 cm^{-1} , attributed to C=N and C=O stretching vibrations, respectively, remain unaltered in the metal-coordinated compounds, suggesting that these functional groups are not involved in complexation. However, the emergence of new bands in IR spectra of metal-coordinated compounds, particularly in the 582-590 cm^{-1} region indicative of metal ion coordination with oxygen, and in the 432-450 cm^{-1} region suggesting metal ion coordination with nitrogen, provide compelling evidence for the complexation of the azo-dye ligand with metal ions. These spectral shifts and the appearance of new bands offer valuable insights into the specific functional groups involved in the coordination process.

Table 2. FT-IR spectral data (cm^{-1}) of MNB and its metal complex

Compounds	V(OH)	V(C=N)	V(N=N)	V(C=O)	V(M-O)	V(M-N)
MNB	3150	1135	1366	1690	-	-
$[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$	3400	1137	1380	1685	450	590

[Ni(MNB) ₂ (OH ₂) ₂]	3385	1138	1381	1690	432	585
[Cu(MNB) ₂ (OH ₂) ₂]	3380	1136	1381	1690	445	582

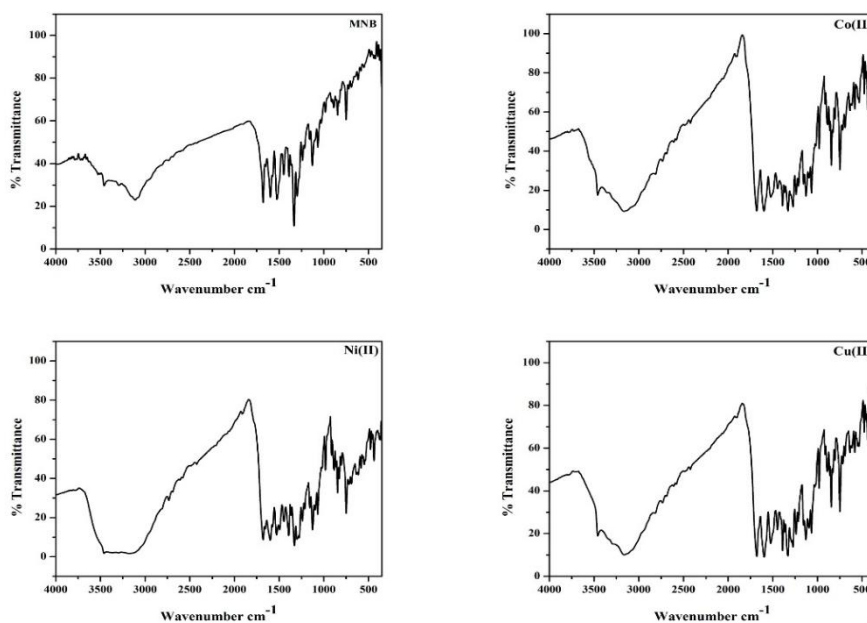


Figure 7. FT-IR spectra of MNB and their metal complexes

3.5 Electronic spectra and magnetic moment studies

The electronic spectra of the synthesized azo-dye ligand and its metal complexes are displayed in Fig.8. and the values are presented in Table 3. Electronic spectra were recorded for all compounds in DMSO solution within the wavelength range of 200-900 nm. The electronic spectrum of the Co(II) complex, exhibiting a light green colour, displayed a broad peak at 21,739, 16,393 and 14,925 cm⁻¹ attributed to ⁴T_{1g}(F)→⁴T_{2g}(F) (ν_1), ⁴T_{1g}(F)→⁴A_{2g}(F) (ν_2) and ⁴T_{1g}(F)→⁴T_{1g}(F) (ν_3) transitions respectively. The observed magnetic moment value of 3.6 B.M suggests an octahedral geometry for this complex. Subsequently, The Ni(II) complex, appearing brown in colour, exhibited two absorption bands at 18,181, 16,129 and 13,157 cm⁻¹. ³A_{2g}(F)→³T_{2g}(F) (ν_1) and the second transition ³A_{2g}(F)→³T_{1g}(F) (ν_2) and third ascribed to ³A_{2g}(F)→³T_{1g}(F) (ν_3). In addition the observed magnetic moment value 2.7 BM indicate octahedral geometry around the Nickel complex. A broad band with a maximum at 11,112cm⁻¹ due to ²E_g(F)→²T_{2g}(F) (ν_1) transition for intense pale green colored Cu(II) and having magnetic moment value of 1.78 B.M for distorted octahedral geometry [25].

Table 3. Electronic absorption spectral bands of metal complexes

Compounds	λ (nm)	Transitions cm ⁻¹	Magnetic Moment
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MNB	340	29,411	-
[Co(MNB) ₂ (OH ₂) ₂]	460	21,739	3.6
	610	16,393	
	670	14,925	
[Ni(MNB) ₂ (OH ₂) ₂]	550	18,181	2.7
	620	16,129	
	760	13,157	
[Cu(MNB) ₂ (OH ₂) ₂]	900	11,112	1.78

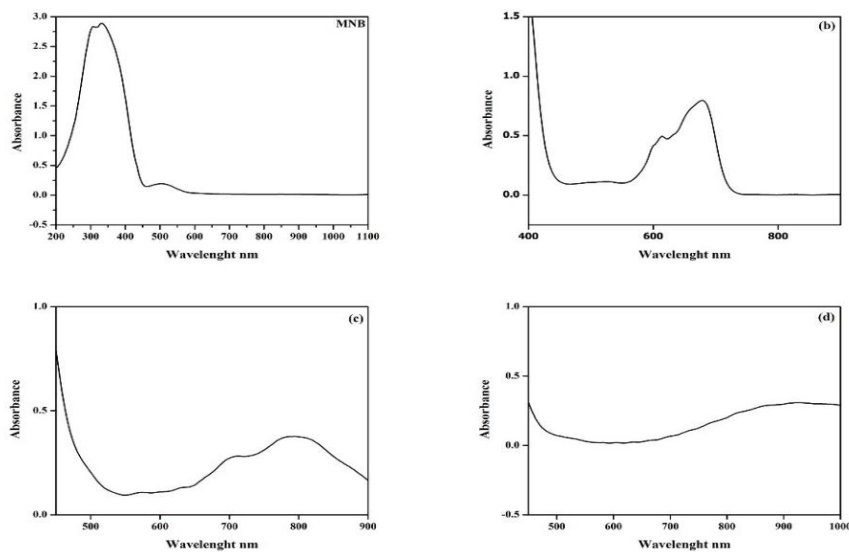


Figure 8. Electronic spectra of MNB and their metal complexes.

3.6 X-ray diffraction studies

The powder X-ray diffraction (XRD) patterns of the synthesized metal complexes were recorded in the 20-80° 2 θ range. The diffractograms are presented in figures 9. The diffraction data, including peak angles (2 θ), relative intensities (%) and interplanar spacing (d) are summarized in tables 4a, 4b and 4c. The sharp peaks observed in the XRD patterns indicate the crystalline nature of the metal complexes. The average crystallite sizes of the complexes were calculated using the Scherrer's formula. The results revealed that the crystallite sizes of the Co(II), Ni(II) and Cu(II) complexes are within the nanometer range. These XRD analyses provide valuable insights into the structural properties and crystallinity of the synthesized metal complexes [26-27]. The crystallite sizes of the complexes, which are 19.20, 7.89 and 20.22 nm, respectively indicate that the complexes are in a nanocrystalline phase.

Table 4a. Powder XRD spectral data of [Co(MNB)₂(OH₂)₂]

Peak No.	2θ	θ (degree)	θ (radian)	$\text{Sin}\theta$	hkl	D		a in Å
						Cal	Obs	
1	26.235	13.179	0.2245	0.2178	1 1 1	2.85	2.80	4.45
2	30.717	15.358	0.2617	0.2587	2 0 0	2.50	2.40	4.45
3	44.945	22.457	0.3839	0.3745	2 2 0	2.10	2.05	4.45
4	52.687	26.347	0.4537	0.4478	3 1 1	1.86	1.80	4.45
5	65.678	32.567	0.5585	0.5489	2 2 2	1.50	1.45	4.45
6	72.789	36.347	0.6283	0.6166	4 0 0	1.38	1.35	4.45
7	75.876	37.690	0.6457	0.6378	3 3 1	1.20	1.15	4.45
8	80.432	40.232	0.6981	0.6855	0 2 4	1.15	1.10	4.45
9	89.032	44.543	0.7679	0.7579	4 2 2	1.11	1.05	4.45

Table 4b. Powder XRD spectral data of $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$

Peak No.	2θ	θ (degree)	θ (radian)	$\text{Sin}\theta$	hkl	D		a in Å
						Cal	Obs	
1	18.862	9.434	0.1570	0.1476	1 0 0	3.20	3.15	3.71
2	23.644	11.675	0.1919	0.1889	1 0 1	2.80	2.75	3.71
3	33.544	15.543	0.2629	0.2578	1 1 0	2.50	2.40	3.71
4	40.308	20.156	0.3490	0.3367	1 0 2	2.10	2.00	3.71
5	43.897	21.987	0.3665	0.3477	2 0 0	1.58	1.50	3.71
6	57.907	27.987	0.4712	0.4632	2 2 0	1.22	1.11	3.71

Table 4c. Powder XRD spectral data of $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$

Peak No.	2θ	θ (degree)	θ (radian)	$\text{Sin}\theta$	hkl	D		a in Å
						Cal	Obs	
1	26.443	13.221	0.2268	0.2136	1 1 1	3.50	3.45	4.43
2	44.345	22.245	0.3839	0.3632	2 2 0	3.10	2.98	4.43
3	53.987	26.876	0.4537	0.4423	3 1 1	2.55	2.39	4.43
4	64.132	32.213	0.5585	0.5309	4 0 0	2.10	1.90	4.43
5	72.931	36.670	0.6283	0.6190	3 3 1	1.45	1.38	4.43
6	84.029	42.123	0.7330	0.7223	4 2 2	1.11	1.07	4.43

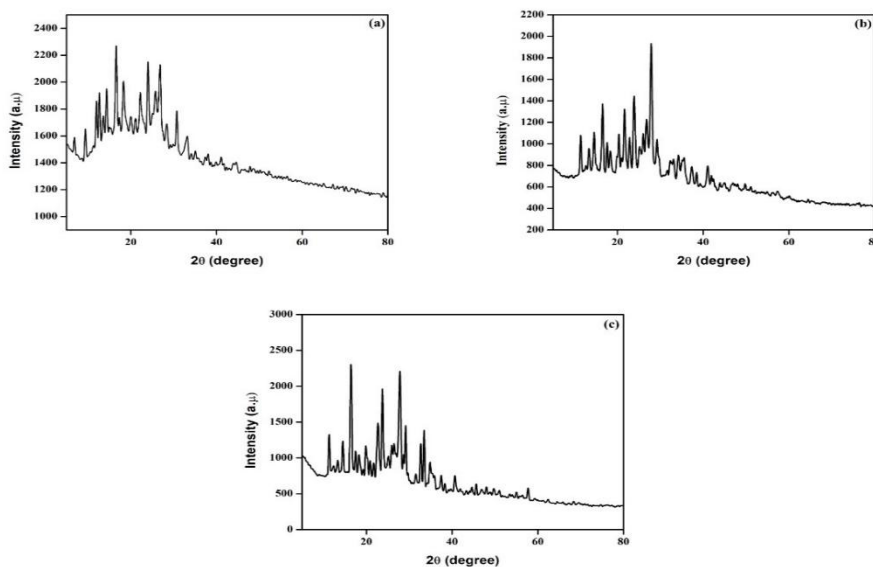


Figure 9. Powder XRD pattern of (a) $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$ (b) $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$ (c) $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$

3.7 Scanning Electron Microscopy (SEM) Analysis

SEM was employed to meticulously examine the surface characteristics of the azo-azomethine ligand and its metal complexes. Figure 10 presents the SEM images of the investigated compounds. The MNB ligand exhibited a cotton structure, while the metal complexes displayed distinct surface morphologies. Notably, $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$ exhibited an prismatic like structure with layered topology. In contrast, $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$ and $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$ revealed granular and threads like structures respectively.

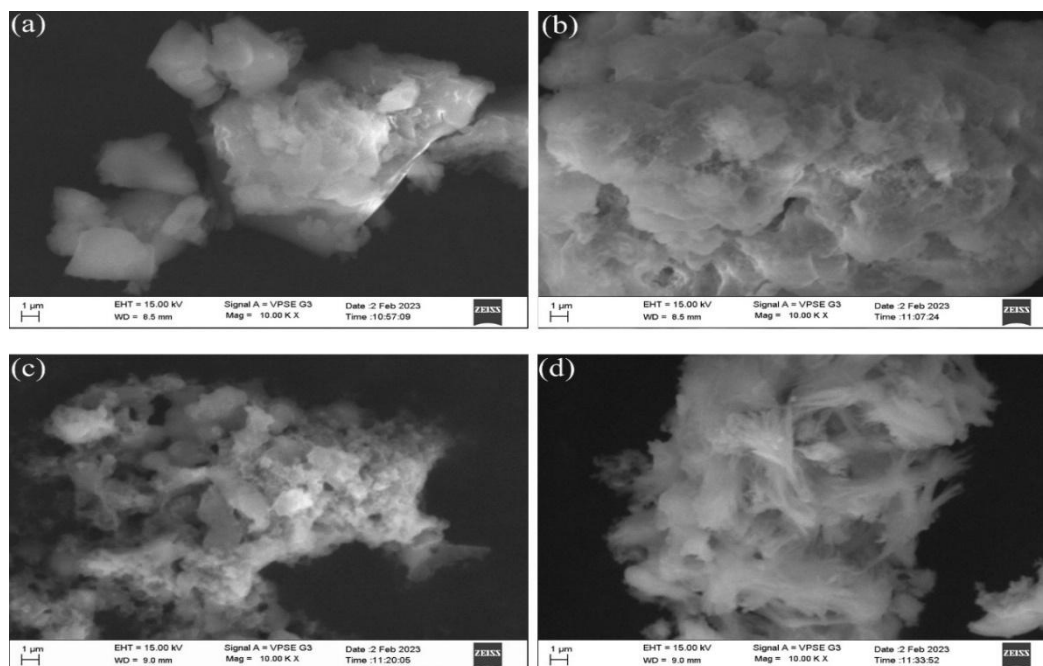


Figure 10. SEM images of (a) $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$ (b) $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$ (c) $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$

4. Photodegradation study

The photodegradation ability of synthesized metal complexes, such as Co(II), Ni(II) and Cu(II) was assessed through irradiation under natural sunlight. The degradation of MB dye was measured at wavelengths of 566.78, 570.33 and 565.98 nm for Co(II), Ni(II) and Cu(II) complexes respectively. As the irradiation time increased a decrease in MB absorbance was observed in the presence of the metal complexes. UV Visible spectra were recorded at regular time intervals of 15 minutes over a degradation time ranging from 0 to 105 minutes. Analysis of the absorbance data revealed degradation percentages of 83%, 64% and 61% for Co(II), Ni(II) and Cu(II) complexes, respectively. These results indicate that Co(II) complex exhibit superior photodegradation efficiency compared to the Ni(II) and Cu(II) complexes for MB dye.

The photodegradation percentage was calculated by using following formula [28-29].

$$\text{Percentage of degradation} = \frac{C_0 - C_t}{C_0} \times 100$$

Where C_0 represents the initial absorbance of the dye solution and C_t represents the absorbance of the dye solution in the presence of the photocatalysts Co(II), Ni(II) and Cu(II) complexes at specific time intervals.

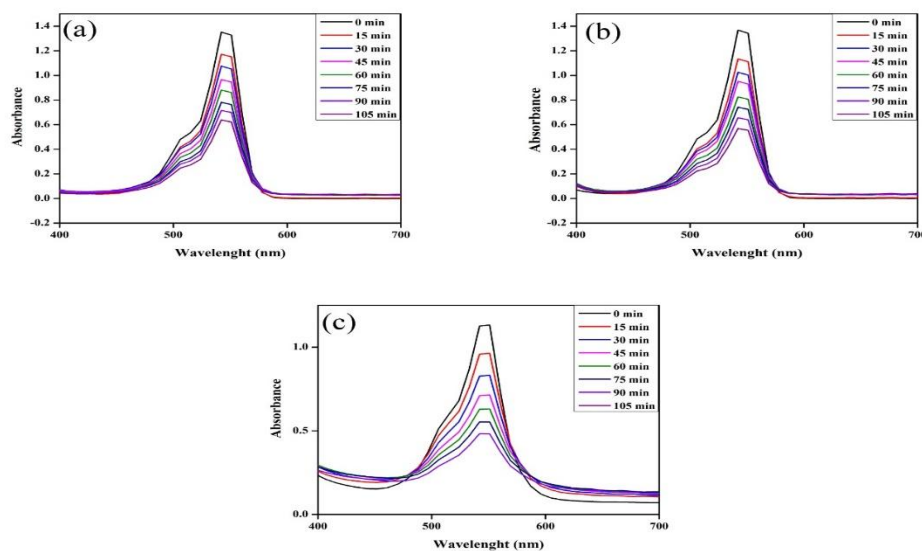


Figure 11. Photodegradation of MB dye by (a) $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$ (b) $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$ (c) $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$

5 Results and Discussion of Biological activities

5.1 Antimicrobial activity

The antimicrobial characteristics of the MNB and its metal complexes were assessed in vitro against various bacterial and fungal species. The results of these activities are presented in table 5 and graphically illustrated in figures 12 and 13. Owing to chelation, which enhances lipophilicity and promotes absorption through the bacterial membrane, leading to the demise of the organisms, metal complexes exhibit superior antibacterial activity compared to ligand, as evidenced by their larger inhibition zones [31-32]. It is noteworthy that within a complex, the positive charge of the metal is partially shared with the donor atoms present in the ligand and there may be n-electron delocalization across the entire chelating space. Consequently, the metal chelates exhibit increased lipophilicity, facilitating their passage through the lipid layer of bacterial membranes. These compounds demonstrate a higher lipophilic character, potentially explaining their enhanced antibacterial efficacy. Additional factors influencing activity include solubility, conductivity and bond length between the metal complexes and ligand. Notably, the MNB-1 and MNB-2 complexes display superior activity against bacteria and fungi, as evidenced by significant zones of inhibition values.

Table 5. Antimicrobial activity of MNB and its metal complexes (inhibition zone in mm)

Compound	Antibacterial activity				Antifungal activity			
	Staphylococcus Aureus		Escherichia coli		A.flavous		P.anomala	
	100	200	100	200	100	200	100	200
MNB	10±1.15	11±1.52	11±1.52	12±0.57	10±1.18	13±1.43	11±0.97	15±1.18
MNB-1	19±1.52	20±0.57	21±1.52	23±0.57	24±1.43	26±0.97	26±0.87	28±1.18
MNB-2	18±1.73	20±0.57	20±1.52	21±1.15	22±0.97	23±1.43	25±0.97	27±0.97
MNB-3	13±0.57	15±0.57	15±1.73	17±0.57	16±1.18	18±0.87	19±1.43	20±1.18
Kanamycin	21.661 ± 0.57	25.78±0.57	25.30±0.57	28.66±0.57	-	-	-	-
Fluconazole	-	-	-	-	30±1.18	34±1.43	32±1.18	36±0.97

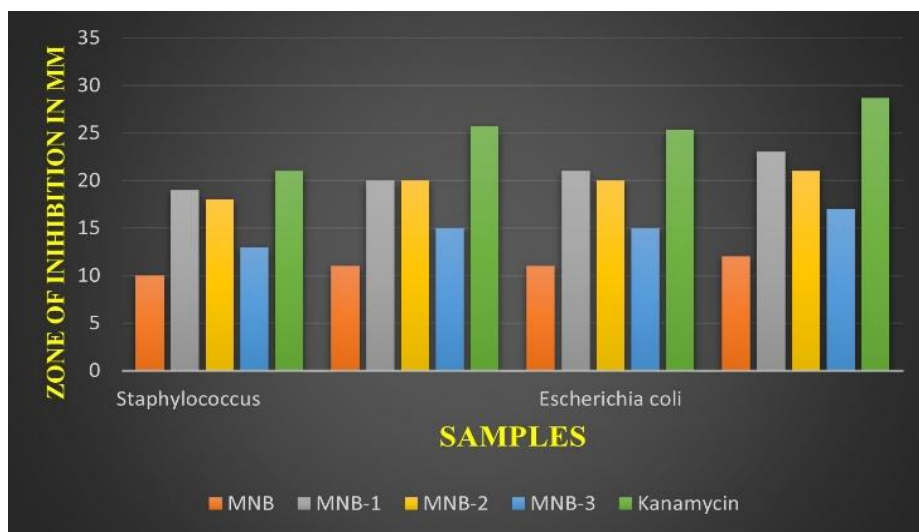


Figure 12. Antibacterial activity of MNB and its metal complexes

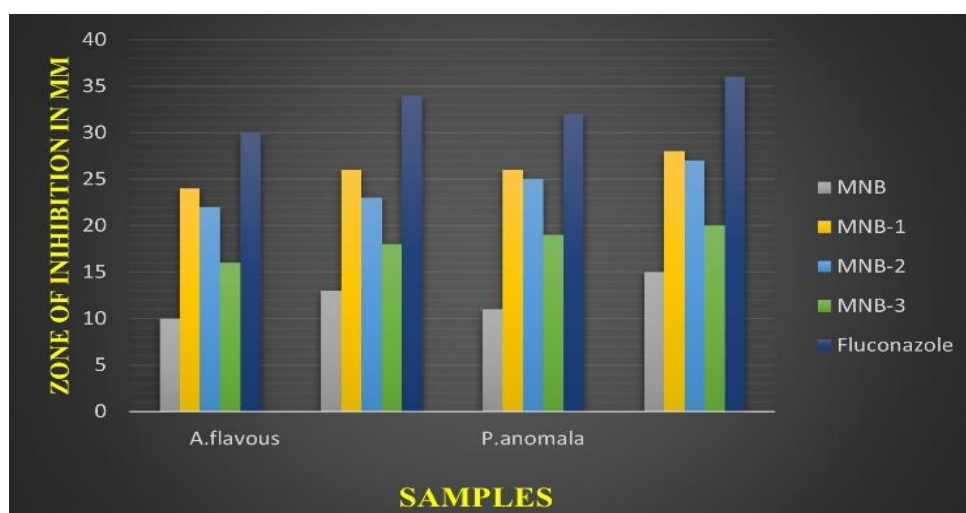


Figure 13. Antifungal activity of MNB and its metal complexes

5.2 Antioxidant Efficacy

The antioxidant capabilities of the synthesized ligand and its corresponding metal complexes were meticulously evaluated in accordance with the established methodology outlined in the methodology section. The detailed results are presented in Table 6, while a comparative analysis is provided in Figure 14. Notably, the Ni(II) and Cu(II) complexes demonstrated significantly enhanced DPPH scavenging activity across varying concentration ranging from 50 to 250 $\mu\text{g/mL}$. Furthermore, the antioxidant activity evaluation through the iron chelating assay revealed that the Ni(II) and Cu(II) complexes exhibited exceptional antioxidant efficacy in comparison to Co(II) and the uncoordinated ligand. However, it is crucial to acknowledge that the antioxidant activity of both the ligand and its complexes was relatively lower when compared BHT (Butylated hydroxytoluene) served as the standard for antioxidant activity assessment using the iron chelating assay [33-34].

Table 6. Antioxidant activity of MNB and its metal complexes

Compound	% of Scavenging activity (Concentration in $\mu\text{g/mL}$)				
	20	40	60	80	100
MNB	12 \pm 0.14	25 \pm 0.13	36 \pm 1.09	59 \pm 0.15	80 \pm 2.9
MNB-1	16 \pm 0.16	30 \pm 0.16	49 \pm 1.15	67 \pm 0.80	89 \pm 0.14
MNB-2	20 \pm 0.10	42 \pm 0.14	65 \pm 0.16	79 \pm 0.70	97 \pm 0.33
MNB-3	22 \pm 0.22	54 \pm 0.01	73 \pm 0.14	85 \pm 0.78	102 \pm 0.01
Std(BHT)	28 \pm 0.18	61 \pm 0.24	85 \pm 0.60	99 \pm 0.14	115 \pm 0.08

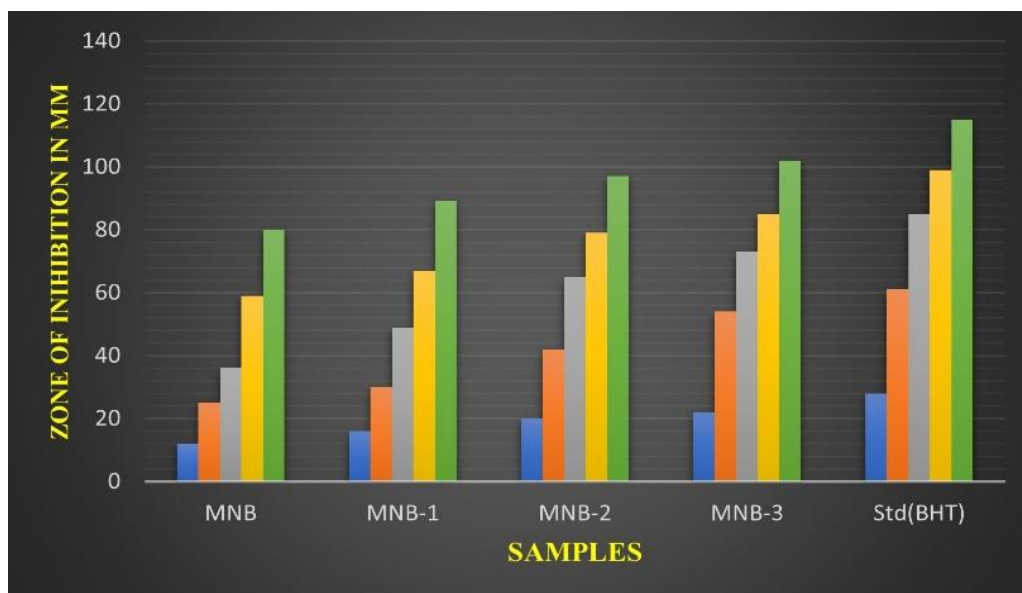


Figure 14. Antioxidant activity of MNB and its metal complexes

5.3 Docking studies

The molecular docking study correspondence with cytotoxic active receptor PDB id: 3F8G were taken and the results obtained in table 7 and their 3D interactions displayed in Fig.15. The synthesized PDP and their metal complexes exhibited binding with several amino acids in the enzyme sites [33], all the compounds displayed good binding affinity. The $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$, $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$ and $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$ complexes gives highest binding interaction of -259.77 , -257.46 and -268.31 $\text{kcal}^{-1}\text{mol}$ respectively. Among the synthesized complexes the $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$ show highest binding affinity because they suggest a more stable and favourable interaction between the ligand and their metal complexes with receptor.

Table7. Binding energy values of MNB and their metal complexes

Compounds	Receptor	E (kcal mol^{-1}) PDB ID: 3F8G
MNB	2A91	-158.25
MNB-1	2A91	-259.77
MNB-2	2A91	-257.46
MNB-3	2A91	-268.31
Actinoin (STD)	2A91	-235.87

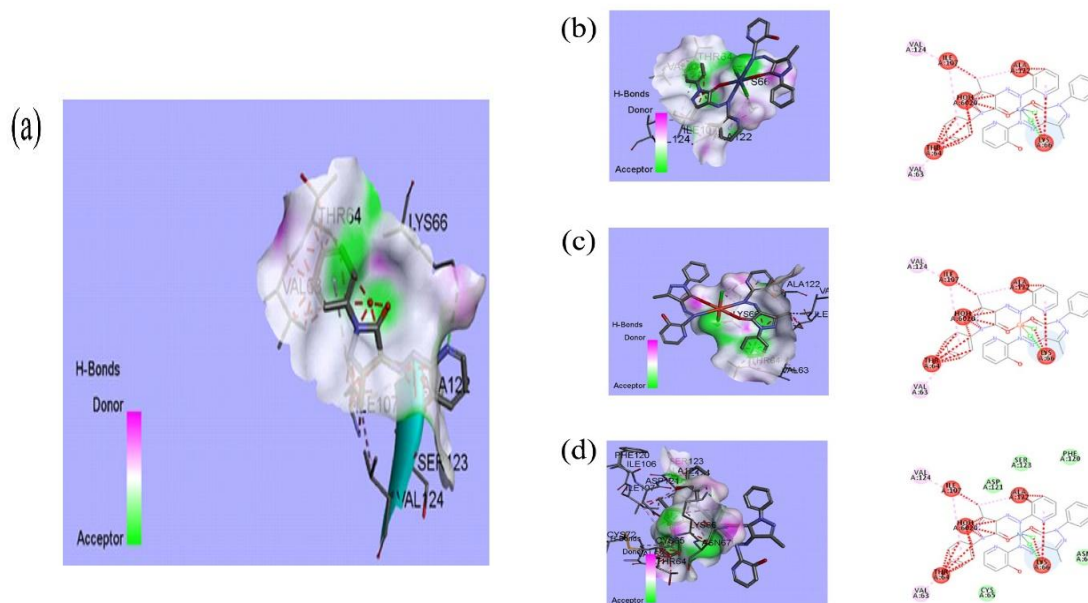


Figure 15. Molecular docking of (a) PDP (b) $[\text{Co}(\text{MNB})_2(\text{OH}_2)_2]$ (c) $[\text{Ni}(\text{MNB})_2(\text{OH}_2)_2]$ (d) $[\text{Cu}(\text{MNB})_2(\text{OH}_2)_2]$

Conclusion

In this study, a novel ligand 7-hydroxy-4-methyl-8-[(*E*)-(6-nitro-1,3-benzothiazol-2-yl)diazonyl]-2*H*-chromen-2-one ligand (MNB) was synthesized to produce biologically active Co, Ni and Cu complex. These complexes were evaluated using a variety of physicochemical and spectral approaches. Using a variety of analytical methods, we were able to determine the structure of MNB and its metallic compounds. The synthetic procedure employed in this investigation revealed the formation of complexes with a metal to ligand molar ratio 1:2. According to molar conductance data, the complexes exhibited non electrolytic behaviour. Based on UV-Vis and magnetic Susceptibility data, the complexes adopt a square planar geometry. The photocatalytic activity of the synthesized complexes was evaluated using MB dye, with the Co(II) complex demonstrating a superior degradation efficiency compared to other metal complexes. Furthermore, the antimicrobial of the uncoordinated ligand and its metal complexes were investigated. The results revealed that the MNB-1 and MNB-2 complexes exhibited enhanced biological activity compared to the ligand itself.

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Declaration of competing Interest

The authors declare that they have no competing financial interests or personal relationships that would have appeared to influence the work reported in this paper.

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