

Preparation, Characterization, and Biological Activity of Cu(II) and Co(II) Complexes of 5-(((E)-3-Phenylallylidene)Amino-1,3,4-Thiadaizole-2-Thiol Schiff Base Ligand

Deepika Puttaveerappa¹, Vinusha Honnalagere Marisamy², Muneera Begum^{1*}, Ramith Ramu³, Prithvi S Shirahatti⁴, Nagendra Prasad M.N⁵, Rekha Nanjappagowda Dharmappa⁶

¹ Department of Chemistry, Sri Jayachamarajendra College of Engineering, JSS Science and Technology University, Mysuru, Karnataka – 570 006, India; deepikaputtaveerappa@gmail.com (D.P.), mbegum20@yahoo.com (M.B.);

² PG Department of Chemistry, Sarada Vilas College, Mysuru– 570 004, Karnataka, India; vinushahm@gmail.com (V.H.M.);

³ Department of Biotechnology and Bioinformatics, School of Life Sciences, JSS Academy of Higher Education and Research (JSS AHER) Mysuru – 570015, India; ramithram@jssuni.edu.in (R.R.);

⁴ Post Graduation Department of Biotechnology, Teresian College, Siddhartha Nagara, Mysuru – 570015, India; psshirahatti@gmail.com (P.S.S.);

⁵ Department of Biotechnology, JSS Science and Technology University, JSS Technical Institutional Campus, Mysuru, Karnataka 570006, India; nagendramnprasad@sjce.ac.in (N.P.M.N.);

⁶ PG Department of Bio-Technology, JSS College of Arts, Commerce and Science (Autonomous) Ooty Road, Mysuru-570 025, Karnataka, India; rekhand1972@gmail.com (R.N.D.);

* Correspondence: mbegum20@yahoo.com (M.B.);

Scopus Author ID 7006460746

Received: 15.05.2023; Accepted: 11.08.2023; Published: 29.09.2024

Abstract: In the current work, we have synthesized a Schiff base ligand (SB) derived 5-amino-1,3,4-thiadaizole-2 thiol with cinnamaldehyde and its Cu(II), and Co(II) metal complexes in 2:1 stoichiometric ratio (2L:M). The synthesized Schiff base ligand (SB) and its metal complexes were evaluated using different instrumental techniques. The free radical scavenging activity of the synthesized compounds was evaluated by employing a series of *in vitro* assays viz., DPPH, ABTS, and Superoxide, whereas BHA was used as a positive control. *In vitro* α – amylase and α – glucosidase activities showed that metal complexes had considerable inhibitory potential compared to the ligand.

Keywords: Schiff base ligand; metal complexes; TG and DTG; antioxidant; inhibitory effect.

© 2024 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The chemistry of metal complexes with Schiff base ligands containing sulfur, oxygen, and nitrogen as donor atoms has continued to attract the attention of researchers. These ligands are known to coordinate with metal atoms in different ways under different reaction conditions. The ligands are derived from the condensation reaction of aldehydes or ketones and primary amines [1].

One of the major areas of research on the Schiff base metal complexes is their biological activity, with the main aim being the discovery of safe and effective therapeutic agents for treating bacterial infections and cancers. Several Schiff base metal complexes have diverse biological and pharmaceutical activities. For instance, transition metal complexes of Schiff base ligands bearing “S”, “O” and “N” donor atoms are very important because of their

biological properties such as antibacterial, antifungal, anti-inflammatory [2], analgesic [3,4], anticonvulsant [5], antitubercular [6], antioxidant [7], and anthelmintic [8]. The Schiff base transition metal complexes have also been used as biological models to understand the structure of biomolecules and biological processes [9].

Schiff base ligands have been extensively studied in coordination chemistry mainly because of their facile syntheses, easy availability, and electronic properties. In recent times, Schiff base coordination chemistry has attracted much attention because of its significance in organic synthesis, analytical chemistry, refining of metals, metallurgy, electroplating, and photography [10-12]. Schiff bases have wide applications in the dye industry, catalysis, fungicidal, and agrochemical [13-14]. Several Schiff bases are reported to possess remarkable antibacterial, antioxidant, antifungal, and anticancer activities [15].

Schiff bases and their metal complexes are extensively studied owing to their wide range of applications in biological activity such as antifungal, antitumor, antibacterial, anticancer, etc.; in pharmaceuticals; and as catalyst [16]. They are also used in dyes and polymers, [17] as well as are applied in nanotechnology [18], laser [19], transistor [20], in defense as gas generating agents [21], and pyrotechnic mixtures [22]. Imine derivatives are employed in optical computers to measure and control the radiation's intensity, in molecular memory storage and imaging systems, as organic material in reversible optical memories and biological systems used as photo-detectors.

The majority of Schiff bases are useful as antibacterial, antifungal, and antioxidant agents. An azomethine (imine) group $-\text{CH}=\text{N}-$, in Schiff base, helps explain the mechanism of trans-amination and racemization reaction in biological systems. Metal–Schiff base complexes have been widely studied for their application as antitumor, antibacterial, antifungal, antioxidant, and herbicidal agents [23-24].

Manganese, cobalt, nickel, copper, and zinc are life-essential metallic elements and exhibit greater biological activity when associated with certain metal protein complexes, participating in oxygen transport, electronic transfer reactions, or the storage of ions [25]. This has created enormous interest in the study of systems containing these metals.

Cu(II) and Co(II) complexes of the Schiff base ligand (SB), 5-((ϵ -3-phenylallylidene)amino-1,3,4-thiadaizole-2-thiol, which, to the best of our knowledge, has neither been synthesized nor antioxidant activities and inhibition of α – amylase and α – glucosidase was studied in our laboratories. The antioxidant activity and Inhibition of α – amylase and α – glucosidase of the new Cu(II) and Co(II) complexes of the Schiff base ligand (SB) 5-((ϵ -3-phenylallylidene)amino-1,3,4-thiadaizole-2-thiol has been investigated and is now reported in this article. The antioxidant evaluation and inhibition of α – amylase and α – glucosidase results revealed that the metal complexes exhibited higher antioxidant activity than the free Schiff base ligand (SB), and results revealed that Cu complex (IC_{50} : 1.30mg/ml) possessed the highest inhibitory activity as compared to its Schiff base ligand (SB).

2. Materials and Methods

5-amino-1,3,4-thiadiazole-2-thiol and cinnamaldehyde were obtained from Sigma-Aldrich and used as received without any further purification. Metal salts and solvents were purchased from E. Merck and were used as without purification.

2.1. Antioxidant assays.

In this study, three standard methods, *viz.*, DPPH free radical, ABTS cation radical, and superoxide anion radical scavenging activities, were determined and measured [26]. Radical scavenging activities were expressed as EC₅₀ values. EC₅₀ signifies 50% of free, cation, and anion radicals scavenged by the samples tested. The standard antioxidant Butylated hydroxyl anisole (BHA) was used as a positive control.

2.2. Inhibition of α – amylase and α – glucosidase.

The α -amylase (EC 3.2.1.1, categorized as type-VI B porcine pancreatic α -amylase) inhibition was assayed using soluble starch (1%) as a substrate, and the yeast α -glucosidase (EC 3.2.1.20, categorized as type-1 α -glucosidase) inhibition was assayed using the substrate *p*NPG according to the modified method [27].

Acarbose was used as a positive control. The α -amylase & α -glucosidase inhibitory activity was expressed in percent inhibition and calculated by the below formula:

$$\text{Inhibition (\%)} = \frac{(A \text{ control} - A \text{ sample})}{2aA \text{ control}} * 100 \quad (1)$$

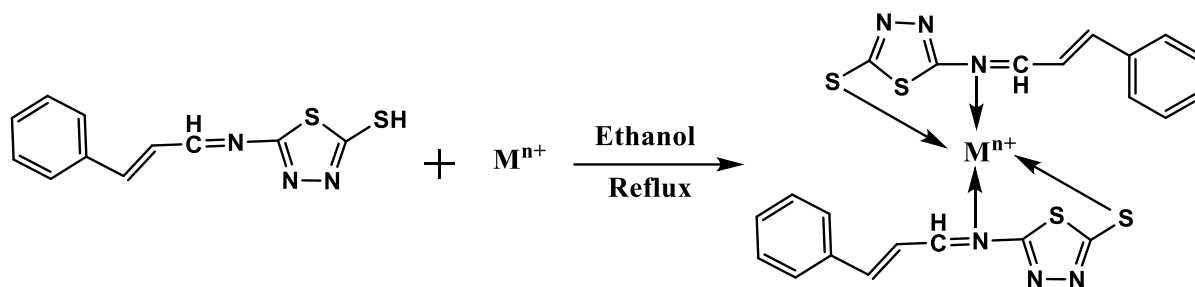
IC₅₀ values were determined from a curve relating the % inhibition of each sample to the concentration of the sample. Each experiment was performed in triplicates, along with appropriate blanks. The concentration required to inhibit 50% of the α -glucosidase activity under the specified assay conditions was described as the IC₅₀.

2.3. Synthesis of Schiff base ligand (SB) 5-(((E)-3-phenylallylidene)amino-1,3,4-thiadaizole-2-thiol.

The Schiff base ligand (SB) 5-(((E)-3-phenylallylidene)amino-1,3,4-thiadaizole-2-thiol was synthesized by reacting equimolar quantities of ethanolic solution of 5-amino-1,3,4-thiadaizole-2-thiol and cinnamaldehyde. A few drops of glacial acetic acid, which acts as a catalyst during the reaction, were added to this reaction mixture. The reaction mixture was refluxed well for 7 hours at 60-70°C [28]. The progress of the reaction was monitored using thin-layer chromatography (TLC). After the completion of a reaction, the solution was evaporated under reduced pressure. The precipitated product was washed with ethanol and dried in a vacuum over anhydrous calcium chloride, and the product was recrystallized with warm ethanol. The yield was obtained around 87%. The Schiff base ligand (SB) was obtained according to Scheme 1.

2.4. General method for the synthesis of metal complexes.

The ligand (**SB**) and metal salts (Cu(II) and Co(II)) were reacted in (2:1) molar ratio in order to form a series of metal complexes. The metal chlorides and ligands were dissolved in ethanol separately. To the ethanolic solution of the ligand, metal salt solutions were added dropwise, followed by a few drops of sodium acetate solution to maintain the pH of the solution. After stirring for 4 h, the precipitate was formed. The obtained precipitate was filtered off, washed with warm ethanol, and dried. The Schiff base ligand metal complexes (M = Cu and Co) was obtained according to Scheme 2.



Scheme 2. General synthesis of Schiff base metal complexes (M = Cu and Co).

3. Results and Discussion

3.1. Instrumentation.

The synthesized Schiff base ligand (SB) and metal complexes were characterized by using different instrumental techniques. The functional groups involving ligand and complexes were confirmed on the Perkin Elmer FT-IR type 1650 spectrophotometer. The compounds' molecular masses were noted using an Agilent TTechnologies (HP) 5973 mass spectrometer. The environment of the proton and carbon of the ligand molecule was studied on Varian 300MHz in DMSO-d₆ as a solvent against tetramethylsilane as an internal standard. The electronic properties were studied using a UV-1800 spectrophotometer (Shimadzu). Thermogravimetric analysis (TGA) was carried out to find the thermal behavior of metal complexes on a Universal TGA Q50 instrument at a heating rate of 2°C/min between 30 and 1000°C.

3.2. FT-IR analysis.

The binding mode of the Schiff base ligand to the metal ions in complexes was determined by comparing the FT-IR spectrum of the free ligand with the spectra of the metal(II) complexes.

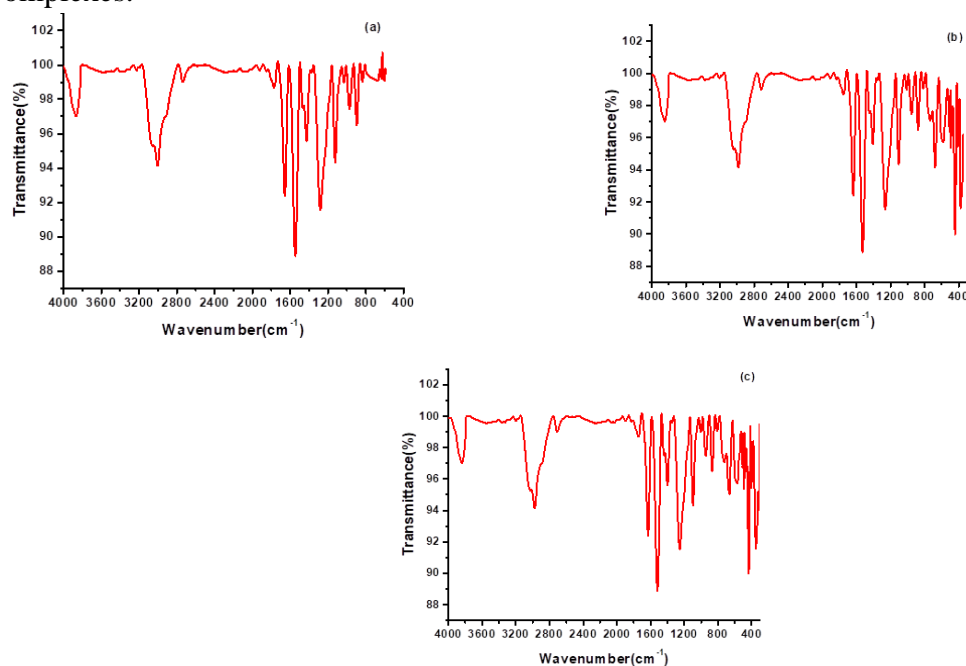


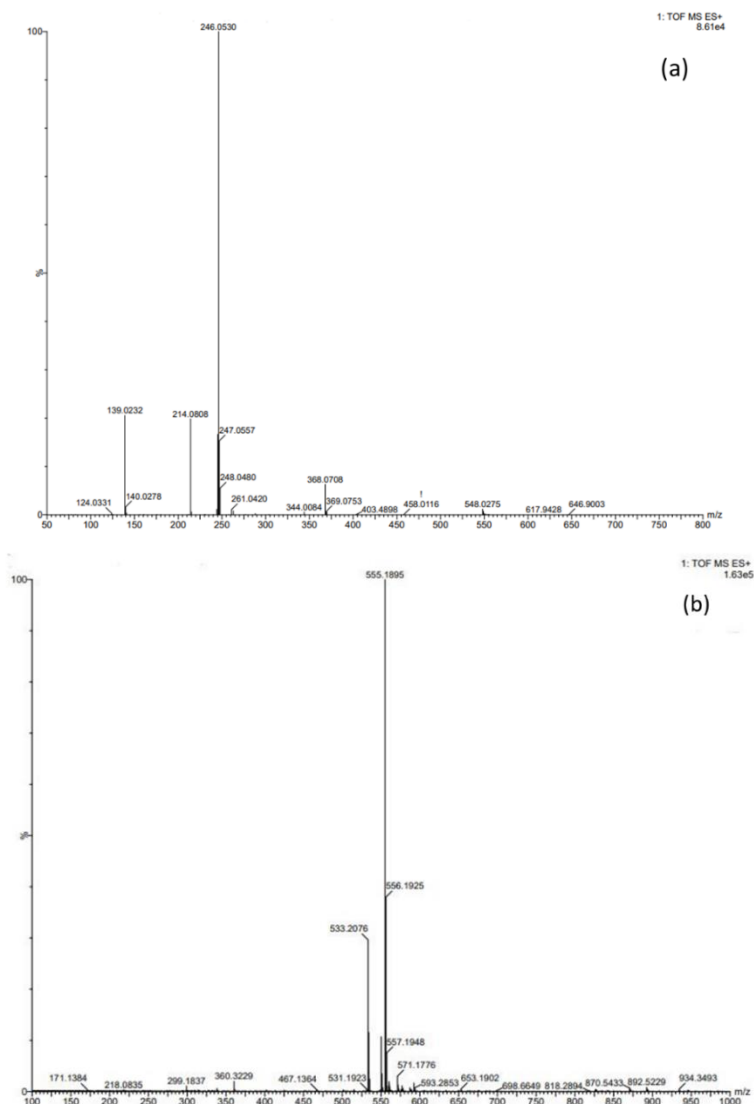
Figure 1. IR spectra of (a) ligand; (b) Cu(II) complex; (c) Co(II) complex.

Figure 1 shows the FT-IR spectra of the synthesized Schiff base ligand (SB) and its metal complexes. The stretching frequency for the azomethine -HC=N- bond, $\nu(-HC=N-)$ was observed at 1667cm^{-1} for the free ligand. The (-HC=N-) stretching frequencies in the metal(II) complexes were observed at 1651 and 1629cm^{-1} for SB-Cu and SB-Co complexes, respectively, with a shift to lower wave numbers. (This indicates the coordination of Schiff base through azomethine nitrogen [30]. Moreover, the appearance of new additional weak bands in the region $359-354\text{cm}^{-1}$ and $445-436\text{cm}^{-1}$ attributed to $\nu(M-S)$ and $\nu(M-N)$, respectively [31], further confirmed complexation [32] (showed that the Schiff base ligand coordinated to the metal via “S” and “N” atoms).

3.3. Mass spectrometric analysis.

The data for confirmation of Schiff base ligand (SB) and its metal complexes was obtained at 70eV by electron ionization technique on Agilent Technologies (HP) 5973 mass spectrometer. The mass spectrum of the Schiff base ligand (SB) was taken and observed to confirm the synthesized ligand. Figure 2 shows the mass spectrum of the synthesized ligand. The molecular ion peak of the ligand ($\text{C}_{11}\text{H}_9\text{N}_3\text{S}_2$) was observed at $m/z = 246.053$.

Figure 2 shows the mass spectra of the Cu and Co complexes. The molecular ion peak for Cu and Co complexes was observed at $m/z = 555.18$ and 552.27 , respectively. It indicates the coordination of Cu and Co ions with the ligand.



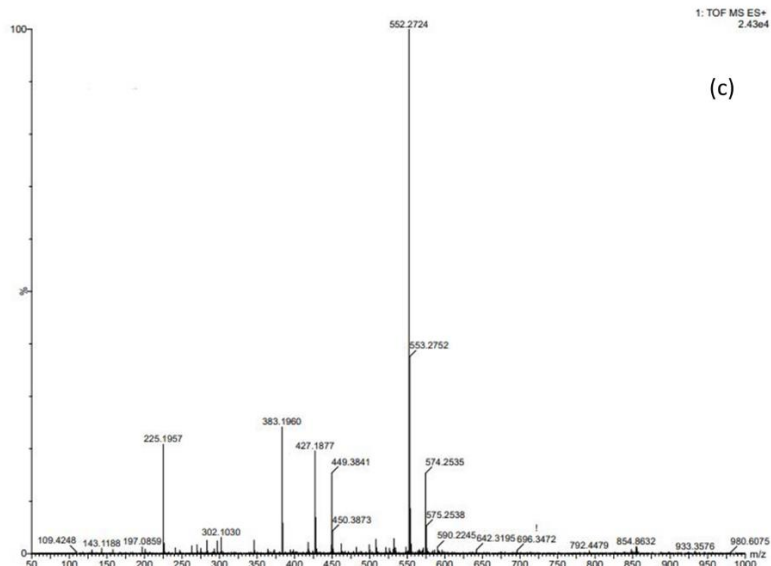


Figure 2. Mass spectra of (a) ligand; (b) Cu(II) complex; (c) Co(II) complex.

3.4. NMR analysis.

The NMR analysis of the Schiff bases ligand(SB) was carried out by using Varian 300 MHz in DMSO- d_6 as a solvent against tetramethylsilane as an internal standard.

3.4.1. 1H NMR.

The 1H NMR spectrum of the Schiff base showed a singlet peak at $\delta = 9.748$ ppm corresponding to the azomethine proton ($-CH=N-$) [33-34], an indication that the Schiff base was formed during the condensation reaction as shown in Figure 3. The singlet peak, at $\delta = 12.319$ ppm, is assignable to the SH group in the Schiff base ligand [35]. In addition to that, peaks between 7.088-8.819 ppm correspond to aromatic protons of the Schiff base ligand.

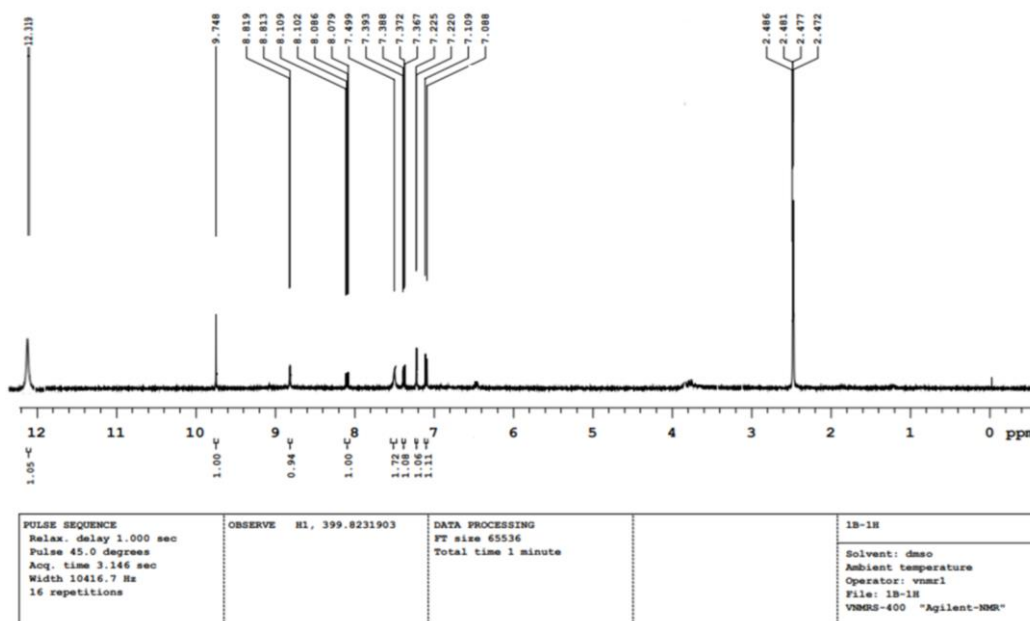


Figure 3. 1H NMR spectrum of ligand.

3.4.2. ^{13}C NMR.

The ^{13}C NMR spectrum was recorded in the DMSO- d_6 . In the ^{13}C -NMR, the peak seen in SB at $\delta=163.6$ ppm supports the existence of the azomethine group, as shown in Figure 4. Between $\delta=107.5$ and 153.7 ppm, aromatic ring carbon signals were detected. The synthesis of the reported ligand SB, is therefore confirmed by ^{13}C -NMR findings [36].

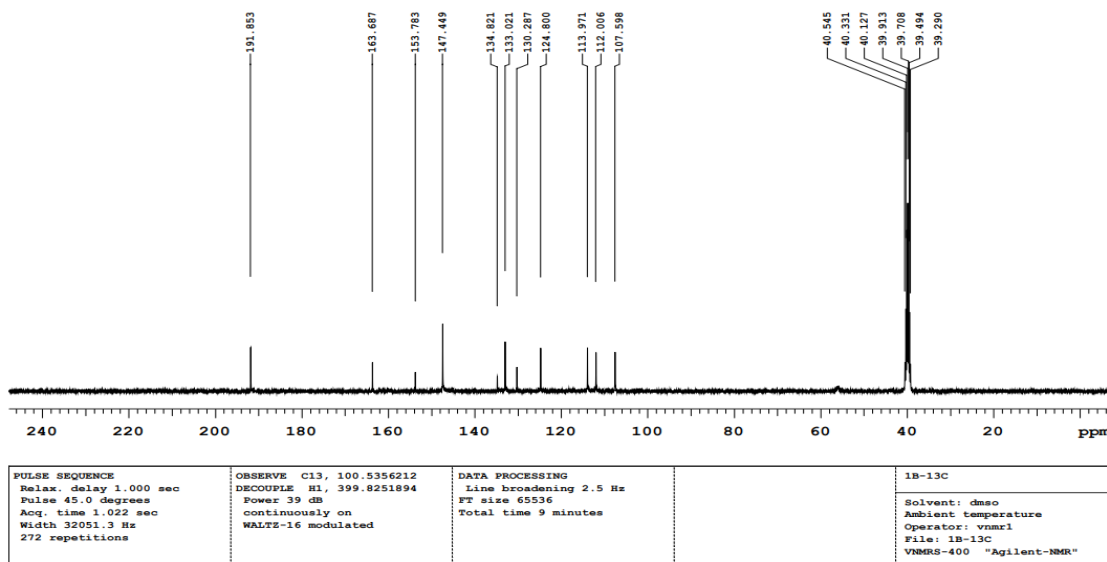


Figure 4. ^{13}C NMR spectrum of ligand.

3.5. Electronic spectra.

The electronic spectra of the ligand and its metal complexes were recorded in DMSO solution at room temperature, as shown in Figure 5.

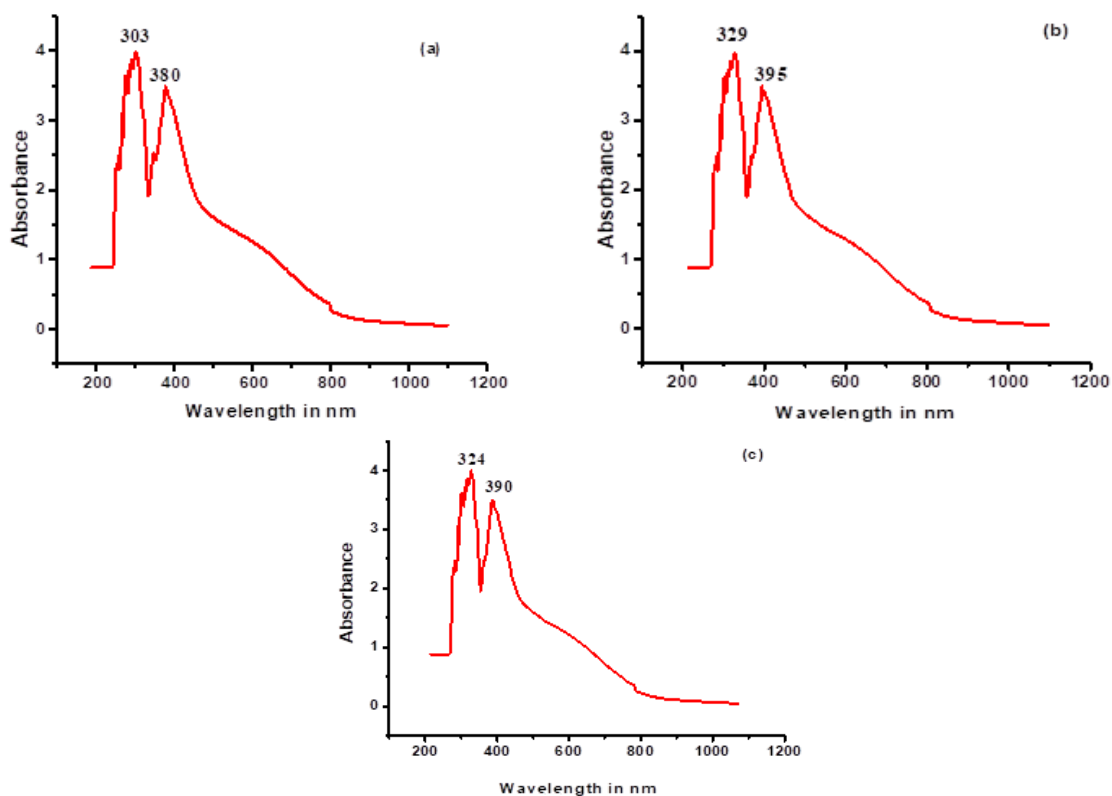


Figure 5. Electronic spectra of (a) ligand; (b) Cu(II) complex; (c) Co(II) complex.

Electronic absorption spectral data of ligand and its metal complexes in nm is shown in Table 1. The absorption bands around 303 and 380nm were observed in the spectrum of the free Schiff base ligand, corresponding to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions associated with benzene rings and azomethine groups, respectively [37]. In the metal complexes, $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions were shifted to longer wavelengths due to coordination to metal, confirming the formation of Schiff base metal complexes [38].

Table 1. Electronic absorption spectral data of ligand and its metal complexes in nm.

Compounds	$\pi \rightarrow \pi^*$	$n \rightarrow \pi^*$
SB	303	380
SB - Cu	329	395
SB - Co	324	390

3.6. Thermal analysis.

The thermal property of the complexes was studied using TGA and DTG studies. Figure 6 shows the TGA and DTG curves of Cu and Co complexes under a nitrogen atmosphere. From the TGA curves, it is clear that Cu and Co complexes undergo decomposition in three steps and leave a residue as their respective metal oxides. The step-wise decomposition of all the metal complexes is given in Table 2.

The results also revealed that the Co(II) complex undergoes decomposition in three steps. In the first step, from 37.5°C to 185.81°C with a weight loss of 10.35%. In the second step, between the range 185.81°C to 358.47°C with a weight loss of 17.31%, corresponds to the loss of organic moiety of a ligand, and in the third step of decomposition between 358.47°C to 772.61°C with a weight loss of 25.68% corresponding to the Schiff base ligand leaving with 46.66% residue as CuO [39].

Similarly, the results also revealed that the Co(II) complex undergoes decomposition in three steps. In the first step, from 27.9°C to 134.96°C with a weight loss of 11.68%. In the second step, between the range 134.96°C to 328.78°C with a weight loss of 20.78%, corresponds to the loss of organic moiety of a ligand, and in the third step of decomposition between 328.78°C to 737.58°C with a weight loss of 25.38% corresponding to the Schiff base ligand leaving with 42.16% residue as CoO [40].

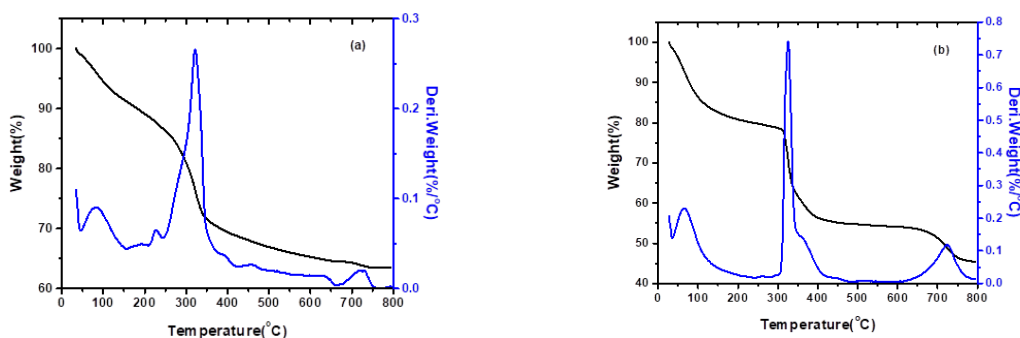


Figure 6. TGA curve of (a) Cu(II) complex; (b) Co(II) complex.

Table 2. Step-wise thermal decomposition of metal complexes.

Compounds	Stages	Range	Weight Loss (%)	Residue (%)
SB - Cu	I	37.5-185.81	10.35	46.66
	II	185.81-358.47	17.31	
	III	358.47-772.61	25.68	
SB - Co	I	27.9-134.96	11.68	42.16
	II	134.96-328.78	20.78	
	III	328.78-737.58	25.38	

3.7. Antioxidant activity.

The free radical scavenging ability of test samples was assessed by employing a series of *in vitro* assays viz., DPPH, ABTS, and Superoxide, whereas BHA was used as a positive control. Results expressed as EC₅₀ values (mg of tests per ml) are summarized in Table 3, revealing that the compounds were comparatively lower (p<0.05) than standard (positive control) in radical scavenging activities. In all the assays used in this study, the complex was more effective than the ligand, and activities ascended in the order BHA > complex > ligand. The Cu complex generally exhibited a higher free radical scavenging activity in three antioxidant assays. The results revealed that the Cu complex possesses strong antioxidant ability and is significantly similar (p<0.05) to the positive control.

Table 3. Antioxidant activity of ligand and its complex.

Test Compounds	EC ₅₀ ^{*,#} (mg/ml)		
	Radical scavenging activities		
	DPPH	ABTS	Superoxide
SB	2.54 ± 0.87	4.55 ± 1.09	4.90 ± 0.88
SB -Cu	0.85 ± 2.62	0.66 ± 0.22	0.75 ± 1.05
SB -Co	1.75 ± 3.33	3.57 ± 2.36	2.66 ± 0.24
Standard ^	0.65 ± 0.06	0.50 ± 0.04	0.70 ± 0.32

* Values are expressed as mean ± SE. Means in the same column with distinct superscripts are significantly different (p ≤ 0.05) as separated by Duncan's multiple range test; # The EC₅₀ value is defined as the effective concentration of the test samples to show 50% of antioxidant activity under assay conditions; ^ Standard: Butylated hydroxyanisole (BHA - positive control).

3.8. Inhibitory effects on yeast α-glucosidase and α-amylase.

In vitro α-glucosidase inhibitory studies revealed that complex had effective inhibitory potential than its ligand. The IC₅₀ values were found to be in the range of 0.72 and 2.14mg/ml. Acarbose, investigated under the same conditions, had IC₅₀ value of 0.70mg/ml. In terms of IC₅₀ values, it is evident that Cu complex tested possessed a strong inhibition on yeast α-glucosidase and was significantly similar (p <0.05) with acarbose and higher than ligand in Table 4. The inhibition ascended in the order: acarbose > complex > ligand.

Furthermore, similar studies were performed to assess whether ligand and complex also inhibited α-amylase, another key carbohydrate hydrolyzing enzyme. The 50% inhibition of α-amylase by the test compounds is detailed in Table 4. Results revealed that the Cu complex (IC₅₀: 1.30 mg/ml) had the highest inhibitory activity compared to its ligand (IC₅₀:3.06 mg/ml). The α-amylase inhibitory effect (based on IC₅₀ values) of compounds was comparatively higher (p <0.05) than the therapeutic drug acarbose (IC₅₀:0.50 mg/ml).

Table 4. Inhibitory activities of ligand and its metal complex against α-amylase and α-glucosidase enzymes.

Test Compounds	IC ₅₀ ^{x,y} (mg/ml)	
	Enzymes	
	α-amylase	α-glucosidase
SB	3.06 ± 2.35	2.09 ± 3.08
SB - Cu	1.30 ± 0.07	0.72 ± 0.16
SB - Co	1.37 ± 0.34	0.85 ± 1.02
Standard ^	0.50 ± 0.21	0.70 ± 0.24

^x Values are expressed as mean ± SE. Means in the same row with distinct superscripts are significantly different (p ≤ 0.05) as separated by Duncan multiple range test; ^y The IC₅₀ value is defined as the inhibitor concentration to inhibit 50% of enzyme activity under assay conditions; ^ Standard: Acarbose (positive control).

4. Conclusion

To sum up, we have synthesized 5-(((5-mercapto-1,3,4-thiadaizol-2-yl)imino)methyl)-2-methoxyphenol (SB) and its Cu(II) and Co(II) complexes. The reported compounds were characterized by using various spectral techniques. The free radical scavenging ability of test samples was assessed by employing a series of *in vitro* assays viz., DPPH, ABTS, and Superoxide, whereas BHA was used as a positive control. The results revealed that Cu(II) complex possesses strong antioxidant ability and is significantly similar ($p < 0.05$) to the positive control. *In vitro* α -glucosidase inhibitory studies revealed that ligand and their complexes had effective inhibitory potential. Results revealed that Cu complex tested possessed a strong inhibition effect and was significantly similar ($p < 0.05$) with acarbose and higher than ligand.

Funding

This research received no external funding.

Acknowledgments

The authors greatly thank TEQIP-III, NPIU, Sri Jayachamarajendra College of Engineering, JSS Science & Technology University, Mysuru, for providing support and an instrumentation facility.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Boulechfar, C.; Ferkous, H.; Delimi, A.; Djedouani, A.; Kahlouche, A.; Boublia, A.; Darwish, A.S.; Lemaoui, T.; Verma, R.; Benguerba, Y. Schiff bases and their metal Complexes: A review on the history, synthesis, and applications. *Inorg. Chem. Commun.* **2023**, *150*, 110451, <https://doi.org/10.1016/j.inoche.2023.110451>.
2. Nath, B.D.; Islam, M.; Karim, R.; Rahman, S.; Shaikh, A.A.; Georghiou, P.E.; Menelaou, M. Recent Progress in Metal-Incorporated Acyclic Schiff-Base Derivatives: Biological Aspects. *ChemistrySelect* **2022**, *7*, e202104290, <https://doi.org/10.1002/slct.202104290>.
3. Afridi, H.H.; Shoaib, M.; Al-Joufi, F.A.; Shah, S.W.A.; Hussain, H.; Ullah, A.; Zahoor, M.; Mughal, E.U. Synthesis and Investigation of the Analgesic Potential of Enantiomerically Pure Schiff Bases: A Mechanistic Approach. *Molecules*. **2022**, *27*, 5206, <https://doi.org/10.3390/molecules27165206>.
4. Kirthan, B.R.; Prabhakara, M.C.; Bhojyanaik, H.S.; Nayak, P.H.A.; Viswanath, R.; Teja, H.B.; Ereshanaik Optoelectronic, Photocatalytic, and DNA interaction studies of synthesised Cu (II), Co (II), and Ni (II) complexes containing schiff base ligand. *Inorg. Chem. Commun.* **2022**, *135*, 109109, <https://doi.org/10.1016/j.inoche.2021.109109>.
5. Bashir, M.; Dar, A.A.; Yousuf, I. Syntheses, Structural Characterization, and Cytotoxicity Assessment of Novel Mn (II) and Zn (II) Complexes of Aroyl-Hydrazone Schiff Base Ligand. *ACS Omega*. **2023**, *8*, 3026-3042, <https://doi.org/10.1021/acsomega.2c05927>.
6. Sinha, A.; Chaudhary, R.; Reddy, D.S.; Kongot, M.; Kurjogi, M.M.; Kumar, A. ON donor tethered copper (II) and vanadium (V) complexes as efficacious anti-TB and antifungal agents with spectroscopic approached HSA interactions. *Heliyon* **2022**, *8*, e10125, <https://doi.org/10.1016/j.heliyon.2022.e10125>.
7. Savcı, A.; Buldurun, K.; Alkış, M.E.; Alan, Y.; Turan, N. Synthesis, characterization, antioxidant and anticancer activities of a new Schiff base and its M(II) complexes derived from 5-fluorouracil. *Med. Oncol.* **2022**, *39*, 172, <https://doi.org/10.1007/s12032-022-01774-0>.
8. Boulechfar, C.; Ferkous, H.; Delimi, A.; Djedouani, A.; Kahlouche, A.; Boublia, A.; Darwish, A.S.; Lemaoui, T.; Verma, R.; Benguerba, Y. Schiff bases and their metal Complexes: A review on the history,

- synthesis, and applications. *Inorg. Chem. Commun.* **2023**, *150*, 110451, <https://doi.org/10.1016/j.inoche.2023.110451>.
9. Gurusamy, S.; Sankarganesh, M.; Asha, R.N.; Mathavan, A. Biologically active oxovanadium(IV) Schiff base metal complex: antibacterial, antioxidant, biomolecular interaction and molecular docking studies. *J. Biomol. Struct. Dyn.* **2023**, *41*, 599-610, <https://doi.org/10.1080/07391102.2021.2009916>.
 10. Senthamil, C.; Hemalatha, J.; Nandhabala, S.; Nivetha, A.; Sakthivel, C.; Prabha, I. Multifunctionalized Metal Chalcogenides and Their Roles in Catalysis and Biomedical Applications. *ChemistrySelect* **2022**, *7*, e202203394, <https://doi.org/10.1002/slct.202203394>.
 11. Chandra, S.; Hassan, A.; Prince; Alam, A.; Das, N. Rapid and Efficient Removal of Diverse Anionic Water Contaminants Using a Guanidium-Based Ionic Covalent Organic Network (iCON). *ACS Appl. Polym. Mater.* **2022**, *4*, 6630-6641, <https://doi.org/10.1021/acsapm.2c00989>.
 12. Jogi, P.; Bhushan, M.; Mrinalini, B. Transition metal (II) complexes with 2-amino methyl benzimidazole derived schiff base: synthesis, characterization and biological activity. *Int. J. Sci. Res. Arch.* **2023**, *08*, 388-392, <https://doi.org/10.30574/ijrsra.2023.8.1.0054>.
 13. Rakhtshah, J. A comprehensive review on the synthesis, characterization, and catalytic application of transition-metal Schiff-base complexes immobilized on magnetic Fe₃O₄ nanoparticles. *Coord. Chem. Rev.* **2022**, *467*, 214614, <https://doi.org/10.1016/j.ccr.2022.214614>.
 14. Pervaiz, M.; Sadiq, A.; Sadiq, S.; Saeed, Z.; Imran, M.; Younas, U.; Bukhari, S.M.; Khan, R.R.M.; Rashid, A.; Adnan, A. Design and synthesis of Schiff base Homobimetallic-Complexes as promising antimicrobial agents. *Inorg. Chem. Commun.* **2022**, *137*, 109206, <https://doi.org/10.1016/j.inoche.2022.109206>.
 15. Mi, Y.; Chen, Y.; Tan, W.; Zhang, J.; Li, Q.; Guo, Z. The influence of bioactive glyoxylate bearing Schiff base on antifungal and antioxidant activities to chitosan quaternary ammonium salts. *Carbohydr. Polym.* **2022**, *278*, 118970, <https://doi.org/10.1016/j.carbpol.2021.118970>.
 16. Xia, Q.-H.; Ge, H.-Q.; Ye, C.-P.; Liu, Z.-M.; Su, K.-X. Advances in Homogeneous and Heterogeneous Catalytic Asymmetric Epoxidation. *Chem. Rev.* **2005**, *105*, 1603-1662, <https://doi.org/10.1021/cr0406458>.
 17. Ceramella, J.; Iacopetta, D.; Catalano, A.; Cirillo, F.; Lappano, R.; Sinicropi, M.S. A Review on the Antimicrobial Activity of Schiff Bases: Data Collection and Recent Studies. *Antibiotics* **2022**, *11*, 191, <https://doi.org/10.3390/antibiotics11020191>.
 18. More, M.S.; Joshi, P.G.; Mishra, Y.K.; Khanna, P.K. Metal complexes driven from Schiff bases and semicarbazones for biomedical and allied applications: a review. *Materialstoday Chem.* **2019**, *14*, 100195, <https://doi.org/10.1016/j.mtchem.2019.100195>.
 19. Kim, S.M.; Kim, J.S.; Sin, D.M.; Kim, Y.G.; Ha, Y.G. Synthesis and Application of the Novel Azomethine Metal Complexes for the Organic Electroluminescent Devices. *Bull. Korean Chem. Soc.* **2001**, *22*, 743-747, <https://doi.org/10.5012/bkcs.2001.22.7.743>.
 20. Wang, L.; Jiao, S.; Zhang, W.; Liu, Y.; Yu, G. Synthesis, structure, optoelectronic properties of novel zinc Schiff-base complexes. *Chin. Sci. Bull.* **2013**, *58*, 2733-2740, <https://doi.org/10.1007/s11434-013-5786-2>.
 21. Sonawane, S.H.; Gore, G.M.; Polke, B.G.; Nazare, A.N.; Asthana, S. Transition Metal Carbohydrazide Nitrates: Burn-rate Modifiers for Propellants. *Def. Sci. J.* **2006**, *56*, 391.
 22. Bushuyev, O.S.; Arguelles, F.A.; Brown, P.; Weeks, B.L.; Hope-Weeks L.J. New Energetic Complexes of Copper(II) and the Acetone Carbohydrazide Schiff Base as Potential Flame Colorants for Pyrotechnic Mixtures. *Eur. J. Inorg. Chem.* **2011**, *2011*, 4622-4625, <https://doi.org/10.1002/ejic.201100465>.
 23. Elkanzi, N.A.A.; Hrichi, H.; Salah, H.; Albqmi, M.; Ali, A.M.; Abdou, A. Synthesis, physicochemical properties, biological, molecular docking and DFT investigation of Fe(III), Co(II), Ni(II), Cu(II) and Zn(II) complexes of the 4-[(5-oxo-4,5-dihydro-1,3-thiazol-2-yl)hydrazono]methyl}phenyl 4-methylbenzenesulfonate Schiff-base ligand. *Polyhedron* **2023**, *230*, 116219, <https://doi.org/10.1016/j.poly.2022.116219>.
 24. Jain, S.; Rana, M.; Sultana, R.; Mehendi, R.; Rahisuddin. Schiff Base Metal Complexes as Antimicrobial and Anticancer Agents. *Polycycl. Aromat. Compd.* **2022**, *43*, 6351-6406, <https://doi.org/10.1080/10406638.2022.2117210>.
 25. Zafar, W.; Sumrra, S. H.; Chohan, Z. H. A review: Pharmacological aspects of metal based 1, 2, 4-triazole derived Schiff bases. *Eur. J. Med. Chem.* **2021**, *222*, 113602. <https://doi.org/10.1016/j.ejmech.2021.113602>.
 26. Mishra, R.; Kumar, N.; Sachan, N. Thiophene and Its Analogs as Prospective Antioxidant Agents: A Retrospective Study. *Mini-Rev. Med. Chem.* **2022**, *22*, 1420-1437, <https://doi.org/10.2174/1389557521666211022145458>.

27. Ramu, R.; Shirahatti, P.S.; Zameer, F.; Ranganatha, L.V.; Prasad, M.N.N. Inhibitory effect of banana (*Musa* sp. var. Nanjangud rasa bale) flower extract and its constituents Umbelliferone and Lupeol on α -glucosidase, aldose reductase and glycation at multiple stages. *S. Afr. J. Bot.* **2014**, *95*, 54-63, <https://doi.org/10.1016/j.sajb.2014.08.001>.
28. Alorini, T.A.; Al-Hakimi, A.N.; Saeed, S.E.-S.; Alhamzi, E.H.L.; Albadri, A.E.A.E. Synthesis, characterization, and anticancer activity of some metal complexes with a new Schiff base ligand. *Arab. J. Chem.* **2022**, *15*, 103559, <https://doi.org/10.1016/j.arabjc.2021.103559>.
29. Vinusha, H.M.; Kollur, S.P.; Begum, M.; Shivamallu, C.; Ramu, R.; Shirahatti, P.S.; Prasad, N.; Veerapur, R.; Ortega-Castro, J.; Frau, J.; Flores-Holguín, N.; Glossman-Mitnik, D. Chemical synthesis, *in vitro* biological evaluation and theoretical investigations of transition metal complexes derived from 2-(((5-mercapto-1*H*-pyrrol-2-yl)imino) methyl)6-methoxyphenol. *J. Mol. Struct.* **2021**, *1244*, 130920, <https://doi.org/10.1016/j.molstruc.2021.130920>.
30. Alias, M.; Kassum, H.; Shakir, C. Synthesis, physical characterization and biological evaluation of Schiff base M(II) complexes. *J. Assoc. Arab Univ. Basic Appl. Sci.* **2014**, *15*, 28-34, <https://doi.org/10.1016/j.jaubas.2013.03.001>.
31. Sharma, A.K.; Chandra, S. Complexation of nitrogen and sulphur donor Schiff's base ligand to Cr(III) and Ni(II) metal ions: Synthesis, spectroscopic and antipathogenic studies. *Spectrochim. Acta A Mol. Biomol. Spectrosc.* **2011**, *78*, 337-342, <https://doi.org/10.1016/j.saa.2010.10.017>.
32. Singh, K.; Singh, D.P.; Singh Barwa, M.; Tyagi, P.; Mirza, Y. Some bivalent metal complexes of Schiff bases containing N and S donor atoms. *J. Enzyme Inhib. Med. Chem.* **2006**, *21*, 749-755, <https://doi.org/10.1080/14756360600838648>.
33. Varshney, A.; Tandon, J.P.; Crowe, A.J. Synthesis and structural studies of tin(II) complexes of semicarbazones and thiosemicarbazones. *Polyhedron* **1986**, *5*, 739-742, [https://doi.org/10.1016/S0277-5387\(00\)84430-7](https://doi.org/10.1016/S0277-5387(00)84430-7).
34. Kaya, I.; Daban, S.; Şenol, D. Synthesis and characterization of Schiff base, Co(II) and Cu(II) metal complexes and poly(phenoxy-imine)s containing pyridine unit. *Inorganica Chim. Acta.* **2021**, *515*, 120040, <https://doi.org/10.1016/j.ica.2020.120040>.
35. Pandiarajan, S.; Hajarabeevi, N.; Shaikh, R.R.; Raghunathan, S.; MubarakAli, D. Synthesis and Characterization of Novel Schiff Bases Derived from 2-Butyl-4-chloro Imidazole for the Enhanced Antimicrobial Property. *Appl. Biochem. Biotechnol.* **2023**, *195*, 253-263, <https://doi.org/10.1007/s12010-022-04112-2>.
36. Kollur, S.P.; Castro, J.O.; Frau, J.; Flores-Holguín, N.; Shruthi, G.; Shivamallu, C.; Glossman-Mitnik, D. Preparation, spectroscopic investigations and chemical reactivity properties of a new schiff base ligand and its copper (II) complexes. *J. Mol. Struct.* **2019**, *1191*, 17-23, <https://doi.org/10.1016/j.molstruc.2019.03.101>.
37. Vinusha, H.M.; Kollur, S.P.; Revanasiddappa, H.D.; Ramu, R.; Shirahatti, P.S.; Prasad, M.N.N.; Chandrashekar, S.; Begum, M. Preparation, spectral characterization and biological applications of Schiff base ligand and its transition metal complexes. *Results Chem.* **2019**, *1*, 100012, <https://doi.org/10.1016/j.rechem.2019.100012>.
38. Deepika, P.; Vinusha, H.M.; Begum, M.; Ramu, R.; Shirahatti, P.S.; Prasad, M.N.N. 2-methoxy-4-(((5-nitropyridin-2-yl)imino)methyl)phenol Schiff base ligand and its Cu(II) and Zn(II) complexes: synthesis, characterization and biological investigations. *Heliyon* **2022**, *8*, e09648, <https://doi.org/10.1016/j.heliyon.2022.e09648>.
39. Kianfar, A.H.; Ramazani, S.; Fath, R.H.; Roushani, M. Synthesis, spectroscopy, electrochemistry and thermogravimetry of copper(II) tridentate Schiff base complexes, theoretical study of the structures of compounds and kinetic study of the tautomerism reactions by ab initio calculations. *Spectrochim. Acta A Mol. Biomol. Spectrosc.* **2013**, *105*, 374-382, <https://doi.org/10.1016/j.saa.2012.12.010>.
40. Aly, F.A.; Abu-El-Wafa, S.M.; Issa, R.M.; El-Sayed, F.A. On the formation of mononuclear and binuclear complexes of pentadentate N₄O₂ schiff base ligands with Co(II), Ni(II) and Cu(II) ions: TGA, spectral and conductance studies. *Thermochim. Acta* **1988**, *126*, 235-244, [https://doi.org/10.1016/0040-6031\(88\)87269-1](https://doi.org/10.1016/0040-6031(88)87269-1).