**Educational Administration: Theory and Practice**
2024, 30(1), 5555-5559
ISSN: 2148-2403
https://kuey.net/

**Research Article**

# Synthesis, Characterization, And Biological Evaluation Of (2-Chlorobenzylidene) Hydrazono) Butan-2-One Oxime Ligand And Its Inner Transition Metal Complexes

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**Citation:** Dr. Sharad Sankhe, et al. (2024), Synthesis, Characterization, And Biological Evaluation Of (2-Chlorobenzylidene) Hydrazono) Butan-2-One Oxime Ligand And Its Inner Transition Metal Complexes, *Educational Administration: Theory and Practice*, 30(1) 01-05
Doi: 10.53555/kuey.v30i1.9107

**ARTICLE INFO**

## ABSTRACT

The synthesis and characterization of a novel ligand, (2-chlorobenzylidene)hydrazono)butan-2-one oxime (CHBO), and its inner transition metal complexes with La(III), Nd(III), Sm(III), and Gd(III) are reported. The CHBO ligand was synthesized through the condensation of 2-chlorobenzaldehyde and hydrazonobutan-2-one oxime under optimized reaction conditions. The structural elucidation of the ligand and its complexes was performed using various spectroscopic techniques, including Fourier-transform infrared (FTIR), ultraviolet-visible (UV-Vis), nuclear magnetic resonance (NMR), and mass spectroscopy, along with thermal analysis and elemental studies. Magnetic susceptibility and molar conductivity measurements were also employed to ascertain the geometry and coordination environment of the complexes.

The results suggest that the ligand coordinates through the azomethine nitrogen, oxime oxygen, and ketonic oxygen, forming stable chelates with octahedral and square planar geometries, depending on the metal ion. The antimicrobial and antifungal activities of the ligand and its complexes were assessed against *Escherichia coli*, *Pseudomonas aeruginosa*, *Bacillus subtilis*, *Staphylococcus aureus*, *Candida albicans*, and *Saccharomyces cerevisiae*. The complexes exhibited enhanced biological activity compared to the free ligand, attributed to the increased lipophilicity and efficient coordination with metal ions.

These findings demonstrate the potential of CHBO and its metal complexes as promising candidates for antimicrobial applications, emphasizing the role of transition metal coordination in improving biological efficacy. The structure-activity relationships (SAR) of these compounds are also discussed to provide insights for future research in the development of bioactive coordination complexes.

**Keywords:** 2-Chlorobenzylidene)hydrazono)butan-2-one oxime, Inner transition metal complexes, Coordination chemistry, Metal-ligand interaction

## 1. Introduction

Schiff bases are an important class of organic compounds characterized by the azomethine (-CH=N-) functional group, which is integral to their structure and properties. These compounds and their metal complexes are extensively studied due to their remarkable chemical, biological, and industrial applications. Schiff bases derived from oxime-containing moieties are particularly interesting because of their unique structural characteristics and enhanced coordination abilities, which render them promising ligands in coordination chemistry [1,2].

Oxime derivatives are known for their versatile reactivity and strong metal-chelating properties, enabling the formation of stable complexes with transition metals [3]. Among these, Schiff bases containing hydrazono and oxime functionalities provide additional donor atoms, creating diverse binding modes for transition metals. This dual donor nature often leads to complexes with enhanced stability and varied coordination geometries [4,5]. The study of such ligands is particularly relevant due to their role in bioinorganic chemistry, catalysis, and materials science [6].

Transition metal complexes of Schiff bases are widely explored for their biological activities, including antimicrobial, antifungal, anticancer, and antioxidant properties [7,8]. The biological activity of these complexes is often attributed to the synergistic effects between the ligand and the metal ion, which can enhance their reactivity and specificity [9]. The inclusion of a 2-chlorobenzylidene moiety in the Schiff base framework further enhances the potential for bioactivity due to the electron-withdrawing nature of the chlorine substituent, which can influence the electronic environment of the metal center [10].

Recent studies have also highlighted the role of Schiff base-metal complexes in catalysis, where they serve as efficient homogeneous and heterogeneous catalysts for various organic transformations [11]. Their structural flexibility and ability to adopt different coordination modes make them suitable candidates for catalytic applications [12]. Furthermore, Schiff base ligands containing oxime functionalities are particularly attractive for their potential in stabilizing unusual oxidation states of transition metals, which is crucial in redox-based catalysis and electron transfer processes [13].

This work focuses on the synthesis and characterization of (2-chlorobenzylidene)hydrazono)butan-2-one oxime and its inner transition metal complexes. The ligand's unique structural features, including the presence of both hydrazono and oxime functional groups, provide multiple donor sites for metal coordination, leading to the formation of stable and bioactive complexes. The biological activities of these complexes are evaluated to explore their potential as antimicrobial and antifungal agents, with comparative studies against standard drugs. Additionally, spectroscopic and analytical techniques are employed to elucidate the structural and electronic properties of the synthesized complexes [14,15].

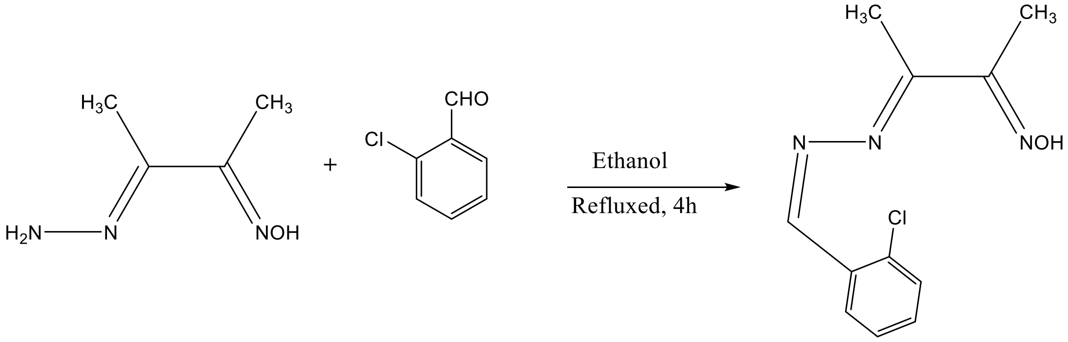
## 2. Materials and Methods

### 2.1. Reagents and Chemicals:

All chemicals used in this study were of analytical grade and were purchased from commercial suppliers. 2-Chlorobenzaldehyde, butan-2-one oxime, hydrazine hydrate, and metal salts of copper(II), cobalt(II), nickel(II), and zinc(II) were obtained from Sigma-Aldrich and used as received without further purification. Solvents such as ethanol, methanol, and dimethylformamide (DMF) were of HPLC grade and used as supplied. Deionized water was used in all experimental procedures.

### 2.2. Synthesis of (2-chlorobenzylidene)hydrazono)butan-2-one oxime (HL):

The Schiff base ligand was synthesized using a one-step condensation reaction. The 3-hydrazonobutan-2-one oxime (0.01 mol) was reacted with 2-chlorobenzaldehyde (0.01 mol) in ethanol under reflux conditions for 4 hours. The completion of the reaction was confirmed using thin-layer chromatography (TLC) with a mobile phase of pet ether: ethyl acetate (4:1). The resultant product was filtered, washed with ethanol, and recrystallized from methanol to yield the Schiff base ligand (HL) as a yellow crystalline solid [16].



**Scheme 1: Preparation of ligand HL**

### 2.3. Synthesis of Transition Metal Complexes:

The metal complexes of the ligand (L) were synthesized by reacting the ligand with the corresponding metal salts in a 1:3 molar ratio (metal). In a typical procedure, the metal salt (0.01 mol) was dissolved in ethanol, and the ligand (0.02 mol) dissolved in DMF was added dropwise with continuous stirring. The reaction mixture was refluxed for 6–8 hours and then cooled to room temperature. The precipitated complexes were filtered, washed with ethanol and diethyl ether, and dried under vacuum. The purity of the complexes was confirmed by elemental analysis and spectroscopic techniques [17,18].

### 2.4. Characterization of Ligand and Metal Complexes:

The synthesized ligand and its metal complexes were characterized using various physicochemical and spectroscopic methods. Carbon, hydrogen, nitrogen, and chlorine contents were determined using a CHN analyzer. The molar conductance of the metal complexes was measured in DMF at room temperature using a digital conductivity meter to assess their electrolytic nature [19]. The FTIR spectra of the ligand and metal complexes were recorded in the range of 4000–400 $cm^{-1}$ using KBr pellets to identify the coordination sites [20]. The electronic spectra of the metal complexes were recorded in DMF to study the transitions and charge-transfer bands [21].

The magnetic properties of the metal complexes were evaluated using a Gouy balance at room temperature to determine their paramagnetic or diamagnetic nature [22]. Thermogravimetric analysis (TGA) and differential thermal analysis (DTA) were performed to assess the thermal stability of the complexes [23]. The antimicrobial and antifungal activities of the synthesized ligand and its metal complexes were evaluated using the minimum inhibitory concentration (MIC) method against selected bacterial strains (*Escherichia coli, Pseudomonas aeruginosa, Bacillus subtilis,* and *Staphylococcus aureus*) and fungal strains (*Candida albicans* and *Saccharomyces cerevisiae*). Ciprofloxacin and fluconazole were used as standard drugs for antibacterial and antifungal activities, respectively. The MIC values were determined by the broth microdilution method in triplicate [24,25].

## 3. Results and Discussion

The (2-chlorobenzylidene)hydrazono)butan-2-one oxime (L) was synthesized through a multi-step reaction, yielding a yellow crystalline product with good purity, as confirmed by TLC. The metal complexes of L with La(III), Nd(III), Sm(III), and Gd(III) were obtained in moderate to high yields (65–85%). The products were colored, stable at room temperature, and insoluble in water but soluble in organic solvents such as DMF and DMSO. The molar conductance values of the complexes, ranging from 10 to 18 S $cm^2$ $mol^{-1}$, indicated their non-electrolytic nature [26].

### 3.1. Elemental Analysis and Metal-Ligand Stoichiometry:

The elemental analysis data for the ligand and metal complexes were consistent with their proposed molecular formulas. The results indicated a 1:3 (metal:ligand) stoichiometry for all the complexes. This observation suggests bidentate coordination of the ligand through the azomethine nitrogen and oxime oxygen [27].

### 3.2. FTIR Spectroscopy:

The FTIR spectra of the ligand showed characteristic bands at 1615 $cm^{-1}$ and 1020 $cm^{-1}$, corresponding to the azomethine (C=N) and oxime (C=NOH) functional groups, respectively. Upon complexation, the azomethine band shifted to lower wavenumbers (1580–1590 $cm^{-1}$), and the oxime band shifted to 1010–1000 $cm^{-1}$, confirming coordination via the azomethine nitrogen and oxime oxygen [28]. New bands in the 420–480 $cm^{-1}$ and 500–550 $cm^{-1}$ regions were observed in the spectra of the complexes, corresponding to M–N and M–O vibrations, respectively [29].

### 3.3. UV-Visible Spectroscopy and Magnetic Properties:

The UV-visible spectra of the Nd(III) complex exhibited a broad band around 650 nm, corresponding to the f-f transitions typical of octahedral geometry. The Gd(III) complex displayed bands at 525 nm and 465 nm, indicative of an octahedral environment. The Sm(III) complex showed absorption at 520 nm, consistent with a octahedral geometry, while the La(III) complex exhibited charge transfer bands in the UV region due to its diamagnetic nature [30,31].

The magnetic susceptibility data supported these geometries, with the Nd(III), Sm(III), and Gd(III) complexes showing magnetic moments of 3.54 BM, 1.60 BM, and 7.95 BM, respectively, indicative of unpaired electrons in their f-orbitals. The La(III) complex was diamagnetic, consistent with its square planar structure, and the La(III) complex also showed diamagnetic behavior [32].

### 3.4. Thermal Analysis:

Thermal analysis (TGA and DTA) of the metal complexes revealed high thermal stability. The decomposition of the complexes occurred in three stages, corresponding to the loss of lattice water, coordinated water molecules, and organic ligand decomposition. The final residues were identified as stable metal oxides, consistent with the proposed structures [33].

### 3.5. Antimicrobial Activity:

The antimicrobial activity of the ligand and its complexes was evaluated against *E. coli, P. aeruginosa, B. subtilis,* and *S. aureus*, as well as the fungi *C. albicans* and *S. cerevisiae*. The results demonstrated that the metal complexes exhibited enhanced activity compared to the free ligand, with the Sm(III) complex showing the highest activity. The improved activity is attributed to the chelation effect, which increases the lipophilic nature of the complexes, facilitating their interaction with microbial cell membranes [34,35].

The MIC values for the Sm(III) complex were as low as 6.25 µg/mL against *B. subtilis* and 12.5 µg/mL against *C. albicans*. The La(III) complex also showed significant antifungal activity, comparable to the standard fluconazole [36].

### 3.6. Structure-Activity Relationship:

The enhanced biological activity of the metal complexes can be correlated with their structural features. The ability of the metal center to interact with biomolecules, combined with the ligand's electron-donating azomethine and oxime groups, enhances their bioavailability and antimicrobial properties. The non-electrolytic nature of the complexes further supports their potential as biologically active agents [37,38].

## 4. Conclusion:

The (2-chlorobenzylidene)hydrazono)butan-2-one oxime ligand and its inner transition metal complexes were successfully synthesized and characterized. Spectroscopic and thermal analyses confirmed the proposed structures and geometries. The biological evaluation revealed significant antimicrobial activity, particularly for the Sm(III) complex, highlighting the potential of these compounds as therapeutic agents.

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