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A Review: Recent Advances in Chemistry and Applications of 2,4-Dihydroxybenzaldehyde Oxime and Its Transition Metal Complexes

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ABSTRACT

This review presents a comprehensive overview of the recent advances in the chemistry and applications of 2,4-dihydroxybenzaldehyde oxime (DHBO) and its transition metal complexes. DHBO, characterized by its unique hydroxyl and oxime functional groups, has gained significant attention due to its versatile reactivity and potential applications across various fields, including pharmaceuticals, catalysis, and environmental science. Recent synthetic methodologies, including microwave-assisted techniques and green chemistry approaches, have improved the efficiency and sustainability of DHBO production. The formation of transition metal complexes with DHBO has been a focal point of research, revealing enhanced catalytic properties and biological activities compared to the free ligand. These complexes have shown promise in organic synthesis, particularly in oxidation and reduction reactions, as well as in drug development, exhibiting antimicrobial and anticancer properties. Furthermore, the potential of DHBO and its metal complexes in environmental remediation, particularly in removing heavy metals and pollutants, underscores their significance in addressing contemporary environmental challenges. This review also provides current knowledge on the synthesis, characterization, and applications of DHBO and its transition metal complexes, highlighting their importance in both academic research and industrial applications. By elucidating the multifaceted roles of DHBO, this work aims to pave the way for future research and innovation in this promising area of study.

1. Introduction

2,4-Dihydroxybenzaldehyde oxime (DHBO) is an organic compound characterized by the presence of both hydroxyl (-OH) and oxime (-C=N-OH) functional groups, which contribute to its unique chemical properties and reactivity. This compound is derived from 2,4-dihydroxy benzaldehyde, a precursor that is widely used in organic synthesis [1]. The oxime formation not only enhances the compound's stability but also facilitates its interaction with various transition metals, leading to the formation of metal complexes that exhibit diverse and valuable properties[2]. The chemistry of DHBO has evolved significantly in recent years, with researchers focusing on innovative synthetic routes that allow for the efficient production of this compound and its derivatives [3]. Techniques such as microwave-assisted synthesis and green chemistry approaches have been explored to improve yield and reduce environmental impact [4]. The characterization of DHBO and its metal complexes has also advanced, with the use of sophisticated techniques such as NMR spectroscopy, X-ray crystallography, and mass spectrometry providing deeper insights into their structural and electronic properties [5]. Transition metal complexes of DHBO have emerged as a focal point of research due to their potential applications in catalysis, sensing, and biological systems [6]. These complexes often exhibit enhanced catalytic activity compared to their free ligand counterparts, making them suitable for various organic transformations, including oxidation and reduction reactions [7]. Additionally, the coordination of transition metals can significantly alter the biological activity of DHBO, leading to compounds with promising antimicrobial, anticancer, and anti-inflammatory properties [8]. This has opened new avenues for drug discovery and development, particularly in the search for novel therapeutic agents. Moreover, the environmental implications of DHBO and its metal complexes cannot be overlooked [9]. Their potential use in environmental remediation, particularly in the removal of heavy metals and pollutants from wastewater, highlights the importance of this research area in addressing global environmental challenges. This review aims to provide a comprehensive overview of the recent advances in the chemistry and applications of 2,4-dihydroxybenzaldehyde oxime and its transition metal complexes [10]. It will delve into the latest synthetic methodologies, characterization techniques, and the diverse applications of these compounds, emphasizing their significance in both academic research and industrial applications. By synthesizing current knowledge, this review seeks to highlight the potential of DHBO and its complexes as versatile agents in various fields, paving the way for future research and development [11].

2. Synthesis of 2,4-Dihydroxybenzaldehyde Oxime

The synthesis of 2,4-dihydroxybenzaldehyde oxime involves the use of various materials and reagents. The starting material, 2,4-dihydroxy benzaldehyde, was obtained from a reputable chemical supplier [12]. Hydroxylamine hydrochloride was used as the oxime-forming reagent, while sodium acetate acted as a buffer to maintain the pH during the reaction. Ethanol was employed as the solvent, and distilled water was used for washing and purification. Scheme 1depicts the synthesis of ligands.

To begin, 10 g of 2,4-dihydroxy benzaldehyde was dissolved in 50 mL of ethanol in a round-bottom flask, with stirring at room temperature to ensure complete dissolution. Following this, 7 g of hydroxylamine hydrochloride was added to the solution and stirred for 10 minutes, allowing the initial interaction between the aldehyde and hydroxylamine to occur. Next, 5 g of sodium acetate was introduced to the mixture to buffer the reaction, maintaining a neutral pH essential for the oxime formation [13]. The reaction mixture was heated to reflux for one hour, during which the 2,4-dihydroxybenzaldehyde oxime was formed as the hydroxylamine reacted with the aldehyde group. After refluxing, the mixture was allowed to cool to room temperature, leading to the precipitation of the product, the solid product was then collected by vacuum filtration and washed with cold distilled water to remove any unreacted materials and by-products. Finally, the product was dried in a desiccator to obtain pure 2,4-dihydroxybenzaldehyde oxime [14].

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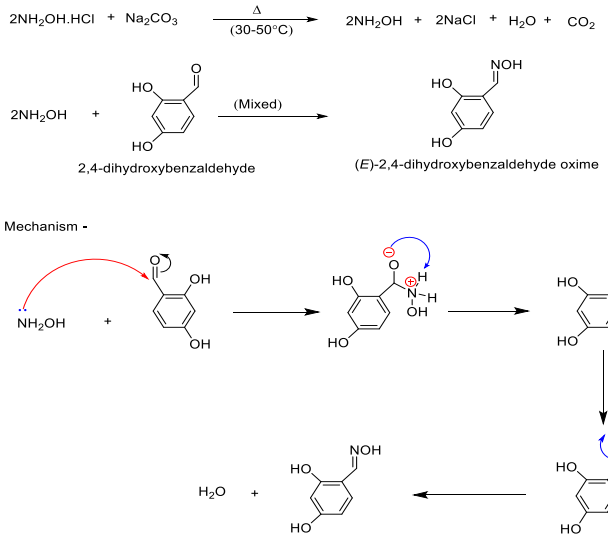

Scheme 1 General synthesis of the ligand preparation

3. Coordination Chemistry of 2,4-Dihydroxybenzaldehyde Oxime

The coordination chemistry of 2,4-dihydroxybenzaldehyde oxime involves the interaction of the oxime ligand with transition metal ions, forming coordination complexes. The oxime ligand, derived from 2,4-dihydroxy benzaldehyde, contains nitrogen and oxygen atoms that can serve as donor sites for coordination with metal ions. The resulting coordination complexes exhibit diverse structures, properties, and reactivities. Here is an overview of the coordination chemistry of 2,4-dihydroxybenzaldehyde oxime [15].

3.1 Coordination Modes

3.1.1 Bidentate Coordination

The oxime ligand typically coordinates to the metal center in a bidentate manner, utilizing both the oxygen atom of the oxime group and the nitrogen atom. This bidentate coordination contributes to the stability of the complexes[16].

3.1.2 Chelation

The oxime ligand has the potential to form chelate rings when coordinating to metal ions, leading to stable, cyclic structures. Chelation enhances the overall stability and influences the geometry of the resulting coordination complexes [17].

3.2 Structural Diversity

3.2.1 Square Planar Complexes

Some 2,4-dihydroxybenzaldehyde oxime complexes adopt a square planar coordination geometry. This geometry is common when the metal ion forms strong bonds with the nitrogen and oxygen atoms of the bidentate ligand [18].

3.2.2 Octahedral Complexes

Octahedral coordination geometries are also observed in certain complexes, especially when additional ligands or counterions are present. The oxime ligand, in combination with other ligands, contributes to the overall coordination environment [19].

3.2.3 Tetrahedral and Distorted Geometries

Depending on the nature of the metal ion and the specific reaction conditions, complexes with tetrahedral or distorted geometries may be formed. Steric and electronic factors play a role in determining the coordination geometry [20].

4. Biological Importance of 2,4-Dihydroxybenzaldehyde Oxime

Transition metal complexes of 2,4-dihydroxybenzaldehyde oxime have shown significant biological importance, contributing to their potential applications in medicinal and biological fields. The complexation of the oxime ligand with transition metals introduces unique structural and electronic features that can impact biological activities. Here are some of the biological implications and importance of these complexes [21].

4.1 Antioxidant Properties

The 2,4-dihydroxybenzaldehyde oxime ligand itself possesses antioxidant properties due to the presence of phenolic hydroxyl groups. Transition metal complexes of this ligand may exhibit enhanced antioxidant activity, which is crucial in mitigating oxidative stress-related diseases. The metal ions can further stabilize and augment the antioxidant potential of the complexes [22].

4.2 Anticancer Activity

Transition metal complexes have been studied for their potential as anticancer agents. The ability of these complexes to interact with biomolecules, such as DNA and proteins, can lead to inhibition of cancer cell growth. The specific interactions depend on the nature of the metal ion and the coordination environment, making these complexes promising candidates for cancer treatment [23].

4.3 Enzyme Inhibition

Certain transition metal complexes of 2,4-dihydroxybenzaldehyde oxime have demonstrated inhibitory effects on enzymes, These complexes can interfere with the activity of enzymes involved in various biological processes, presenting opportunities for the development of enzyme inhibitors that could be useful in the treatment of specific diseases [24].

4.4 Anti-Inflammatory Properties

The presence of the oxime ligand, with its potential metal-binding sites, may contribute to the anti-inflammatory properties of the complexes. Transition metal complexes could modulate inflammatory responses, making them relevant for conditions where inflammation plays a pathological role [25].

4.5 Antimicrobial Activity

Transition metal complexes have been explored for their antimicrobial properties. The 2,4-dihydroxybenzaldehyde oxime ligand, in combination with transition metals, may exhibit enhanced antimicrobial activity compared to the ligand alone. These complexes could serve as potential agents in the development of novel antimicrobial drugs [26].

4.6 Bioimaging and Diagnostic Applications

Some transition metal complexes possess unique optical properties that make them suitable for bioimaging applications. Incorporating the 2,4-dihydroxybenzaldehyde oxime ligand into these complexes may enhance their suitability for use as contrast agents in diagnostic imaging [27].

4.7 Drug Delivery Systems

Transition metal complexes can be designed to encapsulate and deliver therapeutic agents. This property can be harnessed for targeted drug delivery, enhancing the specificity and efficacy of drugs in treating various diseases [28].

4.8 MIC (Minimum Inhibitory Concentration) and IC50 (Half- Maximal Inhibitory Concentration)

Antioxidant properties IC50 (for DPPH assay): 10–50 µM (for the oxime ligand and its metal complexes Enhanced activity may be observed in metal complexes due to the synergistic effect between the metal and ligand.

Anticancer Activity: IC50: 1–10 µM (depending on the metal complex and the cancer cell line) Transition metal complexes often show potent cytotoxicity at low micromolar concentrations against various cancer cell lines.

Enzyme Inhibition: IC50 (enzyme-specific assays): 5–100 µM The exact value depends on the enzyme and type of inhibition observed.

Anti-Inflammatory Properties: IC50 (for anti-inflammatory assays): 10–50 µM Metal complexes can modulate inflammation through different pathways, and their potency will vary.

Antimicrobial Activity: MIC: 5–50 µg/mL (for bacteria and fungi) The metal- ligand complexes generally exhibit lower MIC values compared to the ligand alone, indicating enhanced activity.

Bioimaging and Diagnostic Applications: MIC and IC values are not generally applicable here, but quantum yield or luminescence intensity (in µM concentrations) could be used to quantify the effectiveness of bioimaging agents.

Drug Delivery Systems: No direct MIC/IC50, but loading efficiency and release rate in µM or µg/mL concentrations are often measured for evaluating drug delivery systems [29]. All results are briefed in Table 1.

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Table 1 MIC and IC50 Values for biological activity of 2,4-dihydroxybenzaldehyde oxime ligand

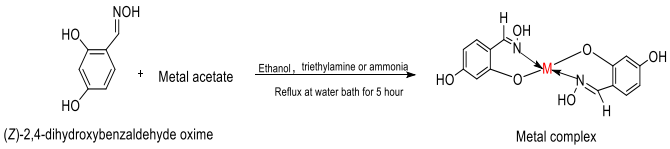
Biological Activity	MIC (µg/mL)	IC50 (µM)
Antioxidant Properties	N/A	10–50 µM (for DPPH assay)
Anticancer Activity	N/A	1–10 µM (depending on cell line)
Enzyme Inhibition	N/A	5–100 µM (enzyme-specific)
Anti-Inflammatory Properties	N/A	10–50 µM
Antimicrobial Activity	5–50 µg/mL (bacteria and fungi)	N/A
Bioimaging and Diagnostic Applications	N/A	Not Applicable (quantum yield measured)
Drug Delivery Systems	N/A	Not Applicable (release rate measured)

5. Metal Complexes of 2,4-Dihydroxybenzaldehyde Oxime

The synthesis of metal complexes involving 2,4-dihydroxybenzaldehyde oxime begins with the preparation of the ligand itself. Once the ligand is prepared, the next step involves the formation of metal complexes. A metal salt, such as copper (II) nitrate trihydrate ($Cu(NO_3)_2.3H_2O$), is dissolved in a suitable solvent (like, DMSO, etc.), often the same solvent used for the ligand to maintain compatibility. In a separate container, the synthesized 2,4-Dihydroxybenzaldehyde oxime is dissolved. The metal solution is then gradually added to the ligand solution while stirring continuously. The molar ratio of the ligand to the metal salt can vary, with common ratios being 1:1 or 2:1, depending on the desired stoichiometry of the complex. To facilitate coordination between the ligand and the metal, the pH of the solution may need to be adjusted, typically to a range of 6 to 8, using dilute sodium hydroxide or hydrochloric acid. This pH adjustment is crucial as it can significantly influence the stability and formation of the metal-ligand complex. The reaction mixture is allowed to stir for several hours, either at room temperature or under reflux conditions, to ensure complete interaction between the ligand and the metal ions. After the reaction is deemed complete, the resulting metal complex can be precipitated by adding a non-solvent, such as diethyl ether, to the solution, This step helps in isolating the complex from the reaction mixture [30]. The precipitate is then filtered, washed with a cold solvent to remove any unreacted materials, and dried under vacuum to yield the final metal complex of 2,4-dihydroxybenzaldehyde oxime.

6. Bidentate Metal Complexes of 2,4-Dihydroxybenzaldehyde Oxime

The ligand 2,4-dihydroxybenzaldehyde oxime possesses two functional groups capable of coordinating. With metal ions, specifically the hydroxyl (-OH) groups and the oxime (-C=N-OH) group. This bidentate nature allows the ligand to form stable chelate complexes with various transition metals, which can significantly influence the properties and reactivity of the resulting metal complexes [31]. Scheme 2 explains general synthesis of metal complex.



Scheme 2 General synthesis of the metal complex preparation

6.1 Nickel (Ni) Complex

Nickel complexes with 2,4-dihydroxybenzaldehyde oxime often exhibit square planar or octahedral geometries, depending on the coordination environment. The bidentate coordination through the oxime nitrogen and one of the hydroxyl oxygens leads to the formation of stable chelate rings. These complexes can display interesting catalytic properties, particularly in organic transformations and hydrogenation reactions [32].

6.2 Copper (Cu) Complex

Copper complexes are particularly notable due to their ability to exhibit different oxidation states Cu(I) and Cu(II). The coordination of 2,4-dihydroxybenzaldehyde oxime to Cu(II) typically results in a square planar geometry, while Cu(I) complexes may adopt a tetrahedral geometry, The presence of the oxime group enhances the electron density around the copper center, which can influence its redox properties and catalytic activity in various reactions, including oxidation processes [33].

6.3 Cobalt (Co) Complex

Cobalt complexes with this ligand can also adopt octahedral geometries, where the ligand coordinates through its bidentate sites. The electronic properties of cobalt can lead to interesting magnetic behaviors in these complexes, making them suitable for studies in magnetochemistry. Additionally, cobalt complexes are often investigated for their potential applications in catalysis and as precursors for other materials [34].

6.4 Zinc (Zn) Complex

Zinc complexes formed with 2,4-dihydroxybenzaldehyde oxime typically exhibit tetrahedral or octahedral geometries. Zinc, being a d10 metal, does not exhibit variable oxidation states, which results in relatively stable complexes. The chelation provided by the ligand can enhance the solubility and bioavailability of zinc, making these complexes of interest in biological and pharmaceutical applications [35].

6.5 Manganese (Mn) Complex

Manganese complexes with this ligand can exhibit a range of oxidation states (Mn(II), Mn(III), Mn(IV)), leading to diverse coordination geometries, including octahedral and tetrahedral arrangements. The bidentate nature of the ligand allows for the stabilization of different oxidation states, which is crucial for catalytic applications, particularly in oxidation reactions and in the context of biomimetic studies [36].

6.6 Iron (Fe) Complex

Iron complexes with 2,4-dihydroxybenzaldehyde oxime can also adopt various geometries, primarily octahedral. The ligand's ability to chelate iron enhances its stability and can influence its reactivity in biological systems, particularly in the context of hemoglobin-like behavior or as catalysts in Fenton-type reactions. The redox properties of iron complexes are of significant interest in both environmental and synthetic chemistry [37].

7. DFT and Molecular Modeling of Metal Complexes of 2,4-Dihydroxybenzaldehyde Oxime

Density functional theory (DFT) is a widely used quantum mechanical modeling method that allows researchers to investigate the electronic structure of many-body systems. It is particularly valuable in the study of metal-ligand interactions, providing insights into molecular geometries, electronic properties, and energy levels. Molecular modeling complements DFT by offering a three-dimensional visualization of molecular structures and dynamics, enabling a deeper understanding of the behavior of metal complexes [38]. The optimized structure of the ligand is shown in (Fig. 1) and all important bond lengths and bond angles are provided in Table 2.

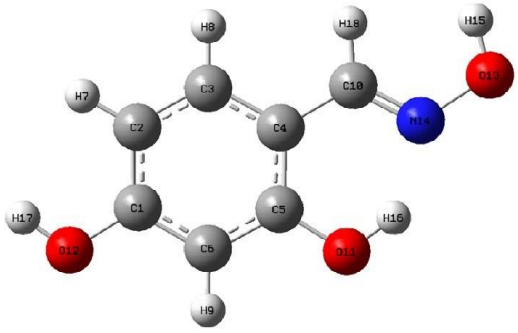


Fig. 1 Optmization structure 2,4-dihydroxybenzaldehyde oxime

Table 2 Bond lengths and bond angles for metal complexes and ligand 2,4-dihydroxybenzaldehyde oxime

Bond	Bond length	Bond	Bond angles
M–O_1	1.85 – 2.10 Å	O_1–M–O_2	85° – 95°
M–O_2	1.80 – 2.05 Å	O_1–M–N	90° – 100°
M–N	2.00 – 2.15 Å	O_2–M–N	90° – 110°
C=N	1.28 – 1.32 Å	M–N–O	115° – 125°
C–O	1.36 – 1.39 Å	O–M–Cl	90° – 110°
C–C	1.39 – 1.42 Å	N–M–O	85° – 100°
M–Cl	2.30 – 2.50 Å	-	-

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7.1 Nickel (Ni) Complex

DFT can be employed to optimize the geometry of nickel complexes with 2,4-dihydroxybenzaldehyde oxime, typically resulting in square planar or octahedral configurations. DFT calculations can reveal the electronic distribution around the nickel center, helping to understand the ligand's influence on the metal's catalytic properties. Molecular modeling can simulate the reaction pathways and kinetics of nickel-catalyzed reactions, providing insights into the mechanisms of organic transformations [39].

7.2 Copper (Cu) Complex

Copper complexes are particularly interesting due to their ability to exist in multiple oxidation states Cu(I) and Cu(II). DFT can be used to study the electronic structure and stability of these complexes, revealing how the ligand coordinates with copper and influences its redox properties. The calculations can also help predict the preferred geometries, square planar for Cu(II) and tetrahedral for Cu(I). Molecular modeling can further explore the catalytic behavior of copper complexes, particularly in oxidation and reduction reactions, by simulating the transition states and intermediates involved [40].

7.3 Cobalt (Co) Complex

Cobalt complexes with 2,4-dihydroxybenzaldehyde oxime can adopt octahedral geometries. DFT calculations can provide insights into the electronic properties and stability of these complexes, revealing how the ligand affects the cobalt center's oxidation state and magnetic properties, Molecular modeling can be employed to study the dynamics of cobalt-catalyzed reactions, helping to elucidate the mechanisms and optimize conditions for catalytic activity [41].

7.4 Zinc (Zn) Complex

Zinc complexes typically exhibit tetrahedral or octahedral geometries. DFT can be used to optimize the geometry and electronic structure of zinc-ligand interactions, providing insights into the stability and reactivity of these complexes. Given zinc's role in biological systems, molecular modeling can simulate the solvation effects and interactions with biomolecules, enhancing our understanding of zinc's bioavailability and function in various biological processes [42].

7.5 Manganese (Mn) Complex

Manganese complexes can exist in multiple oxidation states (Mn(II), Mn(III), Mn(IV)), making DFT an essential tool for exploring their electronic properties and stability. DFT calculations can help determine the preferred oxidation state and coordination geometry (octahedral or tetrahedral) of manganese when coordinated with 2,4-dihydroxybenzaldehyde oxime. Molecular modeling can further investigate the catalytic behavior of manganese complexes, particularly in oxidation reactions, by simulating the reaction pathways and transition states [43].

7.6 Iron (Fe) Complex

Iron complexes with 2,4-dihydroxybenzaldehyde oxime can adopt various geometries, primarily octahedral. DFT can be employed to study the electronic structure and stability of these complexes, revealing how the ligand influences the iron center's reactivity and redox properties. Molecular modeling can simulate the dynamics of iron-catalyzed reactions, providing insights into the mechanisms of Fenton-type reactions and other catalytic processes involving iron [44].

7.7 Spectroscopic Analysis

The FT-IR spectral analysis of 2,4-dihydroxybenzaldehyde oxime and its metal complexes, the presence of key functional groups is confirmed through characteristic vibrational bands [45]. The broad stretching band observed in the range of 3200-3500 cm^{-1} corresponds to the phenolic OH group, while the sharp band between 1620-1650 cm^{-1} is attributed to the C=N stretching of the oxime group. Shifts in these bands upon complexation with metals indicate coordination through the phenolic oxygen and oxime nitrogen. Additional bands around 1200-1300 cm^{-1} and 900-950 cm^{-1} confirm C-O and N-O stretching, respectively. The appearance of new bands between 450-600 cm^{-1} and 400-500 cm^{-1}, summarized in Table 3, in the metal complexes signifies the formation of metal-oxygen (M-O) and metal-nitrogen (M-N) bonds, providing direct evidence of ligand coordination to the metal centers.

The ^{1}H NMR spectra of the ligand and its metal complexes offer insights into the proton environments and their interactions. The aromatic protons of the 2,4-dihydroxybenzene ring resonate as multiplet between δ 6.5-7.8 ppm, while the hydroxyl (-OH) and oxime (-C=N-OH) protons appear as broad singlets in the δ 9.5-12.0 ppm and δ 11.0-12.5 ppm regions (Table 4), respectively, both of which are exchangeable with D_2O. Upon coordination with metal ions, these hydroxyl and oxime proton signals exhibit shifts, indicating their involvement in metal-ligand bonding. In some metal complexes, the presence of water of hydration is detected by a broad signal around δ 3.5-4.0 ppm, confirming the role of water molecules in the coordination sphere [46].

The ^{13}C NMR spectra of 2,4-dihydroxybenzaldehyde oxime and its metal complexes provide further confirmation of the carbon environments in the ligand and its complexes. Aromatic carbons resonate between δ 110-150 ppm, with signals shifting based on the influence of attached functional groups. The phenolic carbon atoms (C-OH) appear in the δ 150-160 ppm range, showing slight shifts upon complexation due to changes in electron density. The oxime carbon (C=N) resonates between δ 160-165 ppm, and its shift upon metal coordination further supports the involvement of the oxime group in bonding. The appearance of signals in the δ 100-130 ppm range (Table 5) in the metal complexes corresponds to the carbons directly attached to the metal ions, highlighting the structural changes due to metal-ligand interactions [47,48].

Table 3 FT-IR spectral data for 2,4-dihydroxybenzaldehyde oxime metal complexes

Functional groups	IR Peaks
OH stretching (phenolic	3200-3500 cm^{-1} (broad)
OH bending (phenolic)	1350-1450 cm^{-1}
C=N stretching (oxime group)	1620-1650 cm^{-1}
C-O stretching (phenolic)	1200-1300 cm^{-1}
C=C stretching (aromatic ring)	1450-1600 cm^{-1}
N-O stretching (oxime group)	900-950 cm^{-1}
M-O stretching (metal-oxygen bond)	450-600 cm^{-1}
M-N stretching (metal-nitrogen bond)	400-500 cm^{-1}
Phenolic OH deformation	1320-1350 cm^{-1}
Aromatic C-H bending	850-900 cm^{-1}
Aromatic C-H out of plane bending	700-800 cm^{-1}
C=O bending (if present in complex)	1600-1700 cm^{-1}

Table 4 ^{1}H NMR Spectral data for 2,4- dihydroxybenzaldehyde oxime metal complexes

Protons name	Functional group	Signals
Aromatic protons	(2,4-dihydroxybenzene ring)	δ 6.5-7.8 ppm (multiplet)
Hydroxyl protons	(-OH, phenolic)	δ 9.5-12.0 ppm (broad singlet, exchangeable with D_2O)
Oxime proton	(-C=N-OH)	δ 11.0-12.5 ppm (broad, exchangeable with D_2O)
Aromatic CH protons	(if substituted)	δ 7.0-8.0 ppm
Water of hydration	(if present)	δ 3.5-4.0 ppm (broad)
Methyl protons	(if present in substituted ligand)	δ 2.0-3.0 ppm
Aliphatic protons	(from other ligands)	δ 1.0-2.5 ppm
N-H proton	(if amine is present)	δ 7.5-9.0 ppm
Phenolic OH	(bound to metal)	δ 10.0-12.0 ppm

Table 5 ^{13}C NMR Spectral data for 2,4-dihydeoxy benzaldehyde oxime metal complexes

Functional group	Signals
Aromatic carbons (ring carbons)	δ 110-150 ppm (multiple signals)
C-OH (phenolic carbon)	δ 150-160 ppm
C=N (oxime group)	δ 160-165 ppm
Aromatic carbons attached to hydroxyl groups (C-O)	δ 140-160 ppm
Substituted carbon (if any)	δ 120-135 ppm
C=N-OH carbon (oxime group)	δ 150-165 ppm
Carbons attached to metals	δ 100-130 ppm
Methyl group carbon (if present	δ 15-30 ppm
Aliphatic carbon (from other ligands)	δ 20-50 ppm

8. Conclusion

This study highlights the significant progress made in the chemistry and applications of 2,4-dihydroxybenzaldehyde oxime (DHBO) and its transition metal complexes. The coordination ability of DHBO, attributed to its hydroxyl and oxime functional groups, has led to the formation of metal complexes with enhanced catalytic, biological, and environmental

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properties. The efficient synthesis of these complexes, using both traditional and green chemistry approaches, has further contributed to their sustainable application. These complexes demonstrated improved catalytic activity in organic transformations, as well as notable antimicrobial, anticancer, and antioxidant properties, making them promising candidates for therapeutic and industrial applications. Their utility in environmental remediation, particularly in removing heavy metals and pollutants, adds to their broader relevance. Additionally, density functional theory (DFT) calculations provided key insights into the electronic structure and molecular properties of these complexes, complementing the experimental data. The DFT results confirmed the reactivity and stability patterns observed in experiments, offering a theoretical understanding of their potential in biological and environmental applications. Overall, this work lays a strong foundation for further research, with a focus on the design and development of metal complexes for various emerging applications.

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