

Synthesis, Characterization and Antimicrobial Activity of 1, 2-Bis ((E)-3-Phenylallylidene) Hydrazine and Its Metal ComplexesEmmanuel A. Ariwoola^{1,2}, Gbadebo E. Adeyeni^{1,3,5*}, Elizabeth T. Olalekan², Lawal M. Kafayat^{3,4}, Ehimwenma V. Ehigior¹, Ayodele A. Alabi^{4,6}¹Chemistry Department, Hallmark University Ijebu-Itele, Ogun State, Nigeria²Chemistry Department, University of Ibadan, Ibadan, Oyo State, Nigeria³Medical Laboratory Technician Department, Crestfield College of Health Sciences and Management Technology, Erin Osun, Osun State, Nigeria⁴Public Health Department, Crestfield College of Health Sciences and Management Technology, Erin Osun, Osun State, Nigeria⁵Industrial Chemistry Department, University of Ilesha, Osun state, Nigeria⁶Department of Community Health, Obafemi Awolowo University, Ile-Ife, Nigeria**ABSTRACT**

Schiff bases and associated transition-metal complexes have garnered significant interest because of their wide range of biological activity and structural adaptability. The growing problem of antibiotic resistance highlights the urgent need to discover and develop alternative antimicrobial agents. In this work, cinnamaldehyde was condensed with hydrazine hydrate to form 1,2-bis (E-3-phenylallylidene)hydrazine (ca), which was then coordinated with Cu(II), Co(II), Mn(III), and Zn(II) ions. Metal analysis, infrared spectroscopy, UV-visible spectroscopy, and magnetic susceptibility measurements were used to characterise the synthesised ligand and its metal complexes. Spectroscopic data confirmed coordination through the azine nitrogen atoms, yielding metal complexes with a 1:2 metal-to-ligand ratio. Magnetic and electronic spectra supported square-planar coordination in the complexes. Using broth dilution and agar diffusion techniques, we assessed the antibacterial properties of the ligand and its complexes against specific strains of fungi, Gram-positive bacteria, and Gram-negative bacteria. Metal complexation greatly increased the ligand's biological activity. The Cu(II) complex, which produced the biggest inhibition zones and the lowest minimum inhibitory concentration (MIC) and minimum microbicidal concentration (MMC) values among the synthesised compounds, had the strongest antibacterial action. Increased lipophilicity and improved interaction of the metal complexes with microbial targets after chelation explain the increased activity. These results indicate that the Cu(II) complex is the most promising option for additional biological research and show that coordination of the Schiff base with transition metal ions enhances its antibacterial activity.

Keywords: Schiff base, Cinnamaldehyde, Hydrazine, Transition metal complexes, Coordination chemistry, Antimicrobial activity.

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Introduction

Due to their structural variety, ease of synthesis, and strong metal-complex-forming ability, Schiff bases are important chemical classes in medicinal and coordination chemistry.¹ The formation of these compounds is typically accomplished by combining primary amines or hydrazines with aldehydes or ketones. The resulting compounds have the distinctive azomethine (-C=N-) linkage.² Schiff bases can easily coordinate with transition metal ions when sulphur, nitrogen, or oxygen atoms are present. This leads to stable complexes with a wide range of biological and physicochemical properties.^{3,4} Researchers have long been interested in Schiff base transition metal complexes because, as a rule, ligand electronic characteristics are improved through coordination with metal ions, which in turn improves their catalytic, analytical, and pharmacological activity. These complexes are intriguing molecules for developing new therapeutic medicines because they have shown promising antibacterial,⁵ antifungal,⁶ antiviral,⁷ antioxidant,⁸ and anticancer effects,⁹ which makes them attractive compounds for the development of new therapeutic drugs.^{10,11,12}

One significant class of these ligands is hydrazone-based Schiff bases, produced from aldehydes and hydrazine derivatives.¹³ Stable transition metal complexes with enhanced biological performance can be formed thanks to their prolonged conjugation and robust chelating activity.^{14,15} Many ligands have their lipophilicity increased through coordination with metal ions, which improves membrane permeability and interactions with biological targets. The diverse biological actions of cinnamaldehyde, a naturally occurring aldehyde, have garnered significant attention. It possesses antibacterial, antioxidant, anti-inflammatory, and anticancer effects, among others.^{20,21} An efficient method for creating physiologically active ligands with increased pharmacological potential is the formation of Schiff bases using cinnamaldehyde.²² These qualities could be enhanced even further by complexation with physiologically significant metal ions such as zinc(II), copper(II), cobalt(II), and manganese(III).^{23,24}

The rising prevalence of microbes resistant to currently used antibiotics creates an urgent need for more effective, less resistant alternative antimicrobial medicines. Schiff base complexes with transition metals show promise as antibacterial agents due to their ability to inhibit key enzymes, interact with nucleic acids, induce oxidative stress, and break microbial membranes.^{25,17} This research details the formation of Schiff base 1, 2-bis (E-3-phenylallylidene) hydrazine, its Cu(II), Co(II), Mn(III), and Zn(II) complexes, and cinnamaldehyde and hydrazine hydrate as its starting materials. We used infrared and UV-Visible spectroscopy, percentage metal analysis and room-temperature magnetic susceptibility measurement to

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characterise the compounds. To determine how metal coordination affected the ligand's biological activity, we tested their antibacterial properties against a variety of bacterial and fungal pathogens.

Materials and Method

Without additional purification, all compounds and solvents utilised in this work were of analytical grade. Cinnamaldehyde, hydrazine hydrate, ethanol, dimethylformamide (DMF), dimethyl sulfoxide (DMSO), acetone, ethyl acetate, diethyl ether, n-hexane, cobalt(II) chloride dihydrate, copper(II) chloride dihydrate, manganese(II) acetate tetrahydrate, zinc(II) acetate dihydrate, triethylamine, ethylenediaminetetraacetic acid, zinc sulphate heptahydrate, ammonium chloride, aqueous ammonia, murexide indicator, Eriochrome Black T, nitric acid, perchloric acid, and distilled water were obtained from commercial sources and used as received. We used a digital melting-point apparatus to determine melting points, and we did not alter these values. With the use of KBr pellets, infrared spectra were captured on a PerkinElmer FTIR spectrometer between 4000 and 450 cm^{-1} . A PerkinElmer Lambda 25 UV-Visible spectrophotometer was used to acquire electronic absorption spectra in the 200-900 nm wavelength range with DMF as the solvent. We measured magnetic susceptibility at room temperature using a Sherwood magnetic susceptibility balance. Using standard protocols, we computed effective magnetic moments (μ_{eff}).

Preparation of 1, 2-Bis (E-3-phenylallylidene) hydrazine (ca)

Cinnamaldehyde and hydrazine hydrate were condensed in a 2:1 molar ratio to create the Schiff base ligand (ca). Hydrazine hydrate (11.41 mmol) was dissolved in 10 mL of ethanol, whereas cinnamaldehyde (22.70 mmol) was diluted in 20 mL of ethanol. At room temperature, the hydrazine solution was added dropwise to the cinnamaldehyde solution for 20 to 30 minutes while stirring continuously and monitoring by TLC. The resultant yellow precipitate was filtered, washed with cold ethanol, air-dried, and stored in a desiccator. Yield: 71%, M.P: 148–150 °C. Anal. Calcd for $\text{C}_{18}\text{H}_{16}\text{N}_2$ (260.34 g mol^{-1}): C, 83.04; H, 6.19; N, 10.76. IR ν_{max} (cm^{-1}): 1631 $\nu(\text{C}=\text{N})$, 1583 $\nu(\text{C}=\text{C})$, 1075 $\nu(\text{N}-\text{N})$. λ_{max} (nm): 298, 363

Preparation of Metal Complexes

$[\text{Cu}(\text{ca})_2]\text{Cl}_2$: In 2 mL of dimethylformamide (DMF), gently heated, the ca ligand (0.192 mmol, 0.5 g) was dissolved. A solution of copper(II) chloride dihydrate (0.96 mmol, 0.17g) in hot ethanol was added dropwise followed by a few drops of triethylamine. After 4 hours of refluxing and overnight cooling, the mixture was filtered to remove the orange precipitate, which was washed with ethanol and air-dried. Yield: 54%, M.P: 192-194 °C, Anal. Calcd for $\text{C}_{36}\text{H}_{32}\text{Cl}_2\text{CuN}_4$ (655.13 g mol^{-1}): C, 66.00; H, 4.92; Cl, 10.82; N, 8.55; Cu 9.70 (Exp., 9.2). IR ν_{max} (cm^{-1}): 1622 $\nu(\text{C}=\text{N})$, 1586 $\nu(\text{C}=\text{C})$, 1076 $\nu(\text{N}-\text{N})$, 573 $\nu(\text{Cu}-\text{N})$. λ_{max} (nm): 297 μ_{eff} : 2.4 B.M.

$[\text{Mn}(\text{ca})_2](\text{OAc})_3$: The ca ligand (0.192 mmol, 0.5 g) was dissolved in 2 mL of DMF and gently heated. After adding a solution of copper(II) chloride dihydrate (0.96 mmol, 0.235 g) in hot ethanol dropwise, a few drops of triethylamine was added followed by 4 hours of refluxing, overnight cooling, filtration, an ethanol wash, and finally air-drying of the brown precipitate. Yield: 39% M.P: 169-170 °C, Anal. Calcd for $\text{C}_{42}\text{H}_{41}\text{N}_4\text{O}_6\text{Mn}$ (752.75 g mol^{-1}): C, 67.02; H, 5.49; N, 7.44; O, 12.75; Mn, 7.30 (Exp., 6.98). IR ν_{max} (cm^{-1}): 1630 $\nu(\text{C}=\text{N})$, 1587 $\nu(\text{C}=\text{C})$, 1075 $\nu(\text{N}-\text{N})$, 578 $\nu(\text{Mn}-\text{N})$. λ_{max} (nm): 314, 362, 798 μ_{eff} : 2.38 B.M.

$[\text{Co}(\text{ca})_2]\text{Cl}_2$: The ca ligand (0.00115 mmol, 0.3 g) was dissolved in 1 mL of DMF and gently heated, respectively. With a steady stream of drops, triethylamine was added to the mixture of copper(II) chloride dihydrate (0.00057 mmol, 0.136 g) dissolved in hot ethanol. The mixture was refluxed for 4 hours, left to stand overnight, filtered, washed with ethanol, and air-dried to produce a light-brown precipitate. Yield: 36%, M.P: 157-158 °C, Anal. Calcd for $\text{C}_{36}\text{H}_{32}\text{Cl}_2\text{CoN}_4$ (650.51 g mol^{-1}): C, 66.47; H, 4.96; Cl, 10.90; N, 8.61; Co, 9.06 (Exp., 8.72) IR ν_{max} (cm^{-1}): 1628 $\nu(\text{C}=\text{N})$, 1588 $\nu(\text{C}=\text{C})$, 1073 $\nu(\text{N}-\text{N})$, 534 $\nu(\text{Co}-\text{N})$. λ_{max} (nm): 296, 364 μ_{eff} : 2.2 B.M.

$[\text{Zn}(\text{ca})_2](\text{OAc})_2$: A solution of ca ligand (0.00115 mmol, 0.3 g) in 1 mL of DMF was gently heated. Then a solution of copper(II) chloride dihydrate (0.00057 mmol, 0.126 g) in hot ethanol was added dropwise followed by a few drops of triethylamine. After refluxing the mixture for 4 hours, we let it stand overnight. After filtering, we washed it with ethanol and then air-dried the yellow precipitate. Yield: 35%, M.P: 171-172 °C. Anal. Calcd for $\text{C}_{40}\text{H}_{38}\text{N}_4\text{O}_4\text{Zn}$ (704.15 g mol^{-1}): C, 68.23; H, 5.44; N, 7.96; O, 9.09; Zn, 9.28 (Exp., 8.92). IR ν_{max} (cm^{-1}): 1629 $\nu(\text{C}=\text{N})$, 1586 $\nu(\text{C}=\text{C})$, 1073 $\nu(\text{N}-\text{N})$, 534 $\nu(\text{Zn}-\text{N})$. λ_{max} (nm): 312, 362.

Antimicrobial Assay

The antimicrobial activities of the ligand and its metal complexes were evaluated against selected Gram-positive bacteria (*Staphylococcus aureus* and *Bacillus subtilis*), Gram-negative bacteria (*Escherichia coli* and *Klebsiella pneumoniae*), and fungi (*Candida albicans* and *Trichophyton rubrum*).

We used the agar well diffusion method to determine microbial susceptibility to antibiotics. We used the 0.5 McFarland standard to inoculate sterile Mueller-Hinton agar plates with standardised microbiological solutions. We injected each synthesised chemical into wells bored into the agar at varying concentrations (0.5, 1.0, and 2.0 mg mL^{-1}). We used ciprofloxacin as the antibacterial positive control, ketoconazole as the antifungal positive control, and DMF as the negative control. We measured zones of inhibition in millimetres after incubating the plates at 37 °C for 24 hours.

Determination of Minimum Inhibitory Concentration (MIC)

Using sterile 96-well microplates and the broth microdilution technique, we determined the minimum inhibitory concentrations. Concentrations ranging from 2.0 to 0.125 mg mL^{-1} were achieved by preparing two-fold serial dilutions of each chemical in tryptone soya broth. The plates were incubated at 37 °C for 24 hours after being inoculated with standardised microbial suspensions. The p-iodonitrotetrazolium violet (INT) indicator was used to measure microbial proliferation. The MIC was determined as the lowest concentration that effectively inhibited the development of detectable microorganisms.

Determination of Minimum Microbicidal Concentration (MMC)

Subcultures were plated onto new nutrient agar plates and incubated at 37 °C for 24 hours using aliquots from wells that showed no growth during the MIC determination.

Results and Discussion

Infrared Spectral Analysis

Coordination of the Schiff base ligand to the transition metal ions was confirmed by the FTIR spectra (Figure 1), which offered compelling proof of its synthesis. As a result of the successful condensation of cinnamaldehyde and hydrazine hydrate, the free ligand exhibited a distinctive azomethine stretching vibration at around 1631 cm^{-1} . The aromatic C=C and N-N stretching vibrations were determined to be the additional bands at 1583 cm^{-1} and 1075 cm^{-1} , respectively, which correspond to the predicted azine framework.^{26,27}

Because the azomethine nitrogen lone pair was coordinated to the metal centre during complexation (Scheme 1), the C=N bond order was reduced, as indicated by a small change in the azomethine stretching frequency to lower wavenumbers (1622-1630 cm^{-1}). Substantial evidence of metal-nitrogen bond formation comes from widespread reports of similar changes in nitrogen-coordinated Schiff base complexes.^{28,29}

Additional evidence for coordination came from the emergence of additional absorption bands in the 534-578 cm^{-1} region, attributed to $\nu(\text{M}-\text{N})$ vibrations. These bands, which indicate coordination via the nitrogen atoms in the azine ring, were not present in the free ligand spectra. The observed characteristic region for transition metal-nitrogen stretching vibrations in Schiff base complexes is well-matched by their locations.²⁶

The infrared data indicate that the ligand coordinates as a neutral bidentate donor through its two azine nitrogen atoms, forming stable metal complexes with Cu(II), Co(II), Mn(III), and Zn(II).

Magnetic Susceptibility Studies

To better understand the electronic configurations and likely geometries of the synthesised complexes, we measured magnetic susceptibility.

The presence of one unpaired electron, indicative of a d^9 metal ion, was confirmed for the Cu(II) complex, which had an effective magnetic moment of 2.40 B.M. Orbital contributions are responsible for the somewhat greater value compared to the spin-only moment in Cu(II) complexes.^{30,4}

A magnetic moment of 2.20 B.M. was measured for the Co(II) complex, which is significantly lower than the value predicted for high-spin tetrahedral Co(II). This value supports a square-planar environment hosting a low-spin Co(II) centre, implying that a reasonably strong ligand field induces extensive electron pairing.³¹

The magnetic moment of the Mn complex was 2.38 B.M. While Mn(II) usually has a magnetic moment of about 5.9 B.M., this number is in agreement with Mn(II) oxidising to low-spin Mn(III) during aerobic synthesis. Prior evidence supports in situ oxidation of Mn(II) Schiff base complexes, which is particularly advantageous in nitrogen-donor settings with high coordination.³⁰

As expected, the Zn(II) complex was diamagnetic because Zn^{2+} possesses a filled d^{10} electronic configuration and therefore contains no unpaired electrons.⁴

Collectively, the magnetic susceptibility data support the proposed complex formulations and are consistent with predominantly square-planar coordination geometries.

Electronic Spectral Analysis

Using DMF as the solvent, we acquired electronic absorption spectra on a PerkinElmer Lambda 25 UV-Visible spectrophotometer over 200–900 nm.

The Schiff base ligand's UV-visible spectra revealed two strong absorption bands at 298 nm and 363 nm, which corresponded to the electronic transitions $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$, respectively. These transitions are characteristic of Schiff base ligands with aromatic π -electron frameworks and originate from the conjugated azomethine system.

These ligand-centred transitions were preserved in the metal complexes, suggesting that coordination did not damage the ligand's conjugated backbone. For the paramagnetic complexes, however, additional low-energy absorptions related to d–d transitions were noted.

The modest absorption seen in the Mn(III) complex at 798 nm was attributed to a ligand-field d–d transition that is typical of Mn(III). Similarly, the Cu(II) complex displayed a wide band at 698 nm, which matched the ${}^2B_1 \rightarrow {}^2A_1$ transition anticipated for square-planar Cu(II) complexes.^{30,32}

For the Co(II) complex, no clear d–d transitions were seen, most likely because the stronger ligand-centred bands obscured these feeble absorptions. As would be predicted for a d^7 metal ion without accessible d–d electronic transitions, the Zn(II) complex exclusively showed ligand-based transitions.

The combined electronic spectrum and magnetic susceptibility data strongly support the proposed square-planar coordination environments of the synthesised complexes.

Antimicrobial Activity

The antimicrobial properties of the Schiff base ligand (ca) and its Cu(II), Co(II), Mn(III), and Zn(II) complexes were assessed against specific Gram-positive bacteria (*Bacillus subtilis* and *Staphylococcus aureus*), Gram-negative bacteria (*Escherichia coli* and *Klebsiella pneumoniae*), and fungi (*Trichophyton rubrum* and *Candida albicans*) presented in Table 1. We used agar well diffusion to evaluate antimicrobial efficacy and the broth microdilution method to determine the minimum inhibitory concentration (MIC) and minimum microbicidal concentration (MMC) presented in Table 2.

The findings showed that the free ligand and its metal complexes had antibacterial action, but coordination with transition metal ions significantly increased the ligand's biological efficacy. This improvement is in line with earlier findings that metal complexation can increase Schiff bases' pharmacological qualities by altering their physicochemical traits and boosting their interaction with microorganisms.^{12,17}

With inhibitory zones of 8–18 mm against most test bacteria, the free Schiff base showed modest antimicrobial efficacy. The uncomplexed ligand has only moderate intrinsic antibacterial potential, as evidenced by the comparatively weak activity against *Klebsiella pneumoniae*, especially at lower doses.

$[Cu(ca)_2]Cl_2$ showed the strongest antibacterial efficacy among the synthesised compounds. At 2.0 mg mL^{-1} , the compound produced 16–22 mm inhibition zones against all tested bacteria. Notably, under the same experimental settings, its action against *Candida albicans* was comparable to ketoconazole, while its suppression of *Staphylococcus aureus* (22 mm) marginally outperformed ciprofloxacin. These findings suggest that copper coordination significantly increased the ligand's antibacterial activity.

After the cobalt(II) and zinc(II) complexes, the manganese(III) complex showed the second-highest activity. The copper complex consistently performed better against both bacterial and fungal isolates, although all complexes showed enhanced antimicrobial effects compared with the free ligand. This suggests that the coordinated metal ion plays a significant role in determining biological activity.

All synthesised compounds showed a concentration-dependent response, with inhibition zones growing from 0.5 to 2.0 mg mL^{-1} . This pattern suggests that higher doses improve growth inhibition by facilitating more efficient interactions between the chemicals and microbial targets.

The MIC and MMC results further corroborated the agar diffusion statistics. With MIC values of 0.0625 mg mL^{-1} against *Candida albicans* and 0.125 mg mL^{-1} against *Klebsiella pneumoniae*, the Cu(II) complex showed the lowest MIC values of all the compounds. The complex has both inhibitory and microbicidal activity at comparatively low doses, as indicated by the corresponding MMC values being only marginally higher than the MIC values.

Tweedy's chelation theory explains the enhanced antibacterial action seen following complexation.¹⁶ By partially sharing the metal ion's positive charge with the ligand's donor nitrogen atoms, coordination lessens the metal ion's polarity and increases the complex's overall lipophilicity. Increased lipophilicity enables greater intracellular accumulation and more efficient interaction with vital biomolecules by promoting diffusion through microbial lipid membranes. Furthermore, transition metal complexes can cause microbial cell death by interfering with enzyme activity, damaging membrane integrity, producing reactive oxygen species, and interacting with nucleic acids.^{25,17}

The biological analysis unequivocally shows that metal coordination greatly increased the Schiff base ligand's antibacterial action. The order of the observed activity was as follows:

$Cu(II) > Mn(III) > Co(II) > Zn(II) > ca$

The Cu(II) complex is the most promising option for further pharmacological research, and this trend emphasises the positive impact of chelation on antibacterial potency.

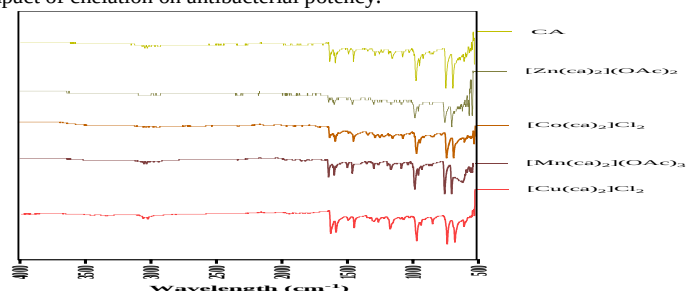
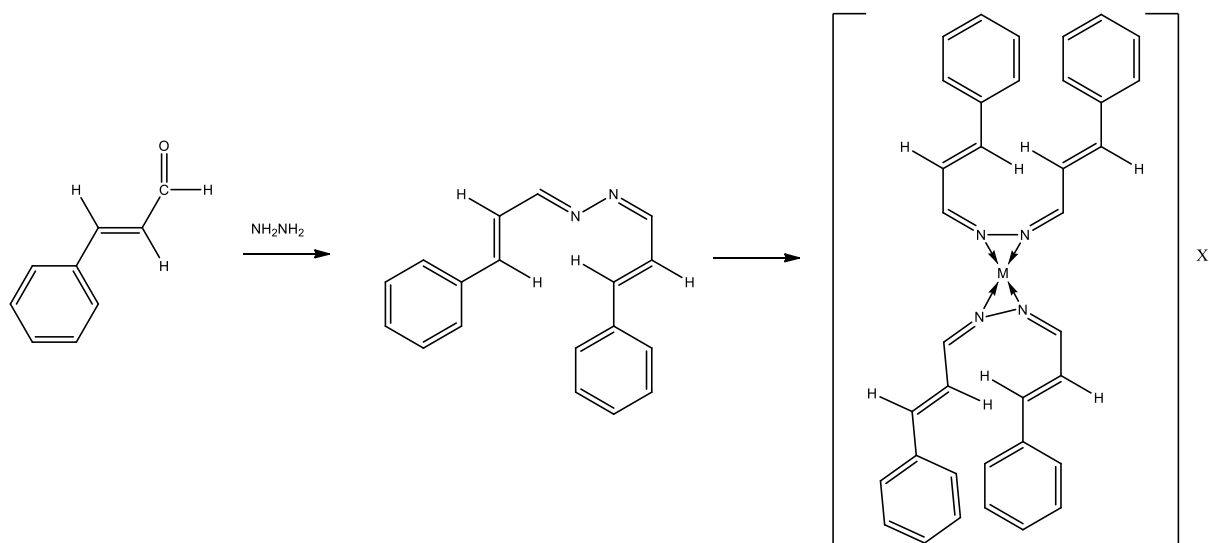


Figure 1: Infrared Spectra of ca and its metal complexes.

Table 1: Antimicrobial Susceptibility Test (AST) Zone of inhibition in mm

Org/Conc.	ca			[Co(ca) ₂]Cl ₂			[Cu(ca) ₂]Cl ₂			[Mn(ca) ₂](OAc) ₃			[Zn(ca) ₂](OAc) ₂			Control	
	2	1	0.5	2	1	0.5	2	1	0.5	2	1	0.5	2	1	0.5	Cipro	Ket
S.a	18	17	12	16	14	13	22	18	16	16	12	10	16	14	0	20	NA
B.s	16	14	10	14	13	12	16	12	0	14	12	12	14	12	10	16	NA
E.c	12	10	8	10	10	8	16	12	10	16	15	12	12	10	0	18	NA
Kleb	14	12	0	12	10	0	18	14	12	15	13	12	12	10	10	18	NA
C.a	18	16	15	12	11	10	20	19	14	18	16	15	12	10	10	NA	24
T.r	12	11	8	12	10	8	14	13	10	14	12	10	14	12	8	NA	20

Key: ORG = Organism, Conc. = Concentration S.a = *Staphylococcus aureus*, B.s = *Bacillus subtilis*, E.c = *Escherichia coli*, Kleb = *Klebsiella pneumonia*, C.a = *Candida albicans*, T.r = *Trichophyton rubrum*, Cipro = Ciprofloxacin, Ket = Ketokonazole, NA = Not Applicable



M: Cu, Mn, Co, Zn; X: Cl₂, (OOCCH₃)₂, (OOCCH₃)₃

Scheme 1: Synthesis of ca and the metal complexes

Table 2: Minimum inhibitory concentration and minimum microbiocidal concentration

Ca		[Co(ca) ₂]Cl ₂		[Cu(ca) ₂]Cl ₂		[Mn(ca) ₂](OAc) ₃		[Zn(ca) ₂](OAc) ₂		Broth Only	Broth And Isolates	Control			
												Cipro ug/ml		Ket%	
ORG.	MIC	MMC	MIC	MMC	MIC	MMC	MIC	MMC	MIC	MMC		MIC	MMC	MIC	MMC
S.a	0.125	0.5	0.0625	1	0.25	0.5	0.5	2	1	1	-	5	5	NA	NA
B.s	0.5	1	0.25	0.2	1	2	0.5	1	1	2	-	5	10	NA	NA
E.c	2	2	>2	>2	1	1	0.5	0.5	2	>2	-	10	>10	NA	NA
Kleb	2	2	2	>2	0.125	0.5	0.5	2	>2	>2	-	10	10	NA	NA
C.a	0.5	0.5	2	2	0.0625	0.5	0.25	0.5	>2	>2	-	NA	NA	0.25	5
T.r	0.5	1	2	>2	1	1	1	2	1	1	-	NA	NA	1	1

Key; ORG = Organism, S.a = *Staphylococcus aureus*, B.s = *Bacillus subtilis*, E.c = *Escherichia coli*, Kleb = *Klebsiella pneumonia*, C.a = *Candida albicans*, T.r = *Trichophyton rubrum*, Cipro = Ciprofloxacin, Ket = Ketokonazole, - = Negative, + = Positive, NA = Not Applicable

Conclusion

Using physicochemical and spectroscopic methods, we synthesised and characterised a novel Schiff base, 1,2-bis(E-3-phenylallylidene)hydrazine (ca), along with its Cu(II), Co(II), Mn(III), and Zn(II) complexes. The development of mostly square-planar complexes with a metal-to-ligand ratio of 1:2 presented in Scheme 1 was substantiated by magnetic susceptibility and electronic spectrum investigations, while infrared spectroscopy verified coordination through the azine nitrogen atoms.

Biological evaluation showed that both the ligand and its metal complexes exhibited antibacterial efficacy against the studied bacterial and fungal pathogens. The Cu(II) complex had the largest inhibitory zones and the lowest MIC and MMC values, indicating that metal coordination greatly increased the ligand's biological activity. The increased lipophilicity and improved interaction of the metal complexes with microbial cellular targets after chelation explain the enhanced antibacterial activity.

The results show that the antibacterial capabilities of 1,2-bis(E-3-phenylallylidene)hydrazine are significantly enhanced when it is coordinated with transition metal ions. A particularly promising scaffold for the creation of novel metal-based antibacterial drugs is the Cu(II) complex.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Declaration

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

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