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Antimicrobial Activities of

Synthesized Mn(II), Ni(II), Cu(II) and Pt(II) Mixed Ligand Complexes of Isonicotinylhydrazide and 4-Hydroxy-3-Methoxy benzaldehyde with Aniline

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Abstract:*This research work synthesized 4-hydroxy-3-methoxybenzaldehyde-isonicotinylhydrazone (HMISH)at room temperature by the condensation reaction of isonicotinylhydrazide with 4-hydroxy-3-methoxybenzaldehyde. The synthesized ligand was used to prepare the mixed ligand complexes of Mn(II), Ni(II), Cu(II) and Pt(II) with aniline as a secondary ligand. The synthesized compounds were characterized using physical methods such as solubility, melting points, conductivity and spectroscopic methods using infrared and UV-vis spectroscopy. The zones of inhibition were determined by the agar well diffusion method while the MIC, MBC and MFC were carried out by agar dilution technique on strains of E. coli, S. aureus, S. typhi, C. albicans, A. niger and T. rubrum and results were compared with streptomycin and fluconazole. The melting points of the ligands and the mixed ligand complexes were found to be very high (211.6-241.8 °C) while the measured conductivities were very low (0.03-1.03 µS). The infrared spectral data available proved that the HMISH coordinated to the metal ions through its azomethine nitrogen and the phenolic oxygen atom of the vanillin ring. The second ligand, aniline coordinated the metal ions through its nitrogen atom. From the UV spectral data coupled with the infrared data and literature of the specified metal ions, octahedral geometry was proposed for the metal complexes while a square planar geometry was proposed for the platinum (II) complexes. The antimicrobial studies showed that the prepared ligands and the complexes had good antimicrobial activities and can be used as raw materials in pharmaceutical industries for the preparation of new drugs.*

Keywords: *synthesis, characterization, antimicrobial, ligand, complex*

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1.0 Introduction

In the last few decades, the field of coordination chemistry has grown very fast, especially in the fields of pharmaceutical, biological and catalytic studies (Hijazi *et al*., 2024). In ancient times, metals were thought to be beneficial to health issues, but nowadays the link between organic–metal substances and

different industrial and medicinal properties is well established. This chemical evolution has led to the synthesis of mixed ligand complexes of Co(II), Zn(II), Ni(II), and Cu(II) (Ashrafuzzaman *et al*., 2023).

Specifically, research focuses on the reaction of complexes synthesized from transition metal reactionchlorides with Schiff bases derived from isonicotinylhydrazide and 4-methoxybenzaldehyde (Abdullahi and Na'aliya, 2018). Ligands such as isonicotinylhydrazone-4-hydroxy-3-methoxybenzaldehyde (ISVN) are formed by condensation reactions at room temperature to produce bidentate structures that coordinate via azomethine nitrogen and phenolic oxygen atoms. When these are paired with secondary ligands like aniline, furan, thiophene, or 1,10-phenanthroline, they demonstrate diverse geometries, from tetrahedral Zn(II) to octahedral Co(II) and Ni(II) (Ashrafuzzaman *et al*., 2023; Muthuppalani *et al*., 2022).

Characterization techniques such as FT-IR, UV-Vis, TGA, and EPR have confirmed that these Mn(II) complexes of transition metal chelates coordinate in 1:1, 1:2, or mixed ratios (Hijazi *et al*., 2024; Muthuppalani *et al*., 2022). Furthermore, the bio-potential activities of these complexes are remarkable. Studies have proven that the synthesized compounds were bactericidal and fungicidal, showing higher inhibition zones against pathogens like *Escherichia coli* and *Staphylococcus aureus* compared to standard drugs like streptomycin and fluconazole (Abdullahi and Na'aliya, 2018). Recent findings also highlight the 100% selectivity of complexes in the oxidation of aniline to azobenzene and their superior antioxidant potential compared to free Schiff base ligands (Hijazi *et al*., 2024; Ashrafuzzaman *et al*., 2023).

2.0 Materials and Materials

All chemicals used for this research were of analytical grade purchased from sigma aldrich, and used without further purification. SHIMADZU FTIR-8400S, Gallenkemp melting point apparatus, UNISCOPE SM 9053 Laboratory oven, isonicotinylhydrazide, 4-hydroxy-3-methoxybenzaldehyde, ethanol, methanol, acetone, DMSO, nutrient agar, potato dextrose agar, autoclave, aluminum foil paper, weighing balance, nose mask, meter rule, cotton wool, hand gloves, petri dishes, wire loop, paper disc.

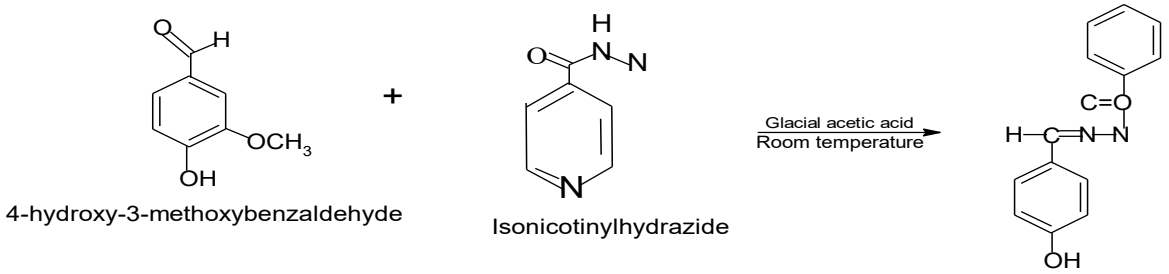
2.1 Synthesis of the ligand

Isonicotinylhydrazide (1.371g, 0.01 mol) in 20 cm^3 ethanol was mixed with 4-hydroxy-3-methoxybenzaldehyde (0.01 mol, 1.521 g) and stirred vigorously for 2 minutes using a magnetic stirrer. Five drops of glacial acetic acid were added as stirring continued for 2 hours. The solution was allowed to stand undisturbed overnight. The pale yellow precipitate formed was filtered, washed with ethanol and dried over fused calcium chloride in a desiccator (Ashraf *et al*., 2011). The percentage yield was calculated using equation 1, while Scheme 1 gives the reaction equation

$$\text{Percentage yield} = \frac{\text{Experimental yield}}{\text{Theoretical yield}} \times 100\ \% \qquad (1)$$

2.2 Synthesis of mixed ligand complexes

A solution of metal (II) chloride (0.01 mol) in 50 cm^3 ethanol was added to a 50 ml solution of the synthesized 4-hydroxy-3-methoxybenzaldehyde-isonicotinylhydrazon(0.001 mol. This mixture was stirred for 15 minutes before 20 cm^3 of aniline was added and stirred for 2 hours. The precipitate formed was filtered, washed with ethanol and dried over fused calcium chloride in a desiccator (Al-Masoudi *et al*., 2023).



Scheme 1:Equation for the reaction between isonicotinylhydrazide and 4-hydroxy-3-methoxybenzaldehyde

3.0 Results and Discussion

4.1 Results

The physical properties of the synthesized ligand and its mixed ligand complexes are presented in Table 1, showing the nature, colour, melting point and molar conductivity values of the compounds. The ligand, 4-hydroxy-3-methoxybenzaldehyde-isonicotinylhydrazone (HMISH), and all the metal complexes were obtained as solid powdery materials, with colours ranging from pale yellow to yellowish brown. The melting points for the ligand and the complexes were relatively high (211.6–241.8 °C), indicating good thermal stability and purity of the synthesized compounds. The conductivity values were very low (0.03–1.02 µS), which confirms the non-electrolytic nature of all the complexes. These observations agree with previous reports on mixed ligand Schiff base complexes, where low conductivity is characteristic of neutral metal complexes with chelating ligands (Table 1).

Table 1: Physical data of the ligands and the complexes

Compounds	Nature	Colour	Melting points (ºC)	Conductivity (µs)
HMISH	Powdery	Pale yellow	237.5	0.11
$[Mn(HMISH)_2(A)_2]$	Powdery	Yellow	241.8	0.90
$[Ni(HMISH)_2(A)_2]$	Powdery	Yellowish green	228.6	0.03
$[Cu(HMISH)_2(A)_2]$	Powdery	Green	211.6	1.02
$[Pt(HMISH)(A)_2]$	Powdery	Yellowish brown	232.5	0.04

The solubility behaviour of the ligand and the complexes in different solvents is shown in Table 2, where all the compounds displayed high solubility in polar organic solvents such as DMSO, ethanol, methanol and acetone, but limited solubility in distilled water. The ligand exhibited complete solubility in all solvents, while the complexes showed slight solubility in distilled water and strong solubility in DMSO and ethanol. This trend reflects increased molecular weight and reduced polarity upon complexation of HMISH with metal ions. Similar solubility patterns have been observed in Schiff base complexes due to hydrophobic interactions and the bulky aromatic moieties of the ligand system (Table 2).

The infrared spectral data in Table 3 provide evidence for the coordination mode of HMISH to the metal ions. The free ligand displayed a strong azomethine band at 1596 cm^{-1}, which shifted to 1590–1599 cm^{-1} upon complexation, indicating coordination through the azomethine nitrogen atom. The phenolic C–O stretching band at 1287 cm^{-1} in the ligand also shifted slightly to 1287–1290 cm^{-1} in the complexes, suggesting involvement of the phenolic oxygen in bonding with the metal centre. New absorption bands appeared in the regions of 402–540 cm^{-1} attributed to M–N and M–O

vibrations, confirming metal–ligand interactions through nitrogen and oxygen donor atoms. The IR data reveal that the ligand acts as a bidentate chelating species, coordinating through the azomethine nitrogen and the phenolic oxygen, while aniline coordinates through its amine nitrogen atom (Table 3).

Table 2: Solubility of the ligand and complexes

Compounds	Distilled water	Ethanol	Methanol	Acetone	DMSO
HMISH	S	S	S	S	S
$[Mn(HMISH)_2(A)_2]$	S	SS	SS	S	S
$[Ni(HMISH)_2(A)_2]$	SS	SS	SS	S	S
$[Cu(HMISH)_2(A)_2]$	SS	SS	SS	S	S
$[Pt(HMISH)(A)_2]$	SS	SS	SS	S	S

Key: S = soluble, SS = slightly soluble

Table 3: Selected IR Vibrational Frequencies (cm^{-1}) of HMISH and Its Metal Complexes

Vibrational Mode	HMISH	$[Mn(HMISH)_2(A)_2]$	$[Ni(HMISH)_2(A)_2]$	$[Cu(HMISH)_2(A)_2]$	$[Pt(HMISH)(A)_2]$
ν(OH)	3441 s	3374 s	3363 s	3460 s	3449 s
ν(N–H)	3236 s	3225 s	3264 s	3232 s	3206 s
ν(C=O)	1662 s	1662 s	1663 s	1665 s	1665 s
ν(C=C)	1506	1513	1506	1506	1508
ν(C=N)	1596 s	1598 s	1599 s	1590 s	1599 s
ν(C–N)	1376 m	1388 m	1419 m	1380 m	1375 m
ν(C–O)	1287 m	1290 s	1289 s	1290 s	1287 s
ν(N–N)	1062 m	1063 m	1111 s	1113 m	1065 m
ν(M–N)	–	540 w	627 w	529 w	535 w
ν(M–O)	–	461 w	441 w	402 w	440 w

The electronic spectral data presented in Table 4 show the absorption bands of the ligand and the metal complexes obtained from UV–visible spectroscopy. The ligand exhibited two characteristic absorption bands at 249 nm, attributable to $n \rightarrow \pi^{**}$ transitions and 326 nm, assigned to $\pi \rightarrow \pi^{**}$ transitions within the aromatic system. Upon complexation, the metal complexes retained similar ligand-centred transitions, indicating preservation of the conjugated system. In addition, d–d transitions were observed for the Mn(II), Ni(II) and Cu(II) complexes around 423 nm, corresponding to electronic excitations such as 6A1g → 4T2g, 3A2g → 3T1g and 2Eg → 2T2g, respectively, which are characteristic of octahedral geometry. The Pt(II) complex showed a band at 422 nm due to a 1A1g → 1A2g transition, consistent with a square planar geometry. These spectral assignments, supported by literature values for similar metal ions, confirm the octahedral structures of Mn(II), Ni(II) and Cu(II) complexes and the square planar arrangement for the Pt(II) complex (Table 4).

The antimicrobial activities of the ligand and the metal complexes were evaluated using the agar well diffusion method and the zones of inhibition are shown in Table 5. All the compounds exhibited antimicrobial activity

against the tested organisms, with the metal complexes showing enhanced inhibition compared to the free ligand. The ligand showed moderate activity with inhibition zones ranging from 11.0 to 16.0 mm, while the complexes displayed significantly higher activities.

Among all the complexes, the Cu(II) complex showed the highest activity with inhibition zones up to 29.0 mm against *E. coli*, followed by the Ni(II) and Pt(II) complexes with values up to 26.0 mm. The improved antimicrobial activity upon complexation can be attributed to increased lipophilicity and cell membrane penetration facilitated by chelation effects (Table 5).

Table 4: uv spectra of the ligand and the complexes

Compounds	Absorbance (nm)	Wavelength (nm)	Bands (cm^{-1})	Assignment	Geometry
HMISH	2.83	249	40,160	n- π*	
	2.27	326	30,674	π- π*	
$[Mn(HMISH)_2(A)_2]$	6.00	247	40,485	n- π*	
	2.63	326	30.674	π- π*	
	0.39	423	23,640	$^6A_{1g} \rightarrow {}^4T_{2g}$	Octahedral
$[Ni (HMISH)_2(A)_2]$	3.79	233	42,918	n- π*	
	3.06	308	32,467	π- π*	
	0.18	423	23,640	$^3A_{2g} \rightarrow {}^3T_{1g}$	Octahedral
$[Cu (HMISH)_2(A)_2]$	2.53	238	42,016	n- π*	
	2.23	343	29,154	π- π*	
	-0.28	423	23,640	$^2E_g \rightarrow {}^2T_{2g}$	Octahedral
$[Pt (HMISH)(A)_2]$	2.73	233	42,918	n- π*	
	2.18	326	30,674	π- π*	
	-0.31	422	23,696	$^1A_{1g} \rightarrow {}^1A_{2g}$	Square planar

Table 5: Zones of inhibition

	S. typhi	*E. coli*	*S. aureus*	*A. niger*	*T. rubrum*	*C. abican*
Compounds	**Zones of inhibition (mm)**					
HMISH	14.0	16.0	13.0	11.0	12.0	12.0
$[Mn(HMISH)_2(A)_2]$	16.0	21.0	19.0	14.0	18.0	24.0
$[Ni(HMISH)_2(A)_2]$	21.0	25.0	26.0	19.0	21.0	22.0
$[Cu(HMISH)_2(A)_2]$	28.0	29.0	24.0	20.0	19.0	24.0
$[Pt(HMISH)(A)_2]$	22.0	24.0	20.0	20.0	24.0	22.0

The minimum inhibitory concentrations (MIC) obtained for the ligand and complexes are given in Table 6, showing that lower MIC values were recorded for the metal complexes against both bacterial and fungal strains. The ligand exhibited MIC values between 5.0 and 10.0 mg/mL, whereas the complexes showed lower MIC values down to 2.5 mg/mL, indicating

stronger inhibitory effects. The Cu(II) complex showed the lowest MIC values against *S. typhi*,

E. coli, and *S. aureus*, while the Ni(II) complex demonstrated better activity against *A. niger* and *C. albicans*. These results confirm the higher antimicrobial potency of the complexes compared to the free ligand (Table 6).The minimum bactericidal and fungicidal concentrations (MBC/MFC) are presented in Table 7, where the complexes again showed lower values than the ligand. The ligand displayed MBC/MFC values between 5.0 and 10.0 mg/mL, while the complexes showed values as low as 2.5 mg/mL, indicating that the complexes are more effective in killing microbial cells.

Table 6: Minimum inhibitory concentration

Compounds/ MIC	*S. typhi*	*E. coli*	*S. aureus*	*A. niger*	*T. rubrum*	*C. abican*
HMISH	10.0	5.0	5.0	10.0	5.0	5.0
$[Mn(HMISH)_2(A)_2]$	10.0	2.5	5.0	10.0	5.0	2.5
$[Ni(HMISH)_2(A)_2]$	2.5	5.0	2.5	2.5	5.0	5.0
$[Cu(HMISH)_2(A)_2]$	2.5	2.5	2.5	5.0	10.0	5.0
$[Pt(HMISH)(A)_2]$	10.0	5.0	5.0	10.0	10.0	10.0

The Cu(II) complex displayed the lowest MBC/MFC values among the tested samples, followed closely by the Ni(II) complex. These results are consistent with the zones of inhibition and MIC values, confirming that the complexes possess strong antimicrobial properties suitable for further pharmaceutical consideration (Table 7).

Table 7: Minimum bactericidal and fungicidal concentrations

Compounds	*S. typhi*	*E. coli*	*S. aureus*	*A. niger*	*T. rubrum*	*C. abican*
HMISH	10.0	5.0	2.5	10.0	10.0	10.0
$[Mn(HMISH)_2(A)_2]$	10.0	2.5	10.0	10.0	10.0	5.0
$[Ni(HMISH)_2(A)_2]$	5.0	5.0	2.5	5.0	10.0	5.0
$[Cu(HMISH)_2(A)_2]$	2.5	2.5	2.5	10.0	10.0	5.0
$[Pt(HMISH)_2(A)_2]$	10.0	5.0	5.0	10.0	10.0	10.0

3.2 Discussion

The physicochemical properties of the ligands and complexes are recorded in Table 1, while their solubilities are shown in Table 2. The ligand and all the synthesized complexes were of different colors due to chromophores and electronic transitions in the d orbitals of the metal ions in the complexes. The recorded conductivities of the ligand and the complexes were very low (0.03-1.03 μS), suggesting few ions of the compounds in solution. Similar results of low molar conductance values of Schiff base complexes have been reported by Osowole and Ogunlana (2015) and Eman *et al*. (2015). The melting point of the synthesized compounds was between 211.6 and 241.8 ºC. The high melting point of these compounds is an indication of their thermal stability and the strong bond formed between the metal and the ligand. The results of the IR spectra of the ligand and the complexes are presented in Table 3. The prominent *ν*(OH) band in the spectrum of the HMISH at 3441 cm^{-1} is due to intramolecular hydrogen bond. The phenolic OH absorption of the HMISH at 3441 cm^{-1} was found to occupy frequencies between 3363-3460 cm^{-1} in the spectra of the complexes. This lowering of –OH vibration often causes a reduction of the intramolecular hydrogen bonding present in the molecule. This shows

that the oxygen atom of the phenolic OH coordinated to the metal ions after deprotonation. A clear affirmation of the formation of this is the decrease in the phenolic C-O band of the ligand from 1287 cm^{-1} to 1220-1290 cm^{-1}.

The azomethine functional group (C=N) of the HMISH was seen at 1596 cm^{-1} as a strong vibration. In the spectra of the complexes, this band was seen between 1590-1599 $cm^{-1,}$ suggesting the azomethine group was involved in complex formation. The bond at this azomethine functional group (C=N) was between the N atom and the metal ions. It was formed by the donation of an electron pair from the nitrogen atom to the metal ions.

The weak vibrational bands seen in the spectra of the complexes between 529-627 cm^{-1} were due to the metal- nitrogen (M-N) bonds (Yahaya *et al*., 2018). This is additional evidence of the participation of the azomethine group in the coordination process. The metal-oxygen (M-O) vibrational bands of the complexes were seen as weak bands between 402-461 cm^{-1}. (Shettima *et al*., 2024). Thus the IR spectra of the compounds proved that the ligand is bidentate with O and N donor atoms.

The results of the UV spectra of the ligand and all the complexes are displayed in Table 4. The d-d transition of $[Ni(HMISH)_2(A)_2]$ appeared at 23,640 cm^{-1} and was linked to $^3A_{2g} \rightarrow {}^3T_{1g}$. These observed transitions are indicative of an octahedral geometry for Ni(II) complex (Lakshmi *et al.*, 2011). The d-d transitions of $[Cu(HMISH)_2(A)_2]$ appeared at 23,640 cm^{-1}. The observed transitions were attributed to $^2E_g \rightarrow {}^2T_{2g}$ transitions, which supports octahedral geometry for Cu(II) complex (Valarmathy and Subbalakshmi, 2013; Lawal *et al.*, 2017). Based on the spectroscopic data obtained, the proposed structures for the synthesized complexes are shown in Fig. 1. The antimicrobial results showed that both the ligand and the complexes have good antimicrobial activities.

The $[Mn(HMISH)_2(A)_2]$ had its best inhibition of 24 mm on the *C. albican* strains and lowest (14 mm) on *A. niger*. The inhibition zone of 26 mm recorded against *S. aureus* was the highest for $[Ni(HMISH)_2(A)_2]$, while the lowest was 19 mm on *A. niger*. The $[Cu(HMISH)_2(A)_2]$ had better antibacterial activities than antifungal activity. It gave its highest inhibition zone of 29 mm on *E. coli* and lowest inhibition of 19 mm for *T. rubrum*. The $[Pt(HMISH)(A)_2]$ gave its best zone of inhibition of 24 mm on *E. coli* and *T. rubrum* and least (20 mm) on *A. niger*.

The complexes displayed far higher inhibition zones than the free ligand. This is because of the combined effect of the two ligands and the metal ions. This can be explained in terms of Tweedy's chelation theory (Dharmara *et al*., 2001). As the complexes are formed, polarities of the metal ions are reduced to a greater extent due to the overlapping of the ligand orbital and partial sharing of the positive charge of the metal ion with donor groups. Moreover, delocalization of the π-electrons over the whole chelate ring is increased and the lipophilicity of the complexes. These properties now facilitate the penetration of the complexes across the membrane and DNA of the microbes, leading to perturbation of the respiration process of the cell and blocking the synthesis of proteins, stopping further growth of the organism. Thus in extreme cases, it may lead to the death of the affected microbes. (Mounika *et al*., 2010).

Minimum inhibitory concentration is the lowest concentration of an antimicrobial agent that can inhibit the growth of microorganisms but may or may not kill them. If it inhibits the growth and activities of bacteria without killing them, it is said to be a bacteriostatic agent. But if it inhibits the growth of fungi without killing them, it is said to be fungistatic. The MIC for the ISVN with its mixed ligand complexes are shown in Table 6.

The low MIC of 2.5 mg/ml recorded for the $[Mn(HMISH)_2(A)_2]$ complex against *E. coli* and *C. albican* shows it can be effectively used

to treat infections caused by these organisms. It also inhibited the growth of other microbes at 5.0-10.0 mg/ml. The $[Ni(HMISH)_2(A)_2]$ inhibited the growth of both bacteria and fungi strains, giving better on effect *S. typhi*, *S. aureus* and *A. niger* at a concentration of 2.5 mg/ml. The $[Cu(HMISH)_2(A)_2]$ had MICs of 2.5 mg/ml and 10.0 mg/ml on the bacteria and fungi strains, respectively. This result showed that it can inhibit bacteria even at a very low concentration, but will require a higher concentration to inhibit fungi strains. The $[Pt(HMISH)(A)_2]$ had a lower MIC of 5.0 mg/ml for all the bacterial strains studied. This result was lower than that obtained on the fungi strains (10 mg/ml). Thus, the Platinum complex proved to be a better antibacterial agent than an antifungal agent.

Minimum bactericidal concentration (MBC) is the minimum concentration of an antimicrobial agent that is required to kill bacterial strains. The minimum fungicidal concentration (MFC) is the lowest concentration needed to kill fungal strains. The minimum bactericidal concentrations (MBC) and minimum fungicidal concentrations (MFC) were determined to determine the smallest concentrations of the ligand and complexes that will be required to kill the microbes completely. The smaller the value of the MBC and MFC, the more effective the sample is against the tested strains. Table 7 shows the results of the minimum bactericidal concentrations (MBC) and minimum fungicidal concentrations (MFC) of the ligand HMISH and its mixed ligand complexes.

The MBC and MFC of the ligand, HMISH, for all the organisms were 10 mg/ml except for *S. aureus* and *E. coli,* which were 2.5 and 5.0 mg/ml, respectively.

The $[Mn(HMISH)_2(A)_2]$ gave its best MBC of 2.5 mg/ml on *E. coli*. Its MBC and MFC for the rest of the organisms were 10 mg/ml except for *C. abican,* which was 5.0 mg/ml. This result showed that it can best be used for the treatment of *E. coli* infections. The $[Cu(HMISH)_2(A)_2]$ presented excellent MBC of 2.5 mg/ml while its MFCs were between 5-10 mg/ml. This is an indication that this complex can be used to treat urinary tract infections, typhoid, caused by *E. coli*, *S. aureus* and *S. typhi* respectively. They can also be used effectively for treatment of diseases caused by fungi such as *A. niger*, *T. rubrumand C. abicans*. The $[Pt(HMISH)(A)_2]$ had bactericidal activity at a concentration of 5.0 mg/ml on *E. coli* and *S. aureus* strains. Its MFC was 10 mg/ml for all the fungi strains. Although it was fungistatic at concentrations lower than 10 mg/ml.

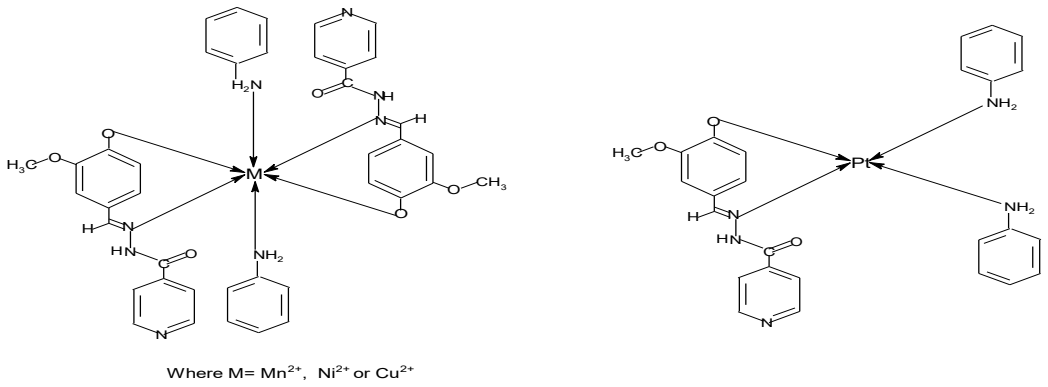


Fig. 1: Proposed structures of the synthesized metal complexes

4.0 Conclusion

A mixed ligand Schiff base, 4-hydroxy-3-methoxybenzaldehyde-isonicotinylhydrazone (HMISH) and its Mn(II), Ni(II), Cu(II) and Pt(II) complexes were successfully synthesized with high yields and good thermal stability as confirmed by melting point values in the range of 211.6–241.8 °C. The very low molar

conductivity values (0.03–1.02 μS) indicated that all the complexes are non-electrolytic, and the solubility pattern showed increased solubility in polar organic solvents relative to water, confirming reduced polarity upon complexation. FTIR spectra showed shifts in both the azomethine (C=N) and phenolic (C–O) bands together with new M–N and M–O vibrations, indicating bidentate coordination through the azomethine nitrogen and phenolic oxygen atoms, while UV–visible spectra supported octahedral geometries for Mn(II), Ni(II), and Cu(II) complexes and a square-planar geometry for Pt(II). The antimicrobial studies revealed enhanced biological activities for the metal complexes compared to the free ligand. The Cu(II) complex showed the highest activity with inhibition zones of up to 29.0 mm against E. coli and MIC values as low as 2.5 mg/mL, followed by the Ni(II) and Pt(II) complexes. The improved activity is attributed to increased lipophilicity and easier penetration of the microbial cell membrane upon chelation. Overall, these results demonstrate that Schiff base metal complexes derived from HMISH are promising antimicrobial agents, especially the Cu(II) and Ni(II) complexes. Further studies including toxicity assessment, mechanism of action, and computational docking are recommended to validate their pharmaceutical potential.

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Isaac T. Iorkpiligh conceived the study, synthesized the ligand and metal complexes, and led manuscript preparation. Timothy T. Weor performed physicochemical and spectroscopic characterization. Grace E. Iniama conducted antimicrobial assays and data analysis. Paula H. Ado supported methodology design, literature review, and interpretation of biological results. All authors reviewed, edited, and approved the final manuscript.