SYNTHESIS, CHARACTERIZATION, AND ANTIMICROBIAL ACTIVITY OF MIXED ANTIBIOTIC-VITAMIN METAL COMPLEXES INVOLVING METRONIDAZOLE AND VITAMIN B1 (THIAMINE)

ABSTRACT

Antimicrobial resistance (AMR) poses a critical threat to global health, making it imperative to develop novel therapeutic strategies. This study focuses on the synthesis and characterization of mixed antibiotic-vitamin metal complexes involving metronidazole and vitamin B1. Metal complexes, known for their unique structural properties, were synthesized with Nickel, Zinc, and Iron salts to enhance the biological efficacy of the parent antibiotics. These complexes were analyzed using various physicochemical methods, including ultraviolet-visible and infrared spectroscopy, and were evaluated for their solubility, elemental composition, and melting points.

The antimicrobial activity of the synthesized complexes was tested against bacterial strains such as *Streptococcus feacalis*, *Escherichia coli*, *Klebsiella pneumoniae*, and *Staphylococcus aureus*, as well as fungal strains like *Aspergillus niger* and *Candida albicans*. The results demonstrated that the metal complexes exhibited enhanced antibacterial and antifungal properties compared to the free ligands. Specifically, the zinc and nickel complexes showed significant inhibition against *Klebsiella pneumoniae* and *Aspergillus niger*, respectively. This study highlights the potential of metal complexes as promising agents to combat AMR, providing a foundation for future research into drug development and clinical applications.

INTRODUCTION

Antimicrobial resistance (AMR) has emerged as a critical public health issue, posing a significant threat to the effectiveness of modern medicine. According to the World Health Organization [1], we are potentially facing a post-antibiotic era where common infections and minor injuries could once again become life-threatening [2]. This alarming scenario is driven by the increasing resistance of pathogens to antibiotics [3], a problem that was foreseen by Alexander Fleming during his Nobel Prize speech in 1945. The widespread use of antibacterial drugs has accelerated the development of resistant strains, creating a global challenge in treating bacterial, viral, and fungal infections [4,5]. Resistance to commonly used antibiotics, such as fluoroquinolones, has become widespread, making the treatment of infections like those caused by Streptococcus pyogenes more difficult, costly, and sometimes ineffective [6]. AMR not only increases the duration of illness and mortality rates, especially among vulnerable patients, but also exerts a significant economic burden on healthcare systems. The development of novel therapeutic approaches is therefore essential to combat this escalating problem [7].

Recent advances in medicinal chemistry have focused on modifying existing drugs by incorporating metal ions, which enhance their biological activity and reduce the development of resistance [8,9]. Metal complexes offer unique structural and electronic properties that can improve the pharmacological profiles of antibiotics [10]. Chelation of antibiotics with metal ions has been shown to increase their potency, reduce toxicity, and provide synergistic effects that enhance antimicrobial efficacy. Combining antibiotics with vitamins and metal ions offers a promising strategy to develop novel drug complexes with improved therapeutic potential [11].

This research aims to synthesize mixed antibiotics and vitamin metal complexes and investigate their antimicrobial activity. By characterizing these complexes using standard analytical methods and evaluating their effectiveness against resistant microorganisms, this study seeks to contribute to the development of new therapeutic agents that can address the growing challenge of AMR.

Metronidazole

Metronidazole is an antibiotic that is used to treat a wide variety of infections. It works by stopping the growth of certain bacteria and parasites [12]. This antibiotic treats only certain bacterial and parasitic infections [13]. It will not work for viral infections (such as common cold, flu). Using any antibiotic when it is not needed can cause it to not work for future infections. Metronidazole may also be used with other medications to treat certain stomach /intestinal ulcers caused by a bacterium.

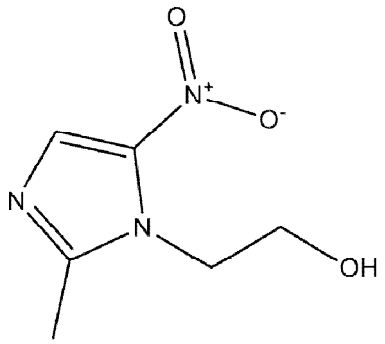


Figure 1: Structure of Metronidazole

This medication is used to treat a variety of bacterial infections. Ciprofloxacin belongs to a class of drugs called quinolone antibiotics. It works by stopping the growth of bacteria. These antibiotic treats only bacterial infections. It will not work for virus infections (such as common cold, flu). Using any antibiotic when it is not needed can cause it to not work for future infections [14].

Vitamin B1

Vitamin B1 (2-[3-[(4-amino-2-methylpyrimidin-5-yl)methyl]-4-methyl-1,3-thiazol-3-ium-5yl]ethanol) also known as thiamin , is a vitamin found in food, and manufactured as a dietary supplement and medication [15,16]. Thiamine is a colorless organosulfur compound with a chemical formula $C_{12}H_{17}N_4OS+$ with molecular weight 265.355 g/mol. Its structure consists of an aminopyrimidine and a thiazolium ring linked by a methylene bridge. The thiazole is substituted with methyl and hydroxyethyl side chains [17,18]. Thiamine is soluble in water, methanol, and glycerol and practically insoluble in less polar organic solvents. It is stable at acidic pH, but is unstable in alkaline solutions. Thiamine, which is a persistent carbene, is used by enzymes to catalyze benzoin condensations in vivo [19]. Thiamine is unstable to heat, but stable during frozen storage. It is unstable when exposed to ultraviolet light and gamma irradiation.

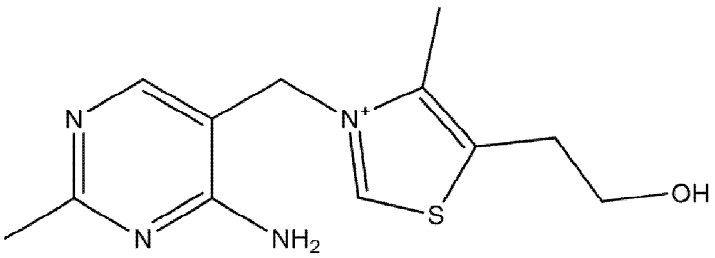


Figure 2: Chemical Structure of Vitamin B1

Thiamine enables the body to use carbohydrates as energy. It is essential for glucose metabolism and plays a key role in nerve, muscle, and heart function. Thiamine deficiency are as follows**:** Poor memory, irritability, sleep disturbance, Bilateral, symmetrical lower extremities paresthesia, burning pain, Muscle cramps. Decreased vibratory position sensation.

Literature Review

Obaleye and Abosede synthesized three new iron (III) complexes of doxycycline *viz*: $[Fe(dox)_2Cl]Cl_2$, $[Febpy(dox)Cl]Cl_2$ (**2**) and $[Fephen(dox)Cl]Cl_2$ (**3**), where dox is doxycycline, bpy is 2,2′-bipyridine and phen is 1,10-phenanthroline, and characterized by elemental analysis, electronic absorption, FT-IR, and electrospray ionization mass spectroscopy. Doxycycline and the polypyridyl ligands behave as bidentate ligands; the polypyridyl ligands coordinate through the two diamine nitrogen atoms and doxycycline through enolate and diketoamide oxygen atoms of ring A in a five-coordinate system with chloride atom in the axial position. The three complexes showed good activity against strains of *Staphylococcusaureus* and *Klebsiella pneumonia* [20]

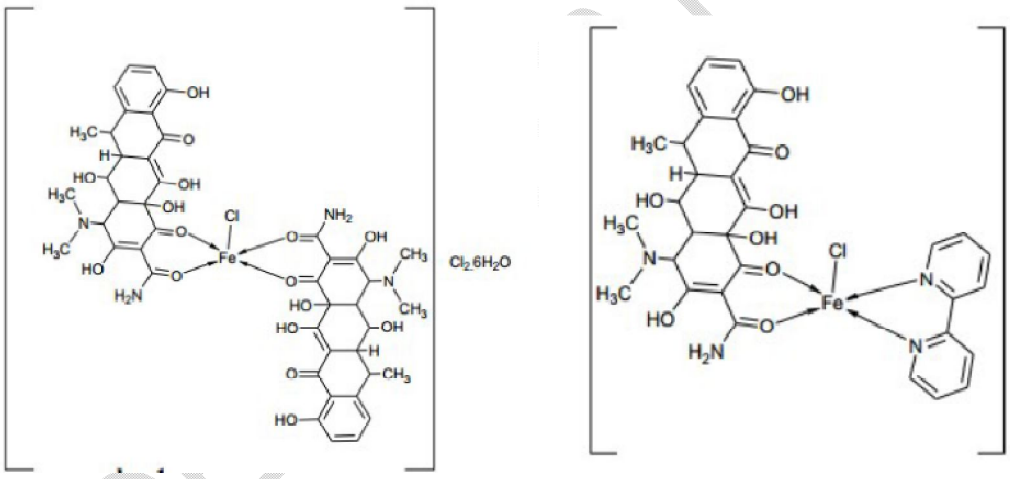
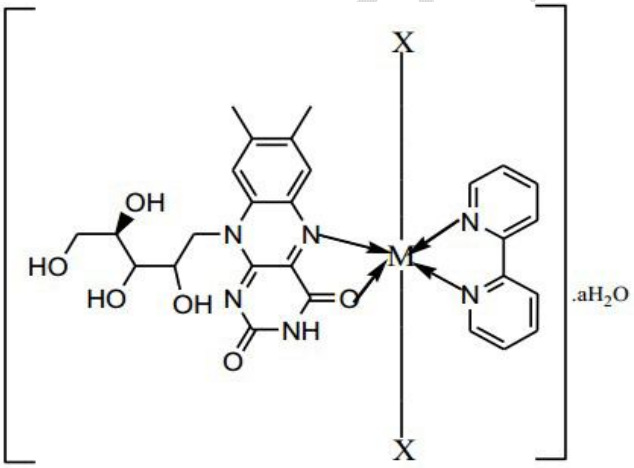


Figure 3: Proposed structure of Complex 1 and 2

Rostamizadeh with his fellow researchers describes the Synthesis of sulfamethoxazole and sulfabenzamide metal complexes; evaluation of their antibacterial activity of ten different complexes the spectroscopic methods such as 1H NMR, UV-Vis spectroscopy analysis, FTIR and XRD confirmed the coordination of both ligands to metals through the nitrogen and oxygen atoms of the sulphonamide group. The antibacterial results showed the metal sulfonamide complexes have important antibacterial activities, especially, zinc (II) sulfamethoxazole have shown more antibacterial than its free ligand. The intention of this report was to discover the antibacterial activity of synthesized compounds and to develop lead molecules for optimization [21].

Osowole*et al.*, reported the synthesis of mixed ligand complexes of Riboflavin (L) and 2,2'Bipyridine (L1) with Mn (II), Fe(II), Co(II), Ni(II), Cu(II) and Zn(II) ions and were characterized by, infrared and electronic spectroscopies, room temperature magnetic moments, melting points and conductance measurements. The elemental analysis confirmed that the complexes analyzed as $[MX_2(L)(L1)]$ where X = Cl/(CH_3CO_2)/SO_4. Infrared spectra data confirmed that coordination is via the imine nitrogen and carbonyl oxygen atoms of the riboflavin, and the nitrogen atoms of the 2,2'-bipyridine molecules respectively. The room temperature magnetic moment and electronic spectra data indicated that all the metal (II) complexes were octahedral, and the Mn (II), Fe (II), Co (II) and Ni (II) complexes showed high spin low spin octahedral equilibrium. Interestingly, the invitro antibacterial studies of these metal (II) complexes, riboflavin and 2,2'- bipyridine against Bacillus cereus, Escherichia coli, Proteus mirabilis, Pseudomonas aeruginosa, Klebsiella oxytoca and Staphylococcus aureus showed that none of the bacteria was sensitive to the former two compounds, except for Proteus mirabilis against the Cu (II) complex and riboflavin. In contrast, all the bacteria were sensitive to 2, 2'-bipyridine, just like Augmentin, although with higher inhibitory zones range of 24.0-47.0 mm proving its potential as a broad-spectrum antibacterial agent [22].



When M = Mn/Ni/Zn, X = Cl/OAc, a =0; Cu/Co, X = Cl, a =3

Figure 4: Proposed structure for some of the Metal (II) complexes

EXPERIMENT

2.1 Materials and Method

All chemicals and solvents used for synthesis were of analytical grade and were used as received without further purification. The lists of the metal salts (chemicals) used are as follows: Nickel (II) Nitrate hexahydrate ($Ni(NO_3)_2.6H_2O$), Ferrous (II) Sulfate heptahydrate ($FeSO_4.7H_2O$), and Zinc Nitrate hexahydrate ($Zn(NO_3)_2.6H_2O$) are all obtained commercially from Labtrade. The

solvents used are methanol, ethanol, chloroform, diethyl ether, distilled water, dimethyl formamide, and dimethyl sulphoxide.

The Ligands (drugs) used for this research work are: i. Metronidazole and ii. Vitamin B1. They were obtained from Bioraja Pharmaceutical, Rabjab Pharmaceutical Ilorin. Kwara State and Peace Pharmaceutical. Ilorin. Kwara State.

2.2. Synthesis of Metal complexes of Metronidazole and Vitamin B1 (Thiamine)

The Vitamin B1 was dissolve in 5mmol of distilled water and mixed with Metronidazole that was dissolve in 15mmol of methanol. The metal salts were added neatly to a stirring 15mL methanolic solution of vitamin B1 (HL_1) and Metronidazoe (HL_2). The resulting homogeneous, colored solutions was buffered with triethylamine to a pH of 9, and then refluxed for 3 hours at 50^0C. The resulting solution were filtered and the filtrate was left for few days to evaporate. The complex formed were washed with methanol and air dry. The filtrate was allowed to evaporate slowly and after 3 days, white crystals were formed [23].

$$M(NO_3)_2.H_2O + Metz + Tham \xrightarrow[\text{Triethylamine, Room temp.}]{\text{Methanol, Water}} M(Metz)(Tham)(NO_3)_2$$

where M is the metal ions, Metz is Metronidazole and Tham is Thiamine

2.3 Antimicrobial Studies

The Agar-well diffusion method was used to evaluate the antibacterial effects of our compounds against *Streptococcus feacalis, Escherichia coli, Klebsiella pneumoniae* and *Staphylococcus aureus*. The strains of bacteria were stored on Nutrient Agar Medium.

A sterile glassy borer was used to dig the well (5 mm in diameter) in the media. After the solidification of the molten Agar, the surface of the Nutrient Agar was inoculated with the selected test organisms using a sterile cotton swab [24, 25]. The test compounds of 40 µL per well (12 mg/2 ml) were gently introduced into the wells respectively. The solution of the test samples was allowed to disperse evenly and the plates were immediately incubated at 370C for 24 h. The zone of clearance (inhibition) was observed, and carefully measured and the value was recorded in millimeters respectively. The inhibitory activity of the compounds was repeated to confirm the findings and the average value was recorded. DMSO was obtained commercially and was used to dissolve the samples and it also served as the control for the antibacterial test [25].

The fungi activity of the Ligands and the metal complexes will be determined using cultures of two fungi which include: *Aspergillus niger and Cadida albiean*. They will be cultured on potato dextrose sugar. The fungal cultures will be incubated at 37 ^{o}C for 38 hours before use. The zone of inhibition was measured after 38 hours and recorded.

3.0 RESULT AND DISCUSSION

3.0 Results and Discussion

The metal complexes of the mixed ligands of Metronidazole and Vitamin B1 were obtained and the results of various analyses are presented in the table below.

3.1. Results of Solubility Test of Ligands and Complexes.

Table 1: Results of Solubility Test of Ligands and Complexes

Ligand/Metal Complexes	**D. Water**		**Methanol**		**Ethanol**		**DMF**		**DMSO**		**Acetone**	
	C	**H**	**C**	**H**	**C**	**H**	**C**	**H**	**C**	**H**	**C**	**H**
Metronidazole	**NS**	**SS**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**NS**	**SS**
Vitamin B1	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**	**S**
Ni(Metz)(Tham)$(NO_3)_2$	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**S**	**S**	**S**	**S**	**NS**	**NS**
[Zn$(Metz)_2(Tham)_2(NO_3)_2$]H$_2$O.Cl	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**S**	**S**	**S**	**S**	**NS**	**NS**
[Fe$(Metz)_2(Tham)_2(SO_4)$(H_2O)] H_2O.Cl	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**S**	**S**	**S**	**S**	**S**	**S**

Keys: S=Soluble, SS= Slightly Soluble, NS= Not Soluble, C=Cold, H= Hot

The solubility of the metal complexes was compared with that of the ligands by dissolving them in cold and hot mediums of some polar solvents such as water, methanol, ethanol, and non-polar solvents such as DMF and DMSO. However, they were found to be more soluble in DMF and DMSO indicating that the complexes are non-polar [26, 27].

3.2 Analytical data of the Ligands and their complexes

Table 2: Result of Analytical data of Metronidazole, Vitamin B1 and their complexes

Ligands/Complexes	Molar mass(g/mol)	Colour	State	Melting point(^{o}C)	Percentage yield
Metronidazole	171.16	White	Crystalline powder	163.6	
Vitamin B1	265.35	White	Powdery	232.0	
$Ni(Metz)(Tham)(NO_3)_2$	621.63	Colourless	Crystal	166.6	79
$[Zn(Metz)_2(Tham)_2(NO_3)_2]H_2O.Cl$	1064.29	White	Crystal	184.2	82
$[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]\ H_2O.Cl$	1046.97	Brown	Powdery	189.0	75

The synthesized metal complexes have colors that are different from the parent ligand and the melting points of the complexes are different from that of the ligands.

3.3 Elemental Analysis (CHN) of the Metal Complexes

Table 3: Result of Elemental Analysis (CHN) of the Metal Complexes

Compounds	Elemental CHN % found (Theory)		
	C	H	N
$[Zn(Metz)_2(Tham)_2(NO_3)_2]H_2O.Cl$	43.50(40.54)	5.17(5.29)	22.84(21.01)
$[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]\ H_2O.Cl$	41.76(41.30)	5.22(5.58)	24.33(18.73)

The elemental composition of the synthesized metal complexes was determined using CHN analysis, and the results are summarized in Table 3. The experimental values for carbon, hydrogen, and nitrogen were compared with the theoretical values calculated from the proposed molecular formulas.

For the complex [Zn(Metz)□(Tham)□(NO□)□]H□O.Cl, the experimental carbon content (43.50%) was found to be in good agreement with the theoretical value (40.54%), indicating accurate synthesis. Similarly, the hydrogen content (5.17%) was close to the expected value (5.29%), while nitrogen (22.84%) was slightly higher than the theoretical value (21.01%).

In the case of [Fe(Metz)□(Tham)□(SO□)(H□O)]H□O.Cl, the carbon (41.76%) and hydrogen (5.22%) values were close to the theoretical predictions (41.30% and 5.58%, respectively). However, the nitrogen content (24.33%) showed a notable deviation from the theoretical value (18.73%), suggesting possible experimental error or incomplete combustion during analysis.

These findings support the successful formation of the desired metal complexes with minor deviations, which are likely due to experimental conditions during synthesis and analysis.

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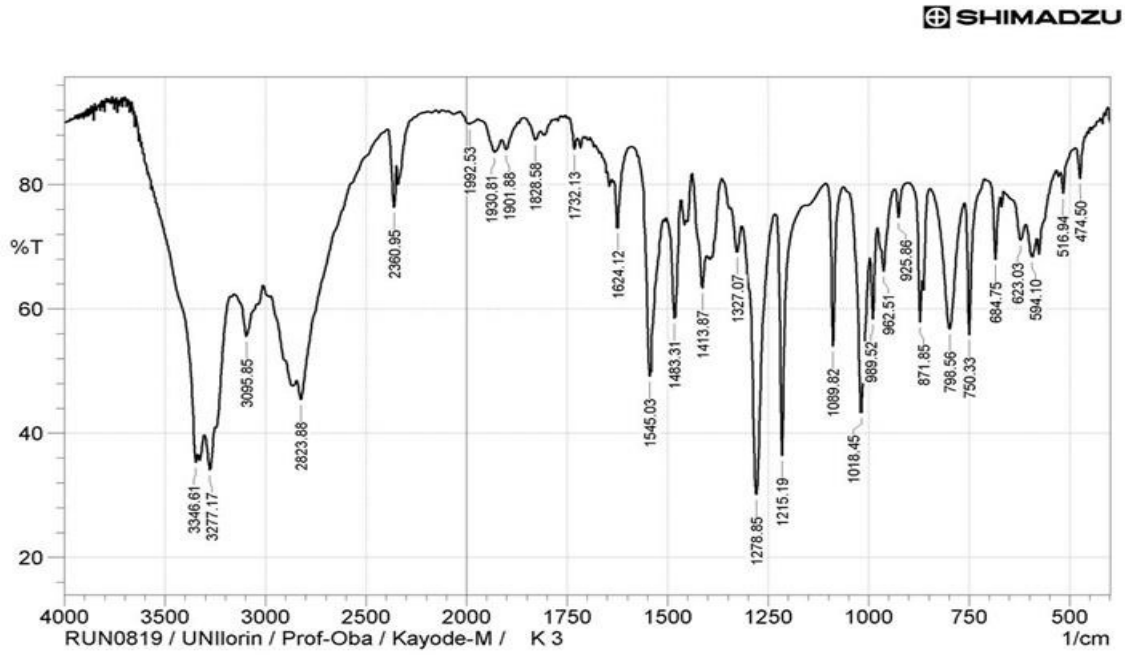
3.4 Infrared Spectra of the Ligands and complexes

Table 4: Results of Infrared Spectra of Metronidazole, Vitamin B1 and their complexes

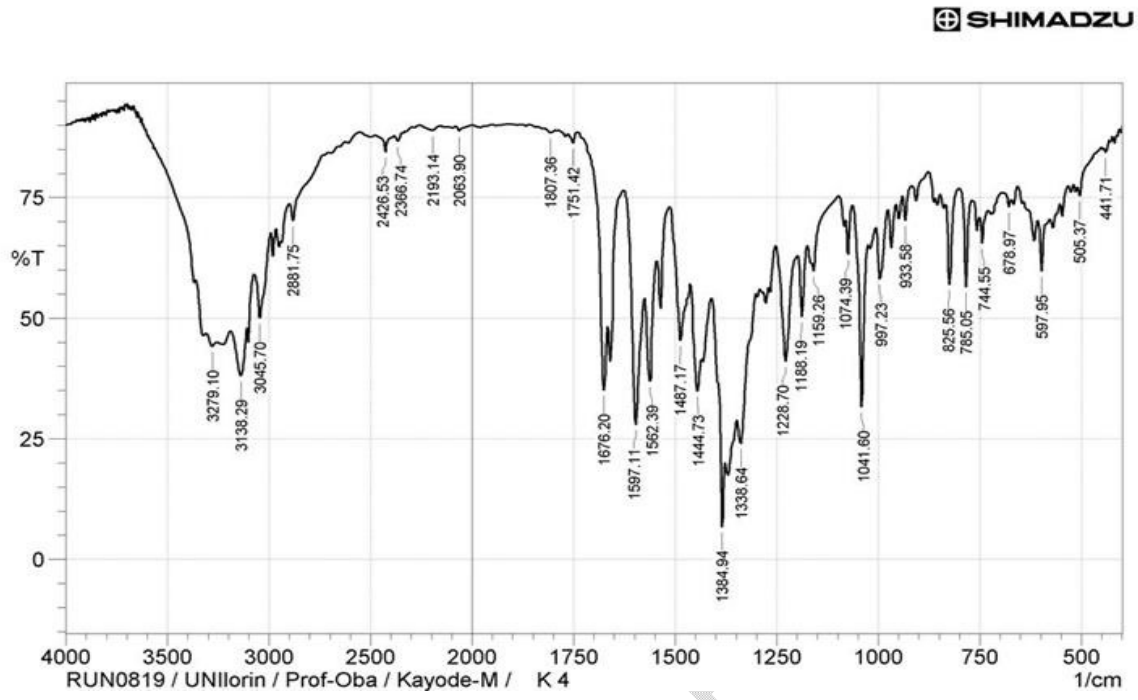
Compounds	**υ(N-H)**	**υ(O-H)**	**υ(N=O)**	**υ(C=C)**	**υ(C=N)**	**υ(C-O)**	**υ(M-N)**
Metronidazole	3223.16 3101.64	3448.84 3423.76	1369.50	1473.66	1535.39		
Vitamin B1	3232.80	3500.92 3441.12		1531.53	1656.91 1614.47	1045.45	
Ni(Metz)(Tham)$(NO_3)_2$	3138.29 3045.70	3279.10	1384.94	1597.11 1562.39	1676.20		441.71
$[Zn(Metz)_2(Tham)_2(NO_3)_2]H_2O.Cl$	3138.29 3045.70	3327.32	1384.94	1597.11	1676.20	1041.60	597.95
$[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]\ H_2O.Cl$	3221.23 3101.64	3408.33	1369.50	1473.66	1535.39	1188.19	420.50

The FT-IR spectra of the complexes synthesized are different from the ligand. The relevant data of both ligands and complexes are presented in the table 4 In the infrared spectrum of metronidazole, stretching vibrations of – OH associated group were indicated by two absorption bands at 3223.16 cm^{-1} and 3101.64 cm^{-1}. Metronidazole IR spectrum showed a characteristic vibrational peak for C-H stretching at 2958.90 cm^{-1} [28, 29]. IR peaks at 1429.30 cm^{-1} and 1535.39 cm^{-1} were assigned to stretching bonds (–C=C–) and (–C=N–) of imidazole ring, respectively. The (N=O) asymmetric stretching was assigned to peak at 1429.30 cm^{-1}, (N=O) symmetric stretching, was assigned to peak at 1369.50 cm^{-1}. IR peaks at 1656.91 cm^{-1} and 1531.53 cm^{-1} were assigned to stretching bonds (–C=N–) and (–C=C–), 3441.12cm^{-1} and 3232.80 cm^{-1} were attributed to υ(O–H) and **υ(**N-H**)** of the vitamin B1.

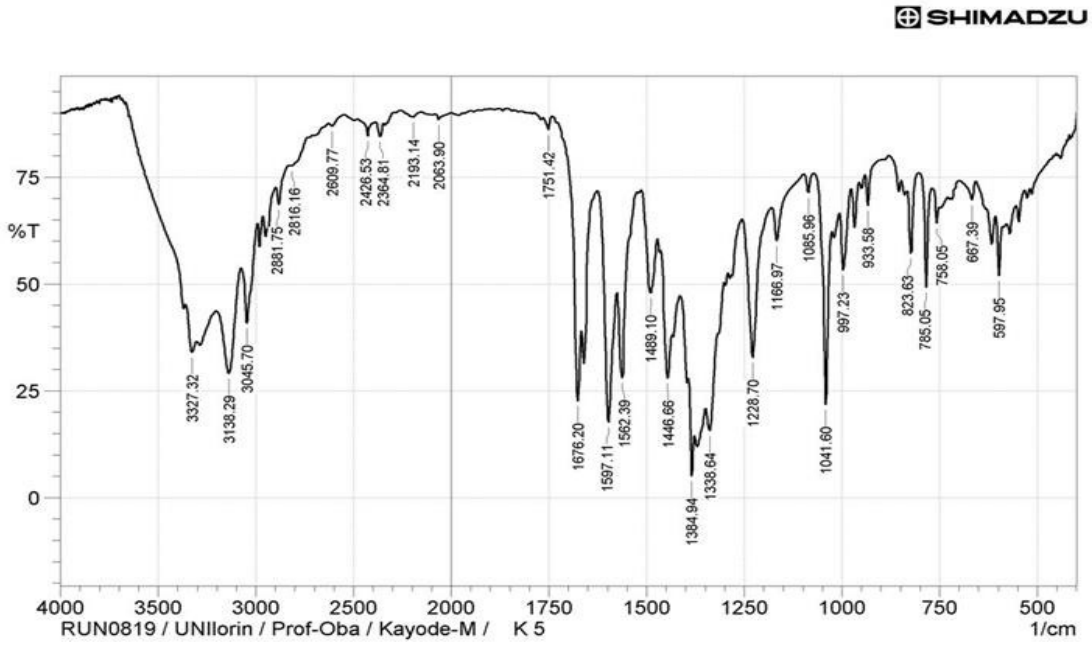
The absorption bands of (–C=N–) of imidazole ring of metronidazole Shifted from 1535.39 cm^{-1} to 1676.20, 1627.97, 1616.40 cm^{-1} for $Ni(Metz)(Tham)(NO_3)_2$, $[Zn(Metz)_2(Tham)_2(NO_3)_2]H_2O.Cl$ and $[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]$ $H_2O.Cl$ respectively. This confirmed a coordination mode of (–C=N–) through the Imide of the metronidazole. All these complexes show the metal coordinated to a nitrogen atom from the aminopyrimidine ring in a monodentate mode and the metal coordination sphere is completed by water and chloride [30]. The new peaks in the range of 500 – 400 cm^{-1} indicating the υ(M-N) is an indication of metal binding to the ligand, which was absent in the spectra of metronidazole and vitaminB1.



Picture 1: IR Spectra of $Ni(Metz)(Tham)(NO_3)_2$



Picture 2: IR spectra of $Zn(Metz)(Tham)(NO_3)_2$



Picture 3: IR spectra of $Fe(Metz)(Tham)(SO_4)(H_2O)$

3.5 Ultraviolet-Visible Spectra Analysis of ligands and their complexes

Table 5: Results of Ultraviolet-Visible of Metronidazole, Vitamin B1 and their complexes

Ligands/Complexes	Wavelength(nm)	Assignment
Metronidazole	**357.0**	$n \rightarrow \pi$
Vitamin B1	**296.0**	$n \rightarrow \pi$
$Ni(Metz)(Tham)(NO_3)_2$	**331.0** **351.0**	$\pi \rightarrow \pi^*$ $n \rightarrow \pi$
$[Zn(Metz)_2(Tham)_2(NO_3)_2]H_20.Cl$	**482.0** **495.0**	$\pi \rightarrow \pi^*$ $n \rightarrow \pi$ no d-d transition
$[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]\ H_2O.Cl$	**447.0** **526.0**	MCLT $^2Eg \rightarrow {}^2T2g$

The result of the UV-vis spectra of the ligands namely, Metronidazole and Vitamin B1, and the complexes range from Ni, Zn, and Fe- showed that the ligands coordinated to the named transition metal ion. In the Table 5 some selected data of the parent ligands and the complexes are given below; From the table below, it was noted that vitamin B1 has a band at 298 nm which is assigned to $n \rightarrow \pi$. Also, bands at 357 nm are attributed to metronidazole which are assigned to $n \rightarrow \pi$.

3.6 Biological Activity Studies

Table 6: Result of the Antibacterial Activity of the Metronidazole, Vitamin B1 and their complexes

Ligands/Complexes	*Steptococcus feacalis*	*Escherichia coli*	*Klebsiella pneumoniae*	*Staphylococcus aureus*
Zone of Inhibition (mm)				
Metronidazole	0	0	0	8
Vitamin B1	29	25	9	10
$Ni(Metz)(Tham)(NO_3)_2$	10	15	13	4
$[Zn(Metz)_2(Tham)_2(NO_3)_2]H_20.Cl$	0	15	14	0
$[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]\ H_2O.Cl$	9	13	11	0

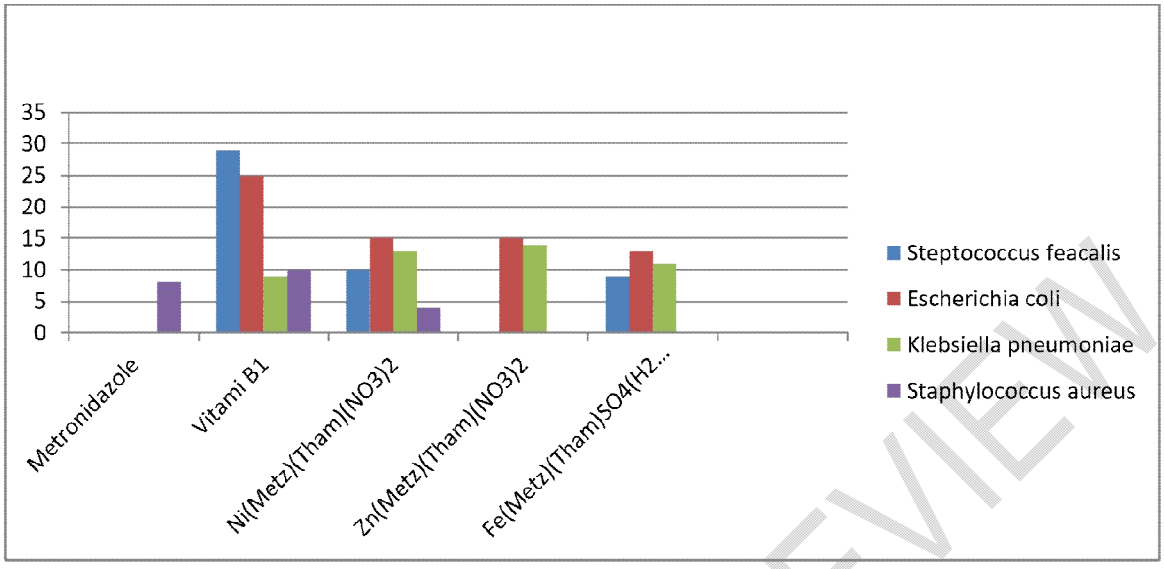


Figure 5: Antibacterial Activity of the Metronidazole, Vitamin B1 and their complexes

The antibacterial activity of Metronidazole, Vitamin B1 and synthesized complexes are presented in table. 6.. They were screened against *Streptococcus feacalis, Escherichia coli, Klebsiella pneumonia, Staphylococcus aureus.* The solvent used was DMSO, the control exhibits no antimicrobial activity against the test micro-organisms and the activities was measured as function of zone of inhibition (mm). "The antibacterial activity of mixed antibiotic-metal complexes against *Escherichia coli* and *Staphylococcus aureus* showed significant inhibitory effects, which aligns with findings in similar metal-based complexes studied previously. In a study by Ayodeji et al. (2024), complexes of amodiaquine and pyrimethamine demonstrated increased inhibition zones for *Escherichia coli* (up to 20 mm) and *Staphylococcus aureus* (25 mm), suggesting that metal coordination enhances antimicrobial efficacy [27]." The metronidazole showed antimicrobial activity on *Staphylococcus aureus* only while Vitamin B1 showed more antimicrobial properties than metronidazole and synthesized complexes. Ni(Metz)(Tham)$(NO_3)_2$ andZn(Metz)(Tham)$(NO_3)_2$ are more effective on *Klebsiella pneumonia* as compared with

that of ligands, this indicates that some of the mixed metal complexes have more antibacterial activity

Table 7: Result of the Antifungal Activity of the Metronidazole, Vitamin B1 and their complexes

Ligands/Complexes	***Aspergillus niger***	***Candida albiean***
Zone of Inhibition(mm)		
Metronidazole	11	0
Vitamin B1	10	15
Ni(Metz)(Tham)$(NO_3)_2$	13	18
[Zn$(Metz)_2(Tham)_2(NO_3)_2$]H_20.Cl	9	14
[Fe$(Metz)_2(Tham)_2(SO_4)(H_2O)$] H_2O.Cl	0	0

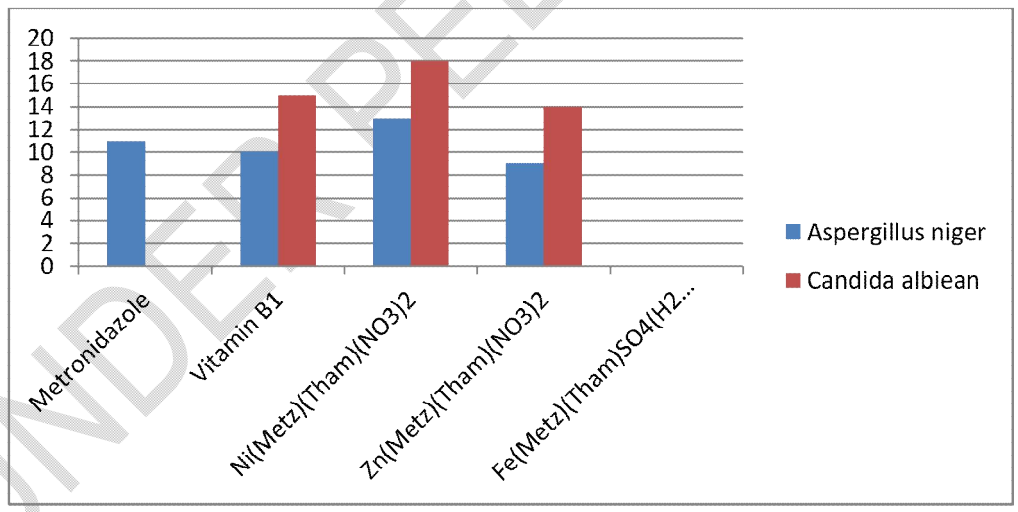


Figure 6: Antifungal Activity of the Metronidazole, Vitamin B1 and their complexes

From the above result, the Ni(Metz)(Tham)$(NO_3)_2$ compound showed a strong activity against *Asperigellus niger* and *Candida albiean*. The activity against fungiis more significant

whereas both metronidazole & vitamin B1 showed little significant against the fungi. And from the above result of the antifungal activity [31, 32], a moderate result of activity was obtained against. *Asperigellus niger for* $Zn(Metz)(Tham)(NO_3)_2$ when compared with metronidazole a strong antibiotic drugs, while $Fe(Metz)(Tham)(NO_3)_2$ showed no significant activity.

Proposed structure of mixed drug metal complexes

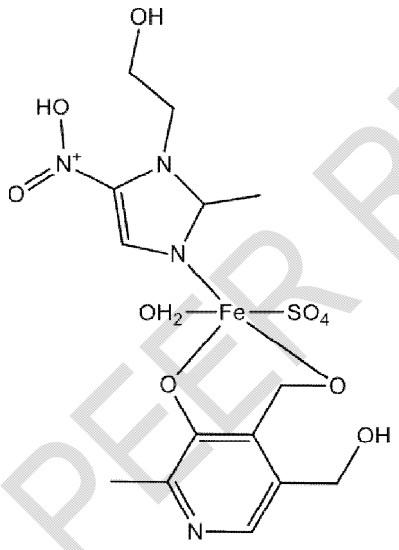


Figure 7: Proposed structure of $Fe(Metz)(Pyr)SO_4(H_2O)$

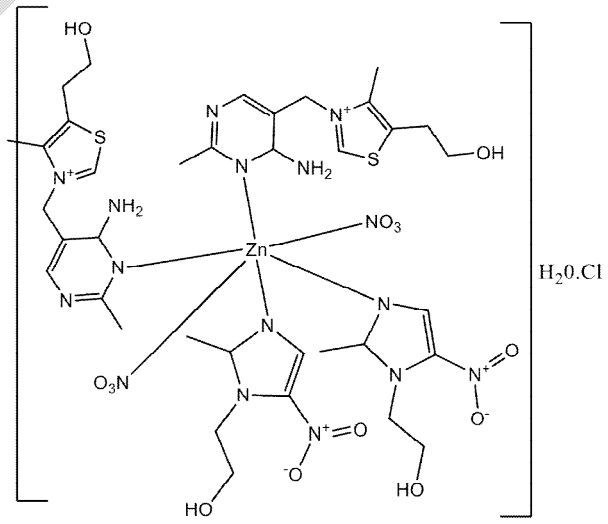


Figure 8: Proposed structure of $[Zn(Metz)_2(Tham)_2(NO_3)_2]H_20.Cl$

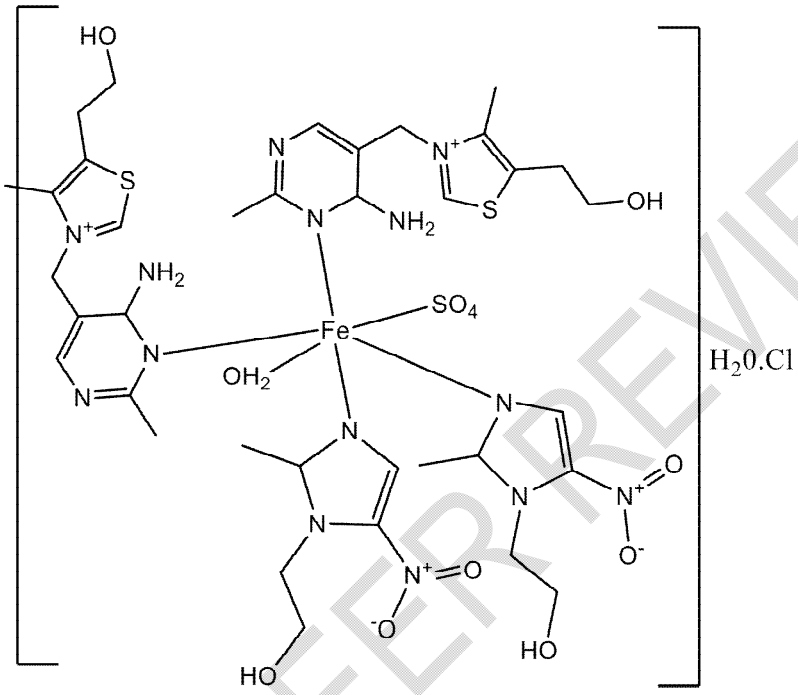


Figure 9: Proposed structure of $[Fe(Metz)_2(Tham)_2(SO_4)(H_2O)]$ $H_2O.Cl$

3.8 CONCLUSION

In this research, new mixed drug-metal complexes of metronidazole, vitamin B1 and vitamin B6 were synthesized by stirring at room temperature. The drug metal complexes were characterized using physiochemical analyses such as melting point, solubility, elemental analysis and spectroscopic techniques such as ultraviolent-visible and infrared spectroscopy.

The Infrared confirmed a coordination mode of (–C=N–) through the Imide of the metronidazole and vitamin B1 coordinated to a nitrogen atom from the aminopyrimidine ring in a monodentate mode. "The IR spectra of the synthesized metal complexes displayed

significant shifts in absorption bands compared to the free ligands, indicating coordination with metal ions. A similar trend was observed in the work by Ayodeji et al. (2024), where the characteristic OH absorption band at 3418.94 cm^{-1} in the ligands was absent in the metal complexes, confirming the coordination of amodiaquine through the hydroxyl group and pyrimethamine through the nitrogen atom of the primary amine." The characteristic C-O peak was observed around 1327.07 cm^{-1} in vitamin B6 and a shift in the peak position towards lower frequency was observed in all the metal complexes which is an indication of metal complex formation. The characteristic stretching frequency of OH shifted from 3346.61 cm^{-1} indicating a coordination mode through the OH of the Vitamin B6.

The ligands and their respective metal complexes were screened against bacteria *Streptococcus feacalis, Escherichia coli, Klebsiella pneumonia, Staphylococcus aureus.* and fungi; *Asperigellus niger* and *Candida albiean*. The antimicrobial results showed that the complexes were more active than the free ligands.

3.9 Recommendation.

It is recommended that further structural characterization should be done on all the metal complexes such as EPR, ES-Mass spectroscopy, magnetic susceptibility, NMR and X-ray crystallography to elucidate the structure of metal complexes.

Stability studies and catalytic effect of the complexes should be studied, and the effects of the drug metal complexes on animals should also be studied to know their strength.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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