

Correlation Between the Electrolytic and Biological Properties of Hydroxamic Acids and their Iron(II/III), Nickel(II), Copper(II) and Zinc(II) Complexes

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***Corresponding author:** Dong Yang, Clinical Laboratory, Shanxi Provincial People's Hospital Affiliated of Shanxi Medical University, Taiyuan 030012, China and The Fifth Clinical Medical College of Shanxi Medical University, Taiyuan 030012, China

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Ibrahima Sory Sow^{1,2} and Dong Yang^{3,4*}

¹Department of Fundamental Sciences, Institut Supérieur des Sciences de l'Education de Guinée (ISSEG), Guinea

²Microbiology, Bioorganic and Macromolecular Chemistry Unit, Faculty of Pharmacy, Université libre de Bruxelles (ULB), Belgium

³Clinical Laboratory, Shanxi Provincial People's Hospital Affiliated of Shanxi Medical University, China

⁴The Fifth Clinical Medical College of Shanxi Medical University, China

Abstract

Hydroxamic acid (HA) and their iron(II/III) (HAFelI, HAFelIICl and HAFelIII), nickel(II) (HANiII), copper(II) (HACuII) and zinc(II) (HAZnII) complexes were synthesized and characterized by a set of physicochemical techniques: infrared (IR), ultraviolet-visible (UV-Vis), ¹H nuclear magnetic resonance (NMR) spectroscopy, mass spectrometry, single-crystal X-ray diffraction, cyclic voltammetry, magnetic susceptibility measurements, elemental analysis and molar conductivity (Λ_m). In this work, we explored potential correlation between electrolytic behaviour and antimicrobial properties of parent HA and their corresponding metal complexes. Λ_m data indicate HA2, HA6, HA8 and HA12 behave as non-electrolytes under the tested conditions. The antifungal activity of HA12 cannot explained by its non-electrolytic character in either methanol or aqueous media. C12-chain metal complexes HA12NiII, HA12CuII and HA12ZnII exert inhibitory activity against *Candida albicans* and exhibit high Λ_m consistent with ionic behavior in aqueous media, where these same complexes show no measurable activity against *Mycobacterium smegmatis* despite their high Λ_m . For the parent HA, a moderate coefficient of determination was obtained for the raw Λ_m -versus-MIC regression. This value must be interpreted cautiously because several MIC values were recorded as > 500mM rather than exact numerical values. For the metal complexes, a strong correlation between electrolytic properties and biological activity was observed. Our observations suggest that ionic species in solution may contribute to the biological performance of HA-metal complexes, although this cannot be established as a definitive causal relationship from the present dataset alone.

Keywords: Hydroxamic acid; Metal complexes; Electrical and molar conductivities; Antifungal and antimycobacterial activities

Introduction

Hydroxamic acid (HA), with the general formula: RCONHOH, are a particularly interesting class of bidentate organic O,O-donor ligands and have many different applications, mainly in drug design and analytical chemistry [1]. HA are electronically flexible compounds for organic and inorganic analyses, due to the more delicate structures compared to carboxylic acid. These acids are easy to deprotonate to produce hydroxamate ions [2]. The derivatives of HA, especially the metal complexes, exhibit a wide variety of roles in biology and medicine. Due to the antimicrobial properties, the chemistry and biochemistry characteristics of HA and their derivatives comprise considerable attention.

The syntheses, physicochemical characterization of benzohydroxamic acid (BHA) and methyl-benzo hydroxamic acid (CH_3 -BHA) and their metal complexes VO(IV), Cr(III) and Ni(II) have been reported [2]. The molar conductivity (Λ_m) values of the complexes are in the range of 0 - $6.82\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, suggesting the non-electrolytic nature of the complexes in solutions [2]. It indicates that the non-existence of free ions acts as electrolytes in the solution [3]. All complexes were non-electrolyte. In concordance with the basic of chelation theory, metal complexes display higher toxicity on human colorectal cancer (HCT116) than their parent ligands, BHA and CH_3 -BHA, where the $[\text{Ni}(\text{CH}_3\text{-BHA})_2]$ shows the highest cytotoxicity with a IC_{50} of $40\mu\text{M}$ [2].

The chemical and biological properties investigation of oxido-vanadium(IV) complexes of acetylsalicyl-hydroxamic acid (N-acetyloxy-2-hydroxybenzamide) were considered to be the potential antimicrobials. They are determined by the Fourier-transform infrared spectroscopy (IR), ultraviolet-visible spectroscopy (UV-Vis), electron spin resonance (ESR) and mass spectrometry along with elemental analyses, Λ_m and magnetic moment measurements. The *in vitro* antimicrobial assays for pathogenic Gram-positive bacteria, Gram-negative bacteria and fungi showed that the appreciable antimicrobial properties, compared with the standard drugs tetracycline and fluconazole [4].

It is known that the Co(II), Ni(II), Cu(II), Zn(II) acetate salts reacted with ortho-amino benzo HA (o-NH_2 -BHA) in ethanol to generate the binary metal complex: tetra coordinate complexes. Their chemical characterizations are further evaluated by IR, UV-VIS, ESR, microanalysis, Λ_m , magnetic susceptibility, mass spectra and thermogravimetric analysis. The *in vitro* experiment was further performed to evaluate the potential activity of these tetra coordinate complexes on cancer cell lines: A549 (lung cancer), SKNSH (Human neuroblastoma cancer) and HeLa (cervical cancer) using MTT assay. These compounds showed activity on cancer cell lines at micromolar concentration. It was reported that the ligand ortho-amino benzo HA and their metal complexes also display the antimicrobial activity and anticancer activity [5], where the Λ_m of the binary metal complexes in DMSO falls in the range $0.0\text{-}4.0\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, indicating that these complexes have non-electrolytic nature [5].

Although the electrolytic properties of HA complexes were studied by Hassan et al. [2], Priya et al. [4] and Anitha [5], the correlations of the electrolytic with antimicrobial or toxicity properties were not well investigated. The Λ_m of HA complexes showed the non-electrolytic properties, with the values ranging from 0 to $6.82\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ [5].

Other aliphatic HA with carbon chains (C_2 to C_{17}) and their metal complexes with iron(II/III), nickel(II), copper(II) and zinc(II), as well as their antibacterial, antimycobacterial and antifungal properties were also described [6]. It was showed that they are both electrolytic and non-electrolytic complexes. In the work of Hassan et al. [2], Priya et al. [4] and Anitha [4], the correlating electrolytic and biological properties of VO(IV)-BHA, Cr(III)-BHA, Ni(II)-BHA, VO(IV)- CH_3 -BHA, Cr(III)- CH_3 -BHA and Ni(II)- CH_3 -BHA [2] and VO(IV) complexes of N-acetyloxy-2-hydroxybenzamide [4]; Co(II),

Ni(II), Cu(II), Zn(II) complexed with o-NH_2 -BHA [5], were not carried out, probably due to the fact that only the non-electrolytic behaviour was observed in their studies.

In view of the contrasting results in previous studies, we also study the electrolytic studies of HA and its complexes. It was demonstrated that the HA12 and the complexes HA12NiII, HA12CuII and HA12ZnII against *Candida albicans*, the complexes HA12FeII and HA12FeIII against *Mycobacterium smegmatis* displayed the selective biological properties [6]. Furthermore, these compounds also showed the electrolytic or non-electrolytic activity.

In the present study, we performed the Λ_m and minimum inhibitory concentrations (MIC) determinations to verify the correlation between electrolytic and biological properties of HA and their complexes.

Material and Methods

The synthetic method of HA and their iron(II/III), nickel(II), copper(II) and zinc(II) complexes and the physicochemical characterization were described in previous work [6]. The electrolytic properties of HA and its complexes were determined on a conductivity meter TetraCon® 345 (WTW, Germany). The solvents utilized are methanol (Sigma Aldrich, USA), MilliQ water. The aqueous potassium chloride solution was 0.01M as a standard electrolyte.

Firstly, the stock solutions were prepared in MeOH with different concentrations (C_0). After taking 1mL of each initial solution, a 20-fold dilution was carried out using the same solvent to obtain a final volume of 20mL (solutions at concentrations C_1). The electrical conductivity of the compounds at concentration C_1 was measured (Λ_{E1}) on the conductivity meter. The Λ_m of the compounds in methanol solution (Λ_{M1}) was calculated using the Equation 1. We then took 1mL of solution (C_1) and diluted it with MilliQ H_2O to obtain 20mL of solution at the final concentration (C_2) containing 5% (v/v) MeOH. After measuring the electrical conductivity of the compounds in aqueous solution containing 5% (v/v) MeOH (Λ_{E2}), we further determined the Λ_m of the compounds (Λ_{M2}) under these conditions (Equation 2). A KCl solution (0.01M) was used as a reference.

$$\Lambda_{M1} = \frac{\Lambda_{E1}}{\text{C}_1} \quad (\text{Equation 1}) \quad \Lambda_{M2} = \frac{\Lambda_{E2}}{\text{C}_2} \quad (\text{Equation 2})$$

C_1 : final concentration in methanol solution (solution C_0 diluted 20-fold),

C_2 : final concentration in aqueous solution containing 5% (v/v) MeOH (solution C_1 diluted 20-fold),

Λ_{E1} et Λ_{E2} : electrical conductivities measured at 22°C of the compounds in methanolic solution and aqueous solution containing 5% (v/v) MeOH respectively ($\Omega^{-1}\text{cm}^{-1}$),

Λ_{M1} and Λ_{M2} : molar conductivities of the compounds in methanol solution and aqueous solution containing 5 percent MeOH, respectively ($\Omega^{-1}\text{cm}^2\text{mol}^{-1}$). The values for concentrations Co-C_2 are recorded in the results section.

The biological properties of HA and complexes was investigated from the previous study [6], including determining the MIC against bacterial, mycobacterial and fungal strains.

Results

Electrolytic properties of HA and their complexes

Firstly, the Λ_M of HA, their complexes and metal chlorides were measured to confirm the electrolytic nature. Initially, we investigated the electrolytic properties of these compounds in MeOH

solution. The Λ_{M1} values of HA and the complexes HAFelI/HAFelII were 0.63-5.63 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, lower than the values of FeCl_2 and FeCl_3 (approximately 90 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$). The Λ_{M1} values of the complexes HANilI (28.17-37.11 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$), HACuII (21.79-24.32 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$) and HAZnII (43.93-48.38 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$) are relatively higher than the values for HAFelI/HAFelII complexes. In addition, HA display the lower Λ_{M1} than their corresponding metal chlorides (NiCl_2 , CuCl_2 or ZnCl_2), which have values of 82.42 and 52 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, respectively (Table 1).

Table 1: The electrical ($\Omega^{-1}\text{cm}^{-1}$) and molar ($\Omega^{-1}\text{cm}^2\text{mol}^{-1}$) conductivities of HA, complexes HAFelI, HAFelII, HANilI, HACuII and HAZnII, and the metal chlorides.

C_0 : concentration of the stock solutions in MeOH;

C_1 : C_0 diluted 20-fold with MeOH;

C_2 : C_1 diluted 20-fold with MilliQ water containing 5% MeOH;

Λ_{E1} and Λ_{E2} : measured electrical conductivities of the compounds in solution in MeOH and in MilliQ water containing 5% MeOH, respectively;

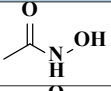
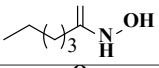
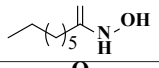
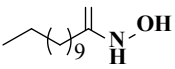
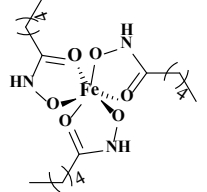
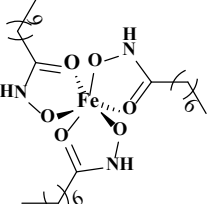
Λ_{M1} and Λ_{M2} : calculated molar conductivities of the compounds in solution in MeOH and in MilliQ H_2O containing 5% MeOH, respectively (Equations 1 and 2).

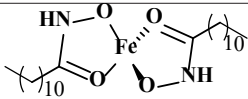
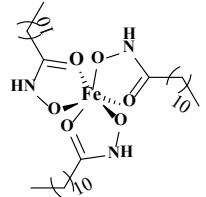
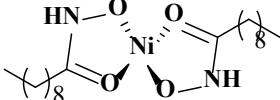
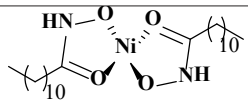
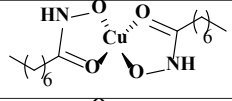
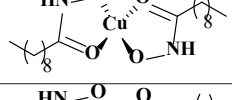
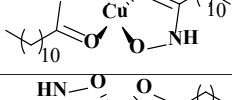
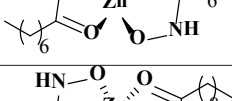
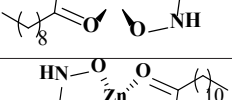
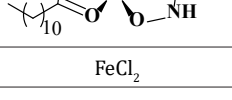
Aqueous KCl (control);

blank: MeOH, MilliQ H_2O and 95% MilliQ H_2O + 5% MeOH ($\Lambda_E = 1 \times 10^{-6} \Omega^{-1}\text{cm}^{-1}$);

In the literature, Λ_E for MeOH = $0.15 \times 10^{-6} \Omega^{-1}\text{cm}^{-1}$ [7];

---: not determined.

Code	Structures	$C \times 10^{-6} (\text{mol}/\text{cm}^3)$			$\Lambda_E \times 10^{-6} (\Omega^{-1}\text{cm}^{-1})$		$\Lambda_M (\Omega^{-1}\text{cm}^2\text{mol}^{-1})$	
		C_0	C_1	C_2	Λ_{E1}	Λ_{E2}	Λ_{M1}	Λ_{M2}
HA2		41.7	2.09	0.105	6	2	2.87	19.04
HA6		46.5	2.33	0.117	7	2	3.00	17.09
HA8		76	3.8	0.19	3	4	0.79	21.05
HA12		63	3.16	0.158	2	2	0.63	12.66
HA6FeIII		10.7	0.53	0.0265	3	1	5.66	37.74
HA8FeIII		16	0.8	0.04	2	1	2.50	25.00

HA12FeII II		10.6	0.53	0.0265	2	1	3.77	37.74
HA12FeIII		10.1	0.51	0.0255	2	1	3.92	39.22
HA10NiII		5.68	0.28	0.014	8	2	28.57	142.86
HA12NiII		4.31	0.22	0.011	8	2	36.36	181.82
HA8CuII		6.58	0.33	0.0165	8	4	24.24	242.42
HA10CuII		3.67	0.18	0.009	4	2	22.22	222.22
HA12CuII		5.99	0.29	0.0145	7	3	24.14	206.90
HA8ZnII		7.74	0.39	0.0195	17	3	43.59	153.85
HA10ZnII		7.44	0.37	0.0185	18	3	48.65	162.16
HA12ZnII		4.67	0.23	0.0115	11	2	47.83	173.91
	FeCl ₂	80.7	4.03	0.2015	365	90	90.57	446.65
	FeCl ₃	35.3	1.77	0.0885	160	165	90.40	1864.41
	NiCl ₂	209	10.5	0.525	860	146	81.90	278.09
	CuCl ₂	270	13.5	0.675	563	219	41.70	324.44
	ZnCl ₂	68	3.41	0.1705	177	308	51.91	1806.45
	KCl	10	---	---	---	1420	---	142
	MeOH	---	---	---	1	1	---	---
	H ₂ O MilliQ	---	---	---	1	1	---	---
	H ₂ O MilliQ + 5 % MeOH	---	---	---	1	1	---	---

Secondly, the electrolytic properties were investigated in an aqueous solution containing 5% (v/v) MeOH. The Λ_m values of HA and the complexes are higher than those in MeOH solution. Based on the Λ_m values, the HA and complexes HAFelI/HAFeII could be in molecular form in aqueous solution, where the Λ_m values are more than $100\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ for the complexes HANiII, HACuII and HAZnII. These complexes in aqueous solution could be the ionic forms with higher Λ_m values compared with the metal chlorides (KCl solution at $10^{-5}\text{mol}/\text{cm}^3$) (Table 1).

Biological versus electrolytic properties of HA and their complexes

The antimicrobial effects of HA and their complexes against bacteria (methicillin-susceptible *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus*, *Bacillus subtilis*, *Corynebacterium glutamicum*, *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*); mycobacteria (*Mycobacterium bovis* BCG, *Mycobacterium marinum*, *Mycobacterium smegmatis*, *Mycobacte-*

rium tuberculosis) and fungi (*Candida albicans*) were determined in our previous publications [6]. Here, we just present the results where the HA and their complexes displayed the activities against *C. albicans* and *M. smegmatis*.

The HA with carbon chains from C₂ to C₈ (HA2, HA6 and HA8) do not display the significant inhibitory effects against *C. albicans*

and *M. smegmatis*. But the C₁₂ homologue (HA12) exhibited significant antifungal and antimycobacterial activity (MIC = 15.63 μM and 62.5 μM, respectively). The low Λ_m of four HA indicate the non-electrolytic nature in the present conditions (Table 2), suggesting that the biological activity is not related to the electrolytic property (non-ionic form in MeOH or aqueous solution).

Table 2: Minimal inhibitory concentrations (MIC) versus Λ_m of HA.

HA	Λ_m ($\Omega^{-1}\text{cm}^2\text{mol}^{-1}$)	MIC (μM)		$\frac{1}{\text{MIC}}$ (μM^{-1})	
		<i>C. albicans</i>	<i>M. smegmatis</i>	<i>C. albicans</i>	<i>M. smegmatis</i>
HA2	19.04	>500	>500	>0.002	>0.002
HA6	17.09	>500	>500	>0.002	>0.002
HA8	21.05	>500	>500	>0.002	>0.002
HA12	12.66	15.63	62.50	0.064	0.016

The iron complexes (HA12FeII and HA12FeIII) with an average Λ_m of 38.48 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ display the antimycobacterial activity (MIC = 125 and 31.25 μM, respectively) (Table 3). The significant inhibitory effect of the nickel(II), copper(II) and zinc(II) complexes with a C₁₂ carbon chain (HA12NiII, HA12CuII and HA12ZnII) against *C.*

albicans may be linked to the presence of metal ions in solution. However, no antimycobacterial effect of these complexes was observed against *M. smegmatis*, although the high Λ_m values indicate the electrolytic nature under the experimental conditions (Table 3).

Table 3: MIC versus Λ_m of iron(II/III), nickel(II), copper(II) and zinc(II) complexes.

Complexes	Λ_m ($\Omega^{-1}\text{cm}^2\text{mol}^{-1}$)	MIC (μM)		$\frac{1}{\text{MIC}}$ (μM^{-1})	
		<i>C. albicans</i>	<i>M. smegmatis</i>	<i>C. albicans</i>	<i>M. smegmatis</i>
HA12FeII	37.74	>500	125	>0.002	0.008
HA12FeIII	39.22	>500	31.25	>0.002	0.032
HA12NiII	181.82	31.25	>500	0.032	>0.002
HA12CuII	206.90	15.63	>500	0.064	>0.002
HA12ZnII	173.91	15.63	>500	0.064	>0.002

Discussion

With regard to the electrolytic nature, it is reported from the literature that the Λ_m values for chemical compounds ranging from 11 to 19 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$ indicate the non-ionic form in solution. By contrast, the chromium(II) complex with a triazole ligand display the Λ_m value with 98 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, indicating the electrolytic character with ionic form in solution [8]. Compared with Λ_m values of FeCl₂, FeCl₃, NiCl₂ and CuCl₂, the complexes HAFelI/HAFeIII, HANiII and HACuII are non-ionic nature in MeOH solution. Under the same conditions, the Λ_m value of HAZnII complex is close to that of ZnCl₂, suggesting an electrolytic nature (Table 1).

The relatively low values of Λ_m of iron complexes (Table 1) can be attributed to the formation of another new complex (metallic ion + solvent). It is well-known that certain metallic ions (Fe²⁺, Ag⁺, Cu²⁺, Ni²⁺) tend to form new complexes with special solvents [9]. Metallic ions tend to form complexes with water, resulting the stable crystalline hydrates [9]. For the HA, the intermolecular hydrogen bonds

generated with the solvent (H₂O, MeOH), may prevent the formation of ionic species.

The Λ_m values of the complexes HANiII, HACuII and HAZnII are more than 100 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, probably due to the ionic forms in aqueous solution under the experimental condition. The Ni(II), Cu(II) and Zn(II) complexes with Schiff bases (sulfanilamides) exhibited the Λ_m values in dimethylformamide (DMF) ranging from 135 to 142 $\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, confirming the ionic forms in aqueous solution [10]. Our results show that the electrolytic behaviours of HA and their complexes were associated with the electrolytic state in the solvent. Due to the hydrolysis or solubility (with the exception of metal chlorides, which are inorganic compounds), using water as a solvent for conductivity measurements is often limited. Therefore, the organic solvents are increasingly used to analysis the conductivity on organic molecules. However, with the wide range of solvents available, it is difficult to judge the substance to be electrolytic or non-electrolytic forms [7].

Notably, the regression analysis between Λ_M and raw MIC values for parent HA yielded $R^2 = 0.7967$ for both antifungal and antimycobacterial datasets (Figure 1A,B). Caution must be exercised in interpreting this R^2 value, because multiple MIC observations were recorded as >500mM (upper-limit censored data) and were assigned the value of 500mM for plotting and regression fitting; this artificial assignment may distort the regression outcome. An R^2 of 0.7967 indicates a moderate statistical association in this fit-

ted model, rather than a complete absence of correlation. To better evaluate the relationship between electrolytic property and antimicrobial potency, potency can alternatively be represented as reciprocal MIC ($1/\text{MIC}$), which weights low MIC (high-activity) points more heavily. Re-analysis using $1/\text{MIC}$ is recommended to further verify this trend. For the parent HA investigated here, Λ_M remains low ($13\text{--}19\Omega^{-1}\text{cm}^2\text{mol}^{-1}$), consistent with predominantly non-ionic character in solution.

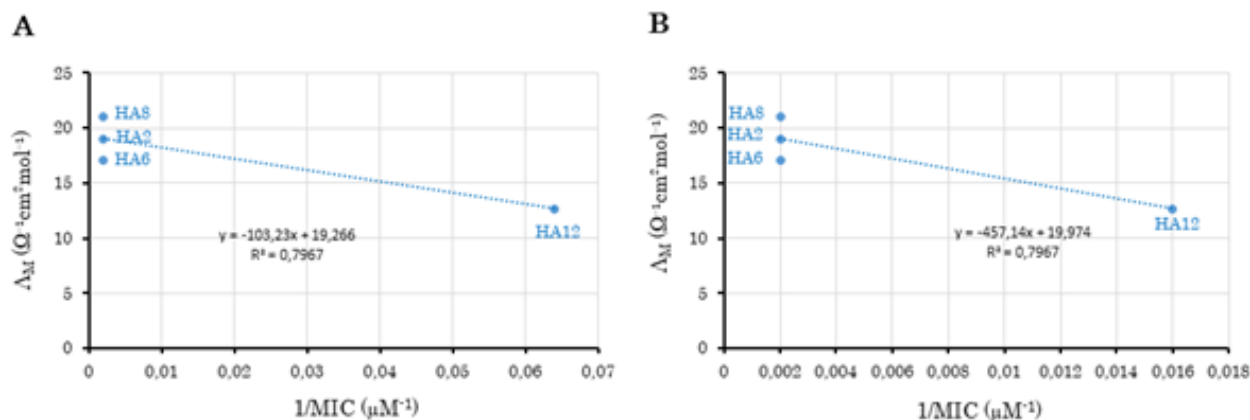


Figure 1: Correlation between Λ_M values and the antifungal effects against *C. albicans* (A) and the antimycobacterial effects against *M. smegmatis* (B) of HA. Note: MIC values reported as >500mM were assigned a numerical value of 500mM for plotting and regression; this censored data treatment may bias the fitted R^2 .

With regard to the active complexes, HA12NiII, HA12CuII and HA12ZnII against *C. albicans* display high Λ_M values ranging from 174 to $206\Omega^{-1}\text{cm}^2\text{mol}^{-1}$, indicating the ionic form in the reactions. A correlation between the electrolytic and biological properties of complexes HA12NiII, HA12CuII and HA12ZnII is existed ($R^2=0.8369$). These results demonstrated that the ionic forms in solution are useful for the biological activity of HA complexes (Figure 2A). However, the MIC of the complexes HA12FeII and HA-

12FeIII measured against *M. smegmatis* indicate that non-electrolytic complexes exhibit significant activity, whereas their electrolytic counterparts are not active (Figure 2B). Whilst a correlation is observed between the electrolytic and biological properties of the complexes ($R^2=0.5558$), the microbial strains exhibit specific characteristics that must be taken into account when studying the parameters responsible for biological activity.

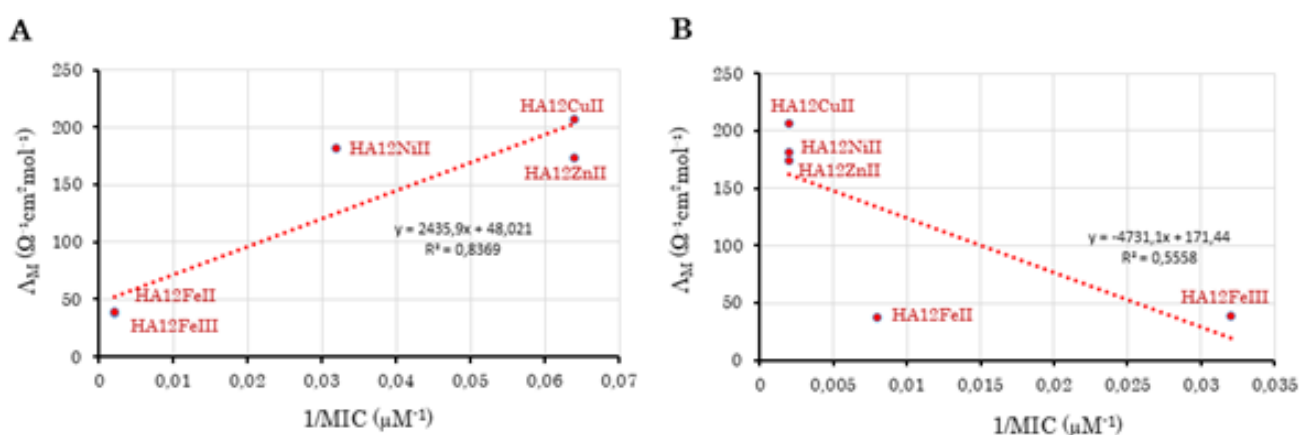


Figure 2: Correlation between Λ_M values and the antifungal effects against *C. albicans* (A) and the antimycobacterial effects against *M. smegmatis* (B) of iron(II/III), nickel(II), copper(II) and zinc(II) complexes.

Conclusion

The electrolytic behaviours of the complexes HA12NiII, HA12CuII and HA12ZnII, which exhibit antifungal activity, is a factor

that could explain their enhanced activity. The partial dissociation of these complexes would account for the redox role of the metal ions against microorganisms, for example in the production of ROS.

It should be noted that for parent HAs tested against *C. albicans* and *M. smegmatis*, the regression using raw MIC data yields a moderate $R^2=0.7967$ (Figure 1). However, several MIC measurements are only known to be above 500mM (censored upper-limit data). Therefore, we cannot reliably conclude a true biological correlation between Λ_M and HA activity from this fit alone. In contrast to HA, a correlation exists between the electrolytic and biological properties of their complexes (Figure 2). This result may explain the biological activity of HA complexes, which is partly due to the ions present in solution. As for the compound HA12, given its non-electrolytic nature observed in aqueous and methanolic solutions, its significant antimicrobial effect cannot logically be attributed to ions. The intermolecular H-bonds between the HA groups and polar solvents (H_2O , MeOH) could be the reason for the absence of ionic forms in solution.

References

1. Muri E, Nieto M, Williamson J (2002) Hydroxamic acids as pharmacological agents. *Curr Med Chem* 9(17): 1631-1653.
2. Hassan LR, Ramasamy K, Tajuddin AM (2019) Synthesis and characterization of benzohydroxamic acid and methyl-benzohydroxamic acid metal complexes and their cytotoxicity study. *Malaysian J Anal Sci* 23(2): 263-273.
3. Temel H (2004) Synthesis and spectroscopic studies of new Cu(II), Ni(II), VO(IV) and Zn(II) complexes with N,N'-bis(2-hydroxynaphthalin-1-carbaldehyde)-1,2-bis-(o-aminophenoxy)ethane. *J Coord Chem* 57(9): 723-729.
4. Priya B, Kumar A, Sharma N (2020) Synthesis, characterization, and biological properties of oxidovanadium (IV) complexes of acetylsalicylhydroxamic acid (N-acetyloxy-2-hydroxybenzamide) as potential antimicrobials. *J Chem Res* 44(7-8): 460-470.
5. Sree DAR (2025) Biological evaluation and anticancer activity of novel binary transition metal complexes derived from ortho amino benzo hydroxamic acid. *J Pharm Pharmacol Res* 9(3): 114-121.
6. Sow IS, Gelbcke M, Meyer F, Vandeput M, Marloye M, et al. (2023) Synthesis and biological activity of iron(II), iron(III), nickel(II), copper(II) and zinc(II) complexes of aliphatic hydroxamic acids. *J Coord Chem* 76(1): 76-105.
7. Geary WJ (1971) The use of conductivity measurements in organic solvents for the characterisation of coordination compounds. *Coord Chem Rev* 7(1): 81-122.
8. Sumrra SH, Zafar W, Javed H, Zafar M, Hussain MZ, et al. (2021) Facile synthesis, spectroscopic evaluation and antimicrobial screening of metal endowed triazole compounds, *BioMetals* 34(6): 1329-1351.
9. Kraus CA (1922) The properties of electrically conducting systems, including electrolytes and metals.
10. Rani S, Sumrra SH, Chohan ZH (2017) Metal based sulfanilamides: A note on their synthesis, spectral characterization, and antimicrobial activity. *Russ J Gen Chem* 87: 1834-1842.