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SPECTROSCOPIC, STRUCTURAL, MOLAR CONDUCTIVITY, MAGNETIC AND ANTIBACTERIAL ACTIVITY STUDIES OF CO(II) AND NI(II) COMPLEXES OF L-METHIONINE AND L-LEUCINE

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Abstract: Four metal(II) amino acids complexes in aqueous basic solution, $[CoL_2(H_2O)_2].H_2O$, $[CoL^1_2(H_2O)_2].H_2O$, (**2**), $[NiL_2].2H_2O$ (**3**) and $[NiL^1_2].2H_2O$ (**4**) with **L**=L-methionine and **L¹**=L-leucine were synthesized and analyzed by means of gravimetric analyses, molar conductivity measurements, magnetic susceptibility measurements, powder X-ray diffraction analysis, UV-Vis and IR spectroscopies. Molar conductivity measurements showed that the composition of the metal complexes correspond to a metal-amino acid ligand ratio of 1:2. The IR spectra showed that the amino acids act as bidentate ligands with coordination involving the carboxyl oxygen and the nitrogen of the amino group. The result also suggests the presence of crystal water in all the complexes. Electronic spectra and magnetic susceptibility measurements suggested a four coordinate local symmetry around the Ni (tetrahedral) ions, and octahedral local symmetry for Co ion. Magnetic susceptibility studies also revealed that the complexes of Co and Ni are paramagnetic with values of magnetic moments ranging from 5.10-6.00 BM for Co(II) and 2.26-4.21 BM for Ni(II) complexes, respectively. The results also suggest that the ligands, L-methionine and L-leucine are weak field ligands as they formed high spin complexes with Co(II), and gave tetrahedral complexes with Ni(II) ions. Metal content and hydration water analyses showed that the complexes of Co contain 1 mole of water of crystallization while those of Ni contain 2 moles. The results also suggest that Co(II) complexes contain two aqua ligands in their inner coordination sphere. Powder XRD studies confirmed that the amino acid complexes are crystalline in nature and that they largely crystallized in monoclinic fashion. It also suggests that the bonding mode in the complexes is similar. The antimicrobial studies showed that the amino acid ligands are biologically active and their metal complexes showed significantly enhanced antimicrobial sensitivity against the studied microbial strains in comparison to the free ligands.

Keywords: Infrared spectra, magnetic moments, molar conductivity, weak field ligand

Introduction

Antimicrobial resistance is fast becoming a global menace with rapid increase in multidrug-resistant bacteria and fungi (Mulligan and Murray-Leisure, 1993; Saha *et al.*, 2010). This has mandated continued search for new antimicrobial compounds, including coordination complexes of biologically important molecules (Farrel, 2003). Promising antimicrobial activity of some amino acids chelates have been reported, including those of histidine (Nomiya *et al.*, 2000; Saha *et al.*, 2010) arginine and glutamic acid (Legler *et al.*, 2001). The ability of metals to lose electrons to form positively charged ions allow them to play their role in biological systems. Whereas metal ions are electrophilic, most biological molecules such as protein and DNA are electron rich. The attractions of these opposing forces lead to a general tendency for metal ions to bind and interact with biological molecules (O'Shea, 2004).

Metal ions have been reported to improve, or induce the activity of biologically important moieties (Sadler and Guo, 1998) and that of some known drugs such as paracetamol, sulfamethoxazole, and aspirin (Agbaje *et al.*, 2014; Osowale, 2017). In recent years the transition metal complexes with amino acids as ligands have received much attention because they proved to be useful antibacterial agents applied against *Staphylococcus aureus*, *Escherichia coli* and *Candida albicans*, etc., antitumoral drugs against sarcoma and leukaemia; nutritive supplies for human and animals, etc. (Sakiyan *et al.*, 2004; Chohan *et al.*, 2006).

Leucine is an essential branched-chain amino acid that is used as a source for the synthesis of blood sugar in the liver during starvation, stress and infection to aid in healing (Chohan *et al.*, 2007). Methionine is one of the amino acids containing sulphur; it helps to prevent disorders of the hair, skin and nails, in lowering the cholesterol levels by increasing the liver's production of lecithin and reduces fat build-up in the liver and body (Cao *et al.*, 2000). It is known that methionine presents antioxidant properties in several models of oxidative stress. It has been shown that it acts as a powerful endogenous antioxidant agent, leading to the reduction of lipid peroxidation in membranes (Gill and Tuteje, 2010).

The present study discusses the synthesis, spectroscopic characterization, molar conductivity and biological screening of L-methionine and L-leucine complexes with Co(II) and Ni(II) ions.

Materials and Methods

Materials

All reagents and solvents used were of analytical grade, and were used without further purification. Melting points (M.P) or decomposition temperature (d) were measured using open capillary tubes on a Stuart automatic melting point apparatus model SMP40, with starting temperature of 40°C at a temperature ramp of 15°C min^{-1}. Molar conductivity measurements were carried out at room temperature using a HACH conductivity meter model Sension5. A 0.001M solution of dimethyl sulphoxide, DMSO was used as solvent to dissolve the complexes. The UV–visible spectra were determined in the DMSO solvent with concentration (1.0×10^{-3} M) for the free ligands and their metal complexes using Cary series UV-Vis Spectrophotometer with 1cm quartz cell, in the range 200–800 nm. The infrared spectra were recorded on an Agilent Cary 630 FT-IR Spectrophotometer within wavenumber range of 4000–650 cm^{-1}.The magnetic susceptibility measurement for the synthesized complexes was obtained at room temperature using an AUTO (Sherwood scientific) magnetic susceptibility balance (MSB) Gouy balance. The gram susceptibility (X_g) of the complexes is thus evaluated using the relationship (Lotz, 2008; Sherwood-Scientific, 2011).

$$X_g = \frac{C \times L\,(R - Ro)}{10^9 \times M} \qquad (1)$$

Where: C is the proportionality constant, 1.0, L is the length of sample in capillary column, R is the magnetic susceptibility of the filled capillary tube, R_o is the magnetic susceptibility of the empty capillary tube and M is the mass of sample in the capillary tube. The molar susceptibility (Xm) was then obtained using the standard formula Xm = Xg × *MW*, where *MW* is the molecular weight of the complex. Hence, effective magnetic moments (μ_{eff}) for the complexes are evaluated using the expression;

$$\mu_{eff} = 2.83\sqrt{Xm \times T} \qquad (2)$$

Where: T is the room temperature in Kelvin, and μ_{eff} is the effective magnetic moments in Bohr magnetons (BM).

Metal content was found gravimetrically by converting the complexes into their corresponding oxides. Weighted amount of the complexes (in a crucible) were ignited using a Nabertherm programmable furnace (Model GmbH) at a temperature ramp of 20°C min^{-1}**,** and held at a plateau temperature of 800°C for three hours (Refat *et al.*, 2013). Percentage metal content was determined using the relationship:

$$\frac{weight\ of\ metal\ oxide \times Gravimetric\ factor}{Weight\ of\ compex\ taken} \times 100\% \qquad (3)$$

The X-ray powder diffraction analysis was carried out using Xpert-Pro X-ray diffractometer with Cu Kα1 radiation with λ=1.54056Å (Å=Angstrom). The scans were made at a temperature of 25°C within 2ϴ range of 5.00-80.00° at scan rate of 8.00°min^{-1}. Unit cell parameters were found by employing trial and error method using the Powder Diffraction File software (PDF-2). The average crystallite sizes for all complexes were calculated using Debye Scherrer's formula;

$$ך_{xrd} = \frac{0.9 \times \lambda}{\beta\ Cos\theta} \qquad (4)$$

Where ך is the average crystallite size, λ is the wavelength of Cu Kα radiation (1.54056 Å), β is the full width at half maximum (FWHM in radians) and ϴ is the Braggs reflection angle. 0.9 is the machine constant K. Inter-planer separations (*d*-spacing) were obtained using the Bragg's equation (Kavitha *et al.*, 2013; Bunaciu *et al.*, 2015).

$$d = \frac{\lambda}{2\ Sin\theta} \qquad (5)$$

Methods

Synthesis of the complexes

The complexes were prepared following the procedure described in the literature (Nomiya and Yokoyama, 2002) with slight modification. 0.010 mol of **L** (1.530 g), and 0.010 mol **L¹** (1.340 g) were dissolved in 40 mL of distilled water. Dissolution took place only with slow heating. For deprotonation of the amino acids 0.010 mol (0.420 g) NaOH in 5 mL distilled water was added. This was to obtain the ionization conditions of the amino acids (**L**=L-methionine and **L¹**=L-leucine). Then, 0.005 mol of the metal salts (1.230 g of $CoCl_2.6H_2O$ and 1.210 g of $NiCl_2.6H_2O$) were dissolved in 5 mL of distilled water, and added to the deprotonated amino acid solution and heated on a water bath under constant stirring for 2 hrs. The precipitate formed was filtered off, washed with water several times, and dried in an oven at 60°C. For most amino acids complexes, precipitation was instantaneous, while some required further concentration and cooling. The complexes were pink for $\mathbf{[Co(L)_2(H_2O)_2].H_2O}$ (69.1%) and $\mathbf{[Co(L^1)_2(H_2O)_2].H_2O}$ (55.8%), blue-green for $\mathbf{[Ni(L)_2].2H_2O}$ (51.7%) and $\mathbf{[Ni(L^1)_2].2H_2O}$ (51.8%). The compounds were found to be soluble in DMSO or DMF.

Antimicrobial screening

The antimicrobial properties of the complexes were obtained using an adaptation of the filter disc diffusion method (Murray *et al.*, 1995; Wikler, 2006; Wayne, 2017). Pathogenic microbes used were clinical strains obtained from the department of medical microbiology, Ahmadu Bello University Teaching Hospital, Zaria. The organisms were four Gram-positive and four Gram-negative bacteria species viz. *Staphylococcus aureus, Streptococcus pyogenes, Bacillus cereus, Methicillin resistant staphylococcus aureus, Escherichia coli, Salmonella typhi, Shigella dysentriae* and *Vancomycin resistant enterococci.* Ciprofloxacin was used as standard drug.

Results and Discussion

Physicochemical properties

The reaction of L-methionine (**L**) and L-leucine (**L¹**) with the metal(II) chlorides (Co and Ni) under basic conditions gave coloured complexes. The colours, percentage yields and melting points (M.P) or temperature of decomposition (d) of the coordination compounds are presented in Table 1. The complexes showed a range of colours that were in agreement with those obtained for similar coordination compounds (Stanila *et al.*, 2007; Aiyelabola *et al.*, 2012a). Fare yields were obtained (50-70 %). The highest yield was recorded for Co-Met complex (69.10 %).

Table 1: Physicochemical properties of metal (II) complexes

Complex	Formula weight ($gmol^{-1}$)	Melting point (°C)	Colour	Yield (%)
Co-Met (**1**) $[Co(L)_2(H_2O)_2].H_2O$	409.35	277-280	Pink	69.10
Co-Leu (**2**) $[Co(L^1)_2(H_2O)_2].H_2O$	373.29	276*	Pink	55.80
Ni-Met (**3**) $[Ni(L)_2].2H_2O$	391.11	233-237	Pale-blue	51.70
Ni-Leu (**4**) $[Ni(L^1)_2].2H_2O$	355.05	269-276	Pale-blue	51.80

***=decomposition temperature**

FT-IR spectroscopy

The infrared spectra analyses of the ligands, **L** (L-methionine) and **L¹** (L-leucine), and their respective complexes were carried out and the relevant peaks in cm^{-1} are given in Table 2. Information about metal(II) ions coordination was obtained by comparing the IR frequencies of the ligands with those of their respective complexes.

In the spectra of the ligands, **L** and **L¹**, the *v*(N-H) stretching vibrations appear at 2944 cm^{-1} and 2955 cm^{-1}, respectively. These bands appear to be shifted towards higher wavenumbers in the spectra of the complexes with 3272 cm^{-1} for Co-Met (**1**), 3280 cm^{-1} for Ni-Met (**3**), 3280 cm^{-1} for Co-Leu (**2**) and 3276 cm^{-1} for Ni-Leu (**4**) complexes. This provides an evidence for the involvement of the $-NH_2$ group in complex formation (Batiu *et al.*, 2005; Kumar, 2011). A supporting evidence for the involvement of the $–NH_2$ group in metal-ligand bonding is obtained from the bands in the spectra of **L** and **L¹** at 1333 cm^{-1} and 1312 cm^{-1} respectively, which are assigned to *v*(C-N) stretching vibrations. This band at 1333 cm^{-1} in the spectra of L appears to be shifted to 1345 cm^{-1} and 1341 cm^{-1} for **1** and **3** respectively. Similarly, the band at 1312 cm^{-1} in **L¹** appear to be shifted to 1304 cm^{-1} and 1397 cm^{-1} for **2** and **4** respectively (Batiu *et al.*, 2005).

The ligands showed strong vibrations at 1651 cm^{-1} for **L** and 1572 cm^{-1} for **L¹** which are attributed to *v*(C=O) stretching. These bands appear to be shifted reasonably in the spectra of the corresponding complexes (Table 2) with the bands appearing at 1565 cm^{-1} (**1**) and 1654 cm^{-1} (**3**), also, appearing for **L¹** complexes at 1587 cm^{-1} (**2**) and 1587 cm^{-1} (**4**), respectively. Such shifts in band positions provide an insight into the bonding modes of the metal(II)-amino acid complexes (Aiyelabola *et al.*, 2012b). The fact that such peaks appear to have shifted bathochromically or hypsochromically in the spectra of their respective complexes can be ascribed to the involvement of the carboxylic oxygen of the amino acid in the metal-ligand coordinate bonding (Stanila *et al.*, 2007). The bands at 1159 cm^{-1} and 1133 cm^{-1} in the spectra of **L** and **L^1** respectively are assignable to the *v*(C-O) vibration. These bands appear to be shifted to lower wavenumbers or higher in the spectra of the corresponding metal(II) complexes providing further supporting evidence that the carboxyl oxygen of the ligand is involved in coordinate bonding with the metal(II) centers (Aiyelabola *et al.*, 2012a).

The bands at 1408 cm^{-1} and 1405 cm^{-1} in the spectra of **L** and **L^1** respectively, assigned to *v*(COO) vibrations are bathochromically shifted in the spectra of the corresponding metal complexes. This fact further supports the assertion that this group is involved in coordinate bond formation with the metal centers (Kulkarni *et al.*, 2014; Aiyelabola *et al.*, 2016). The *v*(O-H) stretching vibration does not appear in the spectra of **L** and **L^1** but does in those of their metal complexes with **1** and **3** at 3347 cm^{-1} and 3339 cm^{-1} respectively. Also, **2** and **4** appearing at 3365 cm^{-1} and 3369 cm^{-1} respectively. This suggests the presence of crystal water in these complexes (Stanila *et al.*, 2011). This finding is in close agreement with that of Stanila and his coworkers in 2009 for similar complexes.

The band at 2914 cm^{-1} in the spectra of the complexes **1** and **3** are attributed to the CH_3-S-CH_2 symmetric and asymmetric vibrations and are not shifted when compared to that of **L** (2914 cm^{-1}). This implies that the sulphur atom of this group is not involved in coordination with the metal(II) centers (Wokaun, 1996). A combined spectrum of the ligands and their respective metal(II) complexes formed from them are shown in Figs. 1 & 2, respectively. The spectra of the complexes in each case appear distinct from those of their ligands with major variations occurring in the –NH_2 and –COO domain. Also, the absences of O-H vibrational bands in the ligands become an exception rather than the rule for the complexes as new resolved peaks emerged for all the complexes at > 3300 cm^{-1} which suggest the presence of crystal water in the complex compounds.

Interestingly, when the spectra of the complexes were superimposed on those of their respective ligands from which they were formed (Figs. 2 & 4), two observations were made. First, the spectra of the complexes show peaks that do not match with those of their respective ligands. This fact infers that a reaction has taken place. Secondly, the spectra of the complexes show peaks deviating from those of their respective ligands at similar positions. Consequently, the spectra of the complexes appear somewhat similar. This fact supports the hypothesis that the bonding modes in these complexes are the same.

Table 2: IR frequencies (cm^{-1}) of the L and L^1 and their metal complexes

Compound	*v*(OH;H_2O)	*v*(N-H)	*v*(C=O)	*v*(C-N)	*v*(COO)	*v*(C-O)	*v*(CH_3-S-CH_2)
Met (**L**)	-	2944	1651	1333	1408	1159	2914
Leu (**L^1**)	-	2955	1572	1312	1405	1133	-
Co-Met (**1**)	3347	3272	1565	1345	1453	1151	2914
Co-Leu (**2**)	3365	3280	1587	1304	1472	1189	-
Ni-Met (**3**)	3339	3280	1654	1341	1420	1185	2914
Ni-Leu (**4**)	3369	3276	1587	1397	1472	1189	-

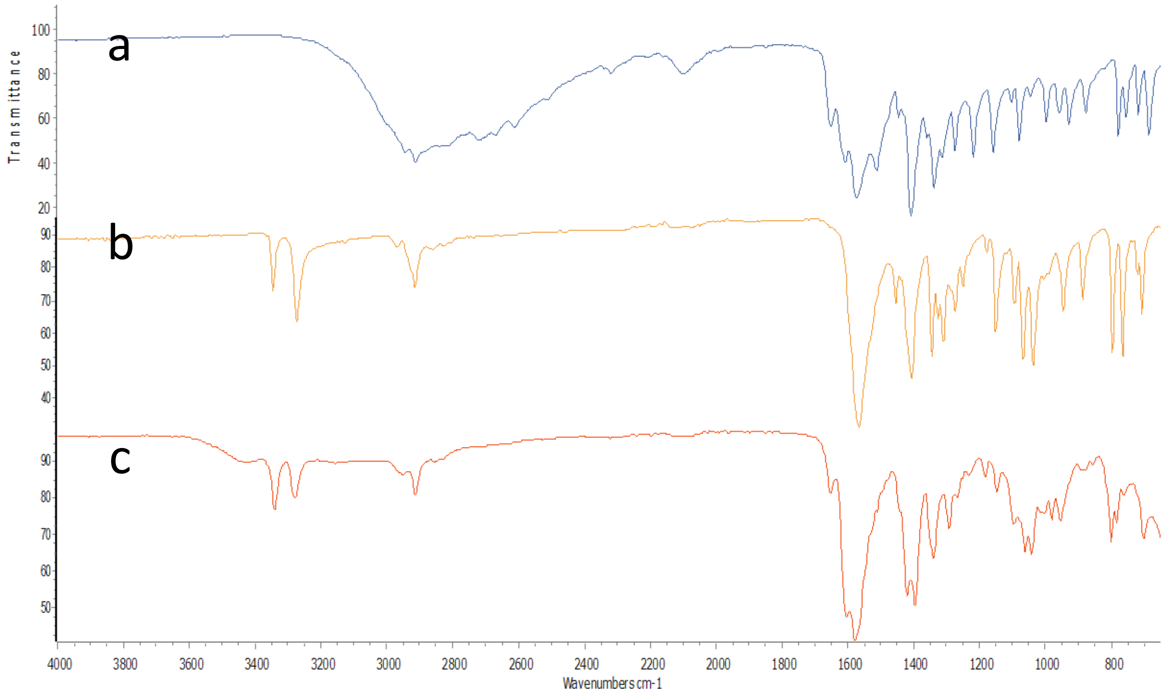


Fig. 1: Combined spectra of L (a), Co-Met (b) and Ni-Met (c)

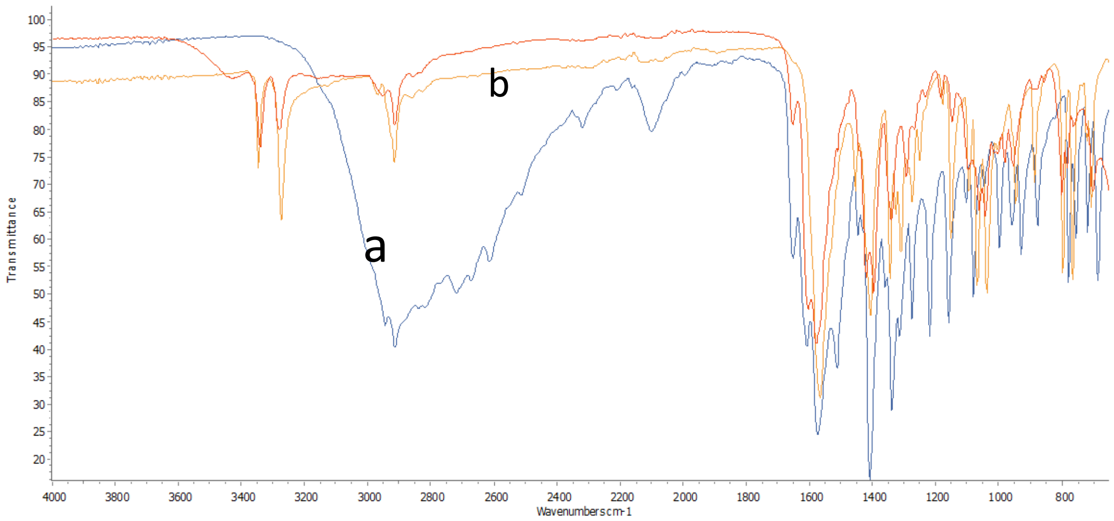


Fig. 2: Stacked spectra of L (a), Co-Met (b) and Ni-Met (b)

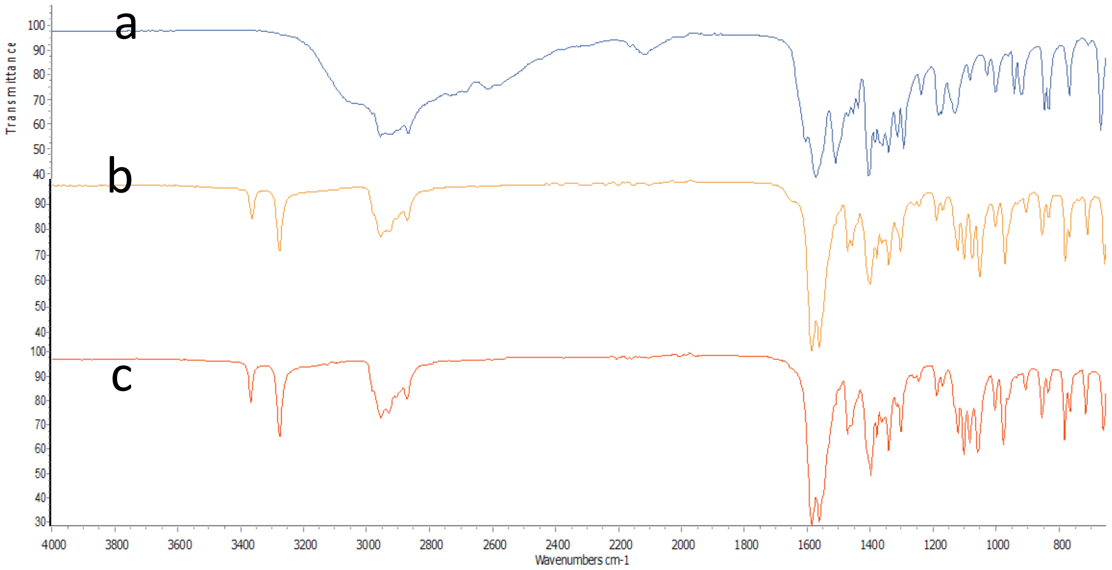


Fig. 3: Combined spectra of L^1 (a), Co-Leu (b) and Ni-Leu (c)

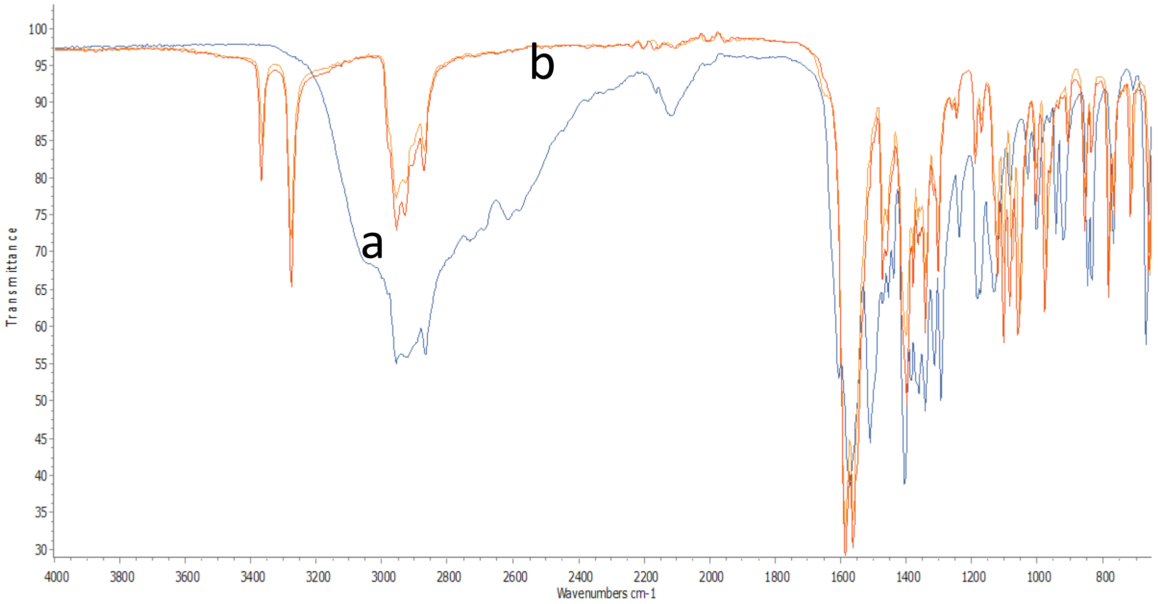


Fig. 4: Stacked spectra of L^1 (a), Co-Leu (b) and Ni-Leu (b)

UV-Visible spectroscopy

The spectra of the two ligands and their complexes in DMSO were obtained and spectra data are listed in Table 3. The free ligands show maximum wavelengths at 270 cm^{-1} **L** and $\mathbf{L^1}$ assignable to n-π* transition within the ligands. The bands at 264 nm (**L**) and 261 nm ($\mathbf{L^1}$) are assigned to π-π* transitions.

Electronic spectra provide valuable information about the arrangement of the ligands around the metal ions (Singh *et al.*, 2012). Ni(II) complexes exhibited bands at 645 nm (**3**) and 731 nm (**4**) respectively, assigned to $^2B_{1g} \rightarrow ^2A_{1g}$ transitions which may be ascribed to a four coordinate local symmetry around Ni(II) ion. Consequently, the *d-d* bands observed for the Ni(II) complexes are a feature that is expected for a four coordinate MO_2N_2 chromophore (Stanila *et al.*, 2007; Stanila *et al.*, 2009). The visible spectra of cobalt complexes exhibited *d-d* transitions whose maxima were at 514 nm (**1**) and 510 nm (**2**) which are assigned to $^4T_{1g}$ (F)$\rightarrow ^4A_{2g}$ (F), characteristic of an octahedral geometry (Patil *et al.*, 2011). The result is in concomitance with the findings of Stanila and his co-workers for similar compounds (Stanila *et al.*, 2009).

Table 3: UV-visible spectra data of L, $\mathbf{L^1}$ and their metal complexes

Compound	λ_{max}(nm)	λ_{max} (cm^{-1})	Assignment
(**L**)	270	37037	n-π* trans
	264	37879	π-π* trans
($\mathbf{L^1}$)	270	37037	n-π* trans
	261	38314	π-π* trans
(**1**)	514	19455	$^2B_{1g} \rightarrow ^2A_{1g}$
	354	28249	n-π* trans
(**2**)	510	19608	$^2B_{1g} \rightarrow ^2A_{1g}$
(**3**)	645	15504	$^2B_{1g} \rightarrow ^2A_{1g}$
	385	25974	n-π* trans
(**4**)	731	13680	$^2B_{1g} \rightarrow ^2A_{1g}$
	392	25510	n-π* trans

Table 4: Room temperature magnetic susceptibility and Molar Conductivity of M (II) complexes (in 1×10^{-3} DMSO Solution)

Complex	μ_{eff} (B.M)	Temperature (K)	$\Lambda(\Omega^{-1}$ mol^{-1} $cm^2)$
(1)	6.00	299.5	43.80
(2)	5.10	299.5	24.90
(3)	2.26	300	29.90
(4)	4.21	300	30.80

μ_{eff} = Effective magnetic moment, Λ= Molar conductivity, B.M=Bohr magnetons, K=Kelvin

Magnetic susceptibility measurement

Magnetic moments for the complexes are shown in Table 4 with the results revealing paramagnetic character for both Co(II) and Ni(II) complexes. Values of magnetic moments in the range 5.10-6.00 BM were observed for cobalt complexes, suggesting a high spin state for them. Such finding could only suggest that the amino acid ligands are so weak that they create only a weak ligand field around the Co(II) center, causing a low energy e_g-t_{2g} *d*-splitting in an octahedral structure of the cobalt complexes. This observation is valuable and important to assist in believing that the amino acids, L-methionine and L-leucine are weak field ligands, and that Co(II) ion is in an octahedral environment in the complexes formed from these ligands. The later assertion being supported by *d-d* transitions in the visible spectra of Co(II) complexes observed at 514 nm and 510 nm for Co-Met and Co-Leu, respectively; which are characteristic of an octahedral local symmetry around Co ion (Ozkan *et al.*, 2005; El-Tabl, 2008). The observed moments of 6.0 BM (Co-Met) and 5.10 BM (Co-Leu) is thus supportive of octahedral geometry since room temperature magnetic moments in the range of 4.6-6.0 BM are reported for octahedral Co(II) complexes as validated by Housecroft and Sharpe, 2005.

The complexes of nickel also showed paramagnetic behaviour with magnetic moments between 2.21-4.11 BM. This obviously rules out the possibility of a square planar local symmetry around nickel in these complexes as square planar complexes of d^8 systems are usually diamagnetic. Consequently, tetrahedral structure is more reasonable for the amino acid complexes of Ni(II) under investigation (Lee, 2013). This also supports the hypothesis that the amino acids, L-methionine and L-leucine are weak field ligands.

Molar Conductivity measurements

The molar conductivity values for the amino acid complexes in 10^{-3} $moldm^{-3}$ DMSO are also recorded in Table 4. The values are in the range of 30-44 Ω^{-1} cm^2 mol^{-1} suggesting these complex compounds to be non-electrolytes. In cases of presence of ions outside the coordination sphere (electrolytes), higher conductivity measurements are observed in the electrolytic range (106-311) Ω^{-1} cm^2 mol^{-1} (Refat *et al.*, 2013b).

Conductivity measurements have frequently been used in structure elucidation of metal complexes (mode of coordination) within the limits of their solubility. They provide a method of probing the degree of ionization of the complexes, the molar ions a complex liberates in solution (Refat, 2007). It becomes clear from the conductivity data that the complexes under study are most likely to be non-electrolytes. This would only infer that the complexes all form in a 1:2 metal-ligand ratio since charge neutrality can only be maintained when 1 mole of M^{2+} combine with 2 moles of Met^- or Leu^-. This fact is important in establishing that there is the absence of such ions as Na^+ in the outer coordination sphere of these complexes which eliminates the possibility of a 1:3 metal-ligand ratio.

Similarly, the possibility of a metal-ligand ratio of 1:1 is untenable as the non-electrolytic nature of these complexes rationalizes the absence of Cl^- ions in their outer coordination sphere (Abou-Hussein & Linert, 2015). This fact is strongly supported by simple qualitative analysis where Cl^- ions are not precipitated on addition of aqueous solutions of silver nitrate to the solution of the complexes (Refat, 2007; Keypour *et al.*, 2015). This proved a good match with the fact that the filtrates (by-products) obtained during isolation of complexes gave white precipitates (due to the presence of chloride ions) instantly on addition of aqueous solution of silver nitrate (Refat, 2010; Refat *et al.*, 2013a).

Table 5: Powder X-ray diffraction analysis (Lattice Parameters)

Complex	a (Å)	b (Å)	c (Å)	α (º)	β (º)	γ (º)	$⅂_{xrd}$ (nm)	V (Å)^3	System
(1)	14.98	2.81	4.90	90.00	95.91	90.00	74.69	205.25	Monoclinic
(2)	4.90	2.81	9.86	90.00	93.40	90.00	55.79	410.49	Monoclinic

$⅂_{xrd}$= Average crystal size, V= Cell volume Å =Angstrom

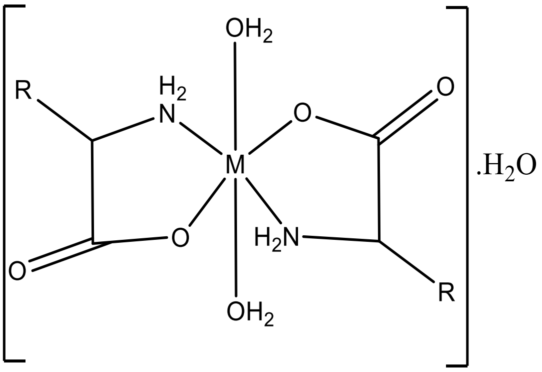
Table 6: Result of zone of antimicrobial inhibition (mm) for ligand and complexes on Gram-positive and Gram-negative bacteria

	S. aureus	*MRSA*	*S. pyogenes*	*B. coreus*	*E. coli*	*VRE*	*S. typhi*	*S. dysentriae*
L	18	20	-	-	24	21	-	-
L^1	-	21	23	20	20	-	-	-
(1)	25	-	27	24	-	-	-	25
(2)	0	-	26	25	24	-	-	-
(3)	25	-	27	-	24	23	-	-
(4)	29	28	26	-	-	27	-	26
C	34	31	-	-	38	32	41	40

C = Ciprofloxacin, *MRSA* = methicillin resistant staphylococcus aureus *VRE* = vancomycin resistant enterococci

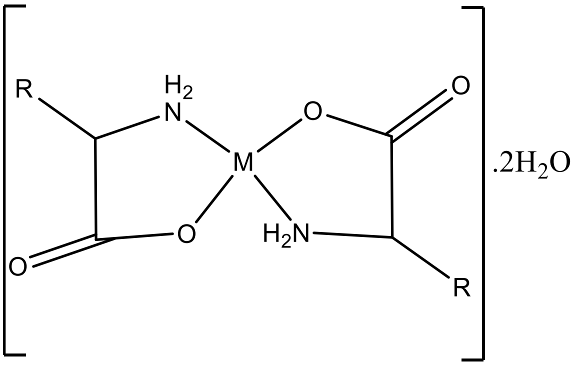
Powder X-ray diffraction studies

Powder XRD patterns of the synthesized metal(II) complexes were recorded. The complexes were characterized at room temperature, 25°C (298 K). The observed cell parameters and average particle sizes are given in Table 5. Clear resolved peaks were observed for all the complexes indicating that the complexes so formed are crystalline in nature (Sharma *et al.*, 2014). The average crystallite sizes of the complexes were observed to be within close range of 56-75 nm, with observed lattice parameters indicating monoclinic crystal system for the complex compounds (Gomez-Ruiz *et al.*, 2010). This suggests that all the complexes possess similar bonding modes (Xiao-Quan *et al.*, 2005). This fact further corroborated with the results of vibrational spectroscopy. The obtained structural data thus allows for the proposition of the structural formula for the studied metal(II) complexes as presented in Figs. 5 and 6.



Where: M=Co(II), R=CH_3-S-CH_2- for L (L-methionine), R=$CH_3-CH_2-CH(CH_3)-$ for L^1 (L-leucine)

Fig. 5: Proposed structure for Co(II) amino acid complexes



Where: M=Ni(II), R=CH_3-S-CH_2- for L (L-methionine), R=$CH_3-CH_2-CH(CH_3)-$ for L^1 (L-leucine)

Fig. 6: Proposed structure for Ni(II) amino acid complexes

Antimicrobial screening

A comparative evaluation of the antimicrobial activity of the ligands, **L** and **L^1**, and the synthesized compounds, **1**-**4** was carried out against four Gram-positive bacteria, four Gram-negative and bacteria (Table 6).

The result indicated that both **L** and **L^1** were inactive against *S. typhi* and *S. dysentriae*. The synthesized complexes also showed no activity against these pathogenic organisms with the exception of complexes **1** and **4** which proved potent against *S. dysentriae*. The ligands exhibited good activity against *E. coli*; however, two of the complexes, **1** and **4** lacked potencies against the organism. All other complexes proved potent against the pathogen and are more active than the parent ligand suggesting the enhanced lipophilicity of the complexes on coordination (Sadlers *et al.*, 2007; Chang *et al.*, 2010).

The vancomycin resistant enterococci, *VRE* showed susceptibility to **L** but not **L^1**. However, the organism appeared to be susceptible to the complexes **3** and **4** with greater activity shown by the complexes than the ligand though the standard drug (Ciprofloxacin) showed better activity against all the Gram-negative bacteria. The standard drug showed slightly better activity than all the synthesized complexes except for the facts that *B. coreus* showed resistance to the standard drug but was susceptible to complexes **1** and **2**, and, *S. pyogenes* proved susceptible to complexes **1, 2, 3** and **4**. This outcome thus suggests the engagement of these complexes in development of new antibacterial agents for therapeutic applications.

Exception of the complexes, **1, 2** and **3,** the complex **4** showed potency against methicillin resistant staphylococcus aureus, *MRSA* including the amino acid from which it was formed with the complex being more potent than the ligand. This outcome is fascinating since *MRSA* causes food poisoning and is highly resistant to most antibiotics. **L** proved active against *S. aureus* but **L^1** did not. However, except for complex **2**, all the other complexes exhibited enhanced activity against the organism suggesting the enhanced lipophilicity of the complexes on coordination.

Generally, the Gram-positive bacteria proved more susceptible to the amino acid complexes than the Gram-negative bacteria. The weak antibacterial activity against Gram-negative bacteria may be ascribed to the presence of an outer membrane which poses hydrophilic polysaccharide chains as a barrier to the amino acid complexes (Walsh *et al.*, 1996; Kabbani, *et al.*, 2007). The comparative studies of the amino acids and their metal complexes thus indicate that the complexes showed significantly enhanced antimicrobial activity against the studied microbial strains in comparison to the free ligands.

Conclusion

In the present study, we synthesized four M(II) complexes of L-amino acids. All synthesized complexes were characterized by using various spectroscopic and classical techniques. The results revealed that all the ligands were coordinated to the M(II) ions in bidentate manner with a metal ligand ratio of 1:2. Magnetic susceptibility studies revealed that the amino acids are weak field ligands. The antimicrobial studies suggested that the amino acid ligands are biologically active and their metal complexes showed significantly enhanced antimicrobial sensitivity against the studied microbial strains in comparison to the free ligands. The amino acid complexes are therefore promising potent broad spectrum antimicrobial agents, and L-methionine and L-leucine can be explored medically to arrest metal overloads or poisoning.

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