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Extraction, Characterization, and Chemical Modification of Ricinine Isolated from Castor Seeds: Formation of Metal Complexes and Evaluation of Antibacterial Activity

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Abstract: Background: Ricinine is a castor alkaloid. Its significance is due to its chemical properties, biological potential and prospects of its antibacterial complexes. Objectives: To extracted and characterized from its castor garden origin, complexes were formed with Platinum, Copper, Cobalt, Nickel and Zinc and the same were tested for their antibacterial activity. Methodology: Seeds were shade dried and sequentially extracted with diethyl ether, acid, base and chloroform. The characterization of the compounds was carried out by FTIR, UV-Vis, ¹H NMR spectroscopy, melting point determination, and mass spectrometry. The antibacterial activity was determined by agar diffusion technique using Escherichia coli and Staphylococcus aureus bacteria. Results: Ricinine crystals weighing 311mg which had a slightly yellowish colour were obtained. The nitrile band at 2219.92 cm⁻¹, maximum absorption at 322 nm, resonance signals at 8.11, 6.43, 3.98, and 3.60 ppm, and melting range of 198.8–199.5 °C supported ricinine identity and purity. The changes in the complexes UV-Vis and infrared spectra with low frequency bands suggest coordination. The platinum complex showed the greatest inhibitory potential (22 & 24 mm), followed by copper (18 & 20 mm), cobalt (14 & 15 mm), nickel (11 & 12 mm) and zinc (8 & 9 mm) against E. coli and S. aureus, respectively. Ciprofloxacin produced 31- and 33 mm, while dimethyl sulfoxide exhibited no inhibition. Conclusion: The metal co-ordinated complex can be found to be more effective for its antibacterial activity, but to confirm structure, activity and safety, MIC test, elemental analysis, stability study and cellular toxicity should be done.

Keywords: Ricinine, Castor Plant, Alkaloids, Metal Complexes, Antibacterial Activity.

Introduction

Ricinus communis L. is a medicinal and industrial important plant. Its seeds are the source of castor oil for pharmaceutical, cosmetic and chemical applications, and its various components also have various bioactive constituents such as fatty acids, phenolics, flavonoids and alkaloids [1]. Another important aspect of castor seeds is that they contain ricin, a toxic protein and ricinine, a small pyridone alkaloid, specific to the plant and defined as 3-cyano-4-methoxy-N-methyl-2-pyridone [2]. Although ricinine differs structurally and functionally from ricin, its presence in castor derived products and the extraction and detection as a biomarker of the exposure to castor-bean products make it relevant in the

field of analysis, toxicology and pharmaceutical research [3]. Isolation of alkaloids from the plant sources is of great significance in the elucidation of their structures, biological activities and their drug-discovery potential. The efficiency of isolation is based on how the compound ionises and how polar/polish it is, so often a sequence of organic, acid/basic, concentrating, and recrystallising is used. In earlier studies, ricinine has been extracted from castor seeds and leaves by solvent extraction using methanol [4] or acid–base extraction technique [5] and its identities was confirmed by spectroscopic and chromatographic studies. Also, some isolated ricinines are reported to possess antifungal activity against some dermatophytes and plant-pathogenic fungi. This discovery indicates ricinine may have an independent biological value beyond its significance as a chemical marker of castor consumption, and thus could be a subject of future research.

Additional analytical methods are needed to confirm ricinine as the isolated compound. The Fourier-transform infrared spectroscopy helps determine the presence of functional groups while the ultraviolet–visible spectroscopy gives information regarding the presence of the absorbing systems and electronic transitions. The proton nuclear magnetic resonance (NMR) spectroscopy will give information about the environment of the hydrogens and the positions of substitutions, and the melting range will give preliminary identification and purity. How much more reliable the conclusion is if these independent findings agree to what values are reported for the compound. However, when possible, other methods like elemental analysis, mass spectrometry, thermal analysis, and single crystal X-ray diffraction [6] are needed to establish the structure of the metal complexes formed. As antimicrobial resistant strains have increased, there has been a surge in the requirement for novel antibacterial chemicals. The increasing isolation of bacteria that are resistant to treatment poses a threat to existing therapies, and adds to illness and death [7].

Escherichia coli and *Staphylococcus aureus* are acceptable models for initial assessment as they are Gram-negative and Gram-positive bacteria that are normally found in infections and which can develop multidrug-resistance patterns [8]. In this context, Coordination chemistry gives a way to modify physico-chemical properties of the organic ligands. Conjugation between an alkaloid and a metal ion can lead to a change in its charge, solubility, lipophilicity, stability and membrane penetration capacity of the alkaloid [9]. The antibacterial activity of metal complexes could occur by several routes such as oxidative stress, disturbance of enzymes/proteins, cell membrane disruption, interference in the uptake of metal ions [10] and also in the possibility of damage to genetic material [11]. Such variety of mechanisms offers a theoretical benefit to these metal complexes over some of the more traditional antibacterial agents that operate through a single mechanism, but must also be carefully distinguished from any nonspecific toxicity. Especially the copper and platinum containing compounds have been revealing interesting pharmacological profiles [12] and their activity and safety depend on their oxidation state, their geometry, the structure of their ligands and the fact if they dissociate in biological media [13]. Therefore a large inhibition zone does not necessarily indicate therapeutic value. The results should then be confirmed by minimal inhibitory and bactericidal concentrations, selectivity and cellular toxicity [14] and stability of complex [15].

The Agar well diffusion method is simple and inexpensive to compare possibly on an initial basis. The size of the inhibition-zone diameter however, depends on such factors as diffusion, solubility, the molecular mass of the antimicrobial, the inoculum density, the depth of the medium and the length of the incubation time. Hence caution should be used in interpreting the results, including controls and standard conditions. In order to confirm the role of metal coordination, the free ricinine and metal salts have to be compared to the complex as well as assessment of complex stability in aqueous media. This study is aimed at extraction and purification of ricinine, identification of ricinine by FTIR, uv spectrum, ^1H -nuclear magnetic resonance (^1H -NMR) and its melting point, preparation of the complexes, its characterization of the change associated with them and the comparison of its antibacterial activity against *E. coli* and *S. aureus*. One goal of the critical reading is to identify what the data actually provide and what further experiments are needed to confirm the data.

Materials and Methods

Study Design and Plant Source

The study was conducted in a multistage experimental design in the laboratory setting. The first stage started by collecting one kilogram of *Ricinus communis* seeds from various locations in Imam Al-Sadiq District in Basrah Province during July 2023. The seeds were shaded dried for 15 days at 25 °C. Some compounds are sensitive to temperature, thus moderate drying helps avoid thermal degradation and helps to standardize mass prior to extraction.

Extraction of Ricinine

The dry seeds (50 g) were charged into a Soxhlet apparatus and 250 mL diethyl ether was added. Extraction was carried out for 24 hours at 35 °C to help to remove the ether-soluble organic matter, particularly the oily fraction which could interfere with subsequent extraction. The seeds were then harvested and washed with water to clean off the solvent. This plant material was placed in a beaker of 1000 mL of distilled water at pH 3.8. The mixture was stirred with a magnetic stir at 60 °C for 24 hours. This extraction was repeated 150 mL distilled water for 3.5 hours at 75 °C. The aqueous extraction resulted in the collection of the acidic alkaloid in the aqueous phase where it was separated from undesirable compounds [16].

Alkalinization, Liquid–Liquid Extraction, and Recrystallization

Aqueous extract was filtered and solid impurities were removed, followed by evaporation in water bath at temperature below 50 °C to obtain the concentrated extract. The solution was made up to 0.5 M NaOH and added drop by drop until pH 9–10 was reached. This was then extracted three times, using 50 mL of chloroform each time, to isolate ricinine. The organic layers were mixed and dried on anhydrous sodium sulfate after filtering and evaporated to give the crude material. Crude material was dissolved in 10 mL of hot methanol at 64 °C and hot filtered to remove the insoluble materials. It was left to cool slowly to room temperature and stored at 4 °C for 4 hours to crystallise. The crystals were filtered, washed with 2 mL of cold ethanol (at 4 °C) and dried in a desiccator. The whole process 10 times, and the mass of the crystals after the process was 311 mg [17].

Characterization of Ricinine

FTIR spectrum was taken in the range 4000 to 400 cm⁻¹ for the identification of functional groups. A stock solution was prepared by dissolving 1.4 mg of ricinine into 7.5 mL of distilled water with stated concentration of 0.001 M and then the same stock solution was diluted to 0.0001 M for the measurement of λ_{max} using UV–Vis method. NMR spectra of ¹H were measured in DMSO-d₆ at 400 MHz and are given in ppm. A heating rate of 5 °C/min was used for the melting point measurement of 3 mg of material around 200 °C.

Preparation and Purification of Metal Complexes

Complexation reactions were performed in a 250-mL flask on a hot plate with a magnetic stirrer at 70 °C. Ricinine (0.182 mmol, equivalent to 30 mg) was used with 0.182 mmol of each metal salt separately in 20 mL of distilled water and in the presence of 0.346 mmol of NaOH. The (Table 1) shows the masses of the salts used. Products which were not soluble in water were washed continuously with distilled water through a 100 ml and a filtration funnel. Four washings per product was conducted. This was to eliminate any salts that were not reacted, any unreacted base, and the water-soluble materials [18].

Table 1. Molar quantities and masses of metal salts used for the preparation of ricinine–metal complexes

Target complex	Metal salt	Molar amount	Salt mass
Ri–Ni(II)	NiCl ₂	0.182 mmol	23.585 mg
Ri–Pt(II)	PtCl ₂	0.182 mmol	48.410 mg
Ri–Co(II)	CoCl ₂ ·6H ₂ O	0.182 mmol	43.300 mg
Ri–Cu(II)	CuCl ₂ ·2H ₂ O	0.182 mmol	31.027 mg
Ri–Zn(II)	ZnCl ₂	0.182 mmol	24.802 mg

Characterization of the Complexes

Complex solutions were prepared at the concentration of 0.0001 M in DMSO and the spectra were recorded in the interval of 200-800 nm. To obtain FTIR spectra, 10 mg of each complex was admixed with 200 mg of KBr, the pellets were prepared and the spectra were recorded in the range of 4000–400 cm^{-1} . In the mass spectrometry, the acetonitrile was used as a volatile solvent, the samples were in direct infusion into the ESI source and were recorded in the positive-ion mode.

Antibacterial Activity Test

The method of agar well diffusion was employed and the bacterial suspension was adjusted to Mc Farland standard of 0.5. *Escherichia coli* and *Staphylococcus aureus* were used to test the complexes. The solutions were prepared in 100 $\mu\text{g/mL}$ in 10% DMSO and 50 μL was pipetted into each well. Inhibition diameter was measured after 24 hours incubation. The positive control was Ciprofloxacin while 10% DMSO was used as solvent control [19]. Tests were repeated three times and the methodology had it written that the results were given as the mean $\pm$ SD, but the results table published did not provide any values for SD - only mean values.

Results

Appearance and Mass

Ricine crystals of slightly yellowish-white were obtained in the extraction and purification process. The mass reported was 311mg. Describe the material as being fine and dry before recrystallizing; it solidified into crystals after purification by repeated crystallization. Although the crude extract is treated to relatively homogeneous crystals the latter gives some practical first indication of a successful separation process, but cannot be a substitute for spectroscopic characterization.

FTIR Spectrum of Ricinine

FTIR spectrum revealed the main bands which are relevant to the ricinine structure. The nitrile stretching band at 2219.92 cm^{-1} was especially significant as it is a characteristic band of the $\text{C}\equiv\text{N}$ species. A carbonyl band at 1638.93 cm^{-1} , unsaturated-ring vibrations around 1600.14 cm^{-1} , C–O and C–N bands around 1312 cm^{-1} were observed (Fig. 1 & Table 2).

Table 2. FTIR absorption bands of isolated ricinine and tentative assignment of functional groups

Wavenumber (cm^{-1})	Functional assignment
3041.81	Unsaturated/cyclic C–H stretching
2955.78	Aliphatic C–H stretching
2219.92	$\text{C}\equiv\text{N}$ stretching of the nitrile group
1638.93	$\text{C}=\text{O}$ stretching
1600.14	$\text{C}=\text{C}$ stretching in the conjugated system
1312.51	C–O stretching
1312.45	C–N stretching
1044.15 and 951.97	C–C vibrations and ring fingerprint

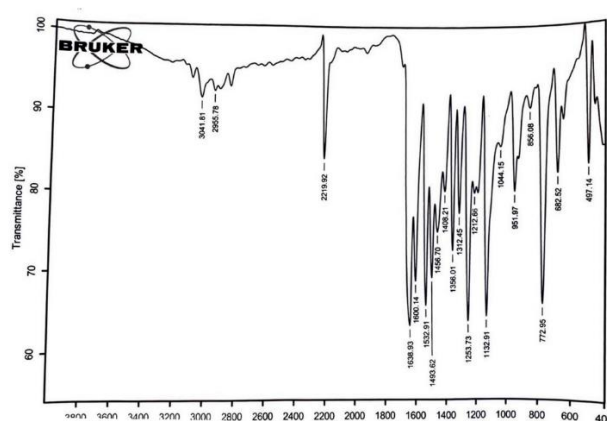


Fig. 1. FTIR spectrum of the extracted ricinine

UV-Vis Spectrum

The maximum absorption of ricinine was observed at 322 nm. The absorption is in line with the electron transition of the conjugated ring system with electron withdrawal (or donation) groups and heteroatoms. The λ_{max} value is important as a starting point in comparing the free ligand with the subsequent metal complexes (Fig. 2).

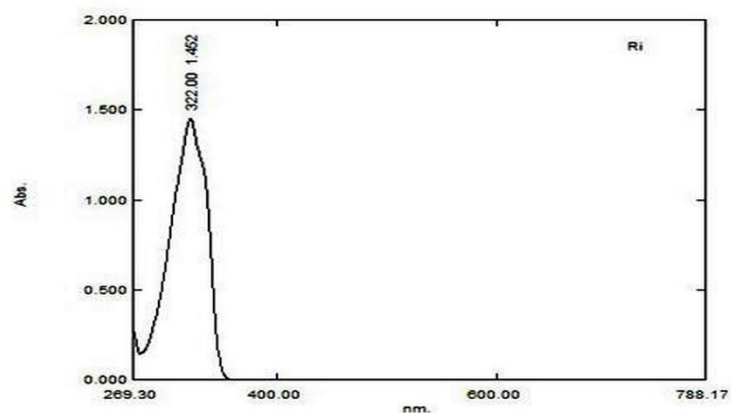


Fig. 2. UV-Vis spectrum of the extracted ricinine showing the maximum absorption near 322 nm

^1H -NMR Spectrum and Melting Point

Four major peaks were observed in the ^1H -NMR spectrum that were consistent with the structure proposed. The ring protons showed up as two doublets at 8.11 and 6.43 ppm, and the methoxy group as a singlet at 3.98 ppm, the N-methyl group as a singlet at 3.60 ppm. A water signal was present at 3.37 ppm and DMSO signal at 2.50 ppm (a little bit high due to the presence of a minor organic impurity at 2.73 ppm) (Fig. 3 & Table 3).

Table 3. ^1H -NMR chemical shifts and multiplicities for the isolated ricinine

Group	Chemical shift δ (ppm)	Multiplicity
Cyclic C=CH-N proton	8.11	Doublet
Cyclic C-CH=C proton	6.43	Doublet
OCH ₃	3.98	Singlet
NCH ₃	3.60	Singlet
Water	3.37	Singlet
Unidentified impurity	2.73	Singlet
DMSO	approximately 2.50	Singlet

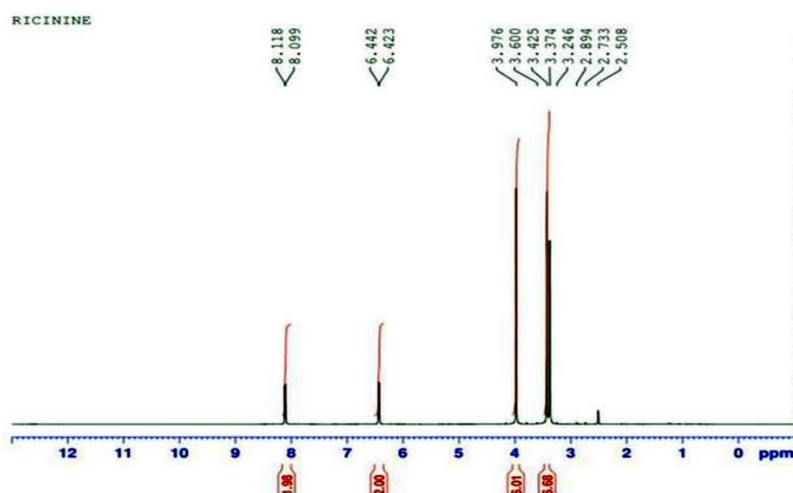


Fig. 3. ^1H -NMR spectrum of the extracted ricinine

UV-Vis Spectra of the Metal Complexes

Concerning the spectra (**Fig. 4**), the positions and intensities of the absorptions varied with the complexes as compared to ricinine as a free species. The nickel complex exhibited a peak at 320.5 nm and 0.756 with an additional peak at 666.5 nm, which can be tentatively considered as d – d transitions. It was observed that the copper complex exhibited a prominent peak at 321.5 with absorbance 0.422 as well as minor peaks at 370.5 nm and 440 nm. The platinum complex exhibited two absorption peaks, one around 321 nm and another around 377 nm which may correspond to charge transfer associated with the coordination. The zinc complex provided peak around 322 nm and weak tail around 380 nm while the cobalt complex provided bands around 284, 324 and 356 nm (**Table 4**).

Table 4. UV-Visible absorption bands of the synthesized ricinine-metal complexes

Complex	Characteristic UV-Vis bands or peaks	Proposed significance
Ri-Ni(II)	320.5 nm; 666.5 nm	Ligand transition and possible d-d transition
Ri-Cu(II)	321.5; 370.5; 440 nm	Change in the electronic system after coordination
Ri-Pt(II)	321; 377 nm	$\pi \rightarrow \pi$ transition and possible charge transfer
Ri-Zn(II)	approximately 322 with a tail near 380 nm	Ligand transition and possible coordination
Ri-Co(II)	284; 324; 356 nm	$\pi \rightarrow \pi/n \rightarrow \pi$ transitions and possible charge transfer

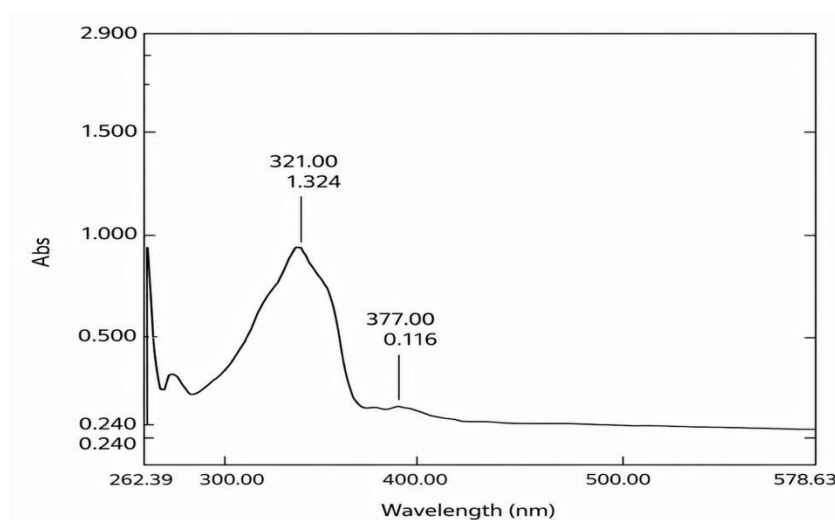


Fig. 4. UV-Vis spectrum of the Ri-Pt(II) complex, with two peaks near 321 and 377 nm

FTIR Results for the Complexes

FTIR spectra showed a greater evidence of coordination with respect to band shifts and emergence of low frequency vibrations. In the zinc complex a band at 577.8 cm^{-1} was attributed to the Zn-N or metal-ligand bond. The cobalt complex showed a Co-N band at 659.85 cm^{-1} . The band corresponding to the nickel was low frequency, at 516.90 cm^{-1} . In case of platinum complex bands at 674.97 cm^{-1} , 564.15 cm^{-1} and 455.83 cm^{-1} were assigned to coordination of Pt-N and Pt-Cl whereas for copper complex a band at 455.61 cm^{-1} was assigned to M-N of the coordination (**Table 5**).

Table 5. Tentative assignments of the principle FTIR absorption bands of the synthesized ricinine–metal complexes

Complex	Principal FTIR bands (cm ⁻¹)	Brief interpretation
Ri-Zn(II)	1689.12; 1539.68; 1447.68; 1177.12; 1128.9; 577.8	Effects on C=O/C=N and appearance of Zn–N or Zn–O bond
Ri-Co(II)	1647.44; 1460.03; 1365.15; 659.85	Coordination through carbonyl/nitrogen and appearance of Co–N
Ri-Ni(II)	1693.88; 1459.73; 1362.02; 1032.81; 516.90	Carbonyl and ring shifts and appearance of a metal–ligand vibration
Ri-Pt(II)	1643.43; 1444.75; 1253.30; 1127.97; 674.97; 564.15; 455.83	Bands consistent with Pt–N/Pt–Cl and change in C=N
Ri-Cu(II)	1695.54; 1649.04; 1506.95; 455.61	Participation of C=O/ring nitrogen and appearance of M–N

Mass Spectrometry

ESI-MS spectra of the five complexes were obtained in the positive-ion mode and a set of ions and fragments of various *m/z* values emerged. The use of these spectra as supporting evidence for the formation of metal – ligand species. It is, however, awkwardly stated that there is no systematic assignment table, given, for the molecular ions available and that a detailed comparison to the isotope pattern of each metal has not been given. Thus, it is prudent to regard mass spectrometry in this context as supporting qualitative data, and not as an absolute way to determine a ligand to metal ratio and/or the chemical formula.

Antibacterial Activity

At a concentration of 100 µg/mL all the complexes were seen to inhibit both test strains with varying extent. Platinum complex was the most active and Copper, Cobalt, Nickel and Zinc was less. No inhibition zone was obtained with the 10% DMSO, the activity observed was attributed to the tested materials, and not the DMSO (Fig. 5 & Table 6).

Table 6. The antibacterial activity of ricinine–metal complexes against *Escherichia coli* and *Staphylococcus aureus* strain bacteria was evaluated

Treatment	<i>E. coli</i> (mm)	<i>S. aureus</i> (mm)
Ri-Pt(II)	22	24
Ri-Cu(II)	18	20
Ri-Co(II)	14	15
Ri-Ni(II)	11	12
Ri-Zn(II)	8	9
Ciprofloxacin	31	33
DMSO 10%	0	0

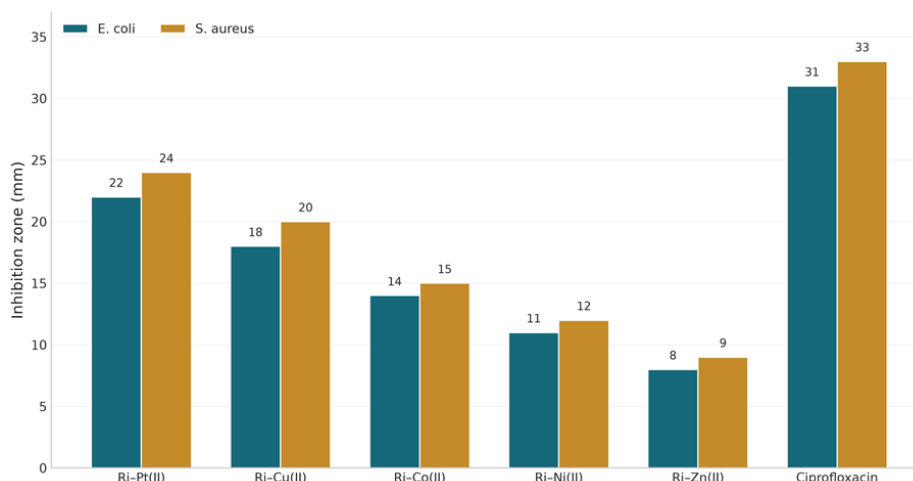


Fig. 5. Comparison of inhibition-zone diameters for the ricinine complexes and the positive control

Discussion

Mass is not enough to assure the identity and purity of the product and the crystals give evidence of an isolable solid. The bands observed in the spectrum of FTIR simultaneously by the occurrence of bands of the nitrile band at 2219.92 cm^{-1} , carbonyl absorption at 1638.93 cm^{-1} along with the bands of conjugated ring and C–O/C–N functions shows support to the proposed identity of ricinine. The signals for the nitrile and carbonyl and heteroatom groups are diagnostically compatible with the 3-cyano and pyridone frameworks. However, assignments may change for each of these: Hydrogen bonding, crystal packing, sample preparation, and instrumental resolution. A spectrum therefore will be chemically consistent with ricinine, but, alone, not inconsistent with structurally related impurities [20]. The UV–Vis spectrum contains a maximum at 322 nm that is characteristic of a conjugated heteroaromatic system, and provides a starting point for analysis of changes in the spectrum upon complexation. The NMR signals at 8.11 and 6.43 ppm reasonably are assigned to two non-equivalent ring protons and the singlets at 3.98 and 3.60 ppm to a methoxy and an N-methyl group, respectively. In the present spectrum, there are some adventitious materials which are identified as the water resonance and minor signal near 2.73 ppm. Valuable for confirmation would be integration values and coupling constants as well as two-dimensional NMR and a carbon spectrum. The combined data therefore reflect the proposed structure, but the data are not considered to be individually definitive [21].

Systematic changes of the UV–Vis and FTIR spectra were obtained with the formation of complex. The presence of a band within the region 321–324 nm is attributed to the presence of the ligand chromophore while the presence of other bands at around 356, 377, 380, 440 and 666.5 nm shows a different electronic environment. The long-wavelength nickel band is possibly a d–d transition while the bands of platinum and cobalt may include charge transfer. These assignments are tentative as the energies of transitions can be influenced by oxidation state, geometry, solvent, concentration, and selection rules. Especially it does not exhibit ordinary ligand-field d–d bands, zinc(II) with the d¹⁰ configuration of the free ion and its weak spectral changes should not be considered as evidence for certain geometry [22]. The FTIR results add some corroborating – though indirect – evidence for coordination. Changes in the carbonyl, ring and heteroatom frequencies are indicative of changes in the ligand framework induced by the coordination, while low frequencies attributed to the M–N or M–O vibrations also indicate coordination effects. It is dangerous to try to assign a donor atom of one low frequency band because the metal-ligand vibrations can be confused with either lattice vibrations or with remaining reagents. Better evidence would include comparison with the free ligand and parent salts, elemental analysis and, ideally, X-ray diffraction or magnetic measurements [23].

Similar to the ESI-MS data, these MS data should be considered as supporting rather than conclusive. Adducts and fragments can be formed during direct infusion, and therefore the species in the gas-phase may not correspond to the complex in the solid form. Isotope-pattern analysis and a complete ion table are not provided to allow for ligand to metal ratio assignment. Mass measurements

for accurate mass, isotope simulation, tandem-MS and elemental analysis would increase the level of confidence [24]. The antibacterial results indicated that the Ri – Pt (II) followed by Ri – Cu(II), Ri – Co(II), Ri – Ni (II) and Ri – Zn (II) exhibited the highest inhibition zone compared to E.coli and S.aureus showing a definite order. The larger response by S. aureus may be caused by differences in the architecture of the cell-envelope, permeability, surface charges or metal-stress responses between Gram-positive and Gram-negative bacteria. But inhibition zones are not only an indication of intrinsic potency. The size of the zone, therefore, depends on the diffusion rate, stability, charge, molecular size and solubility of the compound, a less diffusible compound could form a smaller zone still overall, the broth would be active in a meaningful way [25].

The marked difference between the platinum derivative and water may be attributed to either an increase or a decrease of interactions with cellular nucleophiles or an increase or decrease of lipophilicity upon complexation, or enhanced distribution of the platinoid in cells. These explanations are only hypotheses, as neither stability nor metal release nor accumulation in cells nor targets have been measured. The result is consistent with platinum metal complex chemistry, and assumes a mechanism different than a clinical platinum agent [26]. The decrease in activity of copper, cobalt, nickel and zinc complexes can be attributed to differences in geometry, ligand exchange rate, hydrolysis, redox and effective concentration of the complex in agar. The activity is thus determined by the entire chemical system not only by the activity of the metal ion [27]. Interpretation is only partial due to lack of free ricinine and metal salts as separate comparators. Therefore, there is no distinction between intact complexation, ligand release or remaining inorganic species. Ciprofloxacin was able to form bigger zones, so it could be used as an assay comparison but not a clinical ranking due to the agents having different diffusion properties and modes of action. The results show lack of inhibition by 10% DMSO suggesting that the lack of inhibition in the other groups was not due to DMSO. However, three replicates (with no standard deviations) make it impossible to determine the variability.

One concentration diffusion assay is not useful for determining the minimum inhibitory concentration, minimum bactericidal concentration, selectivity or toxicity. Concentration dependent activity should be determined by broth microdilution with follow up time kill, cytotoxicity and stability studies [28]. Agar diffusion is still appropriate for screening, but effects due to diffusion and media must be taken into account [29]. Mechanistic experiments should focus on membrane damage, oxidative stress, macromolecular interactions and released metal ions, and not be based on the assumption of mechanism from zone diameter alone [30]. Ri–Pt(II) and Ri–Cu(II) were found to be the initial candidates, and still additional steps are required to confirm their structure, susceptibility evaluation, variance reporting, and safety evaluation are needed [31].

Study Limitations

Limitation of this study is incoming use of locally acquired seed and imperfect reporting of yield on the extraction. Elemental analysis, ^{13}C -NMR, high resolution mass spectrometry, magnetism and X-ray diffraction were not used to confirm purity or identity of ricinine and the structure of the metal complexes. Agar well diffusion was the only method used for the study of antibacterial activity and this was carried out at a single concentration; MIC/MBC/cytotoxicity/stability/statistical analysis was not performed as well as separate controls for the free ricinine and the metal salts. Thus, the results are preliminary in nature.

Conclusion

Ricinine has been extracted from *Ricinus communis* seeds and the same has been tentatively identified by FTIR, UV–Vis and ^1H -NMR spectroscopy and melting point determination. Presented initial spectrographic proof of coordination in its complexes with Ni(II), Pt(II), Co(II), Cu(II) and Zn(II), which also inhibited E. coli and S. aureus. The Ri– Pt(II) complex was the most active one followed by Ri–Cu(II) complex, but all the complexes were less active than ciprofloxacin. These should be followed with additional structure, antimicrobial quantitative, stability and toxicity studies to draw definite conclusions regarding their therapeutic potential.

REFERENCES

- [1] V. R. Patel, G. G. Dumancas, L. C. Kasi Viswanath, R. Maples, and B. J. J. Subong, "Castor oil: Properties, uses, and optimization of processing parameters in commercial production," *Lipid Insights*, vol. 9, pp. 1–12, 2016.
- [2] C. T. Pittman, J. M. Guido, E. I. Hamelin, T. A. Blake, and R. C. Johnson, "Analysis of a ricin biomarker, ricinine, in 989 individual human urine samples," *Journal of Analytical Toxicology*, vol. 37, no. 4, pp. 237–240, 2013.
- [3] V. Coopman, M. De Leeuw, J. Cordonnier, and W. Jacobs, "Suicidal death after injection of a castor bean extract (*Ricinus communis* L.)," *Forensic Science International*, vol. 189, nos. 1–3, pp. e13–e20, 2009.
- [4] M. M. Abomughaid, J. O. Teibo, O. A. Akinfe, A. M. Adewolu, T. K. A. Teibo, M. Afifi, A. M. H. Al-Farga, H. M. Al-kuraishy, A. I. Al-Gareeb, A. Alexiou, M. Papadakis, and G. E.-S. Batiha, "A phytochemical and pharmacological review of *Ricinus communis* L.," *Discover Applied Sciences*, vol. 6, p. 315, 2024.
- [5] P. Saravana Kumar, Y. Li, M. He, P. Yuvaraj, K. Balakrishna, and S. Ignacimuthu, "Rapid isolation of ricinine, a pyridone alkaloid from *Ricinus communis* (L.) with antifungal properties," *Journal of Biologically Active Products from Nature*, vol. 12, no. 1, pp. 33–41, 2022.
- [6] R. M. Silverstein, F. X. Webster, D. J. Kiemle, and D. L. Bryce, *Spectrometric Identification of Organic Compounds*, 8th ed. Hoboken, NJ, USA: Wiley, 2014.
- [7] World Health Organization, "Antimicrobial resistance: Fact sheet," updated Jul. 16, 2026. [Online]. Available: <https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance>
- [8] W. Tyasningsih, S. C. Ramandinianto, R. Ansharieta, A. M. Witaningrum, D. A. Permatasari, D. K. Wardhana, M. H. Effendi, and E. N. Ugbo, "Prevalence and antibiotic resistance of *Staphylococcus aureus* and *Escherichia coli* isolated from raw milk in East Java, Indonesia," *Veterinary World*, vol. 15, no. 8, pp. 2021–2028, 2022.
- [9] A. Frei, J. Zuegg, A. G. Elliott, M. Baker, S. Braese, C. Brown, F. Chen, C. G. Dowson, G. Dujardin, N. Jung, A. P. King, A. M. Mansour, M. Massi, J. Moat, H. A. Mohamed, A. K. Renfrew, P. J. Rutledge, P. J. Sadler, M. H. Todd, C. E. Willans, J. J. Wilson, M. A. Cooper, and M. A. T. Blaskovich, "Metal complexes as a promising source for new antibiotics," *Chemical Science*, vol. 11, no. 10, pp. 2627–2639, 2020.
- [10] A. Pandey and E. Boros, "Coordination complexes to combat bacterial infections: Recent developments, current directions and future opportunities," *Chemistry—A European Journal*, vol. 27, no. 26, pp. 7340–7350, 2021.
- [11] J. A. Lemire, J. J. Harrison, and R. J. Turner, "Antimicrobial activity of metals: Mechanisms, molecular targets and applications," *Nature Reviews Microbiology*, vol. 11, no. 6, pp. 371–384, 2013.
- [12] A. Evans and K. A. Kavanagh, "Evaluation of metal-based antimicrobial compounds for the treatment of bacterial pathogens," *Journal of Medical Microbiology*, vol. 70, no. 5, Art. no. 001363, 2021.
- [13] C. E. Maciel-Flores, J. A. Lozano-Alvarez, and E. Y. Bivián-Castro, "Recently reported biological activities and action targets of Pt(II)- and Cu(II)-based complexes," *Molecules*, vol. 29, no. 5, p. 1066, 2024.
- [14] M. Balouiri, M. Sadiki, and S. K. Ibnsouda, "Methods for in vitro evaluating antimicrobial activity: A review," *Journal of Pharmaceutical Analysis*, vol. 6, no. 2, pp. 71–79, 2016.
- [15] Clinical and Laboratory Standards Institute, *M100: Performance Standards for Antimicrobial Susceptibility Testing*, 34th ed. Wayne, PA, USA: CLSI, 2024.
- [16] Q.-W. Zhang, L.-G. Lin, and W.-C. Ye, "Techniques for extraction and isolation of natural products: A comprehensive review," *Chinese Medicine*, vol. 13, p. 20, 2018.

- [17] S. D. Sarker and L. Nahar, Eds., *Natural Products Isolation*, 3rd ed., vol. 864, Methods in Molecular Biology. Totowa, NJ, USA: Humana Press/Springer, 2012.
- [18] T. B. Rauchfuss, Ed., *Inorganic Syntheses*, vol. 35. Hoboken, NJ, USA: John Wiley & Sons, 2010.
- [19] J. B. L. Tan and Y. Y. Lim, "Critical analysis of current methods for assessing the in vitro antioxidant and antibacterial activity of plant extracts," *Food Chemistry*, vol. 172, pp. 814–822, 2015.
- [20] D. L. Pavia, G. M. Lampman, G. S. Kriz, and J. R. Vyvyan, *Introduction to Spectroscopy*, 5th ed. Boston, MA, USA: Cengage Learning, 2015.
- [21] T. D. W. Claridge, *High-Resolution NMR Techniques in Organic Chemistry*, 3rd ed. Oxford, U.K.: Elsevier, 2016.
- [22] A. B. P. Lever, *Inorganic Electronic Spectroscopy*, 2nd ed. Amsterdam, The Netherlands: Elsevier, 1984.
- [23] K. Nakamoto, *Infrared and Raman Spectra of Coordination Compounds: Part B—Applications in Coordination, Organometallic, and Bioinorganic Chemistry*, 6th ed. Hoboken, NJ, USA: Wiley, 2009.
- [24] J. H. Gross, *Mass Spectrometry: A Textbook*, 3rd ed. Cham, Switzerland: Springer, 2017.
- [25] B. Bonev, J. Hooper, and J. Parisot, "Principles of assessing bacterial susceptibility to antibiotics using the agar diffusion method," *Journal of Antimicrobial Chemotherapy*, vol. 61, no. 6, pp. 1295–1301, 2008.
- [26] B. Rosenberg, L. VanCamp, J. E. Trosko, and V. H. Mansour, "Platinum compounds: A new class of potent antitumour agents," *Nature*, vol. 222, pp. 385–386, 1969.
- [27] C. E. Housecroft and A. G. Sharpe, *Inorganic Chemistry*, 5th ed. Harlow, U.K.: Pearson, 2018.
- [28] J. M. Andrews, "Determination of minimum inhibitory concentrations," *Journal of Antimicrobial Chemotherapy*, vol. 48, suppl. 1, pp. 5–16, 2001.
- [29] A. Klančnik, S. Piskernik, B. Jeršek, and S. S. Možina, "Evaluation of diffusion and dilution methods to determine the antibacterial activity of plant extracts," *Journal of Microbiological Methods*, vol. 81, no. 2, pp. 121–126, 2010.
- [30] M. A. Kohanski, D. J. Dwyer, B. Hayete, C. A. Lawrence, and J. J. Collins, "A common mechanism of cellular death induced by bactericidal antibiotics," *Cell*, vol. 130, no. 5, pp. 797–810, 2007.
- [31] I. Wiegand, K. Hilpert, and R. E. W. Hancock, "Agar and broth dilution methods to determine the minimal inhibitory concentration (MIC) of antimicrobial substances," *Nature Protocols*, vol. 3, no. 2, pp. 163–175, 2008.