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FOREWORD

Dear friends and colleagues,

On behalf of the International Scientific Committee and the Organizing Committee, we are delighted to welcome you to Udine, Italy, for the 2026 edition of the International Symposium on the Thermodynamics of Metal Complexes (ISMEC2026).

ISMEC 2026 continues a long-standing tradition of scientific meetings that began in Parma in 1973 as the annual congress of the Italian *Gruppo di Termodinamica dei Complessi*. Over the years, the symposium evolved into an international forum bringing together researchers from across Europe and around the world to exchange ideas, foster collaborations, and advance knowledge in the field of metal complex thermodynamics and coordination chemistry.

Hosted by the University of Udine in the beautiful region of Friuli Venezia Giulia, the conference will take place at the historic Palazzo Garzolini Di Toppo Wassermann in the heart of Udine.

The scientific program of ISMEC 2026 highlights the most recent advances in metal ion speciation and solution chemistry, with particular emphasis on the thermodynamics, stability, coordination, and kinetic behavior of metal complexes in solution. The symposium will provide an interdisciplinary platform covering analytical, biological, environmental, inorganic, medicinal, and physical chemistry, while promoting discussion on emerging methodologies and applications.

Main topics include, but are not limited to:

- Complexation thermodynamics and kinetics
- Solution equilibria and coordination chemistry
- Complexation processes in supramolecular chemistry
- Separations of metals from complex matrices
- Metal-based reactivity and catalysis
- Computational modelling of metal complexes
- Metal–complex interactions with biomolecules
- Metals in diseases: transport, homeostasis, and toxicity
- Metal-based drugs in diagnosis and therapy
- Metal speciation in the environment
- Nanostructured and functional metal complexes
- Analytical methods and sensors based on complexation equilibria
- Computer methods for equilibrium and speciation analysis

The program will feature 4 plenary and 5 keynote lectures delivered by internationally recognized scientists, together with 34 oral and 25 poster communications showcasing the research from both senior and young researchers. ISMEC 2026 will also host the ISMeC "S. Sammartano" and "F. Pulidori" prizes, recognizing outstanding contributions by PhD students and early-career postdoctoral scientists.

Also, we are pleased to announce a Special Issue dedicated to ISMEC 2026 in *Coordination Chemistry Reviews*, offering participants an opportunity to publish high-quality contributions related to the symposium topics.

Beyond the scientific sessions, we hope you will enjoy the unique atmosphere, history, culture, and hospitality of Udine and the Friuli Venezia Giulia region, creating opportunities for fruitful discussions and lasting collaborations.

We thank all participants, speakers, sponsors, and committee members for contributing to the success of ISMEC 2026, and we look forward to welcoming you to Udine for an inspiring and memorable symposium.

On behalf of the International Scientific Committee and the Organizing Committee

Andrea Melchior - ISMEC2026 Chair

Marilena Tolazzi - ISMEC2026 co-Chair

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The venue

Palazzo Garzolini Toppo Wassermann, in Via Gemona 92 in Udine, is one of the most significant historic palaces in Friuli, both for its architectural value and for the role it has played in the cultural and educational life of the city over more than three centuries. Originally conceived as an aristocratic residence in the early eighteenth century, the palace has continuously evolved, reflecting the political, social, and cultural transformations of Udine from the Venetian era to the present day.

It was built between 1705 and 1706 by Marzio di Polcenigo on land inherited by his wife, Tranquilla Gugliola, from her first husband Pietro Bortoli. Designed according to the models of Venetian architecture, the palace combined sobriety on the exterior with richly decorated interiors. The painted decorations include illusionistic architecture, mythological scenes, landscapes, and heraldic motifs. The dome above the staircase preserves the date "1705" commemorating the palace's completion.

In 1790 the palace changed ownership when the Polcenigo family sold it to Margherita Annibale Mangilli, wife of count Giuseppe Garzolini. Under the Garzolini family, the residence entered a new phase of expansion and modernization that continued throughout the nineteenth century. The interiors were enriched with neoclassical decorative schemes, reflecting the aesthetic transition from the late Venetian world to Napoleonic and Restoration tastes. The decline of the noble family line led to another transformation: Maria Sbroiavacca, widow of Giusto Garzolini had no heirs and left the property to the Giovanni Battista Job, who shortly afterward transferred it to the Casa di Carità Orfanotrofio Renati. This marked the end of the palace's exclusive aristocratic function and the beginning of its social and educational vocation. At the beginning of the XX century, the city of Udine acquired the complex to establish the Toppo-Wassermann institute, created according to the wishes of Francesco di Toppo. The Wasserman comes from the Di Toppo first wife Antonietta Wassermann. The palace was then adapted for educational purposes and became a place of instruction and formation for generations of students. During World War I part of the building was temporarily converted into a military hospital, adding another layer to its historical significance.

In 2002 the palace was granted to the University of Udine. After extensive restoration, it was officially inaugurated in 2015 as the headquarters of the "Scuola Superiore" of the University of Udine. Today the complex combines its historical identity with contemporary academic life, housing student residences, classrooms, an auditorium, and cultural exhibition spaces.

SCIENTIFIC PROGRAM

Monday, June 15th

14:30 – 16:30	**Registration**
16:30 – 17:00	**Opening Ceremony** **Angelo Montanari**, Rector of the University of Udine **Alessandro Gasparetto**, Head of the Polytechnic Department of Engineering and Architecture **Tarita Biver**, President of Group ISMEC **Andrea Melchior**, Chair of ISMEC2026
	Chairperson: **Vieri Fusi**
17:00 – 18:00	**PL01:** Porphyrinoid–Based Chemical Sensors and Sensor Arrays **Roberto Paolesse** Department of Chemical Sciences and Technology, University of Rome Tor Vergata, Italy
18:00 – 18:30	**KN01:** The contribution of thermodynamics and theoretical calculations to interpreting the spectroscopic properties of trivalent lanthanide coordination compounds **Fabio Piccinelli** Luminescent Materials Laboratory, Department of Biotechnology, University of Verona, Italy
19:00–20:30	**Welcome Party**

Tuesday, June 16th

	Chairperson: **Antonio Bianchi**
9:00 – 10:00	**PL02:** Self–Assembled Metallocages with Heterocyclic Polyamines, a Cyclic Story **Enrique García–España** Departments of Inorganic and Organic Chemistry, ICMOL, University of Valencia, Spain
10:00 – 10:15	**OC01:** Polyamino–polyphosphonates: Determination of stability constants in the metal ion – NTMP / EDTMP / DTPMP systems **Petr Hermann** Department of Inorganic Chemistry, Charles University, Czech Republic
10:15 – 10:30	**OC02**: Selective Recognition and Quantification of Hard–Soft Acid–Base Properties of Anions from the Primary and Secondary Sphere Interactions with Cationic ZnII and CuII Tripodal Amine–Benzene CF3 Ligands **Anastasios D. Keramidas**

	Department of Chemistry, University of Cyprus, Cyprus
10:30 – 10:45	**OC03:** N/O Macrocycles for Pd(II) Recovery and Catalysis: A Hard–Soft Balance of Selectivity and Robustness **Matteo Savastano** Department for the Promotion of Human Science and Quality of Life University San Raffaele Roma, Italy
10:45– 11:15	**Coffee Break**
	Chairpersons: **Michel Meyer & Sofia Gama**
11:15– 11:45	**KN02:** Zinc detection using responsive MRI contrast agents: from rational design to in vivo applications **Célia Bonnet** Centre de Biophysique Moléculaire, CNRS Université d'Orléans, France
11:45– 12:00	**OC04**: Coordination of Sc(III) by pyridinecarboxylates: implications for picolinate–based chelator design **Vladimir Sladkov** Pôle Santé, IJCLab/CNRS/Université Paris–Saclay, France
12:00– 12:15	**OC05:** Thermodynamic Insights into Pb^{2+} Chelators for $^{212/203}$Pb complexation with acyclic ligands **Jennifer Storchi** Department of Chemical and Geological Sciences, University of Modena and Reggio Emilia, Italy
12:15– 12:30	**OC06:** From Speciation to Thermodynamic Stability: A Rigid HBED Analogue Controls Isomerization in Gallium-68 Complexes **Erika Ferrari** Chemical and Geological Sciences, University of Modena and reggio Emilia, Italy
12:30– 12:45	**OC07:** Impact of carboxylate substitution by pyridine/imidazole in pyridine-based complexes: stability, dynamics, and relaxation properties of Ln^{3+} complexes **Martina Sanadar** Centre de Biophysique Moléculaire, CNRS, France
12:45– 13:00	**OC08:** Chiral NIR-emitting Yb(III) complex: a promising water-soluble optical probe **Silvia Ruggieri** Luminescent Materials Laboratory, Department of Biotechnology, University of Verona, Italy
13:00– 15:00	**Lunch**
	Chairpersons: **Montserrat López Mesas & Silvia Berto**
15:00– 15:30	**KN03:** Adsorption: Thinking beyond pollution remediation **José L. Barriada**

	Department of Chemistry, University of A Coruña, Spain
15:30– 15:45	**OC09:** Unravelling shifts in DOM ion-binding dynamics across the land-ocean interface **María Martínez Cabanas** Department of Chemistry, University of A Coruña, Spain
15:45– 16:00	**OC10:** Bergamot Pomace as a Biosorbent for Rare Earths: Outcomes of the Wastezilla Project **Gabriele Lando** Dipartimento di Scienze Chimiche, Biologiche, Farmaceutiche ed Ambientali, Università degli Studi di Messina, Italy
16:00– 16:15	**OC11:** Horse hoof waste cleaning and heavy metals removal optimization merging chemometrics and speciation studies towards upcycling **Lisa Rita Magnaghi** Dipartimento di Chimica, Università degli Studi di Pavia, Italy
16:15– 16:30	**OC12:** What Binds What? Metal–Ligand Interactions of MGDA and GLDA with Environmentally Relevant Cations: A Comprehensive Investigation **Clemente Bretti** Dipartimento di Scienze Chimiche, Biologiche, Farmaceutiche ed Ambientali, Università degli Studi di Messina, Italy
16:30– 17:00	**Coffee Break**
	Chairperson: **Beata Godlewska–Żyłkiewicz**
17:00– 17:15	**OC13:** Electrochemical Enzymatic Biosensing of Phenols in Deep Eutectic Solvents **Rossella Svigelj** Department of Agrifood, Environmental and Animal Sciences, University of Udine, Italy
17:15– 17:30	**OC14:** Chemical speciation of inositol phosphates in grape seeds applied to wine waste valorization **Manuel Valiente** Department of Chemistry-GTS center, Universitat Autònoma de Barcelona, Spain
17:30– 18:00	**KN04:** Targeted and suspect LC-HRMS strategies for screening multiclass micropollutants and their transformation products in environmental and food samples **Dimitra A. Lambropoulou** Department of Chemistry, Environmental Pollution Control Laboratory, Aristotle University of Thessaloniki and Centre for Interdisciplinary Research and Innovation (CIRI-AUTH), Greece
18:00– 19:30	**Poster Session**

Wednesday, June 17th

	Chairperson: **Demetrio Milea**
9:00 – 10:00	**PL03:** Design and Thermodynamic Assessment of Functionalized Ionic Liquids for Selective Rare Earth Element Recovery **Slobodan Gadžurić** Faculty of Science, University of Novi Sad, Serbia
10:00 – 10:15	**OC15:** Unraveling Metal Ion Solvation in Ionic Liquids through a Combined X-ray Absorption Spectroscopy and Molecular Modelling Approach **Matteo Busato** Department of Chemistry, Sapienza Università di Roma, Italy
10:15 – 10:30	**OC16:** Functionalized ionic liquids containing ferrocene moiety **Pavel Kozáček** Institute of Chemistry and Technology of Macromolecular Materials, University of Pardubice, Czech Republic
10:30 – 10:45	**OC17:** Phase equilibria and thermodynamic properties of the nickel(II) methanesulfonate – methanesulfonic acid – water system **Femke Derison** Department of Chemistry, KU Leuven, Belgium
10:45– 11:15	**Coffee Break**
	Chairpersons: **Maria Rosa Beccia & Jorge Gonzalez**
11:15– 11:30	**OC18:** Dysprosium and Samarium Recovery via Natural Zeolite: A Study of Process Dynamics and Equilibrium Conditions **José Alejandro Ricardo García** Polytechnic Department of Engineering and Architecture, Università di Udine, Italy
11:30– 11:45	**OC19:** Dual-purpose Ni-sensitive bioplastic film as jewelry smart coating for allergen detection and skin exposure prevention **Raffaela Biesuz** Dipartimento di Chimica, Università di Pavia, Italy
11:45– 12:00	**OC20:** Uranyl Chelation by Pincer-Like Dihydroxamic Acids **Michel Meyer** Institut de Chimie Moléculaire, Université Bourgogne Europe, France
12:00– 12:15	**OC21:** Design and Modulation of Selectivity toward Vanadium(V) and Uranium(VI) Ions: Coordination Properties, Affinity and Applications of Hydroxylamino-Triazine Siderophores **Angelos Amoiridis** Department of Chemistry, University Of Cyprus, Cyprus
12:15– 12:30	**OC22:** Silver(I), copper(II) and zinc(II) complexes: their solution behavior, solid state study and bioevaluation

	Gabriela Kuzderová Department of Inorganic Chemistry, Pavol Jozef Šafárik University in Košice, Slovakia
12:30–13:00	**KN05:** Metal–ligand coordination and supramolecular assemblies in luminescent Au(I) and Pt(II) complexes **Laura Rodríguez** Inorganic Chemistry Section, Faculty of Chemistry, Universitat de Barcelona, Spain
13:00– 15:00	**Lunch**
	Chairperson: **Raffaela Biesuz**
15:00– 15:15	**OC23:** Metallochlorin Photosensitizers for Enhanced Photodynamic Therapy: A Computational–Experimental Approach **Juliana Machado** Department of Chemistry and Biochemistry, University of Porto, Portugal
15:15 – 15:30	**OC24:** Tailored oxaliplatin(IV) monohaloacetate complexes with redox-activation and multimodal anticancer activity **Francesca Binacchi** Department of Chemistry and Industrial Chemistry, Università di Pisa, Italy
15:30 – 15:45	**OC25:** The Acid-Base and Complex-Forming Properties of Cytokinins **Přemysl Lubal** Department of Chemistry, Masaryk University, Czech Republic
15:45 – 16:00	**OC26:** Effects of the structural modification of ambidentate hydroxy-pyridinonates on their metal ion binding **Péter Buglyó** Department of Inorganic & Analytical Chemistry, University of Debrecen, Hungary
16:00– 16:30	**Coffee Break**
16:30–18:00	**ISMEC Group Meeting**
18:00–19:30	**City Tour of Udine**

Thursday, June 18th

	Chairperson: **Petr Hermann**
9:00 – 10:00	**PL04:** Supramolecular recognition of DNA and RNA junction structures for anti–viral and anti–cancer therapy Michael J. Hannon School of Chemistry, University of Birmingham, UK
10:00 – 10:15	**OC27:** Biological properties of first row transition metal complexes of Schiff base ligands **Giampaolo Barone** Dipartimento di Scienze e Tecnologie Biologiche Chimiche e Farmaceutiche, Università di Palermo, Italy
10:15 – 10:30	**OC28:** Targeting G–quadruplexes using Supramolecular Strategies **Jorge González García** Department of Inorganic Chemistry, University of Valencia, Spain
10:30 – 10:45	**OC29:** Complex formation and metal ion induced hydrolytic processes of fragments of tau and tubulin proteins **K. Várnagy** Inorganic and Analytical Chemistry, University of Debrecen, Hungary
10:45 – 11:15	**Coffee Break**
	Chairpersons: **Péter Buglyó & Zuzana Vargova**
11:15 – 11:30	**OC30:** New organotin(IV) syringates as potential PPAR–γ agonists: from chemical characterization to biological activity towards colon cancer HCT116 cells **Claudia Pellerito** Dipartimento di Fisica e Chimica–Emilio Segrè, Università di Palermo, Italy
11:30 – 11:45	**OC31:** How does the –DPHVW– Motif Contribute to Metal Coordination in Neisseria gonorrhoeae?" **Karolina Pawlik** Faculty of Chemistry, University of Wroclaw, Poland
11:45 – 12:00	**OC32:** Investigation of transition metal complexes of tau fragments containing cysteine and one or more histidines Faareha Mazhar Department of Inorganic and Analytical Chemistry, University of Debrecen, Hungary
12:00 – 12:15	**OC33:** Metal ion binding affinity of native and phosphorylated human Tau(28–34) protein fragment and the role of phosphorylation in the hydrolytic process Gomaa E. Amer Department of Inorganic and Analytical Chemistry, University of Debrecen, Hungary

12:15 – 12:30	**OC34:** Small Change, Big Impact: Dual Amino Acid Swap Influence Metal Binding and Antimicrobial Activity of a MUC7–Derived Peptide Klaudia Szarszoń Faculty of Chemistry, University of Wrocław, Poland
12:30 – 14:30	**Lunch**
	Introduction: **Maurizio Remelli**
14:30–15:00	**PR1:** Harnessing solution thermodynamics to develop functional drug delivery platforms **Giuseppina D. G. Santonoceta** Department of Chemical Sciences, University of Catania, Italy
15:00–15:30	Introduction: **Concetta De Stefano and Demetrio Milea**
	PR2: Unveiling chemical speciation of vanadium(IV/V)/8–hydroxyquinoline–2–carboxylic acid system in aqueous solution **Matteo Marafante** Department of Chemistry, University of Torino, Italy
15:30–15:40	**Best Poster and best Oral Communication awards**
15:40–16:00	**Presentation of ISMEC2027 and Closing Ceremony**
19:45 –	**Gala dinner at the “Casa della Contadinanza”**

PLENARY LECTURES

Acta of the International Symposia on Metal Complexes – ISMEC Acta
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Porphyrinoid-Based Chemical Sensors and Sensor Arrays

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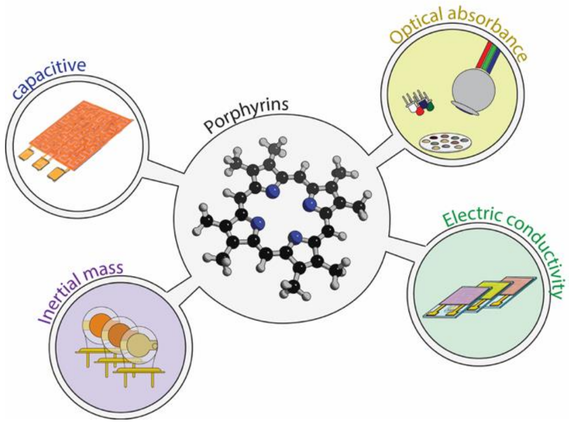
Porphyrins are versatile macrocycles that fulfill vital functions in living systems; the property richness of porphyrins allows their exploitation in different application fields, and in my group, we have been particularly interested in sensing applications [1]. Practical applications are further allowed by using sensor arrays, where the cross-selectivity of sensing layers plays a key role in the analysis of complex matrices. The optimal design of sensor arrays greatly benefits from both the synthetic flexibility and molecular properties of porphyrinoids. Mimicking the role played by porphyrins and related macrocycles in Nature, the sensing behavior of porphyrin-based materials can be tuned by synthetic modifications. Our group recently reported that quartz crystal microbalance (QMB) sensors coated with corrole and porphyrin complexes exhibit distinct sensing properties, demonstrating their value as gas-sensing tools. In addition to the synthetic aspects, a further important step in preparing reliable devices is the solid-state organization of the sensing material. Although it is true that monomeric porphyrins possess valuable properties, their self-assembly into sophisticated, size- and shape-controlled suprastructures, coupled with their integration with inorganic species to form hybrid materials, can significantly enhance their potential, leading to advanced functional materials with improved properties.

Figure 1. Porphyrin based chemical sensors



The deposition of layers of porphyrin-based materials onto the surfaces of different transducers (Figure 1) [2], such as QMB, has led to the preparation of sensor arrays successfully exploited in various application fields, including environmental control and medical diagnosis [3].

Furthermore, the implementation of elements of chirality on such systems widens their applicability to chiral discrimination, a challenging task for chemical sensors. Chiral porphyrin-based architectures can be obtained from either chiral or achiral platforms.

The latest progress in the development of these systems will be presented and discussed.

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Self-Assembled Metallocages with Heterocyclic Polyamines, a Cyclic Story

Enrique GARCÍA-ESPAÑA, Esther NAVARRO-BLASCO, Irene BONASTRE, Jesús ESCOBAR, Estefanía DELGADO-PINAR, M. Paz CLARES, Josu URTARAN, Teresa ALBELDA, Hermas R. JIMÉNEZ, Salvador BLASCO, Begoña VERDEJO

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Gaining controlled self-assembled chemical complexity from simple building molecular blocks is of paramount relevance across many areas of chemistry and biology. Micelles, viruses, liquid-crystals, and the impressive self-organization of polynucleotides to form different canonical and non-canonical structures are among the many examples of these organizations.

Here we present a dual approach to the construction of metallorganic cages. First, we show as controlling the pH and length of the polyamine bridges in 1H-pyrazole azamacrocycles leads to Cu(II) complexes with different spatial organizations [1]. In the second approach, we will describe the construction of cages in which hydrolytic processes are regulated and modulated by a specific ligand and metal. To the best of our knowledge, this represents a rather new milestone in coordination and supramolecular chemistry, particularly in aqueous media [2]. Indeed, metal hydrolysis is generally a rather complicated process that often runs out of control, with the formation of many species of different nuclearities and formation kinetics, ultimately leading to insoluble polymers. Just a few very nice examples of related hydrolytic metallorganic cages have been described but usually involving Al(III) and Fe(III) or lanthanides and the synthesis was carried out in mixed solvents rather than in pure water as in the present case [3,4]. We will show as a very simple ligand made up by a pyridine ring functionalized in meta position with a terminally methylated ethylenediamine is able to consistently provide the formation of a hydrolytic metallocage assembled by ten Cu(II) ions and eight ligands, both in water and in the solid state.

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Acknowledgments

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Design and Thermodynamic Assessment of Functionalized Ionic Liquids for Selective Rare Earth Element Recovery

Slobodan GADŽURIĆ,[a)] Milan VRANEŠ,[a)] Snežana PAPOVIĆ,[a)] Sanja BELIĆ,[a)] Tatjana TRTIĆ-PETROVIĆ,[b)] Bojan ŠARAC,[c)] Andrea MELCHIOR [d)]

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The increasing demand for rare earth elements (REEs) in modern technologies requires the development of more sustainable and efficient separation processes to overcome the limitations of current methods, which are often associated with high toxicity, flammability, and significant environmental pollution. This study presents a thermodynamic and synthetic approach for the design of functionalized ionic liquids (ILs) tailored as dual-function solvents and extractants for selective REE recovery.

Our strategy focuses on the synthesis of aprotic, hydrolytically stable ILs through simple, rapid neutralization reactions. We have selected a range of hydrophobic quaternary cations, including tetrabutylphosphonium, tetrabutylammonium, benzyltrimethylammonium, as well as aliquote cation, to evaluate the influence of cation structure on the overall hydrophobicity, stability, and toxicity of the resulting ILs. These cations are paired with chelating anions specifically chosen for their affinity towards lanthanides. The target anions include etidronic acid, a powerful complexing agent for REEs; picolinic acid, which forms stable chelates with increasing stability across the lanthanide series; and thiosalicylic acid, which offers a higher degree of hydrophobicity. These anions act as the primary ligands, allowing the ILs to function simultaneously as the solvent, extractant, and complexing agent, thereby simplifying the separation process. Apart from these anions, anthranilate and oxychinolinate were also investigated as good chelators for the REE metal ions.

The central focus of this work was to establish the thermodynamic parameters governing the formation, stability, and selectivity of these novel ILs and their interactions with REEs. Key thermodynamic investigations included:

Synthesis and Characterization: Determining the purity, structure, and key physical properties (e.g., viscosity, thermal stability) of the synthesized ILs.

Selectivity and Binding Thermodynamics: Quantifying the separation factors and binding constants for a series of REEs using the designed ILs. The enthalpy and entropy of the extraction process are determined to understand the driving forces behind selectivity.

Stability and Recyclability: Evaluating the chemical stability and the consistency of thermodynamic extraction performance of the ILs over multiple extraction-stripping cycles to assess their viability for sustainable industrial applications.

By correlating the molecular structures of the IL components (cation hydrophobicity, anionic donor atom type, and basicity) with their thermodynamic extraction properties, this research aims to establish a predictive framework for designing highly selective and recyclable IL-based separation systems. The results will provide crucial thermodynamic insights necessary for overcoming current challenges related to cost, scalability, and process efficiency in the recovery of critical metals.

Acknowledgments
This research was supported by the FREECOVER project (grant agreement #101182579) under the European Community's Horizon Europe Program HORIZON-MSCA-2023-SE-01.

Supramolecular recognition of DNA and RNA junction structures for anti-viral and anti-cancer therapy

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We use the outer surfaces of metallo-supramolecular cylinders (helicates) to create a perfect match for the central cavities of DNA and RNA junctions (Figure). They bind strongly to DNA and RNA Y-shaped junctions, forks and bulges - nanomolar to picomolar affinities - and modulate their dynamic behaviour [1]. We can control the activity of these agents by encapsulating them in a curcubituril ring to create a rotaxane structure, with release from the rotaxane switching on the junction-binding activity [2].

Recognition of a specific nucleic acid shapes is a powerful approach: In RNA-viruses the ends of the genome are non-coding parts which fold into specific structures and regulate viral replication. The same structures are common to many different viruses and an exciting new anti-viral target. We have shown that some of our agents can bind junction and bulge structures in the untranslated regions of both SARS-CoV-2 and HIV-1 and show potent anti-viral activities at concentration levels where they are not cytotoxic to mammalian cells [3].

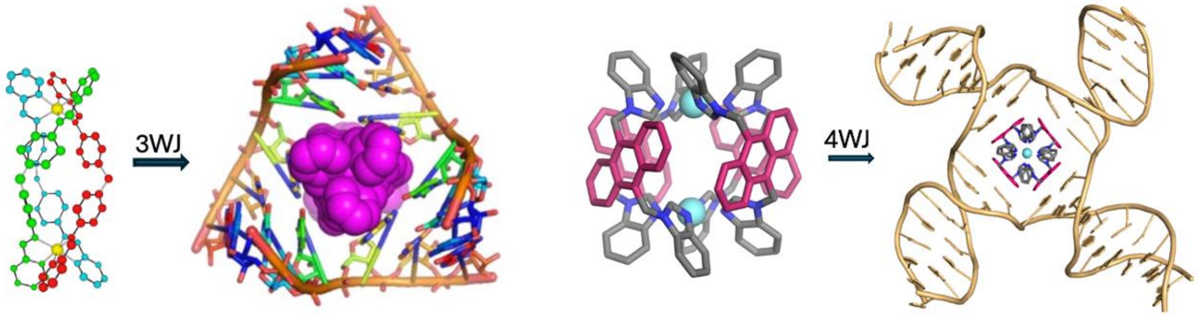

Figure: Supramolecules recognising 3-way and 4-way junctions

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KEYNOTE LECTURES

The contribution of thermodynamics and theoretical calculations to interpreting the spectroscopic properties of trivalent-lanthanide coordination compounds

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Lanthanide-based coordination compounds exhibit a wide range of compelling applications in luminescent materials, spanning from biomedicine [1] to technologically oriented fields [2]. A molecular-level understanding of the processes governing the optical response of a luminescent material is essential for interpreting and rationalizing the behavior of optical sensors. In this contribution, we present representative studies in which thermodynamic analysis and theoretical simulations (DFT calculations) jointly provide key insights into the optical and chiroptical properties of Tb(III)- [3], Eu- [4–6], and Yb-based complexes [7], all of which are promising candidates for optical or chiroptical probes in biomedical and technological applications (Fig.1).

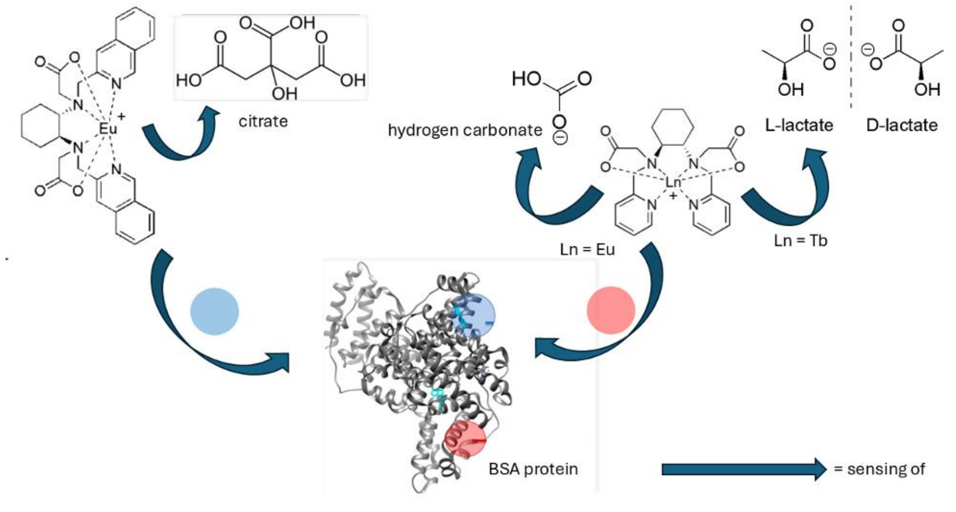

Figure 1. Graphical overview of the systems discussed in this contribution

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Zinc detection using responsive MRI contrast agents: from rational design to in vivo applications

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Magnetic Resonance Imaging (MRI) has been devoted for a long time to obtaining anatomical and functional images. Recently, emerging applications in molecular imaging seek information at the molecular level, looking at the biochemical or physiological abnormalities underlying the diseases. Unlike anatomic imaging, molecular imaging always requires an imaging probe that is selectively responsive to the parameter to detect. Gd^{3+}-based contrast agents are particularly well-adapted for this purpose and most often the changes on the efficacy (relaxivity) are based on changes of the hydration number and/or rotational dynamics of the complexes; these two parameters being the easiest to be tailored by the chemist. Among the biomarkers of interest, Zinc is particularly relevant. It is an essential transition metal ion and its concentration is tightly regulated. Disturbances in its homeostasis is implicated in various diseases such as neurodegenerative diseases (Alzheimer, Parkinson), diabetes, or cancers (prostate, pancreas and breast) [1]. Therefore, monitoring zinc *in vivo* by non-invasive technique such as MRI is important in biomedical research to better understand its biological role, and to provide earlier diagnosis for specific pathologies [2].

We will present the rational design of small molecular Gd^{3+}-based responsive contrast agents to which a cation complexing unit has been added through a linker [3]. We will show how structural modifications can affect the response of the contrast agent, help to understand the behavior of these systems [4], and ultimately allows the design of highly sensitive contrast agents. Challenges in terms of selectivity, affinity, and quantification [5] will be discussed, as well as in vivo results [6].

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Adsorption: Thinking beyond pollution remediation

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Over the last three decades, adsorption has attracted considerable attention from the scientific community. Early studies focused on the use of biomaterials—mainly of plant origin—to evaluate their basic adsorptive properties. Subsequently, research progressively expanded to include geomaterials and, more recently, a wide variety of nanoadsorbents and nanostructured materials. Throughout this evolution, the primary objective has been the removal of contaminants of diverse nature from aqueous solutions.

These studies have addressed a broad range of pollutants, including inorganic species—predominantly metallic cations, although anions have also been investigated—as well as organic compounds, ranging from dyes to biologically active molecules such as antibiotics and other pharmaceutical contaminants.

The efficiency of adsorption-based decontamination processes is largely governed by the pH of the medium and by the physicochemical characteristics of both the adsorbent and the target adsorbate. In the case of biomaterials, their intrinsic structural and chemical complexity introduces additional considerations, as it can promote the occurrence of redox processes during contaminant sequestration.

In many cases, enhancing adsorbent performance requires surface modification or functionalization, either through chemical treatments or by combination with other substances. This is particularly relevant for the removal of anionic species, which often presents significant challenges.

The development of strategies aimed at improving sorbent performance has opened new application niches for (bio)adsorption. In this context, the resulting materials, rather than becoming potentially hazardous wastes, can be valorized as functional products with added value and potential secondary applications. The rational design of sorbents with these objectives represents a further step towards the implementation of a circular economy, in contrast to the traditional linear economic model that still predominates in modern society.

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Targeted and suspect LC-HRMS strategies for screening multiclass micropollutants and their transformation products in environmental and food samples

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Food safety and water quality are intrinsically linked through environmental pathways that transfer micropollutants from aquatic ecosystems into the human food chain. Thousands of organic chemicals — including pesticides, pharmaceuticals, personal care products, PFAS, and other industrial substances — are released into surface waters via agricultural runoff, municipal discharges, and industrial effluents. These micropollutants can undergo environmental transformation into transformation products (TPs) that may exhibit greater toxicity, persistence, or mobility than parent compounds. Current regulatory frameworks predominantly target parent chemicals, leaving significant knowledge gaps regarding TPs and their behavior across the water-food continuum. Targeted [1-2] and suspect screening strategies [3-4] based on high-resolution mass spectrometry (HRMS) offer a powerful and comprehensive framework for the investigation of micropollutants, facilitating the detection, prioritization, and identification of a broad spectrum of chemical substances in complex matrices.

In this context, this study aimed to develop and apply integrated liquid chromatography coupled to Orbitrap high-resolution mass spectrometry (LC-HRMS) screening methodologies combining a wide-scope target method (≥ 350 compounds) and a suspect approach (≥ 2500 Compounds) to characterize multiclass micropollutants and their TPs in interconnected environmental water and food matrices. Aqueous samples were collected from river (Aliakmonas River basin) and wastewater treatment plants and agricultural water sources with direct food production linkages. Dual solid-phase extraction protocols (OASIS WAX and HLB cartridges) enabled comprehensive analyte recovery across diverse chemical classes. Analysis employed liquid chromatography coupled to Orbitrap high-resolution mass spectrometry. Screening strategies integrated targeted quantification of priority substances with suspect screening using an extensive database of >2500 compounds and TPs compiled from literature and laboratory-generated references. Food samples (peaches) were extracted by a QuEChERS-based sample preparation protocol and were analyzed by LC Orbitrap HRMS system. The combined targeted-suspect workflow successfully detected and identified multiple micropollutant classes and TPs in both water (Pharmaceuticals, PFAS, etc) and food-relevant samples (pesticides etc). Findings revealed contamination patterns reflecting agricultural and urban inputs, with several TPs detected at concentrations comparable to or exceeding parent compounds. This comprehensive LC-HRMS screening approach provides critical data on micropollutant occurrence and transformation across the water-food interface. Understanding contaminant fate through environmental compartments into food chains is essential for developing evidence-based management policies and protecting both ecosystem integrity and food safety.

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Metal–ligand coordination and supramolecular assemblies in luminescent Au(I) and Pt(II) complexes

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From luminescent materials to molecular sensors, chemistry provides powerful tools to manipulate and design matter at the smallest scale. A key strategy in modern materials science is the use of noncovalent interactions, that are subtle but fundamental forces that control how molecules self-assemble, recognize each other, and organize into functional structures. Inspired by nature, chemists use these forces to develop advanced materials with tuneable properties, particularly in sensing, luminescence, and supramolecular architectures.

In our research, we focus on gold(I) and platinum(II) complexes, two classes of metal-containing compounds that exhibit remarkable luminescent and supramolecular properties. Their behaviour is largely determined by the organic ligands coordinated to the metal, as well as the weak intra- and intermolecular interactions they can establish. Supramolecular interactions provide powerful tools to control molecular organization and tune material properties. In this context, noncovalent forces play a key role in modulating luminescence by governing how molecules assemble and interact.[1]

By tailoring the environment of the molecules and their resulting assemblies, we achieve precise control over their aggregation, supramolecular architecture, and resulting photophysical properties. These strategies enable the rational modulation of luminescence, from isolated molecular emitters to structured assemblies.

Such systems show strong potential as luminescent materials and molecular sensors, as well as in optoelectronic applications. In particular, we develop room-temperature phosphorescent emitters, sensors and singlet oxygen ($^1O_2$) photosensitizers, relevant for OLED technologies and light-driven processes.[2]

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ISMeC PRIZES LETURES

Harnessing solution thermodynamics to develop functional drug delivery platforms

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In the search for a strategy to overcome the intrinsic limitations of several drugs (low solubility, poor permeability, and short biological half-life), which can affect their efficacy and/or induce toxicity, the past decades have witnessed many efforts in developing nanocarriers to deliver many and varied classes of payloads [1]. However, the rational design of these systems still remains challenging, as it requires a quantitative understanding of the molecular recognition processes governing drug-carrier interactions. In particular, binding affinity plays a crucial role in determining drug loading and release, while its thermodynamic characterization provides fundamental insights into the mechanisms underlying complex formation [2,3].

Within this framework, solution thermodynamics emerges as a strategic tool to unravel the driving forces of the complexation processes and to establish predictive criteria for the design of functional systems (Figure 1). Accordingly, the detailed analysis of the equilibria occurring in solution represents a key strategy for designing and developing efficient and stimuli-responsive drug delivery platforms [3].

pH-responsive carriers were prepared by exploiting the non-covalent assembly of selected drugs (quercetin, Que, and methotrexate, MTX), pH-sensitive polymer (poly(acrylic acid)) and metal ions of biological interest (Cu^{2+}, Zn^{2+} and Co^{2+}). The detailed thermodynamic analysis, performed at 25 °C and physiological pH by UV-Vis and isothermal titration calorimetry (ITC), enabled the determination of species, stability constants and energetics of the multiple equilibria occurring in solution. This approach allowed the determination of the key parameters controlling assembly formation, ultimately enabling the optimization of drug loading and release. The systems were physicochemically characterized and their stability, pH-triggered release, and cytotoxicity properties confirmed their effective performance [3,4].

A similar approach was used to develop micellar nanocarriers based on amphiphilic calixarene derivatives. A polycationic choline-calix[4]arene micellar aggregate (CholCalix) was proposed as a supramolecular iodophore for iodine stabilization and delivery in aqueous medium. The interactions between iodine species and the amphiphilic calixarene in both micellar and monomeric forms were investigated by ITC at 25 °C in KI solution to determine the driving forces of the process [5]. Experiments involving polyvinylpyrrolidone-iodine (PVP-I) and polyvinylpyrrolidone (PVP) allowed us to assess the ability of the CholCalix micelles to stabilize PVP-I solution and clarify the role of the polymeric scaffold. Spectroscopic and physicochemical characterization supported the formation of stable nanosized aggregates and elucidated the complexation process in solution. Retention and release studies demonstrated the ability of the supramolecular micelle to enhance iodine stability and modulate its availability, highlighting its potential as an efficient nanocarrier for antiseptic applications [3,5].

In addition, a *p*-sulfonato-calix[4]arene-O-hexyl ether (SC_4OEs) micellar aggregate was investigated as a carrier for quercetin (Que) and its zinc(II) complex (ZnQue) with the aim of enhancing kinetic stability and antioxidant efficacy. Binding equilibria of Que or ZnQue with the calixarene in the micellar, monomeric or non-amphiphilic forms were studied by ITC in aqueous solution at 25 °C and pH 7.4 [4]. NMR experiments allowed the identification of the main functional groups involved in the binding events. Kinetic stability studies were performed to assess the ability of the micellar systems to increase the half-life of Que and ZnQue; antioxidant assays enabled to evaluate the effect of the micellar formulation on the radical scavenging activity of both species.

Overall, this work highlights the central role of solution thermodynamics in the development of nanocarriers able to stabilize and delivery bioactive compounds.

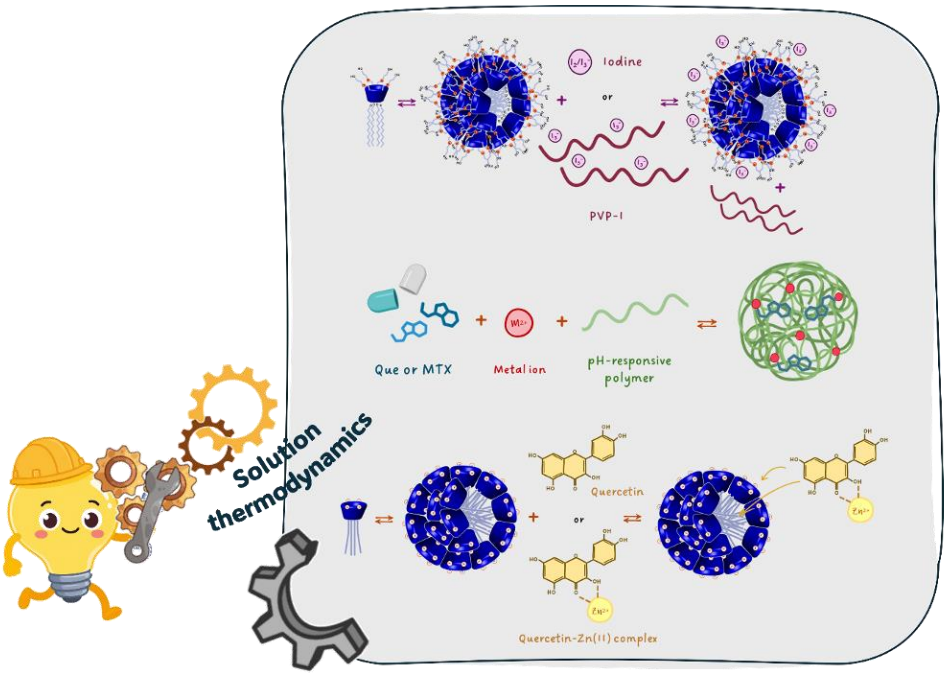

Figure 1. Sketch of the functional nanocarriers developed in this study using a solution thermodynamics based approach.

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Unveiling chemical speciation of vanadium(IV/V) / 8-hydroxyquinoline-2-carboxylic acid system in aqueous solution

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The coordination chemistry of 8-hydroxyquinoline derivatives has attracted increasing attention due to their prominent metal-chelating properties and their implications in medicinal and bioinorganic chemistry. Among these ligands, 8-hydroxyquinoline-2-carboxylic acid (8-HQA) has emerged as a biologically relevant compound [1], whose implications are strongly influenced by its interaction with metal ions [2]. Through the biologically relevant metals, vanadium represents an element which is known for its diverse biological roles and pharmacological potentials. In this context, vanadium(IV) and vanadium(V) are the predominant oxidation states under physiological conditions [3] and represents an interesting target for 8-HQA coordination.

In this work, the chemical speciation of oxidovanadium(IV) and dioxidovanadium(V) ions in the presence of 8-HQA was investigated in aqueous solution at $T = 298.2$ K, $I = 0.20$ $\mathrm{mol{\cdot}dm^{-3}}$ KCl. A multi-technique approach was adopted, combining H^+-ISE potentiometry and UV-Vis spectrophotometry, together with Electron Spin Resonance (ESR), Nuclear Magnetic Resonance (NMR), Electrospray Ionization Mass Spectrometry (ESI-MS) and Density Functional Theory (DFT) calculations.

Speciation studies reveal that both oxidation states of vanadium form monoligated complexes with 8-HQA which are stable in mildly acidic conditions. In particular, oxidovanadium(IV) predominantly forms the neutral complex $V^{IV}O$(8-hqa) in the range $3 < pH < 6$, with minor contributions from protonated and hydrolyzed species. However, the stability of $V^{IV}O^{2+}$ complexes is strongly affected by redox processes: as pH increases, oxidovanadium(IV) undergoes rapid oxidation to vanadium(V). Under strictly anaerobic conditions, $V^{IV}O^{2+}$ complexation can persist up to alkaline pH, highlighting the critical role of oxygen in controlling redox speciation of the system.

Dioxidovanadium(V) forms a highly stable $[VO_2(\text{8-hqa})]^-$ complex, which dominates the speciation over the range $2 < pH < 7$, as confirmed by potentiometric, spectrophotometric, and NMR data. At higher pH, this species gradually converts to hydrolytic forms. Mass spectra measurements further support the predominance of the monoligated complex.

ESR and DFT investigations suggest that 8-HQA coordinates oxidovanadium(IV) mainly as bidentate ligand involving the phenolic oxygen and pyridinic nitrogen, although tridentate coordination cannot be completely excluded. On the other hand, DFT calculations indicate a preference for tridentate binding in the case of dioxidovanadium(V) complexes.

The sequestering ability of 8-HQA toward oxidovanadium(IV) and dioxidovanadium(V) was compared with that toward other metal ions [4], providing insight into its selectivity and binding preferences. Additionally, preliminary interaction studies with biological targets, including DNA and bovine serum albumin (BSA) were performed to evaluate the behavior of the metal-ligand system in biologically relevant environments.

Overall, this study provides a comprehensive thermodynamic and structural description of the vanadium(IV/V) and 8-HQA system in aqueous solution, highlighting the interplay between coordination and redox behavior as a function of pH. These findings contribute to a deeper understanding of the chemical behavior of vanadium in biologically and environmentally relevant conditions in combination with 8-hydroquinoline derivatives.

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ORAL COMMUNICATIONS

Polyamino-polyphosphonates: Determination of stability constants in the metal ion – NTMP / EDTMP / DTPMP systems

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Polyamino-polyphosphonates are important industrial compounds which are used in water treatment applications as scale or corrosion inhibitors as well as water softening agents. Generally, they are derivatives of linear/cyclic polyamines where all primary/secondary amine groups are fully substituted with $–CH_2PO_3H_2$ groups. The most commonly used compounds are analogues of linear polyamino-polycarboxylates where the carboxylate groups are replaced with the phosphonate groups, *i.e.* NTA / NTMP, EDTA / EDTMP or DTPA / DTPMP (Figure 1). All these compounds behave as rather hard ligands and they are strong chelators for almost any metal ions. Despite their wide utilization in industry, their solution chemistry is not well understood, and data in literature are not fully consistent and only some of them could be considered as reliable [1–4].

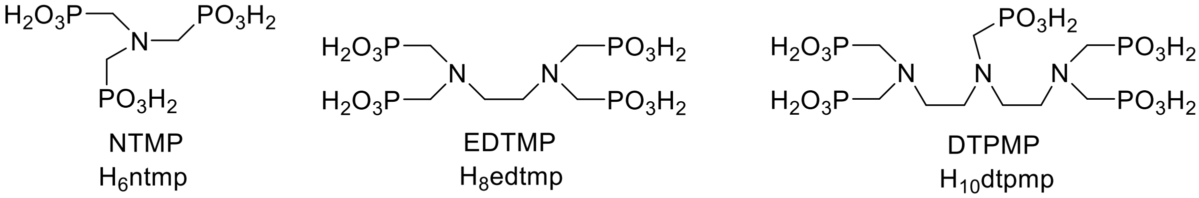

Figure 1. Structures of NTMP, EDTMP and DTPMP.

Stability constants of complexes of polyamino-polyphosphonates are an example of data which are rather unreliable in literature. It is given (*i*) by problems with purity of the ligands originating from their syntheses producing a lot of hardly removeable by-products; industry generally utilizes products which have purity ~90% or less. (*ii*) The protonated complexes with overall charge zero are often insoluble in water. (*iii*) Protonation constants are spread throughout the entire pH range, and the last deprotonation often takes place at pH > 13. And (*iv*) a number of complex species can be present in a chemical model. It is also connected with a possible formation of soluble coordination polymers. These problems can be only partially solved. In this contribution, we will show how we dealt with these issues and we present our results on equilibrium constants of NTMP, EDTMP and DTPMP, and their complexes with Na(I), K(I) and divalent metal ions.

Titration were run with $(Me_4N)Cl$ as a background electrolyte and $(Me_4N)OH$ and/or HCl as titrant. Thus, influence of a weak complexation of alkali metal ions on the equilibrium constants was removed. To get the equilibrium constants, potentiometric, NMR and spectrophotometric titrations had to be combined. As kinetics of precipitation of complexes, if going from alkaline to acidic solutions, is slow, the problem with insolubility of protonated complexes was partially overcome with potentiometric titrations starting in alkaline solutions.

The protonation constants of the ligands are spread throughout water pH range with logK_a from about 1 up to 14. The first protonation constants have to be determined by NMR titrations. The protonation sequence of the ligands follows that of polyamino-polycarboxylate analogues. The first/second/third protonations take place on the amine groups in NTMP/EDTMP/DTPMP followed by monoprotonations of each phosphonate group; a constant corresponding to the second protonation of a phosphonate group was found only for NTMP.

Chemical models for the metal ion-ligand systems involve a lot of species as protonated, mono-/dinuclear and hydroxide complexes have to be considered (Figure 2). The K_{ML} stability constants are generally higher than those of the carboxylate analogues as the overall basicity of the polyamino-polyphosphonates is significantly higher. For most of the complexes, protonated species have the protons bound on (coordinated) phosphonate groups. The K_{M2L} stability constants are significantly smaller than the K_{ML} stability constants and they are becoming more important in the order NTMP < EDTMP < DTPMP as it is expected due to the increasing number of donor atoms.

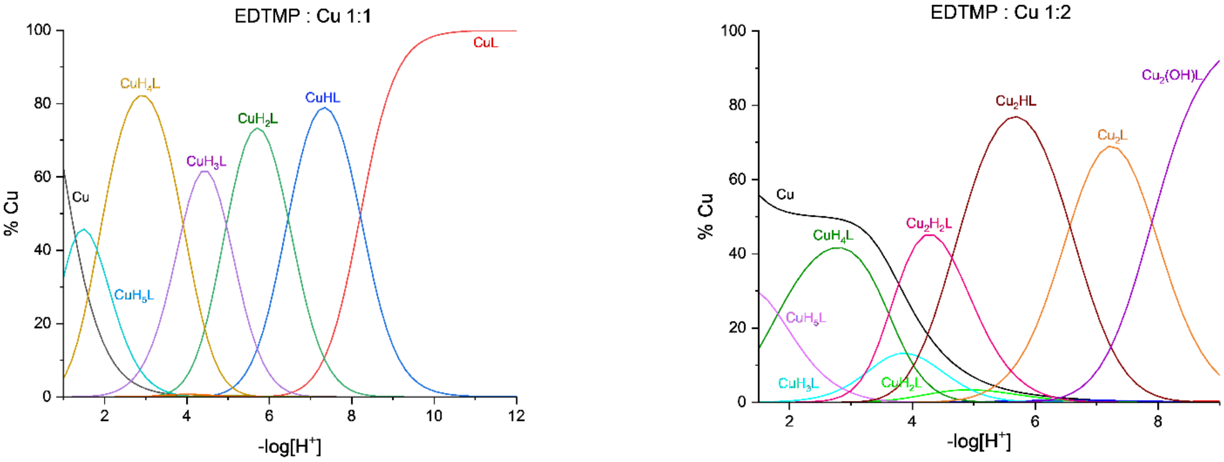

Figure 2. Distribution diagrams for Cu(II)-EDTMP systems (L:Cu = 1:1 and 1:2).

The data will be used by industry involved in utilization of these chelator to model speciation of the compounds in water and to estimate a fate of the compounds in environment.

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Selective Recognition and Quantification of Hard-Soft Acid-Base Properties of Anions from the Primary and Secondary Sphere Interactions with Cationic Zn^{II} and Cu^{II} Tripodal Amine-Benzene CF_3 Ligands

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The interactions of the outer secondary coordination sphere of metal complexes with either ionic or neutral species are of significant scientific interest due to their critical role in the catalytic reactions of metal complexes or metal proteins and the activation of small molecules. While the strength of X-H---A interactions is associated with the hardness or softness of X, the interpretation of hydrogen bonds is predicated on the strength of acidity and basicity, rather than being situated within the framework of the Hard-Soft Acid-Base (HSAB) theory.

This study focuses on the synthesis and characterization of CuII and ZnII complexes bearing a tripodal amine ligand functionalized with trifluoromethyl groups tris(2-((2-(trifluoromethyl)benzyl)amino)ethyl)amine (TFMBA). This ligand design is inspired by metalloprotein active sites, providing a nitrogen-rich donor environment with an accessible coordination site for anion binding. The incorporation of $–CF_3$ groups it enhances the acidity of proximal C–H bonds through the strong electron-withdrawing effect of fluorine, promoting potent C–H···A hydrogen bonding crucial for outer-sphere anion interactions, and enables sensitive monitoring of coordination dynamics via 19F NMR spectroscopy.

1H and 19F NMR spectroscopy, electrochemical methods, UV-Vis spectroscopy, X-ray crystallography and theoretical calculations were employed to elucidate the nature and consequences of secondary sphere hydrogen bonding of these positive charged metal complexes with the counter anions. ZnII and CuII ions exhibit a clear preference for coordinating hard anions such as fluoride and nitrate within the primary sphere, consistent with HSAB principles. In contrast, softer anions, including iodide and sulfite, engage more strongly through secondary sphere interactions, predominantly via C–H···A hydrogen bonds. The distinction extends the HSAB theory beyond covalent primary coordination, underscoring the importance of secondary sphere effects in the selective recognition of anions. Moreover, electrochemical studies reveal that secondary sphere interactions affect the redox potentials centered on metal ions, indicating their functional relevance to the activity mechanisms of proteins and potential applications in sensing technologies. The capability to discriminate and quantify anions based on their hardness or softness through the integration of primary and secondary sphere coordination presents promising analytical opportunities for complex solution environments.

N/O Macrocycles for Pd(II) Recovery and Catalysis: A Hard-Soft Balance of Selectivity and Robustness

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Selectivity in metal recovery remains a significant challenge in the primary production of metals, particularly the lanthanides. While the problem is generally less severe for transition metals, the rising demand of technologically critical elements (TCEs), and especially so-called platinum group metals (PGMs), have driven the market to significantly value the secondary production, i.e. recycling. Metal recovery from waste or wastewater offers additional challenges due to the simultaneous presence of different metals, the complexity of real matrices, and sometimes the dilution of the system. At the same time, secondary production could offer some advantages. Wastewater, generally produced in high amounts by metallurgic and electroplating industry, is generally a regulated hazardous waste, which requires costly dedicated treatments before its re-introduction in the environment. If one could envisage the production of a high-value TCE- or PGM-containing useful product and the way to source the TCE/PGM directly from wastewater, then the pairing of waste treatment/disposal with a new production cycle could boost significantly the overall sustainability of the process under a circular economic perspective.

As an example, PGM metal cations could be directly incorporated into a catalyst [1,2]. To pursue this goal, we modified the surface of multi-walled carbon nanotubes by supramolecular anchorage of ligands possessing 4-donors-bearing macrocycles. In this way it is possible to immobilize PGM cations as their supported complexes at the surface of a material. As a testing ground for the effectiveness of the catalysts, we selected the oxygen reduction reaction in alkaline medium: optimization of this electrodic process is a currently a key challenge in fuel cell technology.

Under a typical metallurgical setting, wastewater or washing water may contain PGM cations, generally active towards ORR (in our case Pd(II)), but also other metal cations: most are typically first-transition divalent cations (Co(II), Ni(II), Cu(II), Zn(II)), but also some heavier cations (e.g. Cd(II)) can be present. Both from a recycling viewpoint and a catalyst performance perspective, selective coordination of the PGM cation would be strongly desirable. In order to achieve this selectivity, we decided to play with the hard/soft characteristic of 12-memebred macrocyclic ligands by using N/O mixed donors (**Figure 1**).

All ligands were characterized for what concerns their acid/base behaviour (potentiometry, UV-Vis) and their metal binding ability (potentiometry, Cu(II) as a test cation, UV-Vis data for both Cu(II) and Pd(II)). In all cases, Cu(II) was found to give rise to 1:1 complexes only. Crystallographic (XRD) data also helped in visualizing the coordination details for some of the complexes. These data, together with general thermodynamics trend (e.g. Irwing-Williams series) provide the basis for an estimation/modeling of selectivity patterns. N-donors favour Cu(II) coordination and are likewise expected to favour Pd(II) coordination.

Then, real competition experiments, in which an equivalent of ligand (immobilized onto carbon nanotubes) is put in contact with a solution containing 1 eq of each metal cation (Pd(II), Co(II), Ni(II), Cu(II), Zn(II), Cd(II)), were performed. Contrary to predictions, the N_4 and the N_3O ligands, in principle more coordinating towards Pd(II) than the N_2O_2 one, were found to be unable to extract Pd(II) selectively, as the formation of binuclear Pd(II)/Cu(II) complexes was observed. On the contrary, the less coordinating N_2O_2 was able to selectively extract Pd(II).

Lastly, ORR reaction electrochemical tests were run within a half/cell rotating ring disk electrode experimental setup. Electrochemistry data show that, at the working pH (13, KOH 0.1 M), the Pd(N_2O_2) complex is unstable, leading to demetallation and loss of catalytic activity. Conversely, the less selective N_3O and N_4 macrocycles, giving more robust complexes, are able to retain the metal, with the latter one resulting the most catalytically active.

The key take home messages are about the fine balance of thermodynamic instability, in this case conferring selectivity to the binding, and robustness of the final catalyst. Results demand caution in transferring coordination models/speciation obtained under controlled experimental settings to real life complex matrices, as further complications may arise.

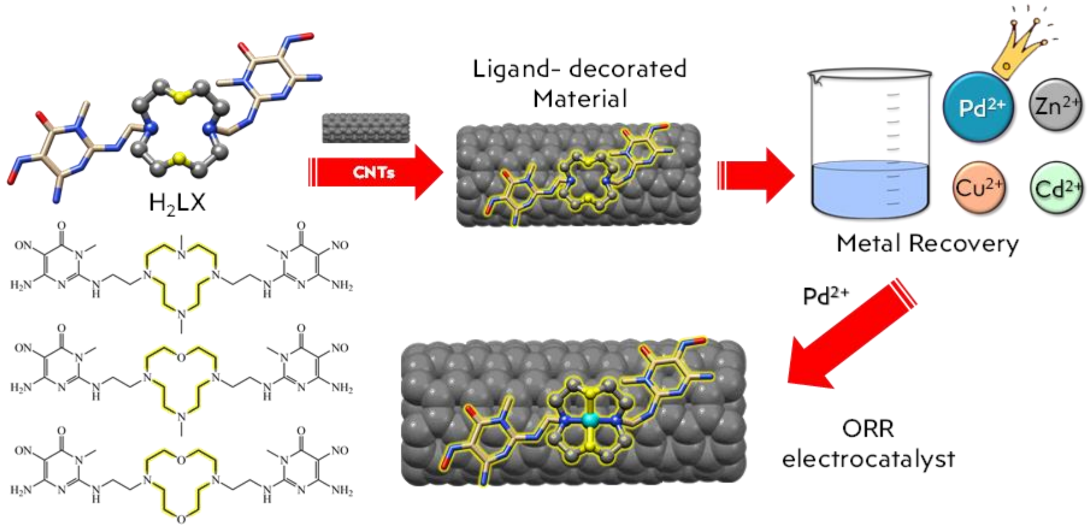

Figure 1. The series of H_2LX studied ligands, possessing a different set of N/O mixed donors, spanning from N_4 to N_2O_2. A general outlook of the work is also provided.

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Coordination of Sc(III) by pyridinecarboxylates: implications for picolinate-based chelator design

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Scandium isotopes are attracting growing interest in nuclear medicine, particularly for theranostic applications combining diagnosis and therapy. Among them, ^{43}Sc and ^{44}Sc are positron emitters suitable for PET imaging, with half-lives (~4 h) well matched to the pharmacokinetics of small biologics such as peptides and antibody fragments. Notably, ^{43}Sc emits lower-energy positrons than ^{68}Ga, resulting in potentially enabling improved imaging resolution. In contrast, ^{47}Sc is a β^- emitter ($t_1/_2 \approx 3.35$ d) that represents an attractive therapeutic counterpart, while its low-energy γ emission also allows SPECT imaging [1–3].

Despite these advantages, the development of efficient chelators for Sc(III) remains challenging. As a small, highly charged hard Lewis acid, Sc^{3+} strongly favors oxygen donor atoms and typically forms octahedral complexes with limited coordination flexibility compared to larger Ln^{3+} ions. Although macrocyclic ligands such as NOTA and DOTA can form stable complexes, their complexation kinetics are slow at near-room temperature and often require heating to 90–95 °C, which restricts their applicability to temperature-sensitive biomolecules. Moreover, rapid complexation is essential for short-lived isotopes such as ^{44}Sc.

Ongoing research focuses on optimizing chelators [3-5]. In this context, we investigate the complexation of Sc(III) with simple pyridinecarboxylic acids (Figure 1) in acidic aqueous media (pH-controlled conditions) to suppress hydrolysis, as model systems to evaluate the relevance of pyridinecarboxylate motifs for Sc(III) coordination. These ligands, combining carboxylate (O) and pyridine (N) donor atoms, constitute simple models of such coordination motifs. Affinity capillary electrophoresis (ACE) was employed to determine speciation and stability constants, taking advantage of its suitability for labile systems [6,7]. In parallel, density functional theory (DFT) calculations were performed to elucidate the binding modes of the complexes.

Both experimental and theoretical results reveal a marked affinity of Sc(III) for picolinic acid, emphasizing the favorable coordination properties of picolinate-type coordination modes. These findings provide new insight into the coordination chemistry of Sc(III) with simple ligands and suggest that picolinate-based motifs could serve as valuable building blocks for the future design of alternative chelators to DOTA for scandium theranostic applications.

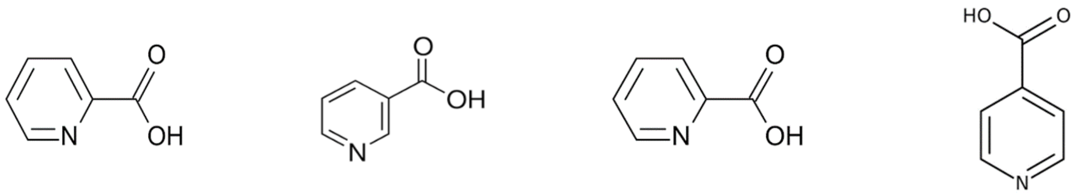

Figure 1: Structural formulas of the studied pyridinecarboxylic acids: picolinic, nicotinic, and isonicotinic acids.

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Thermodynamic Insights into Pb^{2+} Chelators for $^{212/203}Pb$ complexation with acyclic ligands

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This work aims to unravel the $[^{203}Pb]Pb^{2+}$ radiolabeling behavior of two hexadentate ligands by means of a through potentiometric and spectroscopic (UV-Vis and NMR) thermodynamic characterization.

H_2bpcd [1] and NH_2bpcd [**Fig. 1**] - *N_4O_2*-type acyclic chelators incorporating a “rigid” cyclohexane ring - were designed for the complexation of the emerging theranostic pair $^{212/203}Pb$. The gold standard macrocyclic ligand that is mostly used in nuclear medicine, namely 1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetic acid (DOTA), shows limited performances with Pb^{2+}, since it suffers from acid-mediated hydrolysis and little affinity for the daughter radionuclide ^{212}Bi produced during the radioactive decay of ^{212}Pb. Although some improvements have been achieved with 2,2,2,2-(1,4,7,10-tetraazacyclododecane-1,4,7,10-tetraacetamide (TCMC), the DOTA amide derivative, ^{212}Bi retention remains an issue [2,3].

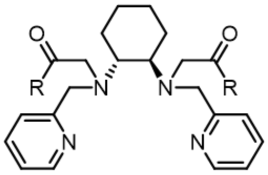

*Figure 1. Structure of the investigated DACH-based ligands. R = OH (**H_2bpcd**); NH_2 (**NH_2bpcd**).*

Both H_2bpcd and NH_2bpcd combine pyridine and carboxylate/carboxamide donor groups, which have been only marginally explored for $[^{212/203}Pb]Pb^{2+}$ coordination, particularly on acyclic systems.

$[^{203}Pb]Pb^{2+}$ radiolabeling experiments showed that only H_2bpcd is able to incorporate the radiometal (RCY% > 95%, [H_2bpcd] = 10^{-5} M, pH 6, 15 min, RT/80°C) while NH_2bpcd showed poor radiolabeling efficiency.

To elucidate this behavior, NMR complexation studies with $^{nat}Pb^{2+}$ were carried out. Both ligands demonstrated to have good affinity for the metal ion, revealing rapid complex formation and high stability in acidic conditions (pH ~1), which is a very good result for acyclic ligands. However, in presence of equimolar amount of $^{nat}Pb^{2+}$, the two ligands differ in the isomerization profiles. Indeed, as shown by ^1H NMR and confirmed by ^{207}Pb NMR, H_2bpcd forms one predominant species in solution, while NH_2bpcd originates two isomers.

Detailed thermodynamic studies were performed combining potentiometric, UV-Vis and NMR pH-titrations. The results demonstrated a significantly higher thermodynamic stability of H_2bpcd compared to NH_2bpcd, as shown by the pPb^{2+} values ($-\log[Pb^{2+}]_{free}$): 15.9 vs. 5.2), Although macrocyclic chelators such as DOTA (pPb^{2+} = 20 [2]) and TCMC (pPb^{2+} > 19 [3]) set the upper limit for Pb^{2+} affinity, H_2bpcd establishes a new benchmark among acyclic ligands, significantly exceeding DTPAm (pPb^{2+} = 9.7 [4]) and H_2ampa (pPb^{2+} = 14.8 [5]).

In summary, pyridine–carboxylate donor combinations emerge as a powerful design strategy for Pb^{2+} coordination in acyclic chelators, identifying H_2bpcd as a particularly strong platform for advancing $[^{212}/^{203}Pb]Pb$ radiopharmaceutical chemistry.

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From Speciation to Thermodynamic Stability: A Rigid HBED Analogue Controls Isomerization in Gallium-68 Complexes

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The hexadentate acyclic ligand N,N′-di(2-hydroxybenzyl)-(1,2-cyclohexanediamine)-N,N′-diacetic acid (HBCD) was designed to improve the coordination chemistry of the positron-emitting radiometal ^{68}Ga by introducing rigidity into the ligand backbone. Specifically, the flexible ethylenediamine spacer of the parent HBED ligand [1] was replaced with a cyclohexanediamine (DACH) scaffold to limit the formation of multiple coordination isomers, a well-known issue of Ga^{3+}–HBED systems that can impact *in vivo* performances [2].

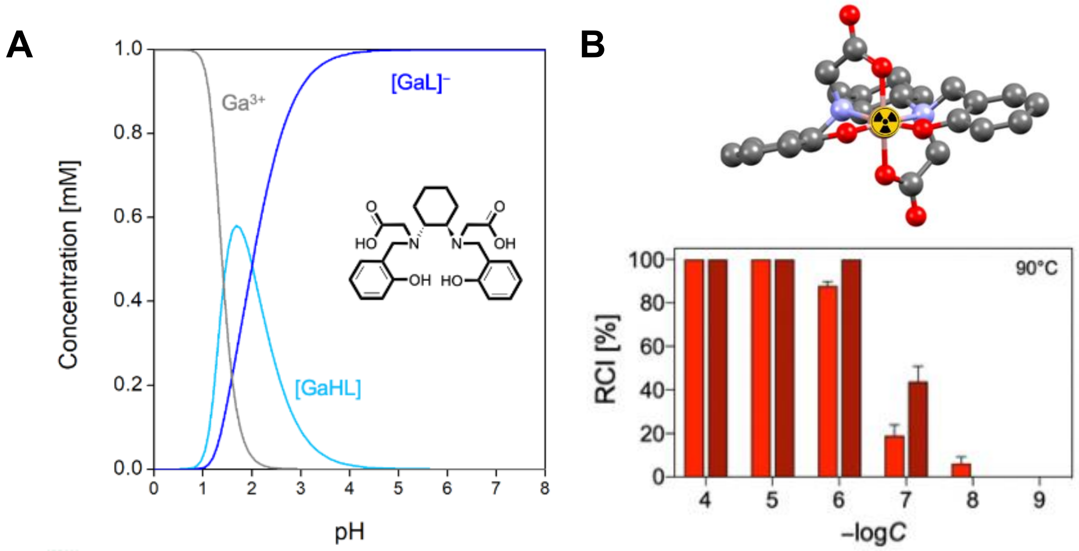

Figure 1. *(**A**) Distribution diagram of Ga^{3+}-HBCD (C_{Ga} = C_L = 1 mM); (**B**) DFT-optimized structure of 6-coordinated cis-trans $[GaL]^-$ (top) and concentration-time-dependent $[^{68}Ga]Ga^{3+}$ radiochemical incorporations (RCIs) of HBCD at 90°C and pH 4.5.*

Here, we report the synthesis of HBCD and a comprehensive investigation of its solution behavior, including protonation equilibria, Ga^{3+} complexation, radiolabeling with generator-produced $[^{68}Ga]Ga^{3+}$, and stability under physiological conditions. Speciation studies, carried out by means of UV-Vis/NMR spectroscopy and MS spectrometry, reveal that the rigid DACH framework directs the formation of a single, well-defined hexacoordinated Ga^{3+} complex, in contrast to the isomeric mixtures observed for HBED [2]. At physiological pH (7.4), the predominant species is $[GaL]^-$ (**Fig. 1A**), with thermodynamic stability comparable to that of Ga^{3+}–HBED and significantly exceeding that of the clinically workhorse DOTA chelator.

HBCD efficiently coordinates $[^{68}Ga]Ga^{3+}$ under highly diluted radiochemical conditions (C_L = 10^{-6} M, 90 °C, pH 4.5–7) (**Fig. 1B**), and the resulting complex $[^{68}Ga][Ga(HBCD)]^-$ exhibits remarkable stability in biological media.

Overall, these results demonstrate that ligand rigidification is an effective strategy to control solution speciation and suppress isomerization equilibria in Ga^{3+} complexes. HBCD thus emerges as a promising platform for the development of next-generation ^{68}Ga-based radiopharmaceuticals.

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Impact of carboxylate substitution by pyridine/imidazole in pyridine-based complexes: stability, dynamics, and relaxation properties of Ln^{3+} complexes

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Lanthanide (Ln) compounds have been widely utilized in medicine, material chemistry, and biosciences.[1] Their medical relevance is primarily due to the extensive use of Gd^{3+} chelates as contrast agents in MRI. Since Ln^{3+} ions are non-endogenous and share a similar radius with Ca^{2+}, they are inherently toxic and require encapsulation within complexes that are both thermodynamically stable and kinetically inert.[2] Understanding the relationship between structure and efficacy is crucial for developing improved contrast agents.

This study focuses on pyridine-based polyaminocarboxylate ligands, which form bishydrated Ln^{3+} complexes. These ligands provide a versatile framework for designing optimized contrast agents.[3-5] Four ligands were synthesized (Fig. 1), and their corresponding Ln^{3+} complexes were systematically characterized in terms of thermodynamic stability, kinetic behavior, structural features, and relaxation properties.

Stability constants and protonation equilibria were determined via pH potentiometry, revealing that replacing a single carboxylate with pyridine or imidazole had minimal impact on stability, while the substitution of two carboxylates significantly reduced stability.[6] Structural analysis via NMR, luminescence spectroscopy, and DFT calculations confirmed the coordination of pyridine and imidazole pendant arms. Gd^{3+} complexes displayed high relaxivity values (r_1 = 8.25 and 7.97 mM^{-1}.s^{-1} at 60 MHz and 25 °C for GdImPy and GdPyPy, respectively), attributed to their bishydrated nature. Variable-temperature ^{17}O NMR and NMRD experiments provided further insights into their relaxation properties, revealing a notably faster water exchange rate in GdImPy compared to GdPyPy, likely due to steric effects near the Ln^{3+} center.

These findings provide valuable insights for the future design of multimodal or responsive MRI contrast agents.

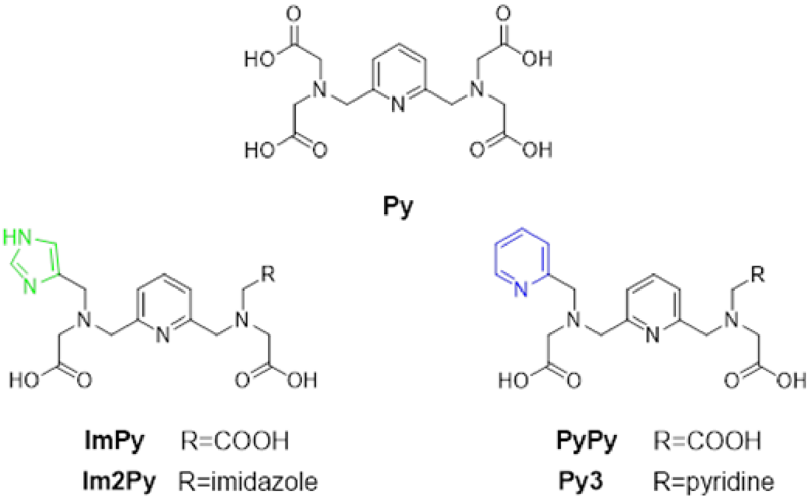

Figure 1. Chemical structure of the discussed ligands.

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Acknowledgments

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Chiral NIR-emitting Yb(III) complex: a promising water-soluble optical probe

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Chiroptical properties of Ln(III)-based complexes make these compounds suitable for being used in different fields, such as optical materials [1] or biological applications [2].

Circularly polarized luminescence stemming from water soluble Ln(III) complexes [3] has been broadly used for biological applications, even though its extension in the NIR spectral region is still poorly developed when compared with the visible range [4].

Particularly important in this field of application is the high thermodynamic stability of the species, indeed, many examples in the literature report the presence of highly stable macrocyclic-based complexes[5].

In this contribution, the synthesis, the thermodynamic and the spectroscopic characterizations, including the study of the chiroptical activity, of the anionic [Yb(cddadox)]$^-$ complex (Figure 1), will be discussed. Interestingly, the presence of the chiral and rigid DACH ring contributes to ensure both a very high thermodynamic stability and circularly polarized luminescence activity at 960-1010 nm.

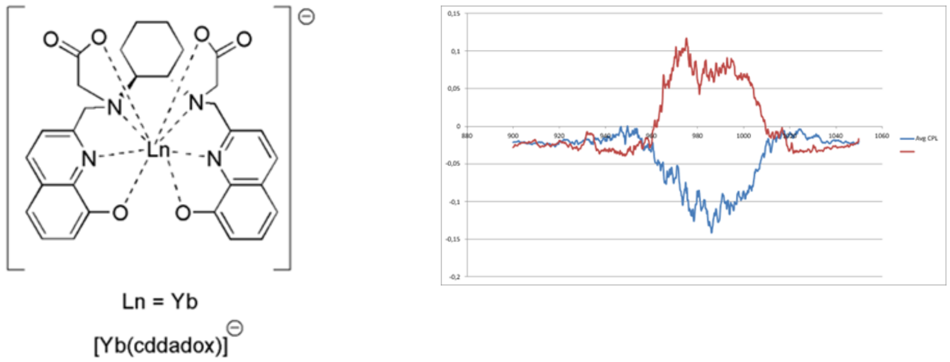

Figure 1. Molecular structure of the Yb(III)-based complex discussed in this contribution (left) and CPL spectra of the two enantiomeric complexes (right)

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Unravelling shifts in DOM ion-binding dynamics across the land ocean interface

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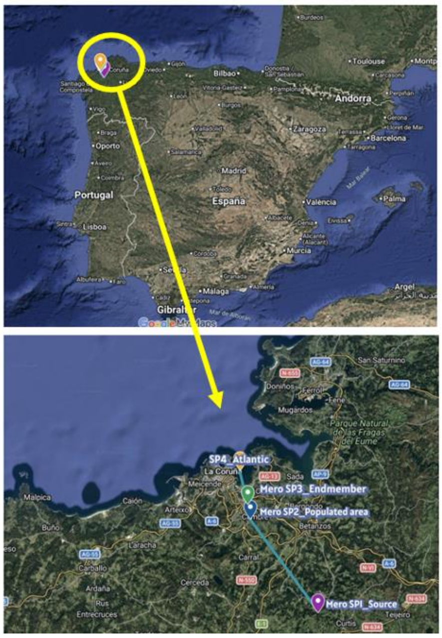
The exchange of carbon between the ocean and the atmosphere is regulated by the oceanic carbonate system. The ocean functions as a major reservoir, storing CO_2 at depth in both organic and inorganic forms. The capacity of the ocean to absorb and retain atmospheric CO_2 is largely governed by the interactions among chemical, biological, and physical processes. Dissolved organic matter (DOM) represents a key component of this system and serves as a bioactive carbon reservoir [1]. In addition to its role in long-term carbon storage, DOM supports marine ecosystems and modulates metal cycling, which is critical for primary production and agricultural productivity. Furthermore, DOM can influence the transport, transformation, and ultimate fate of pollutants in the environment. Dissolved organic matter (DOM) encompasses a wide array of structurally complex organic compounds, typically defined by a size fraction below 0.2 µm. Although marine dissolved organic matter (DOM) exhibits well-defined acid–base properties arising from the abundance of carboxylic and phenolic functional groups, it displays considerable chemical heterogeneity [2,3]. The composition of DOM is expected to control both the strength and distribution of its intrinsic ion-binding affinities, which are arranged across a continuum of values referred to as affinity spectra. These spectra are indicative of the presence of diverse organic acid groups that drive the complex binding behaviour of DOM. Furthermore, the total proton-binding capacity reflects the maximum number of binding sites that can be occupied by other chemical species competing with protons. Consequently, examining proton binding represents a fundamental initial step in elucidating the mechanisms through which DOM interacts with nutrients, metals, and pollutants.

In this study, we investigated the variability of ion-binding properties in DOM collected from the Mero River basin (northwest Spain), including its estuary and discharge into the Atlantic Ocean. Three sampling sites were chosen along the river to evaluate changes in DOM across the land–ocean transition zone. Seasonal variations in DOM concentration and related parameters were also examined. The integration of the non-ideal competitive adsorption (NICA) isotherm with the Donnan electrostatic model enabled the identification of shifts in DOM binding affinities. In addition, this approach allowed the derivation of a robust set of intrinsic binding parameters that are thermodynamically consistent and independent of specific sample conditions, supporting their use in projections of future environmental scenarios.



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Bergamot Pomace as a Biosorbent for Rare Earths: Outcomes of the Wastezilla Project

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This study summarizes the main outcomes of the two-year *Wastezilla* project, focused on the recovery of Rare Earth Elements (REEs) from aqueous systems using waste biomasses from the agri-food industry. In particular, bergamot (BP), olive (OP), and grape (GP) pomaces, as well as biochar derived from *Posidonia oceanica* residues (CP), were investigated as low-cost and sustainable biosorbents for Nd^{3+} and Dy^{3+} (and, for comparison, La^{3+}) under controlled conditions. Preliminarily, a comprehensive characterization of the materials by Attenuated Total Reflectance Fourier Transform Infrared spectroscopy (ATR FT-IR) and Scanning Electron Microscopy – Energy Dispersive X-Ray Spectroscopy (SEM-EDX) confirmed the presence of surface functional groups suitable for metal binding, and Ion Selective Electrode (ISE-H$^+$) potentiometry helped us in establishing desirable experimental conditions (pH ≈ 5) to study the sorption process [1]. Batch adsorption experiments showed that equilibrium is reached very quickly (~ 120 min) and that the sorption process is well described by a pseudo-second-order kinetic model and Langmuir isotherms. For the first time, isothermal titration calorimetry (ITC) was applied to directly determine the thermodynamic parameters of REE adsorption onto biomass [2]. Among the tested materials, water-pretreated bergamot pomace and H_3PO_4-activated biochar (ABCP) exhibited the highest adsorption capacities, with a general selectivity trend Dy^{3+} > Nd^{3+} > La^{3+}, an average maximum sorption capacity (q_{max}) of 0.45 mmol·g^{-1}, and good reusability over four adsorption/desorption cycles [2, 3].

The performance of bergamot pomace was further tested in a scaled-up scenario under dynamic conditions using column experiments with synthetic acid mine drainage (AMD) containing REEs and interfering ions. The AMD contained 27 metal cations: 16 REEs (excluding Sc) and 11 interfering ions (Ca^{2+}, Mg^{2+}, Mn^{2+}, Na$^+$, Zn^{2+}, Co^{2+}, Ni^{2+}, Sr^{2+}, Ge^{2+}, As^{3+}, Se^{2+}). Breakthrough curves (C/C_0 vs. pore volumes) revealed preferential retention of lanthanides, while sequential desorption with H_2SO_4 [4] enabled effective recovery and partial fractionation of light and heavy REEs with a concentration factor of ~ 3.

In parallel, bergamot pomace was also valorized as a precursor for the synthesis of carbon quantum dots (CQDs), whose photoluminescence properties of CQDs were exploited for sensing applications. Particle size evaluation and surface group analysis of CQDs was done through Transmission Electron Microscopy (TEM) and ATR-FTIR spectroscopy [5]. The obtained CQDs showed efficient fluorescence quenching in the presence of selected metal ions, including Nd^{3+} and Dy^{3+}, allowing the evaluation of binding interactions via Stern–Volmer analysis.

Finally, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), and Techno-Economic Assessment (TEA) highlighted the environmental and economic sustainability of the proposed approach. Overall, the results demonstrate the strong potential of bergamot pomace as a multifunctional platform for REE recovery and sensing, supporting circular economy strategies for critical raw materials.

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Horse hoof waste cleaning and heavy metals removal optimization merging chemometrics and speciation studies towards upcycling

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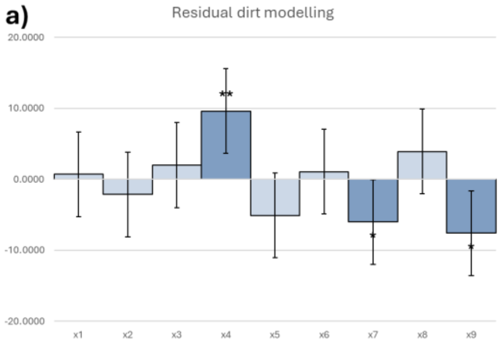
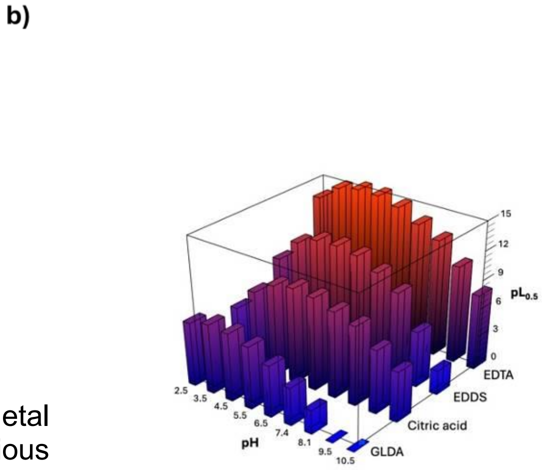
In recent years, the scientific community has shown a growing interest in upcycling strategies for keratin-rich non-edible animal tissues; mammalian sources such as wool, hair, nails, hooves, horns, and claws predominantly produce α-keratin, while bird feathers, quills, beaks, and fish or reptile scales yield β-keratin [1]. These materials, primarily by-products of slaughtering operations, are increasingly abundant, with keratin production from livestock alone reaching 11.82 million tons in 2020, mainly from chicken feathers and wool [2,3].

Among all keratinous wastes, horse hoof (HH) waste generated from shoeing and trimming offers a sustainable, traceable, and cruelty-free keratin source with distinct advantages [4-6]. Horse hoof trimmings represent a niche resource if compared to slaughtering-related waste, but their unique properties and potential applications should justify its targeted valorization. One of the main concerns limiting horse hoof upcycling is represented by heavy metals contamination because of shoeing practices: in fact, most of the papers claim to have selected only barefoot horses to avoid metal ions [6].

In this scenario, we want to investigate the possible path for a cleaning process of HH merging chemometrics and speciation studies to optimize the procedure, from raw HH acquisition to decontaminated materials upcycling. At the beginning, we apply Plackett-Burman Design for a first screening of the influent steps and parameters in a general 3-steps protocol: in this case, cleaning protocols efficiency is measured by quantifying the residual dirt (UV-Vis spectroscopy), ashes and metal content and the coefficients in Figure 1a depict the relative importance of each parameter. While the first two steps are easily defined by this preliminary evaluation, metals (*e.g.* Mn, Fe, Cu, Zn) decontamination requires further investigation.

Figure 1: Computed coefficients for Plackett-Burman Design, using residual dirt as response (a); Fe^{3+} sequestering abilities as $pL_{0.5}$ for EDTA, EDDS, citric acid and GLDA at various pH (b).





For this reason, the speciation of metal ions during cleaning is considered and various ligands were compared by means of their sequestering abilities in terms of $pL_{0.5}$ [7] (see Figure 1b for Fe), to identify the best compromises between metal chelation ability and sustainability (Figure 1b). This *in silico* investigation leads to the selection of 4 candidates, namely ethylenediaminetetraacetic acid (EDTA), citric acid, ethylenediaminedisuccinic acid (EDDS) and glutamate diacetate (GLDA), together with the definition of optimal working pH and ligands concentration.

The selected ligands are then tested for metals removal in horse hoof samples. After the first two steps, metal decontamination is performed by suspending HH powder in ligands solution in an ultrasonic bath three times. In search of a reliable comparison between different ligands, a batch of HH from different animals is sampled and used in all the cleaning procedures to assume a homogeneous starting material. Individual metals are quantified, using ICP-OES after microwave digestion (800W) with nitric acid and hydrogen peroxide, both in the solid material, before and after each cleaning step, and in the ligands solutions to validate *in silico* investigations and define optimal cleaning strategy (Figure 2a). 2- and 3-Way PCA are used for a easier and reliable comparison of cleaning efficiency associated with different ligands (Figure 2b).

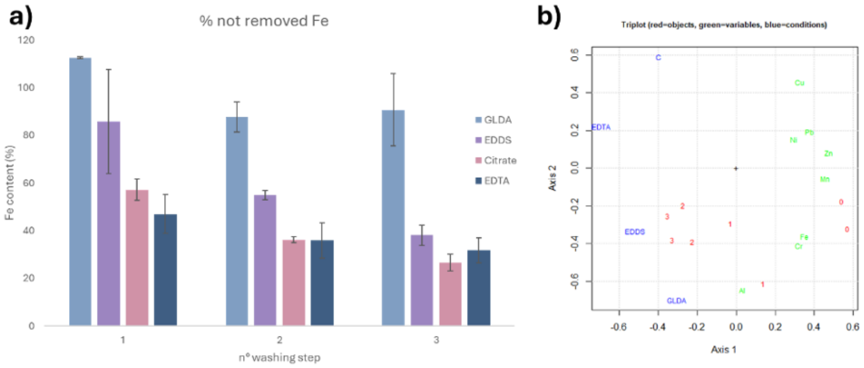


Figure 2: % not removed Fe after 1, 2 and 3 washing steps, compared to the starting HH (a); 3-WAY PCA triplot for cleaning efficiency comparison (b).

Lastly, the ligand and pH roles in decontamination are evaluated by comparing the efficiency of cleaning solutions at each pH in presence or absence of the ligand, applying multivariate data treatment to extract valuable information from the data.

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What Binds What? Metal–Ligand Interactions of MGDA and GLDA with Environmentally Relevant Cations: A Comprehensive Investigation

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The study of metal–ligand interactions in aqueous solution is fundamental for assessing the potential application of chelating agents as effective sequestration tools. These investigations are particularly relevant in industrial, agricultural, and environmental contexts, where the control of metal ion concentration and mobility is required. A reliable evaluation of sequestration efficiency depends on the accurate determination of thermodynamic parameters, especially the stability constants of the complexes formed in solutions. Aminopolycarboxylic ligands (APCs) are widely known for their strong affinity toward a broad range of metal ions [1] and are extensively employed in several applications, including water treatment, agriculture, and environmental remediation. In recent years, increasing attention has been directed toward more sustainable and biodegradable alternatives to conventional chelating agents. Among these, methylglycinediacetic acid (MGDA) and glutamic acid diacetic acid (GLDA) have emerged as promising candidates due to their favorable environmental profiles and significant complexing abilities. In this work, new experimental measurements by ISE-H^+ (glass electrode) potentiometric titrations have been performed to investigate the interaction of a series of metal cations (M^{2+}, M^{3+} and alkyltin (IV)) with both MGDA and GLDA in aqueous solution of potassium or sodium chloride at different temperatures. The results allow for a comprehensive description of the speciation of the systems over a wide pH range, highlighting differences in coordination strength and complex stability between the two ligands. Overall, both MGDA and GLDA demonstrate a strong ability to metal cations, although variations in their thermodynamic behavior suggest differences in their sequestration performance under specific conditions.

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Electrochemical Enzymatic Biosensing of Phenols in Deep Eutectic Solvents

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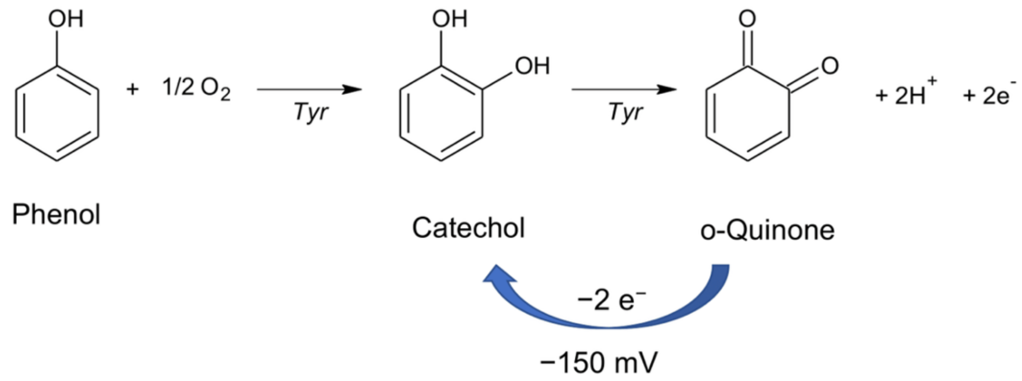
Volatile phenols and other phenolic compounds, including bisphenol A (BPA), are significant environmental and food contaminants due to their toxicity, endocrine-disrupting activity, and detrimental effects on product quality. [1] Consequently, the development of rapid, sensitive, and sustainable analytical methods for their detection is of growing importance. In this context, deep eutectic solvents (DESs) have emerged as promising green alternatives to conventional media because of their low volatility, tunable physicochemical properties, biocompatibility, and ability to enhance electrochemical and enzymatic processes. [2,3] In fact, several enzymes have been successfully employed in DES and “water-in-DES” systems to catalyze chemical reactions. [4]

Within this framework, we investigated the activity of tyrosinase in DES-based media [5] and subsequently developed electrochemical sensing platforms for the detection of phenolic compounds (4-ethylphenol, 4-ethylguaiacol and 4-vinylphenol). The direct electrochemical oxidation of phenolic compounds usually leads to polymeric product build-up on the electrode surface, so their previous oxidation to quinones catalyzed by tyrosinase (TYR) enzyme is here highlighted as alternative, as shown in Figure 1.

Figure 1: The oxidation process of phenol to ortho-quinone catalyzed by tyrosinase.



The gas-phase sensing device consists of a disposable screen-printed carbon electrode (SPCE) coupled with a porous paper support impregnated with tyrosinase and soaked with DES. This simple and low-cost set-up allows efficient confinement of the DES within the paper matrix while preserving the disposable nature of the platform. The resulting configuration operates as a highly sensitive membrane-free gas sensor, in which the analytical response is governed by the kinetics of the enzymatic reaction.

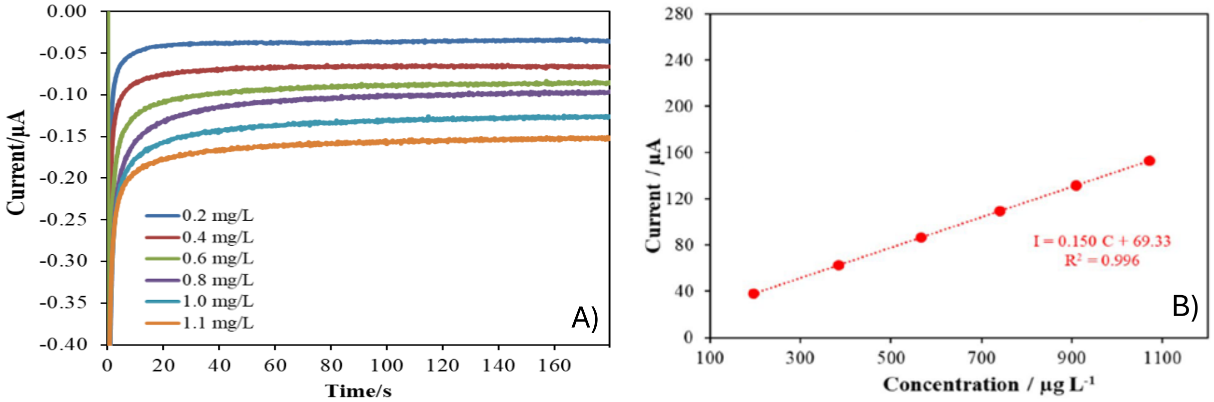


Figure 2: A) Headspace chronoamperograms recorded for different 4-ethylguaiacol solutions (Applied potential, − 0.1 V), B)

As shown in Figure 2a we performed chronoamperometric measurements in the headspace at increasing concentrations of the target phenol. The current intensity was sampled after 120 s, resulting in the calibration curve shown in Figure 2b with a limit of detection (LOD) of 92 μg/L.

The DES-based environment significantly influenced the electrochemical response, leading to enhanced peak definition, improved sensitivity, and greater signal stability compared with aqueous systems. Overall, the proposed DES-assisted tyrosinase sensing strategies combines sustainability, simplicity, and high analytical performance. The integration of DESs as functional electrolytic media with enzyme-based electrochemical sensing represents a promising approach for the development of sensitive, and disposable analytical platforms for environmental monitoring and food quality control.

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Chemical speciation of inositol phosphates in grape seeds applied to wine waste valorization

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Introduction

Phosphate inositols (IP1, IP3, IP5, and IP6) constitute a family of bioactive compounds present in seeds and plant tissues, with relevant functions in cellular signaling, phosphorus storage, and potential antioxidant activity. In this study, the chemical speciation of these species was evaluated in grape seeds from four origins in Mendoza (Argentina): Catena Zapata, Dervinsa, INTA Mendoza, and Cades (Catalunya, Spain). These samples are obtained as waste from wine production and subsequently dried.

Methodology

The grape seed samples were subjected to microwave digestion using concentrated nitric acid, following the standard procedure for complete mineralization of plant matrices. The analysis was carried out after acid digestion and treatment in a microwave oven. Subsequently, the extracts were analyzed by HPLC coupled to ICP-MS, a technique that allows the separation of the different inositol phosphates and their quantification through elemental phosphorus detection using calibration curves for the various phytates. The results were finally expressed as mg of inositol phosphate species per gram of dry seed.

Objectives

1. Quantify the concentrations of IP1, IP3, IP5, and IP6 in grape seeds from four Mendocinian origins obtained from wine-production residues.
2. Compare maximum and minimum values among varieties to identify relevant biochemical differences.
3. Determine which type of inositol phosphate predominates in each origin and evaluate variability between replicates with the aim of revalorizing these residues.

Results

The analysis revealed marked differences among the studied origins. In general, IP6 was the most abundant compound, followed by IP1 and IP5, while IP3 showed the lowest concentrations in all samples. Maximum values observed: IP1 reached its highest value in INTA Mendoza, approximately 28.8–47.1 mg/g. Meanwhile, IP6 showed its absolute maximum in samples from Catena Zapata, with values between 29.5–30.9 mg/g. IP5 also reached its highest concentration in the same samples, around 7.5–7.7 mg/g, higher than in the other origins. Although IP3 concentrations were generally low across all samples, the maximum value was also recorded in Catena Zapata, with values close to 0.25 mg/g.

Conclusions

1. Grape seeds (Catena Zapata) isolated from wine-production residues showed the highest levels of IP6 and IP5, suggesting a profile richer in higher-order inositol phosphates.

2. Seeds isolated from INTA Mendoza showed the highest IP1 content but the lowest IP5 and IP6 levels, this distinct chemical profile indicates a higher evolution of the vineyard growing.
3. Seeds isolated from Dervinsa and Cades residues exhibited intermediate levels, although the latter stood out for its relatively high IP6 values, indicating a low level of grape formation.
4. In all samples, IP3 was the least abundant compound, with minimal variation among origins.

Unraveling Metal Ion Solvation in Ionic Liquids through a Combined X-ray Absorption Spectroscopy and Molecular Modelling Approach

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Ionic liquids (ILs) have emerged as alternative solvents for a wide range of applications, including chemical separations, catalysis, metallurgy, and energy-related technologies. In many of these contexts, metal ions and their complexes play a central role, making the understanding of their solvation and coordination properties essential for the rational design of advanced functional systems.

In this contribution, a combined experimental–computational strategy is presented to investigate the local structure and solvation thermodynamics of transition metal ions in ILs. This approach is based on X-ray Absorption Spectroscopy (XAS) and molecular modelling techniques, including molecular dynamics (MD) and density functional theory (DFT) simulations. XAS analysis provides element-specific insight into coordination geometry, ligand identity, and structural disorder in these highly heterogeneous media. The experimental evidence is interpreted and validated through classical and ab initio MD simulations, enabling a quantitative description of solvation structures and the extraction of thermodynamic quantities such as solvation free energies and ion-transfer energetics. This integrated methodology has been applied to metal ions of industrial and environmental relevance (*e.g.*, Co^{2+}, Zn^{2+}, Ag^{+}), in widely used ILs based on $[Tf_2N]^-$ (bis(trifluoromethylsulfonyl)imide) and $[BF_4]^-$ (tetrafluoroborate) anions combined with $[C_n\text{mim}]^+$ (1-alkyl-3-methylimidazolium) cations [1-4].

By bridging spectroscopy, simulations, and data-driven analysis into a unified framework, this approach provides a powerful strategy to probe ion solvation beyond conventional molecular solvents, offering fundamental insight relevant to green chemistry, separation processes, and energy-related applications.

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Functionalized ionic liquids containing ferrocene moiety

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Ionic liquids currently represent an extensively studied field, particularly in the context of sustainability trends and the principles of green chemistry. Owing to their unique properties, such as low vapor pressure, high thermal stability, and non-flammability, they have found application as alterative solvents across numerous areas of chemistry and chemical technology [1]. Variation of their structural motifs enables fine-tuning of their physicochemical properties to meet the requirements of specific applications. By introducing additional functionalities, these fundamental types of ionic liquids (Fig. 1, type A) can be further modified, giving rise to so-called task-specific ionic liquids (Fig. 1, type B) [2]. In the field of polymer chemistry, functionalized ionic liquids can serve as building blocks for polymers, yielding poly(ionic liquids) (PILs), as well as platforms for the preparation of porous materials, components of composite systems, reaction media, or initiators for various polymerization processes [3]. Recently, metal-containing ionic liquids (MILs) have also been shown to act as highly efficient catalysts for epoxy polymerization [4].

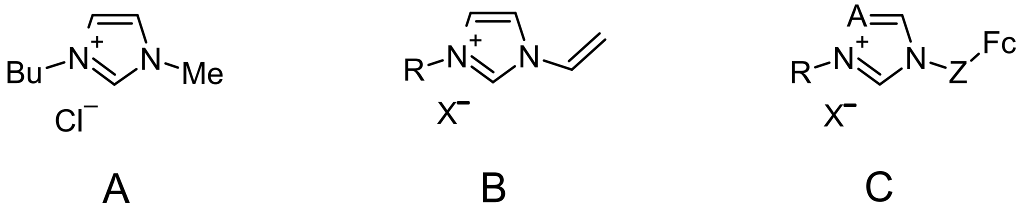

Figure 1: Examples of ordinary (A) and task-specific functionalized (B, C) ionic liquids.

In this contribution, the synthetic approach to functionalized ionic liquids containing ferrocene moiety (Fig. 1, type C) will be presented. It will cover several structure types differing in the spacer between the ferrocene moiety and the azolium ring. Attention will be given to the introduction of the functional groups on the azolium moiety, enabling incorporation of the ionic liquid catalyst into the polymeric network. The synthesized compounds were characterized by spectroscopic and thermoanalytical methods, and in particular cases also by single-crystal X-ray diffraction and cyclic voltammetry. The catalytic activity of functionalized ionic liquids containing ferrocene moiety toward ring-opening copolymerization will be discussed, including mechanistic insights obtained using MALDI-TOF spectrometry.

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Phase equilibria and thermodynamic properties of the nickel(II) methanesulfonate – methanesulfonic acid – water system

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Methanesulfonic acid (MSA) is a promising reagent for hydrometallurgy, but the chemical properties of methanesulfonate salts remain largely underexplored [1]. Given the important role of nickel in cathode-active materials of lithium-ion batteries, the solubility of nickel(II) methanesulfonate and the influence of MSA on the solubility of this salt were studied. Solid-liquid equilibria of $Ni(CH_3SO_3)_2$–H_2O–MSA systems were investigated by the isothermal solubility method, followed by water activity and density measurements on the saturated aqueous solutions. Solid phases of different hydrates were formed and identified by thermogravimetric analysis and single-crystal X-ray diffraction, showing the presence of three hydrates: $Ni(CH_3SO_3)_2{\cdot}2H_2O$, $Ni(CH_3SO_3)_2{\cdot}6H_2O$ and $Ni(CH_3SO_3)_2{\cdot}12H_2O$. The solubility behavior of nickel(II) methanesulfonate in mixtures of MSA and H_2O shows a decrease in solubility with increasing acid concentration, reaching a minimum at 95 wt% MSA. Experimental data were obtained over a wide range of $Ni(CH_3SO_3)_2$ and MSA concentrations at different temperatures and used to build a thermodynamic model with the *Mixed-Solvent-Electrolyte* (MSE) thermodynamic framework of OLI Systems [2]. Thermodynamic properties of the different hydrates and interaction parameters for the aqueous phase were optimized. The model successfully integrates solid-phase speciation, solubility, water activity, and density. There is a good agreement between calculated and experimental data under varying conditions, as illustrated in Figure 1, which compares model predictions with measured solubility at 25 °C and 50 °C.

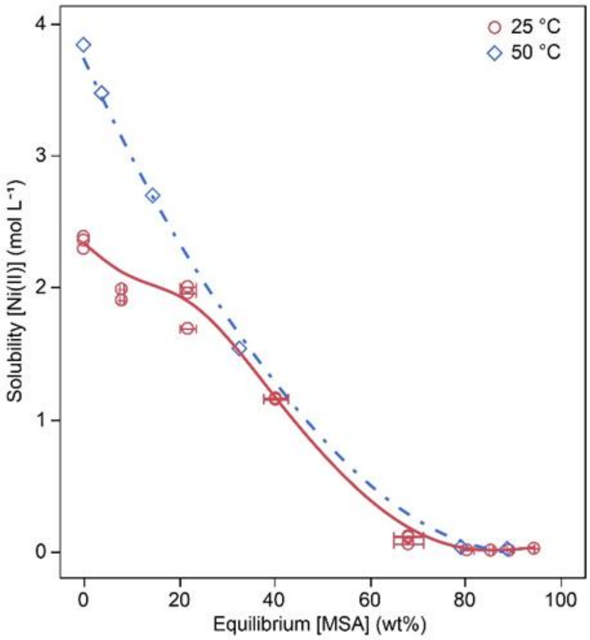

Figure 1: Model fit (line) to experimental solubility data from this work (open markers) for $Ni(CH_3SO_3)_2$ as a function of equilibrium MSA concentration at 25 °C (red circles) and 50 °C (blue diamonds).

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Dysprosium and Samarium Recovery via Natural Zeolite: A Study of Process Dynamics and Equilibrium Conditions

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Dysprosium (Dy) and samarium (Sm) are critical components in high-performance permanent magnets, widely employed in technologies such as wind turbine generators, electric traction motors, and advanced robotic systems [1,2]. However, their high cost, limited recycling rates, and strong dependence on external supply chains make their recovery increasingly important [3]. Among the available approaches, hydrometallurgical processes offer significant advantages for the recovery of rare earth elements (REEs) from end-of-life magnets, including high separation efficiency, lower environmental impact, and reduced energy consumption [4]. These processes typically involve techniques such as leaching, precipitation, solvent extraction, and solid-phase adsorption [5]. In this context, zeolites have emerged as promising materials for metal separation due to their high ion-exchange capacity, selective affinity for cations, large surface area, and well-defined porous structure [6]. Furthermore, their low cost, wide availability, and excellent chemical and thermal stability enable their regeneration and reuse over multiple cycles [7,8]. In this work, the recovery of Dy^{3+} and Sm^{3+} is investigated using a natural clinoptilolite-type zeolite as sorbent material. The experiments were conducted to evaluate the main parameters affecting the sorption process, identifying optimal conditions at pH 6, a sorbent dose of $2\ g\cdot L^{-1}$, and a contact time of 90 minutes. The kinetic behavior was best described by the pseudo-second-order model, while equilibrium data were well represented by the Langmuir isotherm, suggesting monolayer adsorption onto a homogeneous surface. Temperature variations showed no significant influence on sorption performance, with maximum capacities of 10.8 and 16.3 $mg\cdot g^{-1}$ for Dy^{3+} and Sm^{3+}, respectively. In addition, dynamic column experiments were performed to evaluate the separation process under continuous flow conditions, providing a more representative approach for potential practical applications.

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Dual-purpose Ni-sensitive bioplastic film as jewelry smart coating for allergen detection and skin exposure prevention

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Nickel allergy is the most common contact allergy in industrialized countries, affecting around 8% to 19% of adults and 8% to 10% of children; women are affected 4–10 times as frequently as men [1]. In southern European countries, nickel allergy is more common than in northern countries, 16% versus 10% and similar situation occurs in the USA [2]. Topical skin nickel exposure mainly occurs from metallic items, household products, and cosmetics [1].

Focusing on the jewelry case, EU regulation (REACH, Annex XVII) sets nickel migration limits at 0,2 μg/cm²/week in piercings and at 0,5 μg/cm²/week in other items with direct/prolonged skin contact [1]. Despite that, the methodological difficulties in Ni release measurements and in direct or prolonged contact systematic definition resulted in the implementation of adjustment factors and, more generally, in a widespread lack of controls from authorities [1]. From a more practical perspective, some commercial solutions have been developed to allow consumers either testing suspect jewelry at home or protecting their skin by the means of protective varnishes or barrier creams with chelating agents [1].

In this scenario, our investigation focuses on developing a dual-purpose Ni-sensitive bioplastic film meant to act as jewelry smart coating for detecting allergen release and prevent its migration. This ambitious goal is achieved by optimizing starch-based bioplastics [3,4] loaded with dimethylglyoxime (DMG) to exploit the well-known complexation ability of the ligand towards Ni^{2+} (Figure 1a) and the glaring $[Ni(DMG)_2]^{2+}$ purple color (Figure 1b) [5].

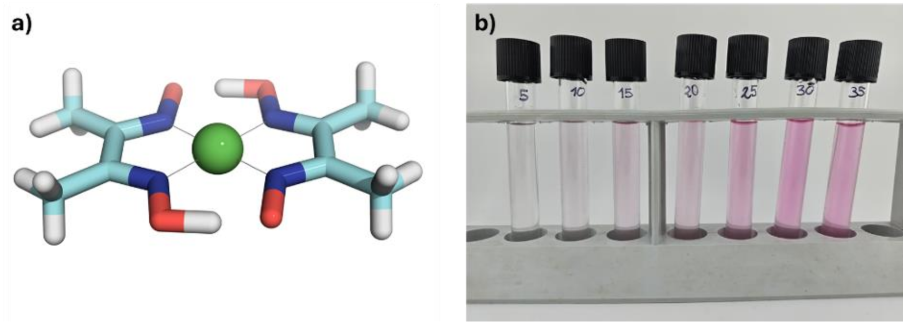

Figure 1: $[Ni(DMG)_2]^{2+}$ complex structure from X-ray data in [6] (a); complex color in solution (DMG 0.1 mM; Ni^{2+} 0-35 ppm) (b).

The investigation can be divided into three main parts: i) Ni^{2+} detection characterization in solution, ii) bioplastic-based smart coating (DMG-BP@) optimization in terms of mechanical properties and Ni^{2+} sensitivity and iii) *proof-of-concept* application of optimized DMG-BP@ for Ni migration detection from Ni-containing metallic items. In the first part, the role of pH, buffering agent and species concentration is optimized by the means of Face Centered Design: per each experimental condition, a regression line is built in the range 0-40 mg/L Ni^{2+} concentration and the main figures of merit (LOD, LOQ, Upper LOQ and linearity range) are used as responses for Doe computation (Figure 2a).

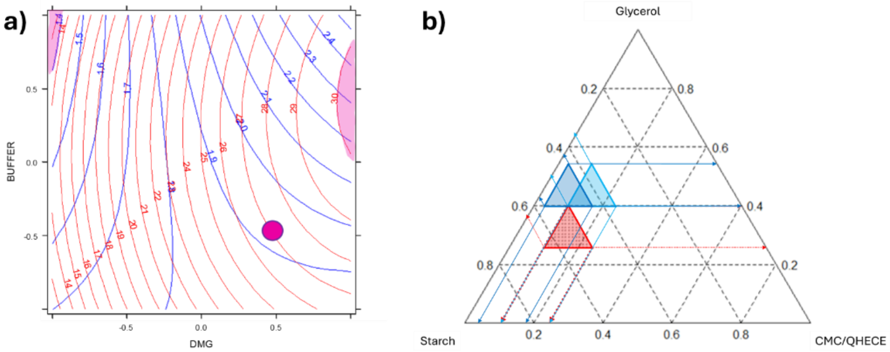

Figure 2: Overlapping FCD isoresponse curves for LOQ and Upper LOQ (a); pseudocomponent domains definition for DMG-BP@ composition optimization (b).

In the second part, bioplastics composition, in terms of starch, glycerol and carboxymethyl cellulose (CMC) or quaternized hydroxyethylcellulose ethoxylate (QHECE) ratios, is optimized by Mixture Design in the pseudocomponents domain (Figure 2b), using a subjective evaluation of films elasticity and resistance as response, together with Ni^{2+} sensitivity upon dropping 30 µL Ni^{2+} solution (100 mg/L). After that, multivariate calibration models are built and validated by the means of Partial Least Square regression, relying on DMG-BP@ color change upon dropping 30 µL of Ni^{2+} solutions at various concentrations (10-100 mg/L), testing both UV-Vis spectroscopy and digital colorimetry as detection techniques.

The last part consists of a *proof-of-concept* application to test the feasibility of using DMG-BP@ as smart coating for jewelry: being widely known in literature the critical role of human sweat in oxidizing Ni^0 contained in metallic items to Ni^{2+}, thus promoting its migration [1], synthetic sponges are used to mimic human skin and soaked in artificial sweat before covering with DMG-BP@ and putting in contact with Ni-containing metallic items.

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Uranyl Chelation by Pincer-Like Dihydroxamic Acids

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Highly radiotoxic actinides, such as uranium, have been used in a wide range of civilian, industrial, and military applications since the end of World War II. In addition, significant amounts of uranium occur naturally in the environment or have been released through human activities, including the processing and disposal of nuclear fuel-cycle wastes, tests of nuclear weapons, nuclear power plant accidents, and the deterioration of storage facilities for nuclear materials. Besides the role of uranium and plutonium in nuclear energy production, the potential use of nuclear weapons and radiological dispersal devices (“dirty bombs”) further increase the risk of environmental contamination and internal human exposure. Once internalized, these elements can trigger both radiological and chemical damages.

To prevent them, decorporation therapy based on chemical chelation is currently the only effective countermeasure for reducing the radiation dose to tissues or organs after accidental intake of radionuclides [1]. This treatment involves the administration of high-affinity chelating agents able to displace contaminating metals from biological ligands or deposition sites within the body (e.g., liver, kidneys, or bones). These agents should form rapidly stable and water-soluble complexes, thereby enhancing the removal of actinides from the bloodstream and organs, and promoting their quick excretion in urine or feces. Currently, Pentetate® (DTPA salts) is the only drug approved worldwide by regulatory agencies for treating plutonium, americium, and curium intoxications despite poor therapeutic performances [2], while DTPA is ineffective for uranium and is not recommended [3].

As part of an on-going research project aimed at designing effective *in vivo* uranium(VI) decorporation agents, we synthesized a series of pincer-like UO_2^{2+} chelators [4], bearing two terminal hydroxamate bidentate groups able to coordinate the uranyl cation in its equatorial plane [5]. In addition to speciation studies in aqueous media, the structural characterization of the ligands and their uranyl complexes were performed by combining NMR, ATR-FTIR, Raman, UV-vis absorption, and electronic circular dichroism (ECD) spectroscopies, the latter method highlighting a chirality transfer from the ligand to the metal.

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Design and Modulation of Selectivity toward Vanadium(V) and Uranium(VI) Ions: Coordination Properties, Affinity and Applications of Hydroxylamino-Triazine Siderophores

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Siderophores are a class of organic ligands containing hard donor atoms, such as nitrogen and oxygen, which exhibit high affinity and selectivity toward hard metal ions, including $U^{VI}O_2^{2+}$ and $V^{V}O_2^{+}$. A major scientific challenge is the design of chelators with enhanced selectivity and thermodynamic stability, particularly for uranyl ion, to facilitate the development of cost-effective materials for uranium extraction from seawater.

Building on the strong binding properties and selectivity [1] of single-site 2,6-bis-[hydroxy(methyl)amino]-1,3,5-triazine ligands, we functionalized the triazine framework with a carbazole moiety to yield the ligand H_2cbht [2] (fig 1). Reaction of this ligand with the uranyl ion results in the formation of several species, which were structurally characterized via single-crystal XRD, while their solution-state behavior was elucidated using NMR. Furthermore, the ligand was evaluated as a fluorescent probe; it enables the precise determination of metal ion concentrations in the nanomolar range through fluorescence quenching.

Expanding beyond single-site systems, a new family of ligands (BLs, fig. 2) incorporating two coordination sites was designed [3]. These ligands facilitate the formation of both homo- and heterometallic complexes upon coordination with hard metal ions. Such complexes are anticipated to exhibit superior thermodynamic stability relative to their mononuclear analogues, driven by the increased number of chelate rings and the favorable entropic contribution associated with the chelate effect.

The metal-binding properties of the new ligands were evaluated via NMR spectroscopy and benchmarked against established hard-donor ligands, such as dipicolinic acid. The results indicate that ligand selectivity toward $U^{VI}O_2^{2+}$ over $V^{V}O_2^{+}$ increases under alkaline conditions, although overall uranyl complexation is less favorable. Furthermore, the kinetics of metal exchange between uranyl and vanadate species were monitored by NMR. Based on these observations, a mechanism is proposed to describe the U(VI)/V(V) exchange process at the ligand binding sites.

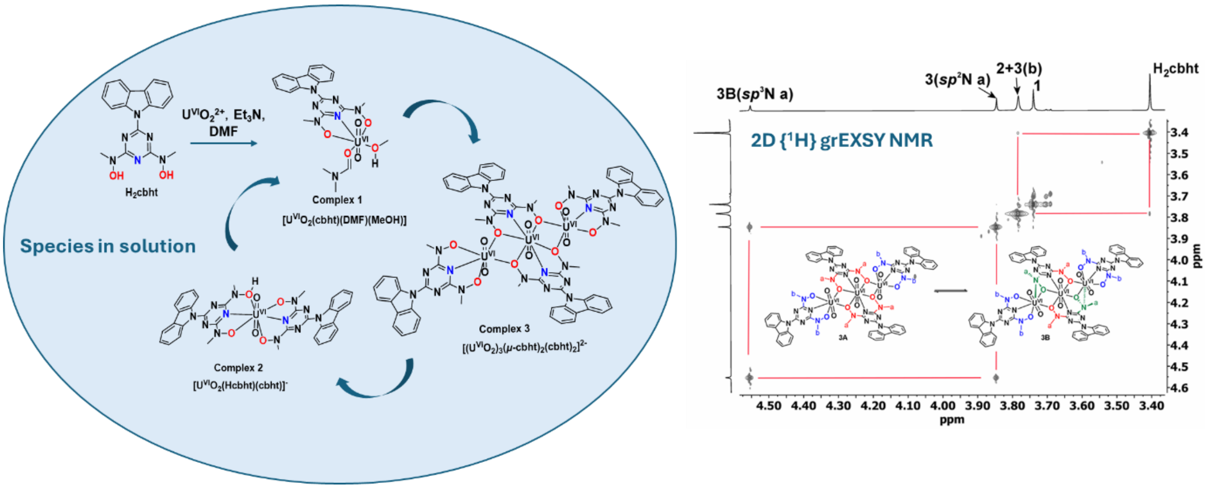

Figure 1: General structures and binding motifs of the single-site BHT family and Uranyl ion**.**

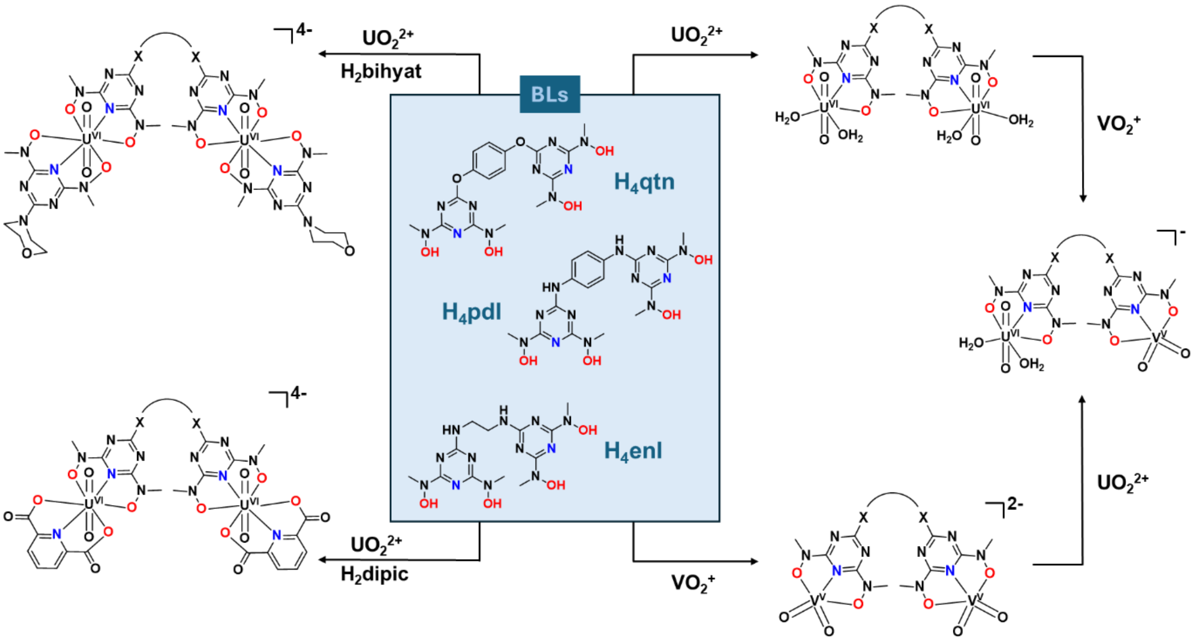

Figure 2: Species of BLs formed with U^{VI}O$_2^{2+}$, V^{V}O$_2^+$ and competitive ligands in aqueous media.

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Silver(I), copper(II) and zinc(II) complexes: their solution behavior, solid state study and bioevaluation

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Currently, the main causes of death include diseases of the circulatory system, cancer, and infectious diseases caused by bacteria, fungi, or viruses. Among the most commonly applied therapeutic approaches are the administration of antibiotics, vaccines, and chemotherapeutic agents. However, due to the emergence of new mutations and the increasing resistance of bacteria, it is extremely challenging to develop new broad-spectrum and highly effective substances [1].

Based on these findings, new substances with various metal ions have also begun to be intensively investigated, including metal ions such as Ag(I), Cu(II), and Zn(II), which possess interesting physicochemical properties and a broad mechanism of action against pathogenic microorganisms [2]. Currently, several more stable forms of these compounds are being developed, with one of the approaches being the coordination of metal ions with ligands to form complexes. Moreover, from a biological point of view, it is necessary to prepare complexes with more biologically accessible ligands, such as amino acids, peptides or simple heterocyclic compounds that are similar to structures found in living organisms or are directly part of them [3].

It is very well known that a complex that is stable in a dry form may undergo partial dissociation in aqueous solution, releasing free metal ions that contribute to antimicrobial or anticancer activity, or, conversely, cause undesired side effects. Additionally, the presence of competing ligands and biomolecules in biological fluids can shift equilibria, affecting the bioavailability of the active species. Therefore, detailed solution studies—such as monitoring speciation, stability constants, and kinetic behavior—are essential to predict and rationalize the biological activity of metal complexes, optimize their design, and minimize toxicity.

In the present study, we investigated the formation of complex species in solution by potentiometric and ^{1}H NMR titrations in order to design the synthesis conditions. Subsequently, we focused on preparation and physicochemical characterization of new Ag(I), Cu(II) and Zn(II) complexes in solid state, and study their antimicrobial and cytotoxic activity.

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Metallochlorin Photosensitizers for Enhanced Photodynamic Therapy: A Computational–Experimental Approach

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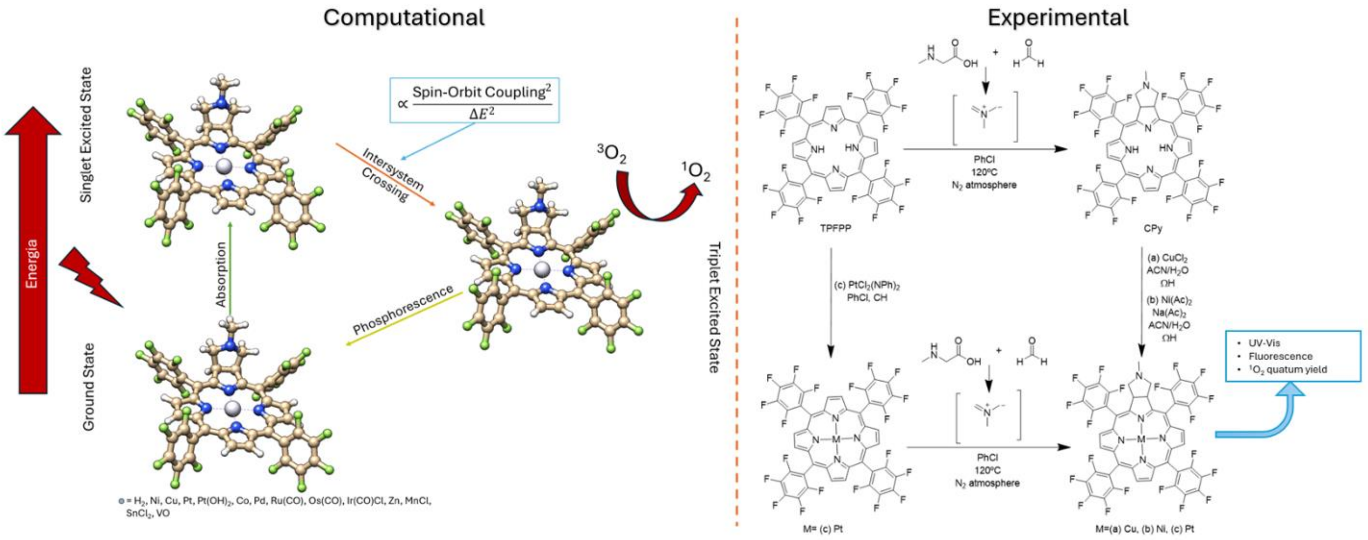
Photodynamic therapy (PDT) is a cancer treatment that relies on light-activated photosensitizers to generate cytotoxic reactive oxygen species, with therapeutic efficacy strongly dependent on molecular structure and excited-state dynamics [1,2]. Structural modulation through metal coordination represents a promising strategy to enhance intersystem crossing and singlet oxygen production, key factors in PDT performance [3].

In this work, we employed a combined computational–experimental approach to guide the design of metallochlorin-based photosensitizers with improved photodynamic activity. Density Functional Theory (DFT), Time-Dependent DFT within the Tamm–Dancoff approximation, and spin–orbit coupling calculations were used to evaluate the impact of different metal centers on excited-state energetics and singlet oxygen sensitization. The computational screening revealed that heavy metal coordination, particularly platinum, significantly enhances spin–orbit coupling, while low triplet-state energy gaps (<0.98 eV) correlate with reduced photodynamic efficiency.

Based on these insights, Pt^{2+}-, Ni^{2+}-, and Cu^{2+}-chlorin complexes were synthesized, using conventional heating (CH) or ohmic heating (ΩH), and experimentally evaluated. Singlet oxygen generation was assessed using DPBF photodegradation assays under LED irradiation. The results were validated through DFT calculations, and the Pt^{2+}-chlorin derivative exhibited the highest photodynamic activity, whereas the Ni^{2+} and Cu^{2+} analogues showed negligible photosensitizing efficiency.

Overall, this study highlights the value of integrating computational design with experimental validation to develop metalated photosensitizers tailored for PDT applications, providing a rational framework for the development of next-generation therapeutic agents.



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Tailored oxaliplatin(IV) monohaloacetate complexes with redox-activation and multimodal anticancer activity

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Platinum(IV) complexes have emerged as promising alternatives to the clinically approved Pt(II) drugs, namely cisplatin, carboplatin and oxaliplatin, due to their higher inertness and ability to act as prodrugs. These compounds, due to the coordinative geometry of the Pt(IV) centre, are endowed with two additional axial ligands, which can be modified to modulate their chemical and pharmacological properties [1]. Platinum(IV) prodrugs remain chemically inert until they are reduced, thus releasing the biologically active Pt(II) species and the axial ligands. This reduction occurs preferentially in the more hypoxic environments of tumour cells, improving selectivity and potentially overcoming many limitations of platinum(II) drugs [2]. Hence, a series of novel oxaliplatin(IV) complexes bearing monohaloacetic acids were synthesised (Figure) with the aim to overcome the well-known issues of conventional platinum-based therapeutic regimens, particularly the severe side effects and resistance phenomena. Both symmetrical and asymmetrical derivatives featuring monofluoroacetate, monochloroacetate, or monobromoacetate were obtained, fully characterised and evaluated their in solution behaviour [3].

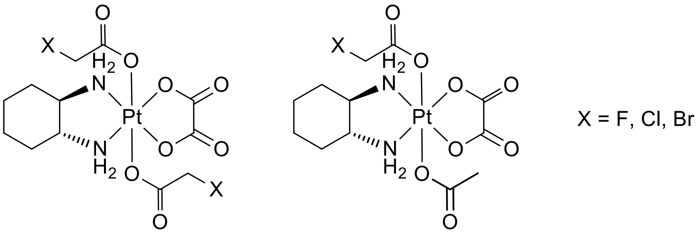

Figure. Molecular structure of the symmetrical and asymmetrical Pt(IV) complexes featuring monohaloacetates.

Moreover, their electrochemical properties were evaluated via cyclic voltammetry. Reduction experiments with dithiothreitol confirmed efficient Pt(IV) → Pt(II) conversion on timescales compatible with physiological conditions. Cytotoxicity studies on human ovarian carcinoma A2780 cells under normoxic and hypoxic environments highlighted increased activity under hypoxia, suggesting preferential prodrug activation in a reducing tumour-like milieu. Asymmetrical complexes generally offered improved solubility and promising antiproliferative profiles, whereas certain monobromoacetate-containing derivatives displayed partial instability linked to the higher leaving group ability of bromide. Notably, mechanistic investigations indicated that the enhanced cytotoxicity of selected bromoacetate-functionalised complexes is not associated with increased DNA damage relative to oxaliplatin, suggesting the contribution of additional non-genomic pathways. These findings emphasise the promise of monohaloacetate-functionalised oxaliplatin(IV) complexes as multimodal prodrugs combining platinum-mediated cytotoxicity with complementary bioactive mechanisms for improved anticancer efficacy.

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The Acid-Base and Complex-Forming Properties of Cytokinins

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Cytokinins (CKs) are among important plant hormones (phytohormones) which fundamentally regulate plant growth and development [1-3]. These signaling molecules can be found in plant tissues in very low concentrations (fM-pM range), which makes their study very difficult. Therefore, it is necessary to employ sensitive hyphenated analytical techniques for their identification and quantification. Because of the low concentration of these compounds in plants, they have been synthetically prepared in larger amounts for biological testing [1-4]. Thanks to a library consisting of several hundred chemical compounds, it was determined that minute structural changes lead to a dramatic change in biological activity [4]. It has been demonstrated that these substances, or their analogous synthetic analogs, exhibit a significant biological effect on animal and human cells [4].

The acid-base properties of CKs having 6-benzylaminopurine (BAP) skeleton were studied using electroanalytical methods in mixed medium 15 years ago [5] and recently by means of multiwavelength molecular absorption spectroscopy in aqueous solutions over the temperature range of 25-50 °C and at ionic strengths of 0.1-0.3 M [6]. The thermodynamic parameters ($\Delta H°$ and $\Delta S°$) of the protonation processes of the studied CKs were estimated from the temperature dependence of these equilibrium constants. In addition, the protonation constants for the BAP derivatives at infinite dilution were calculated from their dependence on ionic strength. The existence of weak Na^+ complexes with the studied ligands is also assumed in aqueous solution. The complexing properties of CK ligands with Zn(II) ions were investigated, and their stability constants were estimated from the shift of their protonation constants determined in the presence of a high excess of metal ion. The LFER demonstrated that the $\log \beta_{ZnL}$ values correlated with the basicity of the CK ligands. The details could be found elsewhere [6].

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Effects of the structural modification of ambidentate hydroxy-pyridinonates on their metal ion binding

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In the framework of an ongoing research program focused on the design and development of heterobimetallic cobalt(III)–platinum group metal (Co/PGM) complexes with potential hypoxia-triggered activation and selective anticancer properties, we have undertaken the systematic synthesis and comprehensive characterization of a diverse library of ligands. These ligands incorporate distinct and spatially separated donor sets, including (O,O), (N,N), and (N,S) coordination motifs. Several of these systems are derived from biologically relevant scaffolds or structurally related to known pharmaceutical agents, thereby enabling the integration of bioactive features into the coordination environment. Particular emphasis has been placed on hydroxy-pyridinonate-based frameworks, which offer versatile chelation properties and tunable electronic characteristics.

To elucidate the solution behavior of these ligands and their corresponding metal complexes, we have employed pH-potentiometry, NMR spectroscopy and ESI-TOF-MS. These methods allowed us to systematically investigate proton dissociation equilibria of the free ligands, as well as their coordination interactions with $[Co(4N)]^{3+}$ cores (where 4N denotes either a tripodal tetradentate N donor or a bis-bidentate 2×2N ligand system), Pd(II) ions, and selected organometallic Ru(II) and Rh(III) centers.

Through this integrated approach, we have been able to characterize key aspects of the coordination chemistry, including donor atom selectivity, metal-ligand binding preferences, complex stoichiometries, and thermodynamic stability constants. Furthermore, we have derived insights into the most probable solution structures of the resulting complexes, highlighting the influence of ligand architecture - such as donor set composition, rigidity, and spatial arrangement - on metal ion binding modes.

The present contribution aims to consolidate and discuss our most recent findings, with particular focus on (i) the donor atom selectivity exhibited by platinum group metals in competitive coordination environments, and (ii) the role of ligand design in modulating the stability of organometallic Ru(II) and Rh(III) species. These insights contribute to a rational design strategy for heterobimetallic systems with potential applications in targeted anticancer therapy [1–3].

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Biological properties of first row transition metal complexes of Schiff base ligands

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First row transition metal complexes of Schiff base ligands effectively bind and stabilize G-quadruplex (G4) DNA, with affinity and selectivity finely tuned by the nature of the metal ion and by the ligand size, shape and substituents [1–6]. The treatment of cancer cell lines with such complexes induced the formation of nuclear G-quadruplexes and a concomitant downregulation of oncogene expression, with only moderate cytotoxicity [2]. These findings suggest that such metal compounds modulate gene expression through G4 stabilization, opening opportunities for selective anticancer strategies.

Distinct mechanisms of action can be accessed by varying the metal ion. For example, a copper(II) complex was found to undergo reduction to copper(I), promoting the generation of reactive oxygen species and triggering oxidative stress [3]. Half-salphen cobalt(III) complexes displayed remarkable Co^{3+}/Co^{2+} redox inertness, even in presence of glutathione [4]. An asymmetric zinc(II) salphen complex exhibited enhanced biological performance, significantly reducing cell viability, inhibiting proliferation, and inducing apoptosis [5]. Finally, π-extension of the ligand scaffold enhances DNA-binding affinity, enabling stronger interactions with both G-quadruplex and duplex DNA targets [6]. Collectively, these studies underline how subtle modifications in ligand framework and the proper choice of the metal element govern not only DNA-binding properties but also the resulting biological response.

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Targeting G-quadruplexes using Supramolecular Strategies

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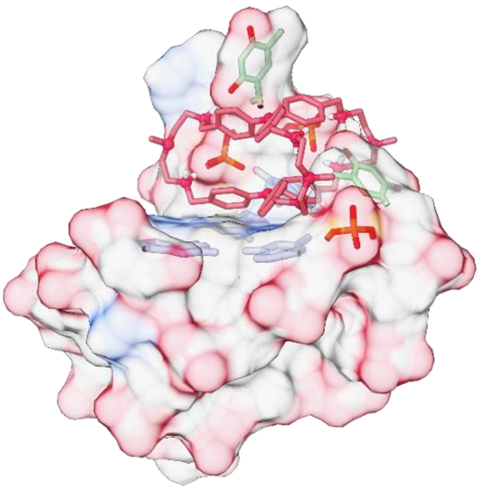
Non-canonical nucleic acids (NCNA) have attracted considerable attention in many science fields, including chemistry, biology, physics, materials and nanotechnology. NCNA structures include triplexes, *i*-motifs, three/four-way junctions, and G-quadruplexes (G4s). The later one is a supramolecular assembly of two or more tetrads, which arise from the hydrogen bonding network of four coplanar guanines. G4s have been proposed as targets of small molecules for therapeutic intervention because of their pivotal role in key biological processes such as ageing and cancer [1].



Moreover, G4s are likely found in aptamers, which are NCNA able to adopt different conformations, showing high affinity and selective for analytes [2]. Herein, we present the application of organic molecules and metal complexes as therapeutic agents in anticancer and antibacterial drugs [3]. A range of biophysical assays (FRET melting, fluorescence spectroscopy and gel electrophoresis) has been used to characterize the interaction towards telomeric and other G4s in addition to duplexes. Then, we evaluated their cell activity by viability, confocal microscopy, gene expression and RNA-seq experiments.

Our results point out the importance of the organic core scaffold, the number and class of the substituents, the molecule net charge and the reinforced structure of the ligands to bind strongly G4s. Finally, we present an aptamer platform to detect toxins present in the food sector with lower LOD for *ocratoxyn A* than current commercial devices.

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Complex formation and metal ion induced hydrolytic processes of fragments of tau and tubulin proteins

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Disruption of metal ion homeostasis is a hallmark of numerous neurodegenerative diseases, including Alzheimer’s disease (AD), Parkinson’s disease (PD), Huntington’s disease (HD), and prion diseases. Transitional metal ions, such as Cu(II), Zn(II), Ni(II), and Fe(II)/Fe(III), interact with proteins and peptides, altering their structure, aggregation propensity, and participation in biochemical processes.[1-2] Short sequence motifs containing serine or threonine, followed two amino acids later by histidine (-Ser-Xaa-His- and -Thr-Xaa-His-; abbreviated as –SXH–/–TXH–), are found in numerous proteins involved in neurodegeneration (e.g., tau and tubulin proteins). These motifs may form metal-binding environments and serve as potential sites for metal-assisted peptide bond hydrolysis.[3-5] On the other hand, the tau protein contains a large number of serine and threonine amino acids, the phosphorylation of which results in a hyperphosphorylated protein that can promote protein aggregation. In addition, the position of the serine and threonine amino acids relative to histidine may also influence the processes that occur in the presence of metal ions.[6]

One focus of our research is thus the study of complex formation and metal-ion-induced hydrolytic processes involving fragments derived from tau and tubulin proteins.[7,8]

In the tau protein, threonine residues are present in a –TXH– sequence in the vicinity of histidines at positions 32 and 388. The presence of threonine also affects the stability and spectral parameters of Cu(II) and Ni(II) complexes of peptides modeling the environments of these two histidines. Thus, we conducted a systematic investigation of the metal complexes of oligopeptides and their mutants containing this sequence, supplemented with a fragment containing His at position 374, which contains a –TH– segment. We also extended our investigations to the phosphorylated derivatives of these fragments.

Similarly, the His residue at position 192 of the alpha-1A tubulin protein is also located in a –TXH– environment; we examined in detail the complex formation and hydrolytic processes of model peptides containing this residue. At the same time, a serine is also located one amino acid away from cysteine at position 200. Thus, we extended our investigations to model peptides containing both the His192 and Cys200 amino acids in the corresponding amino acid environment (tub(189-203) fragment).

The studies showed that peptides containing the -TXH- sequence form complexes with both Cu(II) and Ni(II) ions have similar stoichiometries and structure as other peptides containing one histidine. The presence of threonine, however, increases the stability of the formed complexes and the metal ion-induced amide nitrogen deprotonation occurs at lower pH. In the presence of Ni(II), hydrolytic processes are already induced around pH 8, but detectable changes are only observed over a longer time period. So the characterization of complex forming processes are reliable. In alkaline media, however, the hydrolytic processes are considerably faster.

Our studies have also shown that these processes clearly occur in the presence of threonine one amino acid away from histidine, while for peptide containing the –TH– segment and for peptide without threonine, only complex formation processes similar to those of other peptides were detected.

However, the phosphorylation of threonine at the –TXH– sequence fundamentally alters complex-forming and hydrolytic properties of peptides.

In the case of histidine-containing peptides, even in a strongly alkaline medium at 25 °C in the presence of Cu(II), no hydrolysis occurring in parallel with complex formation is observed. The investigation of nickel(II) complexes of tubulin fragments containing the –SXC– sequence revealed a much more complex picture, as redox processes must also be taken into account in addition to complex formation.

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New organotin(IV) syringates as potential PPAR-γ agonists: from chemical characterization to biological activity towards colon cancer HCT116 cells

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As members of the nuclear receptor (NR) family of transcription factors, peroxisome proliferator-activated receptors (PPARs) regulate essential cellular processes, including lipid metabolism, glucose uptake, cell proliferation, and programmed cell death through ligand-mediated activation. Within the PPAR subfamilies, PPAR-γ (PPARG) is crucial to the development of fat cells, sensitivity to insulin, apoptosis, and metastasis.[1] PPARG is also reported to be a promising target for patients diagnosed with colorectal cancer (CRC) and it is significantly expressed in 70% of the sporadic CRC. In individuals with CRC, the precise function of PPARG remains not entirely comprehended and elucidation of the PPARG transcriptional regulation in CRC seems promising.[2] There are different ongoing works aimed at exploring the PPAR-activating capability of a wide range of natural products such as phenolic compounds. These compounds exhibit different molecular interactions with PPAR, which could be determined by their specific binding affinity to the receptor and therefore, their capacity modulating its activity.[3]

Syringic acid (SA), chemically known as 4-hydroxy-3,5-dimethoxy benzoic acid, is one of the most common phenolic acids. SA has a chemical structure featuring a benzene ring bonded to a hydroxyl (-OH), a carboxylic acid (-COOH), and two methoxy (-OCH3) groups. The strategic placement of these methoxy groups at positions 3 and 5 on the aromatic ring is responsible for its beneficial therapeutic properties.[4] On the other hand, it is well known that organotin(IV) act as powerful agonists for PPARG and stimulate adipocyte differentiation via the PPARG signalling pathway.[5]

With the aim of studying the modulation of antitumor efficacy and the interaction with receptor PPARG of SA, we synthesized new triorganotin(IV) syringates. Complexes structures were investigated in solid state and in solution by Fourier Transform Infrared (FT-IR), Electrospray Ionization Mass Spectroscopy (ESI-MS), Nuclear Magnetic Resonance (NMR) spectroscopies and by X-ray single crystal analysis.

The interactions of SA with a series of organotin(IV) cations were also investigated in KCl(aq) at I = 0.2 mol dm-3 and at T = 298.2 K, by ISE-H+ (glass electrode) potentiometric titrations. The stability constants determined enabled us to model the chemical speciation of SA / organotin(IV) systems in aqueous solution, to get further insights on the behavior of their complexes in biological fluids.

Furthermore, molecular docking and dynamics revealed triorganotin(IV) syringates stably binding to PPARG interacting with Cys285, Arg288, Lys263, Ile325, Leu228 amino acids of the ligand-binding domain (LBD) of the receptor.

Finally, biological studies evidenced that tributyltin(IV) syringate (TBT-SA) shows a significant cytotoxic activity in tumour cells, reducing the proliferation of colon cancer HCT116 cells of about 80% at 500 nM after 48 h of treatment. At the same dose, the free ligand SA was completely ineffective. The analysis of cell cycle distribution confirmed the results and demonstrated the presence of a preG0-G1 peak (from 1.86% to 23.40% in treated cells) in colon cancer cells. Taken together, our results strongly suggest that the combination of organotin(IV) moieties with natural polyphenols ligands represents a promising therapeutic strategy for colon cancer.

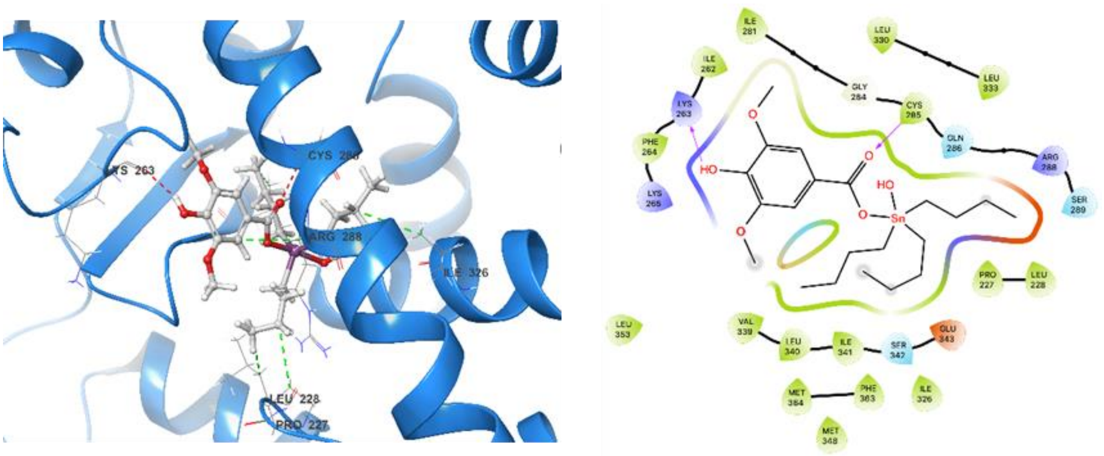

Figure 1. Structure of the (TBT-SA)-PPARG complex and graphical representation of TBT-SA docking to the LBD of PPARG.

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Acknowledgements

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How does the -DPHVW- Motif Contribute to Metal Coordination in *Neisseria gonorrhoeae*?

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Neisseria gonorrhoeae, the causative agent of gonorrhea, relies on transition metal acquisition for pathogenicity, proliferation, and survival within the host environment. Mn(II) is particularly important, as it supports oxidative stress defense and metabolic processes [1]. The MntABC system mediates high-affinity uptake of Mn(II), Fe(II), and Zn(II), with the periplasmic protein MntC playing a central role in metal binding. Notably, a flexible, histidine-rich loop adjacent to the binding site contains a conserved -DPHXW- motif, suggesting a potential role in metal coordination [2-4]. This motif has been identified in numerous periplasmic binding proteins across bacteria, yet its function remains unclear.

We've characterized two model peptides derived from His-rich loop of *N. gonorrhoeae's* MntC protein, with and without the -DPHXW- motif, to investigate their affinity and selectivity for Mn(II), Fe(II), Cu(II) and Zn(II). Despite the experimental challenges, and lack of literature associated with Mn(II) and Fe(II) coordination chemistry, stability constants were determined using a systematic approach [5-8]. Our results indicate that the -DPHVW- motif modulates metal binding, supporting its involvement in Mn(II) uptake and oxidative stress resistance. These findings provide insight into how *N. gonorrhoeae* exploits His-rich motifs to thrive under metal-limited and oxidative conditions.

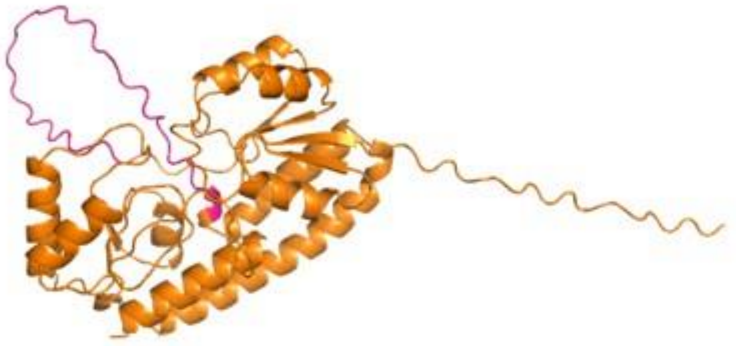

Figure 1. Structure of MntC protein from UniProt database (Structure: Q5FA63) visualized using UniProt software. The unstructured loop fragment is marked in pink.

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Investigation of transition metal complexes of tau fragments containing cysteine and one or more histidines

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Alzheimer’s disease (AD) is the best known and most common form of neurodegenerative disorders, taupathies. Its development is associated with the accumulation of amyloid-β plaques and hyperphosphorylated tau protein into neurofibrillary tangles [1, 2]. Different factors like oxidative stress, phosphorylation and dyshomeostatis causes the tau protein to dissociate from the microtubule and aggregate resulting in the formation of intracellular neurofibrillary tangles in a multistep process. It starts with the abnormal conformational changes and continues by dimerization or oligomerization with subsequent formation of neurofibrillary tangles [3, 4]. The dyshomeostasis of essential zinc, iron and copper may lead to the enhancement of free metal ions in neuron which results in conformational changes and consequent misfolding by binding of metal ions. The 2 cysteines and 12 histidines found in the tau protein may serve as potential binding sites for these metal ions [5].

In our research work, we synthesized peptides containing cysteine and/or histidine. Two tau fragments containing the amino acids Cys291 and His299 (tau(288-301), Ac-QSKCGSKDNIKHVP-NH2) and Cys322, His329 and His330 (tau(320-333), Ac-SKCGSLGNIHHKPG-NH2) were studied. For comparative analysis, shorter fragments of these regions (tau(289-300), Ac-SKCGSKDNIKHN-NH2; tau(288-293), Ac-QSKCGS-NH2; tau(292-301), Ac-GSKDNIKHVP-NH2), as well as a mutant containing 3 histidines (tau(320-333(H)), Ac-SKCGSLGNIHHHKPG-NH2) were also included in the studies.

The electrochemical and coordination behaviors of Ni(II), Zn(II) and Fe(II) complexes of these ligands were studied. The pH potentiometric titrations of Fe(II) with tau protein fragments were performed under an inert atmosphere achieved using glove box which is crucial to avoid redox processes of Fe(II) complexes. Comparative analysis of the stability constants calculated for all peptides and their Ni(II) complexes showed that, the peptides containing both His and Cys in the sequence are more stable than peptides containing only His, suggesting that if Cys is present in the sequence, it is involved in coordination with the metal ion. Spectrophotometric and CD curves of Ni(II) complexes clearly supported that Cys is the preferred binding site for Ni(II) in those tau fragments where both Cys and His are present in the sequence. Whereas, for Zn(II) complexes of these ligands we observed an increase in stability constants of the complexes with an increase in the number of histidine residue in the fragment. This behavior suggested a multidentate binding forming stable complexes owing to the multiple primary binding sites present in the sequence.

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Metal ion binding affinity of native and phosphorylated human Tau(28-34) protein fragment and the role of phosphorylation in the hydrolytic process

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Metal ion-protein interactions are very common in the human body and represent many biological processes, such as coordination, phosphorylation, oxidative reactions, and hydrolytic processes [1].

One of the most important proteins in the body is tau protein, which has a significant role in the brain, because it stabilizes the neuronal microtubules under normal physiological conditions [2]. However, in the context of incomprehensible pathological mechanisms, tau protein undergoes structural modification, primarily via the process of hyperphosphorylation, which is induced by kinase enzymes. This process ultimately results in the destruction of the protein, accumulation of toxic aggregates, and generation of neurofibrillary tangles, leading to neurodegeneration [3].

Involving metal ions in neurodegenerative diseases has been demonstrated by many analytical data. Both essential and toxic metal ions have been identified in significant quantities in plaques, which are characterized by the aggregation of proteins [4]. The sequence of tau protein consists of 441 amino acid residues, including 12 histidyl residues, which are effective binding sites for coordinating metal ions, as well as several seryl and threonyl residues, which are potential sites for phosphorylation [5].

Hydrolysis of the peptide bond of tau protein can occur in the presence of specific metal ions like Ni(II) ions. One of the conditions of this hydrolytic process is the presence of the (-Z1T(S)XHZ2-) sequence in the molecule, where Z1 and Z2 represent any amino acid residue and X is not proline. The position of the hydrolyzed bond is between Z1 and the threonyl or seryl residue. Our previous studies have shown that fragments of tau containing His32 have an outstanding metal ion binding capacity [6]. This binding site is present as a -TMH- motif, where His32 is an anchor for metal ions and the threonyl residue is a potential site for phosphorylation. In our work, we studied the metal complexes of tau(28-34) protein fragment (Ac-GYTMHQD-NH_2) and its phosphorylated derivative.

We investigated the coordination chemistry of the peptides with essential Cu(II), Zn(II) and toxic Ni(II) ions. In addition, we examined the hydrolytic processes of the native and phosphorylated peptides in the presence of Ni(II) ion. pH-potentiometry, spectroscopic techniques (UV-Vis, CD), RP-HPLC, NMR, and ESI-MS were used for a comprehensive analysis of this work.

These new results may provide valuable new information for understanding the development of neurodegenerative diseases.

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Small Change, Big Impact: Dual Amino Acid Swap Influence Metal Binding and Antimicrobial Activity of a MUC7-Derived Peptide

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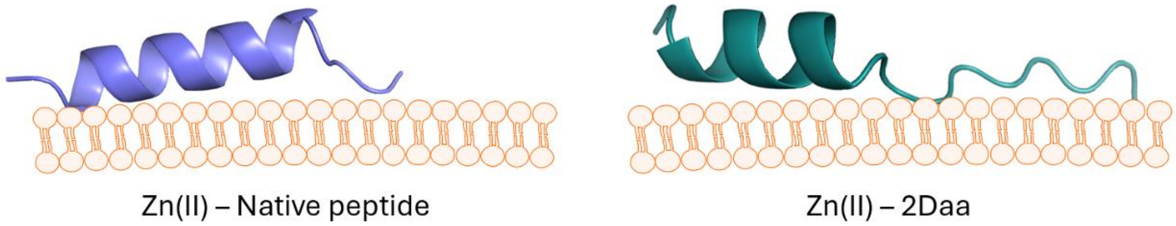
Mucin 7, a salivary protein involved in non-immune defense, undergoes proteolytic cleavage in saliva, yielding fragments with antimicrobial properties [1]. To overcome the proteolytic instability of antimicrobial peptides (AMPs), a Mucin 7-derived sequence was modified by introducing two D-amino acids (2Daa) at the site most susceptible to proteolytic cleavage [2].

In this study, the coordination, structure, and activity of the modified peptide in the presence of Cu(II) and Zn(II) ions were investigated using potentiometry, mass spectrometry, multiple spectroscopic techniques (UV–Vis, CD, EPR), and quantum-chemical calculations, complemented by antimicrobial and antibiofilm assays.

The results show that this subtle peptidomimetic modification leads not only to enhanced proteolytic stability but also to altered coordination and biological properties compared to the native peptide [3]. The modification induces a reorganization of Cu(II) binding, resulting in more thermodynamically stable complexes, while having a less pronounced effect on Zn(II) coordination. A decrease in secondary structure ordering in the presence of metal ions, resulting in increased conformational flexibility, was also observed. These changes correlate with a marked improvement in antimicrobial activity (Figure 1) – the modified peptide exhibits selective activity against oral bacteria (*Streptococcus mutans* and *Streptococcus sanguinis*) and inhibits biofilm formation while remaining non-cytotoxic toward human cells.


Zn(II) – Native peptide

Zn(II) – 2Daa

Figure 1. Proposed mechanism of action: metal coordination–induced activation, combined with increased conformational flexibility, enhances interaction with the bacterial cell surface (left: native peptide complex; right: 2Daa peptidomimetic complex with higher antimicrobial activity).

These findings demonstrate that subtle stereochemical modifications can effectively modulate peptide properties, enabling the rational design of stable and biologically active peptidomimetics with therapeutic potential.

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POSTERS

Factors affecting the complexation of novel ambidentate pyridinone derivatives with platinum group metal ions

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Platinum-based anticancer drugs currently used in the treatment of various malignancies exhibit poor selectivity and therefore frequently cause severe side effects. To address this limitation, considerable research efforts have focused on the development of novel metal-based complexes with anticancer potential, taking advantage of the distinct physiological and biochemical differences between cancerous and healthy cells. One notable characteristic of many tumor tissues is hypoxia, which provides an opportunity for the design of hypoxia-activated prodrugs capable of selectively targeting tumor cells. Such compounds can release cytotoxic agents through the reduction of cobalt(III) complexes to the Co(II) oxidation state under low-oxygen conditions [1,2,3].

The aim of the present work was the synthesis and characterization of novel ligands based on hydroxy-pyridinone and amino acid moieties (such as methionine and S-methyl-cysteine), which may serve as promising platforms for the construction of mixed cobalt(III) and platinum-group metal (PGM) complexes with potential anticancer activity.

The newly synthesized ligands were characterized using a range of analytical techniques, including pH-potentiometric measurements in solution, NMR spectroscopy, and ESI-TOF mass spectrometry. In addition, solution equilibrium studies were carried out with organorhodium and organoruthenium ions, as well as with various $[Co(4N)]^{3+}$ (4N = tren, tpa) cations, in order to investigate the metal-binding capabilities of the ligands and the donor-atom preferences of the metal ions. These results provide valuable insight into how structural modifications of the ligands influence metal-ion binding strength in solution and support the planned synthesis of heterobimetallic complexes in the solid state. This contribution summarizes our recent findings in this research area.

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Actinide uptake in marine macroalgae: Europium as a kinetic and chemical proxy for Americium in *Ascophyllum nodosum*

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Understanding the fate of actinide radionuclides in marine environments is critical for evaluating long-term ecological risk. Among transuranic elements, americium is of particular environmental concern due to its persistence, radiotoxicity, and potential interaction with marine biota.

This study investigates the bioaccumulation behavior of ^{241}Am and europium isotopes in the brown macroalga *Ascophyllum nodosum*, with ^{152}Eu employed as a chemical surrogate.[1] The environmental and chemical analogy between Eu(III) and Am(III) is assessed, supporting europium as a robust proxy system for actinide uptake studies.

Biokinetic analysis across trace and ultra-trace concentrations reveals a consistent mono-exponential saturation behavior, indicating a dominant, kinetically controlled uptake pathway. Speciation analysis highlights the central role of algal polysaccharides, particularly alginate, in metal binding, with evidence supporting the formation of stable metal-alginate complexes within algal tissues.

These results demonstrate that actinide accumulation in macroalgae is strongly governed by surface biopolymer chemistry and provide quantitative insight into uptake kinetics under environmentally relevant conditions. The study contributes to a mechanistic understanding of metallic radionuclide-biota interactions in marine systems and supports improved modelling of ecological exposure pathways.

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Girard T–based multidentate ligands for selective binding of UO_2^{2+} in aqueous media

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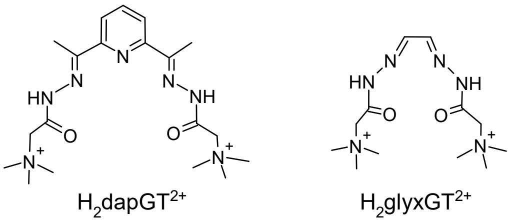
The development of chelating agents that operate effectively and selectively in aqueous solution is a central challenge for uranium extraction from seawater and in biological detoxification strategies [1,2]. To achieve this goal, it is necessary to face the low concentrations and the competition from other hard metals. Particularly due to competing complexation by vanadium and iron ions. The equatorial plane of $U^{VI}O_2^{2+}$ is the sole site available for coordination, therefore, planar ligands with multiple hard donor atoms fulfill the ligation requirements of $U^{VI}O_2^{2+}$. In contrast, competing metal ions such as $V^{V}O^{2+}$ possess fewer available coordination sites and distinct geometric preferences, suggesting that equatorial plane saturation may disfavor their binding [3-5].

In this work the behavior of two water-soluble Girard-T-based acylhydrazone ligands (Scheme 1) towards $U^{VI}O_2^{2+}$, $V^{V}O^{2+}$ and Fe(III) was investigated. A planar pentadentate ligand, 2,2'-(((1E,1'E)-pyridine-2,6-diylbis(ethan-1-yl-1-ylidene)bis(hydrazin-1-yl-2-ylidene))bis(N,N,N-trimethyl-2-oxoethan-1-aminium) (H_2dapGT^{2+}), and a tetradentate analogue, 2,2'-(((1E,2E)-ethane-1,2-diylidene)bis(hydrazin-1-yl-2-ylidene))bis(N,N,N-trimethyl-2-oxoethan-1-aminium) ($H_2glyxGT^{2+}$) were considered.



Scheme 1. Molecular structures of H_2dapGT^{2+} and $H_2glyxGT^{2+}$.

Combining single-crystal X-ray diffraction, ^1H and ^{51}V NMR spectroscopy, UV-vis spectrophotometry, H^+-ISE potentiometry, ESI-MS spectrometry, and theoretical calculations, a comprehensive picture of the protogenic and complexation ability of the two molecules was provided. Protonation constants and stability constants of complex species were defined at T = 298.2 K and ionic strength 0.1 mol dm^{-3} in $KCl_{(aq)}$. Data collected on $U^{VI}O_2^{2+}$ - H_2dapGT^{2+} aqueous mixtures indicate the formation of a mono-chelated uranyl complex $[U^{VI}O_2(dapGT)]^{2+}$ at acidic pH, that remains stable up to mildly alkaline pH. H_2dapGT^{2+} fully saturates the uranyl equatorial plane, forming highly stable hexagonal bipyramidal complexes, while its Fe(III) counterparts adopt distinct pentagonal bipyramidal geometries.

Notably, solution studies reveal that dapGT²⁺ maintains pronounced selectivity for $U^{VI}O_2^{2+}$ over $V^{V}O^{2+}$, outperforming amidoxime-based chelators under competitive aqueous conditions. By contrast, the more flexible H_2glyxGT²⁺ ligand forms less stable but still selective uranyl complexes in solution. In $U^{VI}O_2^{2+}$-H_2glyxGT²⁺ aqueous mixtures, mono-chelated uranyl species were formed at low percentages at acidic pH, the formation of a mixed acetate-glyxGT uranyl species $[U^{VI}O_2(\text{glyxGT})(\text{ac})]^+$ was observed in the pH range 4-7, while for pH > 8 hydrolytic complex $[U^{VI}O_2(\text{dapGT})(\text{OH})]^+$ was formed. Overall, this study highlights how ligand denticity and equatorial plane saturation govern metal ion selectivity in water, establishing key design principles for next-generation actinide chelators applicable to uranium extraction, aqueous waste treatment, and environmental remediation.

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From Sensor Supports to Water Remediation: Starch-Based Bioplastics as Green Adsorbents for Dyes

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There is a pressing global challenge related to water resource contamination, further exacerbated by the limited availability of drinking water in many regions of the world. In this context, particular concern is associated with the presence of synthetic dyes in industrial wastewater. These compounds are especially problematic due to their chemical stability, persistence in aquatic environments, and resistance to conventional treatment methods, posing significant risks to both ecosystems and human health [1].

Within this framework, adsorption is recognized as one of the most effective and widely applied techniques for dye removal due to its operational simplicity and efficiency. Biosorption, based on the use of biologically derived materials, has emerged as a promising alternative to traditional methods, offering advantages in terms of sustainability, cost-effectiveness, and environmental compatibility [2].

This study focuses on the development and application of bioplastic biofilms composed of starch, glycerol, and carboxymethyl cellulose (CMC), initially designed as solid supports for sensor devices [3–4, oral Biesuz], and here investigated for their potential in bioremediation processes. These materials exhibit a high affinity for dyes, and the carboxylic groups present in CMC are expected to act as cation exchangers.

The biofilms were engineered to achieve an optimal balance between mechanical stability, solubility, and controlled swelling, ensuring their practical applicability in aqueous environments, where the trade-off between usability and intrinsic biodegradability is of paramount importance [3–4]. In previous investigations, the biofilm composition was optimized through different Mixture Design approaches. The same formulations presented in [4] were employed in this study, enabling a systematic evaluation of how different component ratios influence key material properties.

To investigate adsorption mechanisms, three dyes - Safranine T (cationic), Titan Yellow (anionic), and Blue Tetrazolium Chloride (cationic) - were examined. Adsorption experiments were conducted using UV–Vis spectroscopy to monitor the dye concentration in solution over time. Adsorption kinetics were interpreted using the Homogeneous Particle Diffusion Model (HPDM), which identifies either film diffusion or intraparticle diffusion as the rate-limiting step. Equilibrium data were analyzed using established isotherm models, including Langmuir, Freundlich, and BET, providing insights into adsorption capacity and surface heterogeneity.

The cationic dyes were adsorbed within 24 hours, with removal efficiencies of 80–90% and an estimated capacity of approximately 0.05 mmol g^{-1} (mass referred to dry biofilm). Interestingly, the anionic dye was also adsorbed from pure water, with a removal of about 20%, increasing to nearly 100% upon addition of 0.5 M KCl.

In all cases, no single sorption mechanism could be identified; rather, the process appears to involve multiple concurrent phenomena, including ion exchange, hydrophobic interactions, and electrostatic effects [5].

Beyond single-component systems, the study explored more realistic scenarios involving multi-dye mixtures and real matrices such as tap water. In practical applications, such as industrial effluents, complex mixtures of contaminants are typically present, and freshwater is the most common medium.

To address the issue of overlapping spectral signals in multicomponent systems, chemometric techniques - including Partial Least Squares (PLS) regression and Multivariate Curve Resolution (MCR) - were employed, with MCR showing superior analytical performance for dye detection. These findings support the feasibility of practical applications, even in the presence of multiple dyes simultaneously. In such systems, dyes were removed almost quantitatively. Further experiments are ongoing, particularly exploring the use of these bioplastics in column and/or packed-bed processes.

Conversely, the composition of the aqueous medium influenced adsorption behavior: the presence of competing ions reduced the sorption of cationic dyes, as expected, while promoting the sorption of the anionic dye. However, ion concentrations in tap water were not sufficient to achieve the complete removal observed in 0.5 M KCl.

Overall, the results demonstrate that starch-based bioplastic biofilms incorporating CMC represent a viable, sustainable, and cost-effective solution for the removal of dyes from contaminated water. By extending the investigation from idealized systems to more complex, real-world conditions, this work provides valuable insights into both the potential and limitations of these materials, contributing to the advancement of bio-based technologies for wastewater treatment and environmental remediation.

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Metal-Dependent Binding Fingerprints: Non-Selective Albumin vs Selective G-Quadruplex Recognition in 8-Hydroxyquinoline-2-Carboxylic and Kojic Acid Complexes

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If complexes of Pt, Ag, Au and other platinum-group elements show promising activities, these metals are relatively rare and expensive, and rather toxic for the organism. Thus, more common elements are also being tested, in particular the essential ones such as iron [1], copper [2] and zinc [3]. TRansforming metal Ions and Low-cost LIgands into next generation metallodrugs (TRILLI) is a national project that aims at unveiling key aspects for a rational design of new metal complexes (MCs) and boost their development as metallodrugs. It will, *inter alia*, determine the binding of several selected low-cost MCs to biomolecules, examine the relationships between the biological activity and thermodynamic stability of the MCs and investigate the role of the organic ligands.

We present here the results obtained for the binding of a panel of metal complexes made from different metal centers (Cu^{2+}, Zn^{2+}, Fe^{3+}) and the ligands shown below (Figure 1) to bovine serum albumin (BSA) and to DNA G-quadruplexes of different topologies.

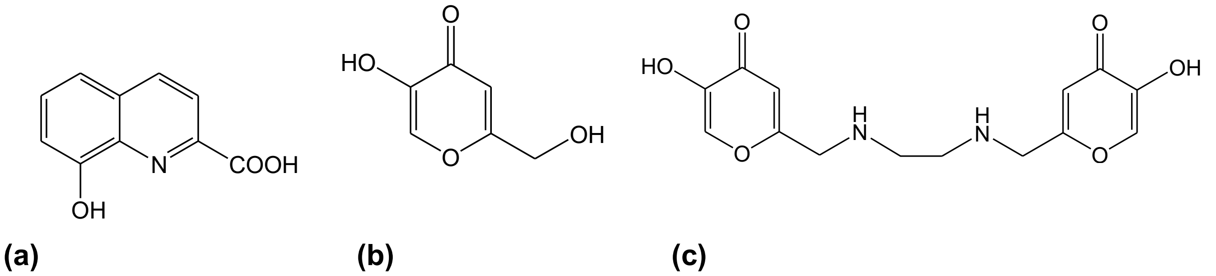

Figure 1. The ligands considered in this study: (a) 8-hydroxyquinoline-2-carboxylic (8-HQA); (b) kojic acid (KA); (c) 2,2'-[ethane-1,2-diylbis(iminomethanediyl)]bis(5-hydrohy-4H-pyran-4-one) (S2).

Spectrofluorimetric titrations are performed under different conditions for all the systems surveyed. The results indicate that all MCs may be transported by the major blood protein albumin with a not so distinctive fingerprint of the binding features. On the contrary, the binding to G-quadruplexes is found to be very selective, with respect to all metal center, type of ligand and G-quadruplex geometry.

Figure 2. The DNA G-quadruplexes of different topologies considered in this study.

Overall, these aspects are compared and discussed in search for a rationalization of the binding mechanism and the identification of the more promising MC.

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Glutathione-Iron Oxide Nanoparticles for Sustainable Arsenic Remediation in Rice Fields

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The deterioration of water quality due to natural and anthropogenic processes has intensified concerns about the presence of toxic heavy metals in aquatic systems, including Cd, Pb, Hg, and As. In rice cultivation systems, water quality is particularly critical due to exchanges between paddy waters and regional shallow aquifers used for human consumption. The high capacity of rice to accumulate arsenic (As) makes these systems especially relevant from both environmental and food safety perspectives. Under flooded conditions,As mobility and bioavailability are mainly governed by chemical speciation (As(III)/As(V)) and interactions with soil components such as metals and organic matter, highlighting the importance of understanding arsenic distribution for effective remediation strategies. [1]

Within this context, ARSENIX- Project 2023.13958.PEX- addresses arsenic remediation in rice paddy systems through an integrated chemical strategy combining environmental characterization (soils and water), nanomaterial design, and mechanistic speciation studies.[2] Rice paddy water (borehole and floodwater) and soils from a Portuguese field site (COTArroz, Salvaterra de Magos) were characterized by ICP-MS at different stages of the cultivation cycle, with water sampled across the field during growth and soils collected before and post-harvest at corresponding locations. This dataset provides a realistic baseline of As and coexisting elements, establishing the environmental framework of the study.

This system-level understanding underpins the development of superparamagnetic iron oxide nanoparticles (SPIONs) designed for arsenic removal from aqueous media. Their magnetic properties enable efficient separation, while high surface reactivity and affinity for arsenic species ensure effective adsorption. Selectivity was enhanced through functionalization with glutathione (GSH), a thiol-containing ligand with strong affinity for As(III), promoting As–S interactions and improving nanoparticle stability, yielding GSH-functionalized SPIONs (SPGS).[3] The nanoparticles were thoroughly characterized by UV–vis, PXRD, FTIR, TEM, DLS, and zeta potential, confirming their structure. SQUID measurements further revealed their superparamagnetic behavior.

Potentiometric equilibrium studies were used to elucidate arsenic speciation and interaction mechanisms in aqueous media, both with relevant ligands (GSH/GSSG) and under conditions simulating nanoparticle surface interactions. Together with speciation modelling, these results enabled characterization of As(III)/GSH and As(V)/GSSG systems, providing insight into complex formation, stability, and redox behavior. Stability constants and thermodynamic parameters were determined as a function of temperature, ionic strength, and pH, enabling a quantitative description of arsenic speciation under environmentally relevant conditions and supporting a mechanistic understanding of immobilization processes.

The adsorption capacity of SPGS in real rice paddy waters has been evaluated, including regeneration and reuse cycles, together with assessment of the relationship between magnetic separation efficiency and adsorption performance.

By integrating environmental characterization, nanoparticle engineering, and chemical speciation modelling within a single coherent framework, this study provides a chemically driven strategy for arsenic remediation in rice paddy systems and other complex aquatic environments.

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Selective binding in a sustainable framework: *trans*-aconitic acid and divalent metal cations

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Trans-aconitic acid (*t*AA) is a naturally occurring, biodegradable tricarboxylic compound emerging as a sustainable alternative to conventional, poorly degradable chelating agents. In this context, its behavior in $KCl_{(aq)}$ solution (I = 0.10-1.00 mol dm^{-3}) at T = 298.15 K was investigated, focusing on acid–base properties and interaction with environmentally relevant cations (Ca^{2+}, Mg^{2+}, Cu^{2+}, Co^{2+}, and Zn^{2+}). Potentiometry, UV–Vis spectrophotometry, and $^1H/^{13}C$ NMR spectroscopy were combined with DFT calculations to link the thermodynamic data with molecular-level insights. In particular, *t*AA forms weak, yet well-defined complexes, with speciation depending on the metal ion: multiple species for Ca^{2+}, Mg^{2+}, and Zn^{2+}, fewer for Co^{2+} and a single dominant species for Cu^{2+}. Sequestering ability, evaluated through $pL_{0.5}$ and pM parameters, reveals a preferential affinity toward Cu^{2+} and Mg^{2+}, consistent with DFT results, which also clarify deprotonation and coordination trends influenced by ionic radius. Binding energies confirm more favorable interaction with Cu^{2+} and Mg^{2+} than Ca^{2+}. Although literature comparison indicate that citric acid remains more effective, *t*AA shows competitive performance compared to other low-molecular-weight carboxylic acids and forms more stable complexes than its analogue tricarballylic acid. Overall, these findings support its potential role as an eco-compatible ligand for applications in water treatment and metal ion control under specific environmental and industrial conditions [1].

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A NEW [20]-MEMBERED AZAMACROCYCLE WITH A LARGE CAVITY

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The α-therapy is one of promising methods in nuclear medicine as α-particles have a short range in tissue and a high linear energy transfer. However, this type of treatment is almost exclusively limited to "large metal ions" such as $^{212}Bi^{3+}$, $^{212}Pb^{2+}$ or $^{225}Ac^{3+}$ which impose specific requirements for suitable ligands. More specifically, these ligands should possess large ligand cavities with multiple donor atoms (coordination number 8–10). The examples of such ligands are MACROPA [1,2] and PYTA [3,4,5]. In this work, we explored coordination behaviour of a ligand featuring even larger macrocyclic cavity in [20]-membered azamacrocycle bearing four acetic pendant arms (PPTA, Figure 1).

This new ligand can be prepared by a template synthesis with La^{3+} ion followed by borohydride reduction and alkylation of four amino groups with a bromo-acetate and final hydrolysis of the ester groups. Since lanthanide(III) ions are considered analogues of actinide ions regarding their chemistry which is defined by their ionic radius, coordination behaviour of the ligand was described across a series of rare-earth metal complexes.

The $\log K_A$ values of PPTA were determined by potentiometry. The results show that all four amine groups of macrocycle are protonated first ($\log K_{1–4}$ 9.20, 8.54, 6.96, and 6.30) followed by protonation of the carboxylate pendants ($\log K_{5–6}$ 2.26 and 1.41) and the four-protonated species is present in a wide pH range. (Figure 1). Unlike other polyazamacrocyclic ligands with coordinating pendant arms, complexation of the metal ions requires a relatively high pH (lanthanide(III) complexation starts approx. above 6.5). Unexpectedly, PPTA was found to form complexes with a relatively low thermodynamic stability in comparison with smaller macrocycles as PYTA. The stability constants range from $\log K_{YbL} = 11.25$ to $\log K_{CeL} = 15.21$.

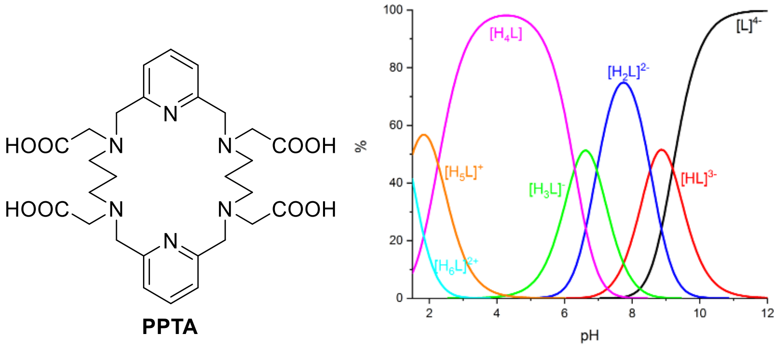

Figure 1. Chemical formula of PPTA and its distribution diagram in aqueous solution.

Studies of formation kinetics revealed that complexation occurs almost immediately within the studied pH range (approx. 6.0–7.0). It is probably caused by flexibility of the macrocyclic skeleton and the complexation rates are approaching those of acyclic ligands. The complexation yields mixtures of several isomers. For larger lanthanide(III) ions, the major isomer was successfully isolated and structurally characterized. It contains two pendant arms coordinated above and two carboxylate groups below the N_6 plane of the macrocycle (Figure 2).

Surprisingly, the large size of the ligand cavity enables formation of dinuclear complexes of even with relatively large lanthanide(III) and Pb(II) ions ($\log K_{\mathrm{Pb2L}}$ = 8.33) in significant abundance. The structure of the dinuclear complex with Pb(II) ion was determined by X-ray diffraction and is shown in Figure 2.

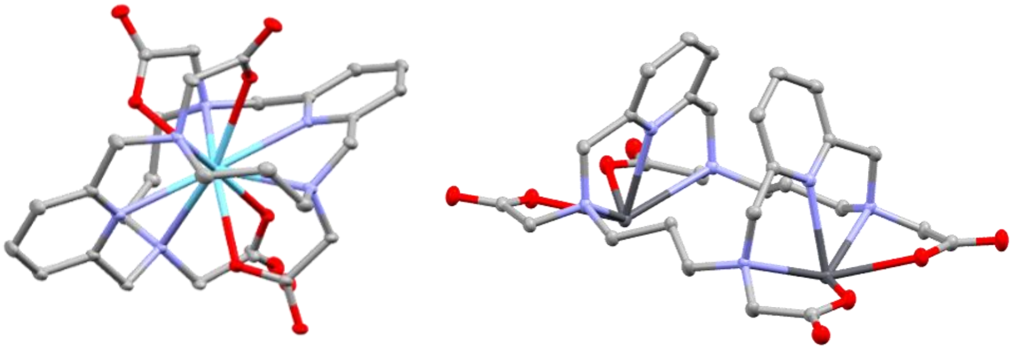

Figure 2. Structure of a major isomer of Ln(III)-PPTA complex (left) and structure of dinuclear complex of PPTA with Pb(II) ions (right).

Overall, the investigated [20]-membered macrocycle derivative PPTA forms complexes with lanthanide(III) ions rapidly. However, due to its insufficient thermodynamic stability and kinetic lability, this ligand is not suitable for applications in nuclear medicine. Nevertheless, its ability to incorporate two large metal ions within a single macrocyclic cavity makes this ligand an interesting subject for structural studies.

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Enantiomeric analogues of the clavanin C antimicrobial peptide and their Cu^{2+} and Zn^{2+} complexes in the fight against MRSA

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Antimicrobial resistance remains one of the most pressing challenges in modern medicine, with methicillin-resistant Staphylococcus aureus (MRSA) representing a major source of persistent and hard-to-treat infections. This highlights the urgent need for novel therapeutic strategies that can overcome resistance mechanisms [1].

Antimicrobial peptides (AMPs) are promising candidates due to their broad-spectrum activity and effectiveness against resistant strains. Their properties can be further modulated through interactions with metal ions such as Cu^{2+} and Zn^{2+}, which may enhance their antimicrobial potency [2]. However, the clinical applicability of AMPs is often limited by their susceptibility to enzymatic degradation.

To address this limitation, peptide modification strategies such as D-amino acid substitution and the *retro-inverso* approach have been developed. The latter combines sequence reversal with chirality inversion, enabling the design of peptidomimetics that retain structural features of the parent peptide while exhibiting significantly improved proteolytic stability [3].

In this study, we explore *retro-inverso* analogues of clavanin C [4] and evaluate their coordination behavior with Cu^{2+} and Zn^{2+} ions, as well as their structural and biological properties. Our results demonstrate that these modifications lead to enhanced enzymatic stability while maintaining or improving antimicrobial activity. Notably, the *retro-inverso* derivatives and their metal complexes exhibit increased efficacy against MRSA compared to the native peptide.

These findings support the potential of *retro-inverso* peptide design combined with metal coordination as a viable strategy for developing stable and effective antimicrobial agents.

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PLATINUM NANOPARTICLES IN ROAD DUST IN POLAND OVER QUARTER OF THE CENTURY. SINGLE PARTICLE ICP-MS APPROACH

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The automotive sector constitutes the dominant global consumer of platinum group elements (PGEs), particularly palladium (Pd), platinum (Pt), and rhodium (Rh). In 2024, the consumption of these metals in automotive applications reached 258.6 tons for palladium, 106 tons for platinum, and 28.9 tons for rhodium, underscoring their critical role in modern emission control technologies [1]. Internal combustion engine vehicles (ICEVs) are equipped with three-way catalytic converters (TWCs), typically installed at the front section of the exhaust system. These devices incorporate a ceramic monolith coated with catalytically active PGEs (Pt, Pd, Rh), which facilitate the simultaneous reduction of harmful exhaust components, including carbon monoxide (CO), nitrogen oxides (NO_x), and unburned hydrocarbons (HCs). The implementation of TWCs enables substantial emission reductions, achieving decreases of up to approximately 90% for CO and NO_x, and around 80% for hydrocarbons.

Importantly, the reliance on PGEs extends beyond conventional ICEVs to include plug-in hybrid electric vehicles (PHEVs) and range-extended electric vehicles (REEVs), both of which retain internal combustion engines and therefore require PGE-based catalytic after-treatment systems. Consequently, despite the progressive electrification of the automotive sector, demand for PGEs remains significant.

However, the widespread use of PGE-containing catalysts has raised environmental concerns. Notably, the emission of platinum and palladium from automotive exhaust systems has been widely documented [2,3]. These emissions result from mechanical abrasion, thermal degradation, and chemical processes that affect the catalyst surface during operation. The released particles, which may consist of metallic PGEs or fragments of catalyst material containing PGEs, are present in airborne particles or deposited on road surfaces and adjacent soils. From there, they can be transported via surface runoff into aquatic systems or accumulate in sewage sludge.

Earlier assumptions suggested that platinum emitted from catalysts predominantly existed in an inert metallic form [4]. However, subsequent studies have demonstrated that a fraction of emitted PGEs may occur as nanoparticles, soluble complexes, or other bioavailable species [5]. The speciation of PGEs in the environment is strongly influenced by local physicochemical conditions, including pH, redox potential, and the presence of organic ligands. These transformations directly affect their mobility, bioavailability, and potential ecotoxicological impacts on plants and freshwater organisms [6].

In this context, the development of advanced analytical methodologies capable of distinguishing between different chemical forms of PGEs and monitoring their environmental transformations is of paramount importance. Such approaches are essential for accurately assessing the environmental fate, transport mechanisms, and ecological risks associated with PGE emissions from the automotive sector.

In this study, single-particle inductively coupled plasma mass spectrometry (sp ICP-MS) was used to characterize and quantify the nano- and dissolved-phase forms of platinum released from road dust into rainwater. The ultrasonic extraction procedure was used to leach platinum species. The strength of sp ICP-MS method lies in the possibility to obtain different types of analytical information, such as mass and particle number-based concentration, particle size and size distribution, as well as the concentration of dissolved forms of metal. Helium, as a collision gas, and ammonia, as a reactive gas, were tested to eliminate spectral interference during platinum determination. The developed method enabled the detection of platinum nanoparticles of sizes ≥ 16 nm in samples at very low concentration levels ($2.0 \cdot 10^5$ particles/L, 0.07 ng/L Pt).

Road dust samples collected since 2000 from the main intersection in Białystok were analyzed to determine the content of rain-soluble platinum nanoparticles.

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CAN THERMODYNAMIC AND CHEMICAL SPECIATION OF TRYPTOPHAN METABOLITES METAL COMPLEXES EXPLAIN THEIR BIOLOGICAL ACTIVITY?

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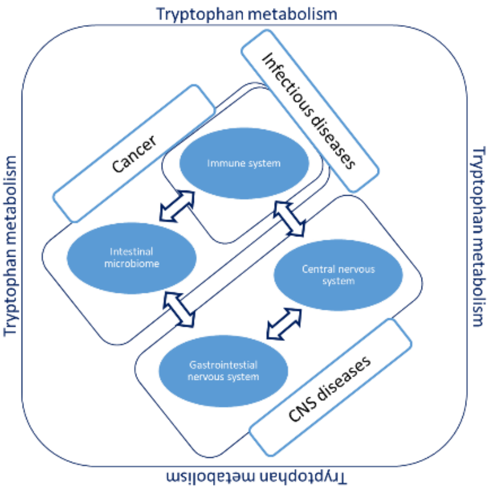
Tryptophan metabolites (TrpM) produced along the kynurenine pathway are increasingly recognized as key players in colorectal cancer (CRC) through their roles in immune regulation, oxidative stress, and microbiota–host interactions. A critical and yet underexplored aspect of this biology is metal coordination. As quinoline-type ligands, TrpM protonation state and metal-binding equilibria change with pH, ionic strength, and biological environment, which ultimately determine which chemical species are bioavailable and biologically active. Here, we present the results obtained under the scope of TrypGut project, an integrated work combining solution thermodynamics and chemical speciation with biological outcomes, aiming to rationalize (and ultimately predict) the behavior of TrpM and their metal complexes in CRC-relevant contexts.



We established a robust thermodynamic platform for key TrpM (8-hydroxyquinoline-2-carboxylic (8-HQA), kynurenic (KynA), and xanthurenic acids (XA)), evaluating the influence of factors such as temperature and molecular structure, enabling physiologically relevant speciation modeling. For this purpose, complementary techniques were applied, such as potentiometry, UV–Vis spectrophotometry, Isothermal Titration Calorimetry (ITC), and NMR [1-3]. 8-HQA emerged as a good chelator, forming well-defined complexes with Ga^{3+}, Fe^{3+}. 8-HQA complexes with divalent metal cations follow the Irving–Williams stability trend [4,5]. These coordination modes were further validated by EPR and quantum mechanical calculations. Conversely, KynA acted predominantly as a bidentate ligand, while XA exhibited ligand-dependent complexation within physiological windows.

To bridge chemistry and biology, we assessed the interactions of TrpM and its metal complexes with human serum albumin (HSA) and DNA. While 8-HQA showed weak DNA binding, which decreased upon metal coordination, XA's affinity for DNA was enhanced by metals. HSA binding was found to be strongly dependent on the specific metal center. Finally, cell-based assays and microbiota studies, including radiation-exposure models, demonstrated that TrpM–metal speciation translates into distinct, strain-dependent biological responses, including anti-inflammatory potential and modulation of bacterial radioresistance [6].

Overall, this work provides a unified, speciation-driven framework for interpreting TrpM metallochemistry and supports the development of metal-tuned TrpM systems as possible candidates for CRC-related therapeutic strategies targeting both tumor biology and microbiota-mediated effects.

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Cracking the Code of CntA: Rational Design of Metallophore-Based Probes to Combat AMR

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The World Health Organization (WHO) identifies antimicrobial resistance (AMR) as one of the ten most pressing global threats to public health and development [1]. This challenge is compounded by the limitations of current diagnostic methods, which are often invasive, time-consuming, and lack the selectivity required to distinguish bacterial infections from sterile inflammation or other pathological conditions [2]. Together, these limitations underscore an urgent need for the development of innovative diagnostic strategies.

A promising approach for addressing this need involves the use of metallophores, small molecules naturally produced by microorganisms, to acquire essential metal ions from their environment [3]. Particularly, Staphylopine (StP), a metallophore produced by *Staphylococcus aureus*, has attracted significant attention due to its ability to chelate metals such as Zn^{2+}, Cu^{2+}, and Fe^{3+} [4,5]. This mechanism allows bacteria to thrive in metal-depleted environments by circumventing the host's nutritional immunity, directly enhancing their virulence and resistance.

However, the synthetic complexity of StP remains a major bottleneck for its practical application. To expand chemical diversity and improve synthetic accessibility, we propose the development of novel StP-inspired metallophore analogues, using noncanonical amino acid design [6]. To guide the rational selection of these analogues, we conduct a preliminary study on the interaction of the new StP copper-based analogues and CntA, the extracytoplasmic solute-binding of the StP/metal transportation system.

Our work begins with molecular dynamics (MD) simulations performed on three distinct systems: the X-ray resolved apo-CntA and CntA/StP/Zn^{2+} complex [7], and a CntA/StP/Cu^{2+} complex modelled by substitution of the metal ion in the Zn^{2+}-bound structure. This comparative approach allows us to characterize the conformational dynamics of the free protein, validate our simulation protocol against experimental data, and predict the structural effects of replacing Zn^{2+} with Cu^{2+}. Subsequently, various StP copper-based analogues will be evaluated. By analyzing binding stability, interdomain conformational changes, and interaction networks within the CntA binding site, we aim to determine if these new analogues retain functional recognition by the StP/metal transportation system. These findings will provide the basis for the rational development of metallophore-based probes for the selective imaging and diagnosis of bacterial infections.

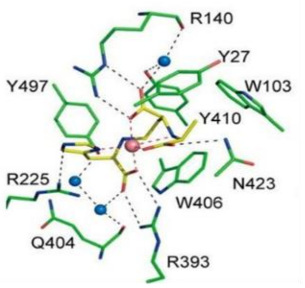

Figure 1. Detailed interactions between CntA and StP/Zn^{2+}. Dashed lines represent hydrogen bonds or coordination bonds. Water molecules are blue spheres. Adapted from *"Mechanistic insights into staphylopine-mediated metal acquisition"* by L. Song *et al. [7]*

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Bioactivity screening of novel Cu(II) and Zn(II) malonate complexes

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The discovery of new bioactive compounds in modern research vastly revolves around small organic molecules and their derivatives. However, an alternative approach is to conjugate these organic ligands with transition metal ions, providing coordination compounds based on Ag, Cu, Zn, Ga etc., many of which have already found success in clinical practice [1]. At first, all newly prepared compounds need to be carefully screened for their biological activity profile to not only determine their unwanted toxicity and potential side effects, but mainly whether they can prove effective in binding to target biomacromolecules, inhibiting desired enzymes or exhibiting cytotoxic, antimicrobial and/or other activities in general. Another important factor is that these molecules need to display favorable pharmacokinetic properties, exhibiting sufficient affinity to human serum albumin (HSA) as the main transport protein in the blood plasma [2].

In this study, two newly-synthesized complexes containing malonate ligands (**MA**), labeled **CuMA** and **ZnMA** (Fig. 1) according to the central atom, were screened for their pharmacokinetic, antioxidant and anticancer properties. Fluorescence binding assays revealed that **CuMA** is a more effective HSA binder than **ZnMA**, albeit its affinity to HSA was only in the range of 10^2-10^3 M^{-1}. The addition of **ZnMA** and the **MA** ligand to HSA did not lead to any significant changes in the fluorescence spectra even at higher concentrations, implying that there is little to no interaction between these compounds and the protein. Thermodynamic analysis of the **CuMA**-HSA binding further revealed that the process is an entropy-driven, endothermic reaction, while conformational studies predicted that the binding almost evenly affects both the polypeptide backbone and the fluorophores. Topoisomerase (Topo) inhibition assays also highlighted **CuMA** as the most potent compound, displaying certain degrees of both Topo I and Topo IIα inhibition as opposed to **ZnMA** and the **MA** ligand itself that did not exhibit any inhibitory activity. Conversely, DPPH antioxidant assay revealed that the **MA** ligand retained better antioxidant activity than the two metal complexes. Although the overall biological activity of the studied compounds was quite low, the results provide novel guidelines for the future design of more potent metal complexes.

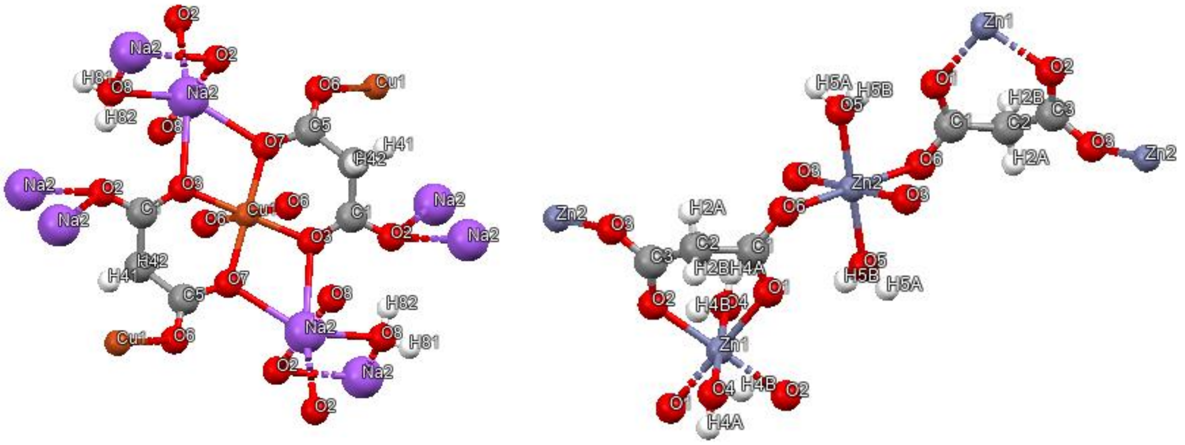

Figure 1. Structure of the studied complexes **CuMA** (left) and **ZnMA** (right)

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Ag(I) and Zn(II) complexes with 3-substituted picolinic acid derivates: solution equilibria, structural characterization and biological activity

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Derivatives of picolinic acid are gaining prominence as pendant groups in linear or macrocyclic chelators, enabling effective metal ion coordination for potential biomedical uses. Classified as non-proteinogenic amino acids, these compounds function as the human body's chief natural chelators, operating as multidentate ligands that bind diverse metal ions. They offer significant therapeutic promise by suppressing cell proliferation, inducing cell cycle arrest, triggering apoptosis in cancer cells, and impeding HIV progression [1,2].

In this work, the coordination ability of two picolinic acid derivatives, 3-methylpicolinic acid (3-MePicH) and 3-hydroxypicolinic acid (3-OHPicH), with Ag(I) and Zn(II) ions examined in aqueous solution and in the solid state. In the solid state, the complexes were characterized using techniques such as elemental analysis, IR spectroscopy, and thermal analysis. In addition, the prepared complexes were evaluated for their antimicrobial and anticancer activity. Potentiometric titrations (25 °C, $I = 0.1$ M) revealed marginal effects of 3-position substitution on pyridine nitrogen basicity, with Ag(I) forming mononuclear species and Zn(II) yielding multiple species including a crystallographically confirmed *N, O*-bidentate bis-complex of modestly reduced stability versus picolinate analogs due to steric factors. Hydroxy-substituted systems showed precipitation challenges but identifiable protonated complexes consistent with literature. pH-dependent ^{1}H NMR titrations further confirmed *N, O*-chelation through systematic chemical shift changes in aromatic protons. Time-dependent ^{1}H NMR studies (96 h, 1% DMSO) demonstrated excellent solution stability with no evidence of ligand dissociation. The prepared Ag(I) and Zn(II) complexes, along with free ligands and metal salts, were screened for antimicrobial activity against Gram-positive/negative bacteria and fungi, as well as anticancer effects on selected cell lines. Silver(I) complexes exhibited selective antimicrobial and anticancer activity, highlighting the value of picolinate substitution for tuning Ag(I) bioactivity.

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Hydroxy-functionalized ionic liquids and their iron compounds

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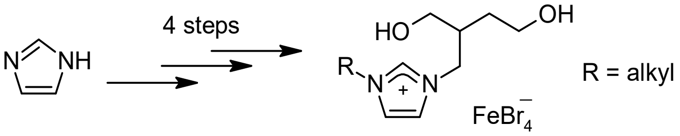
Metal-containing ionic liquids have attracted considerable attention over the past decade due to their unique magnetic and redox properties. These features, together with their ionic structure and low melting points, led to applications in fields of analytical microextraction and non-enzymatic sensing. In our group, we focus on their use in homogenous catalysis, where ionic liquids containing iron [1] and vanadium [2] were found to be highly active in the formation of polymeric networks though epoxy–anhydride copolymerization.



Scheme 1: Synthesis of functionalized ionic liquids.

Our interest in hydroxy-functionalized ionic liquids arises from the need to incorporate the ionic liquid into the polymeric network. This approach is expected to minimize catalyst leaching from the cured materials while also modifying their properties. A series of hydroxy-functionalized, imidazolium-based ionic liquids containing iron in the counterion has been synthesized via a four-step protocol starting from imidazole and dimethyl itaconate (Scheme 1). An ester-functionalized imidazole, obtained through an aza-Michael-type addition, was reduced and quaternized by alkyl bromide. The final products were prepared by reaction with anhydrous iron(III) bromide. The ionic liquids were characterized using analytical and spectroscopic methods. Evaluation of their catalytic activity and their incorporation into polymeric networks is currently underway.

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Cyclodextrins-flavonoid inclusion complexes for dental therapies

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The successful repair of dental tissues remains a challenge as it requires proper remineralization of collagen. To achieve this, inhibition of enzymatic degradation at the interface between the restorative material and the tooth structure is necessary [1]. Flavonoid antioxidants are promising candidates for this purpose due to their specific properties and low toxicity [2]. They are, however, susceptible to degradation over time and this limits their clinical applications. To allow these molecules to protect the materials for several weeks, a drug-delivery carrier is needed to stabilise and gradually release the antioxidant. This work assesses cyclodextrins as carriers for flavonoids, aiming to promote inclusion complex formation and their potential integration into dental repair materials. Commercial natural cyclodextrins and synthetic ones produced following previously established synthetic routes were used in this study. The encapsulation of the flavonoid antioxidants was characterised using experimental methods (^{1}H NMR and UV–Vis spectroscopy) and theoretical methods (Molecular Dynamics). Finally, the best candidates have been tested *in vitro* using three-dimensional collagen fibril models. Cyclodextrins have shown a remarkable ability to form inclusion complexes with flavonoid antioxidants, effectively shielding these compounds from oxidative degradation and hydrolysis. Furthermore, cyclodextrin-flavonoid complexes facilitate a controlled and sustained release of the active molecules, which is especially beneficial for applications in tissue engineering and dental biomaterials, where extended antioxidant activity can support collagen integrity and promote remineralisation.

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Synthesis, Structural and solution Characterization, of Uranium(VI) and Vanadium(IV/V) Complexes with Catechol-Derived Ligands

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The selective complexation of the uranyl ion (UO_2^{2+}) remains a key challenge for uranium recovery from seawater, where low concentrations and strong competition from other metal ions such as vanadium significantly limit extraction efficiency. In this work, we investigated the coordination chemistry of U(VI) and V(IV/V) with catecholate and oxime-based ligands, aiming to probe structure-property relationships relevant to selective uranyl binding.

A series of uranium and vanadium complexes were synthesized using 2,3-dihydroxybenzaldehyde (H_2DHBA) and its oxime derivative (H_3dihybo). These systems yield di- and tetra-nuclear U(VI) species, alongside a trinuclear mixed-valence vanadium complex, depending on ligand functionalization and reaction conditions. Structural characterization by single-crystal X-ray diffraction revealed that the uranium-H_2DHBA species adopt pentagonal bipyramidal geometries, while the uranium-H_3dihybo complexes promote higher nuclearity structures with distortions in their geometry.

Complementary spectroscopic (UV-vis, IR, NMR) and electrochemical studies were employed to examine the solution behavior, ligand coordination modes, and redox properties. UV-vis titrations demonstrated systematic changes with different metal-to-ligand equivalents in solution, indicating controlled complex formation, while cyclic voltametric experiments were characterized by ligand-based oxidations.

Synthesis of novel hydroxy-pyridinone conjugates and investigation of their metal-binding properties for targeted anticancer applications

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The underdeveloped vascular network of tumor tissues results in significantly lower oxygen levels compared to healthy cells, offering a strategic target for highly selective pharmacological interventions. The characteristic hypoxic environment of malignant growths enables the selective reduction of inert Co(III) complexes with appropriate redox potentials, leading to the triggered release of bioactive ligands. If the complexed ligand possesses ambidentate properties, it may further facilitate the coordination of a secondary metal ion known for its anticancer activity.[1, 2]

The redox potential of Co(III) complexes can be precisely tuned by utilizing ligands with a donor set. Previous research has demonstrated that redox and coordination behaviors can be refined by modifying the aromatic or aliphatic nature of the 4N unit, as well as the functionality of the 2O component.

The objective of this work was to synthesize novel ambidentate hydroxy-pyridinone conjugates and to conduct a comprehensive study of their metal-binding capabilities. We modified the coordinating (N,N) terminus of the ligands by incorporating pyridine, pyrrole, or imidazole rings.[3] This allowed us to investigate how the position of the N-donor atom influences complex formation. Furthermore, we examined how varying the length of the aliphatic chain connecting the hydroxy-pyridinone and the heteroaromatic ring affects the interactions with $[(\eta^5\text{-Cp}^*)\text{Rh}]^{2+}$ or $[(\eta^6\text{-}p\text{-cym})\text{Ru}]^{2+}$ ions.

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Coordination Chemistry and Isomerism of Lanthanide(III) Complexes with a Tripyridinophane Ligand

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Macrocyclic ligands are widely studied metal chelators with applications in radiomedicine, catalysis, and related fields, owing to their high stability and kinetic inertness. In particular, ligands designed for larger metal ions such as lanthanides, lead, and bismuth are of interest due to their medically relevant radioisotopes. For these applications, the rates of complex formation and dissociation, together with stability under physiological conditions, are critical.

In this work, we focus on a tripyridinophane-based macrocyclic ligand containing three pyridine and three amine donor groups [1]. The ligand is functionalized with three acetate pendant arms that, together with the macrocyclic scaffold, provide a coordination number of nine. We use this ligand as a model system to gain a clearer understanding of its coordination behavior with lanthanide(III) ions.

The presence of pyridine units is expected to increase the rigidity of the complexes, which can influence both their stability and kinetics. The system forms two isomeric species that differ in the orientation of the pendant arms upon coordination. These isomers were identified using HPLC, NMR spectroscopy, and single-crystal X-ray diffraction.

We further explore how factors such as pH and temperature affect the formation and distribution of these isomers, as well as their interconversion. The data provide insight into the properties and potential limitations of these compounds in practical applications, which remain relatively unexplored despite reports of isomerism in similar scaffolds [2].

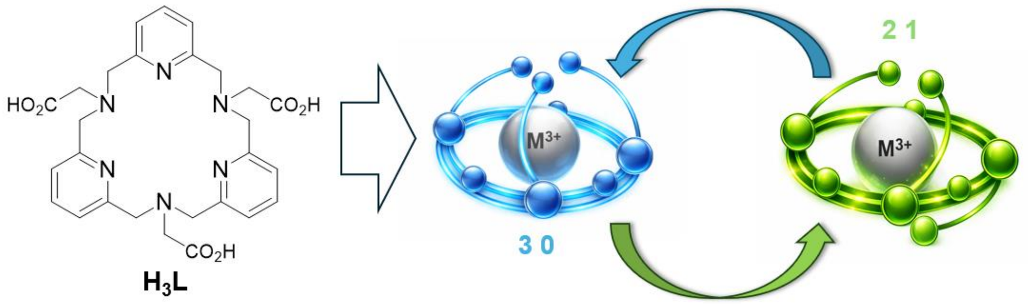

Fig. 1. Ligand investigated in this work.

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In silico optimization of tunable pH-indicating dye mixtures

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pH is a key target parameter in a broad range of applications from environmental to industrial and biomedical [1] since chemical and biological properties of many substances are dependent on the pH of their mediums, like solubility of metals, the toxicity of some species and chemical reactions rate. [2] Therefore, measuring pH in various environments represents a crucial analytical task.

Glass pH electrode is universally known as the principal pH measurement tool, and it is currently employed in laboratories, factories, hospitals, and so on. [3] However, glass pH electrode has few but crucial disadvantages, like the size, rigid design, fragility, unsuitability for long-term monitoring or small sample volumes. [1] Most of these limitations can be overcome by exploiting pH indicators that change their color in the pH range of interest and ensure a more easy, robust and handy estimation of pH. [4]

Considering the flip side of pH indicators, we have to keep in mind that each single dye exhibits a quite limited pH range in which its color change is clearly visible, generally considered around 1 log unit above and below the pK_a, and this range can be further reduced whether the protonated or deprotonated species are characterized by less visible hues. For this reason, some pH-indicating dye mixtures have been developed over the years for specific applications such as Tashiro indicator (Methyl Red + Methylene Blue, pH 4.4–6.2), Screened Methyl Orange (Methyl Orange + Xylene Cyanol, pH 3.1–4.4) and Screened Methyl Red (Methyl Red + Methylene blue, pH 4.5–6.3).

In this context, we develop an *in silico* workflow to design pH-indicating dye mixtures that can be tuned in terms of color variation and pH range, according to target application requirements, and fully optimized for pH measurements both by UV-Vis spectroscopy and colorimetric analysis. The experimental work for the optimization is reduced to the minimum since only a simple library of common pH indicators is required, thus enhancing the approach sustainability, while the entire workflow can be easily automatized to reduce time and effort.

The overall workflow can be divided into two main parts, as summarized in Figure 1: single dye simulation and dye mixture optimization. As for single dye simulations, spectra of all the pH-dependent species are firstly acquired at few significant concentrations, if not already available. Then, different mathematical models are tested to calculate the spectra of each pH-dependent species vs. concentrations, including linear, quadratic, exponential and multivariate algorithms. [5,6] The *in silico* approach is then experimentally validated acquiring intermediate spectra and verifying their compatibility with the predicted ones. On the other side, species fractions vs. pH are instead computed by the means of Medusa software using literature pK_a values. All the spectra calculated are then summed to obtain the overall spectra of each dye vs. pH and ColorLab GUI allows to calculate the color variation starting from UV-Vis spectra.

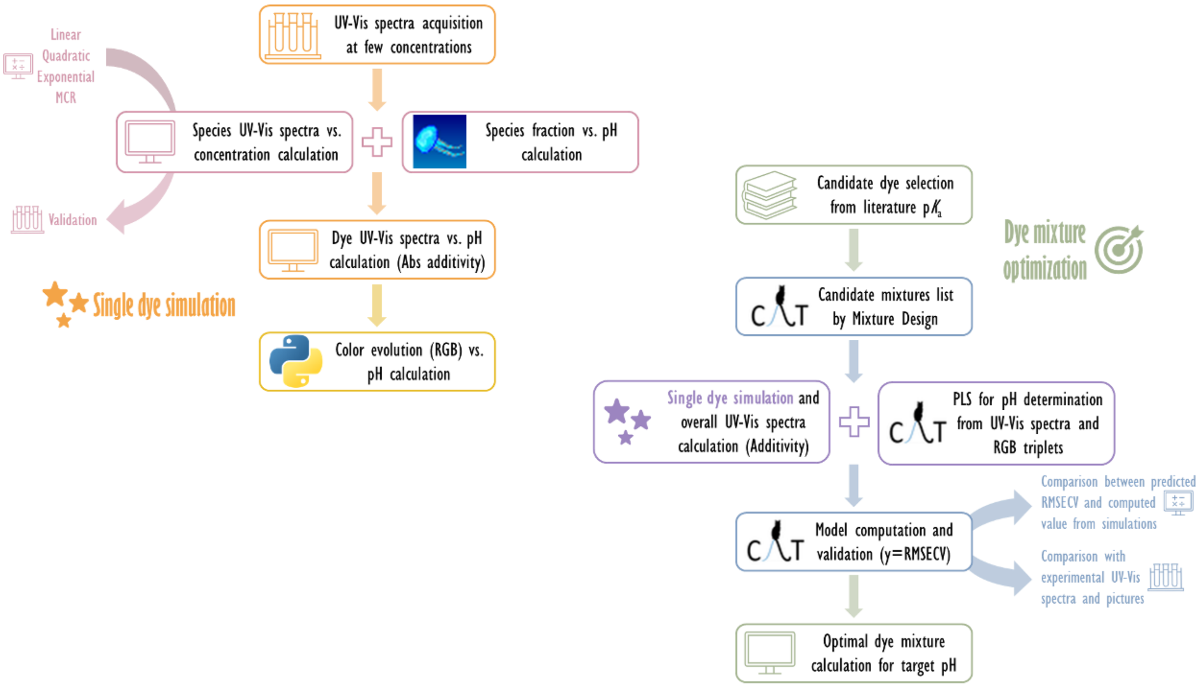

Figure 1. General workflow for pH-indicating dye mixtures *in silico* optimization

To optimize pH-indicating dye mixtures composition, Mixture Design is applied on the candidate dyes ratios (0-1), fixing a suitable dye total composition to obtain absorbances between 0.1 and 1, to compute dyes amount per each experiment; per each mixture, overall spectra and color variation are computed, as described above, and submitted to Partial Least Square regression to evaluate pH measurements efficiency, both relying on spectroscopic and colorimetric detection; this latter parameter, expressed as RMSECV, is exploited as Mixture Design response, together with other colorimetric features. Mixture Design models are validated both computationally and experimentally and the optimal composition is predicted and then prepared and characterized.

The general protocol described above is applied to optimize three different pH-indicating dyes mixtures, optimal for pH measurements in the range 2-7, 4.5-9.5 and 7-12, and preliminary applications of three mixtures are presented.

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Phosphate anions and DNA fluorescent sensing by PPD-based metallo-receptors

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Transition metal complexes are widely investigated in bioinorganic chemistry for their ability to interact with biomacromolecules and modulate their structural properties [1,2]. In this study, the interaction between copper(II) and zinc(II) complexes of 2,5-diphenyl[1,3,4]oxadiazole (PPD)-based polyazacyclophanes [3] and phosphate anions as well as calf thymus DNA was explored in aqueous solution under near-physiological conditions (Figure 1).

The binding behavior of the complexes toward the guests was investigated by UV–Vis absorption, fluorescence spectroscopy and circular dichroism. A screening performed with several phosphate ions revealed the affinity of metallo-receptors for some of them *via* clear spectral variations. Moreover, incremental addition of DNA to metallo-receptors drastically modified the absorption and emission spectra of the complexes, indicating the formation of stable complex–DNA adducts [4]. The observed fluorescence changes are consistent with alterations in the local environment of the complexes following interaction with the biomolecule, confirming the formation of metal complex-DNA assemblies in solution.

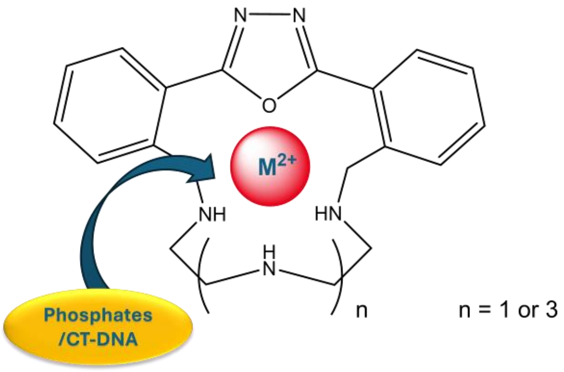

Figure 1

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Binding thermodynamics of metal complexes of 8-hydroxyquinoline-2-carboxylic acid with serum albumin

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The rational development of metal-based drugs requires a detailed understanding of the interactions occurring between metal ions, drug and biological targets as these can significantly influence drug bioavailability, biodistribution and metabolism of the drug *in vivo*.

In this context, one of the key aspects of the PRIN2022 project "*TRansforming metal Ions and Low-cost LIgands into next-generation metallodrugs" (TRILLI)* aims at elucidating the fundamental factors governing the thermodynamic stability and the energetics of the binding processes involving metal complexes (MCs), based on abundant and biocompatible ligands, and molecules of biological interest.

We focused on 8-hydroxyquinoline-2-carboxylic acid (8-HQA, Figure 1), a naturally occurring 8-hydroxyquinoline derivative exhibiting antimicrobial and antiproliferative activities [1-3], and capable of forming stable complexes with several biologically relevant metal ions [4].

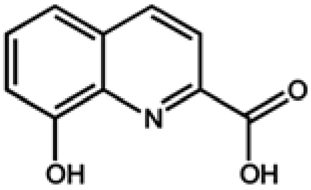

Figure 1. Structure of 8-hydroxyquinoline-2-carboxylic (8-HQA).

We investigated the interactions of MCs, formed by 8-HQA and essential metal ions (such as Cu^{2+}, Zn^{2+} and Fe^{3+}), with bovine serum albumin (BSA), here employed as a model system for the main transport protein in the bloodstream. The study was performed at 25 °C and pH 7.4 using isothermal titration calorimetry to obtain a detailed description of the energetics of the complexation processes [5]. The determination of the entropic and enthalpic contributions to the standard Gibbs energy provided a comprehensive picture of the forces driving the binding events, arising from favorable non-covalent interactions and strongly influenced by the structural features of both the metal complexes and the protein.

Overall, this work contributes to providing a quantitative description of MC-protein interactions in solution, thus helping to clarify the role of serum albumins in the transport of metal-based systems. Future integration of thermodynamic results with complementary spectroscopic and computational characterization represents an important step toward the rational design of metallodrugs based on low-cost, biologically relevant metal ions.

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Thermodynamic study of Cu(II) adsorption by Cuban Natural Clinoptilolite

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Natural clinoptilolite has attracted increasing interest as a low-cost aluminosilicate adsorbent for aqueous metal-ion removal, owing to its ion-exchange capacity, porous framework and intrinsically heterogeneous surface chemistry [1, 2]. In this work, Cuban natural clinoptilolite was investigated as an adsorbent for Cu(II), with the aim of elucidating the influence of solution chemistry, mass-transfer conditions and adsorption-site heterogeneity on metal uptake. The thermodynamic and isotherm analyses were carried out at 25, 50 and 65 °C, using two particle-size fractions, 280 and 500 µm, in order to evaluate the coupled effects of temperature-enhanced diffusion and particle-size-dependent mass transfer.

Cu(II) adsorption was strongly pH-dependent, with maximum uptake observed at around pH 5. This condition was selected for the reported characterization as it provided enhanced metal retention while limiting precipitation-related artefacts. Time-dependent adsorption profiles displayed a rapid initial uptake followed by a slower approach to equilibrium, consistent with the progressive occupation of readily accessible sites and subsequent diffusion-controlled transport toward less accessible adsorption domains. An apparent equilibrium time of 240 min was therefore adopted. The influence of adsorbent dosage indicated that a solid–liquid ratio of 1 g L^{-1} was sufficient to achieve efficient Cu(II) removal under the selected experimental conditions.

The Cu(II) adsorption capacity increased nonlinearly with equilibrium concentration, evidencing the non-ideal and energetically heterogeneous nature of the clinoptilolite surface. The nonlinear Freundlich isotherm provided a suitable description of the global Cu(II) adsorption behaviour over the investigated temperature range of 25-65 °C. Emphasis was placed on the Freundlich exponent, which was interpreted as an operational descriptor of the concentration-dependent adsorption response rather than as a fixed intrinsic property of the adsorbent. Its dependence on temperature and particle size revealed a transition from diffusion-limited, high-energy-site-dominated adsorption to broader multi-site participation [3, 4].

For the 500 µm fraction, which showed the clearest temperature-dependent transition, Cu(II) adsorption at 25 °C was characterized by $n < 1$, suggesting preferential uptake on externally accessible high-energy sites under significant intraparticle diffusion constraints. At 50 °C, the increase in n accompanied by poorer fitting quality indicated a transitional regime, in which low- and high-concentration adsorption domains were not adequately represented by a single Freundlich relationship. At 65 °C, the improvement of the overall fit, with R^2 close to 0.98, suggested that mass-transfer limitations were substantially reduced and that adsorption sites with different energetic contributions became effectively involved in Cu(II) uptake.

On this basis, segmented Freundlich modelling was applied to the 65 °C, 500 μm system to resolve concentration-dependent adsorption regimes. The low-equilibrium-concentration region was associated with a high Freundlich exponent, reflecting a strong sensitivity of adsorbed amount to Cu(II) concentration and preferential occupation of high-affinity sites. Conversely, the high-concentration region displayed a markedly reduced exponent, consistent with progressive saturation of high-energy sites and increasing contribution from lower-affinity adsorption domains. The segmented approach therefore provides a mechanistic interpretation of site heterogeneity and concentration-dependent adsorption pathways, rather than a purely statistical improvement of isotherm fitting.

Overall, the combined pH optimization, kinetic assessment, thermodynamic/isotherm modelling and segmented Freundlich analysis demonstrate that Cu(II) adsorption on Cuban natural clinoptilolite is controlled by the interplay between solution pH, surface heterogeneity, particle-size-dependent diffusion and temperature-enhanced site accessibility. These findings establish a mechanistic basis for subsequent adsorption-site studies and may further support the rational design of structured zeolite-based adsorbents for water treatment and metal recovery applications.

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Preparation of a novel Bio-Z sorbent using biomodification and immobilization methods for the removal of $[PtCl_4]^{2-}$ in aqueous solution

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Persistent pharmaceutical contaminants, such as Pt (II) cytostatics commonly used in cancer therapy, have been detected in water bodies at low concentrations. Electrochemical, photochemical, and biological treatments for the removal or degradation of these contaminants are costly and sometimes inefficient [1,2]. Solid-phase extraction is a viable and potentially effective for water treatment [3,4]. The objective of this study was to obtain and characterize the inactive biomass of *Aspergillus niger O-5* immobilized on the zeolitic material from the San Andrés deposit, as a sorbent for the removal of $[PtCl_4]^{2-}$ from aqueous solution. The sorbent material (Bio -Z) was prepared using two methodologies: 1) biomodification and 2) immobilization. The model $[PtCl_4]^{2-}$ dissolution was prepared from potassium tetrachloroplatinate (II) in 0.9% NaCl. The quantification of Pt (II) in the assays was performed using UV-Vis Molecular Absorption Spectrometry with orthophenylenediamine (OPDA). The adsorbent material was characterized by scanning electron microscopy, infrared spectroscopy (IR), and pH at the zero-charge point (pHpzc). Micrographs showed growth of *Aspergillus niger O-5 biomass* on the zeolite surface using method 1), and a deposited layer using method 2). IR Spectroscopy revealed the main vibration patterns characteristic of both materials. The pHpzc analysis allowed understanding of the net charge distribution on the material's surface. The influence of pH [2-8] on Pt (II) retention (%) for materials from both methods was studied under the following conditions: Bio-Z mass 10 mg, $[PtCl_4]^{2-}$ volume 10 mL, concentration 10 $mg \cdot L^{-1}$, time 30 min, and stirring speed of 105 rpm. For both methods, retention ranged from 91% to 89% from pH 2 to 7.

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Synthesis of novel bis-imidazolyl-containing ligands and investigation of their metal ion binding

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Chemotherapeutic platinum metal complexes – due to their lack of selectivity – have serious side effects and resistance may also develop. To overcome this, we have been working on the development of more selective metal complexes, considering the differences between cancer and healthy cells, such as high iron(III) demand, a more reductive cellular environment, or hypoxia due to poorly developed vascular networks. After administration, these compounds are activated only in cancer cells due to one of their unique properties.

Cobalt(III) complexes may be suitable among the candidates activated by hypoxia. With four nitrogen and two oxygen donor atoms bound to Co(III), complexes having the suitable redox potential can be obtained that can selectively be reduced to Co(II) in cancer cells only due to the more reductive milieu releasing therefore the ligand with anticancer potential. As a bioligand, (O, O) donors, e.g. hydroxypyridinones can be used, which are excellent Fe(III) binding agents. The anticancer effect can be enhanced if the ligand is chemically modified to contain an (N, N)-donor moiety too that may be suitable for binding platinum group metals.

In our research, novel ligands containing a bis-imidazole unit as an (N, N)-donor, which are linked to a hydroxypyridinone were synthetized and characterized. Their metal ion binding was investigated depending on the length of the linker and the type of the functional group formed at the site of the connection (secondary amine, peptide bond). In the course of the work so far, the synthesis of ligands containing a peptide bond, as well as the solution equilibrium study of the ligands by pH potentiometry and the structure elucidation by NMR spectroscopy in the presence of pentamethylcyclopentadienyl rhodium(III) cation have been successfully completed.

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From ATCUN motifs to tetrabranched assemblies: copper binding in peptide-based enzyme mimics

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Peptides containing the ATCUN (Amino Terminal Copper and Nickel binding) motif represent a class of systems of significant interest due to their ability to strongly coordinate metal ions and modulate redox processes. In this study, we investigated the metal-binding properties and potential biological implications of two rationally designed peptides, AAHAWG-NH_2 and AAHAWGELLKKLLEELKG-NH_2, both incorporating an ATCUN motif capable of binding Cu(II) ions (see Figure 1). In parallel, tetrabranched systems were designed to explore a new class of peptide-based enzyme mimics: a central cyclam-based scaffold has served as the core of the tetramer structure, to which the abovementioned ATCUN peptides were attached [1].

The primary aim of this work was the thermodynamic and spectroscopic characterization of Cu(II) complex formation with the selected systems in aqueous solution. Potentiometric titrations were performed to determine both the protonation constants of the ligands and the stability constants of the corresponding metal complexes. Complementary UV–Vis absorption and circular dichroism spectroscopy provided insight into the coordination environment of the copper ion across a range of pH conditions. High-resolution mass spectrometry was employed to corroborate the obtained speciation model and confirm the stoichiometry of the formed species [2].

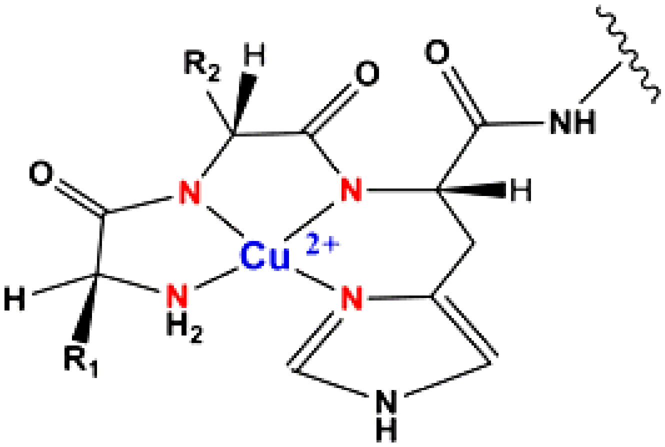

Figure 1. Exemplificative structure of a Cu^{2+} complex formed by the N-terminal ATCUN domain of a generic peptide.

Given the well-established role of copper in biological redox processes, the ability of the peptides and their Cu(II) complexes to generate reactive oxygen species (ROS) was also evaluated *via* UV–Vis spectrophotometric monitoring of ascorbic acid oxidation under physiological conditions. The observed ROS production suggests a possible mechanism underlying the antimicrobial activity of these systems, highlighting their potential as candidates for the development of novel antibacterial or antifungal agents. Finally, to assess their potential biological applicability, the stability of the peptides was investigated in human plasma.

A key outcome of this work is the identification of ATCUN-containing peptides as very promising systems. These compounds exhibited well-defined coordination properties (forming square planar complexes, according to the typical coordination of the ATCUN site [N_{NH2}, N_{Im}, $2N^{-}$]), high metal-binding affinity and suitable redox behaviour, as demonstrated by an extensive multi-technique characterization. In parallel, tetrabranched systems confirmed their capability to coordinate multiple metal ions, forming tetranuclear complexes, with one copper ion per each "peptide arm" of the system.

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