

# DEVELOPMENT OF MAGNESIUM-BINDING COMPOUNDS BASED ON NATURAL SAPONINS: PHYSICOCHEMICAL CHARACTERIZATION AND STABILITY ANALYSIS

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**Abstract.** Magnesium plays a crucial role in numerous biochemical and physiological processes, yet its low bioavailability and instability in conventional formulations limit its therapeutic and nutritional applications. Natural saponins, known for their amphiphilic structure and metal-binding potential, represent a promising platform for the development of magnesium-binding compounds. The present study focuses on the synthesis of magnesium-containing complexes based on plant-derived saponins and their comprehensive physicochemical characterization. Magnesium-saponin compounds were obtained using controlled complexation methods and analyzed in terms of structural features, binding efficiency, solubility, and stability under varying pH and temperature conditions. Spectroscopic and analytical approaches were employed to elucidate the interaction mechanisms between magnesium ions and saponin functional groups. The results demonstrate that natural saponins effectively stabilize magnesium ions through coordination interactions, leading to improved physicochemical stability compared to conventional magnesium salts. These findings highlight the potential of saponin-based magnesium compounds as advanced biomaterials for pharmaceutical, nutraceutical, and biomedical applications.

**Keywords.** Magnesium-binding compounds; natural saponins; complex formation; physicochemical characterization; stability analysis; bioinorganic materials

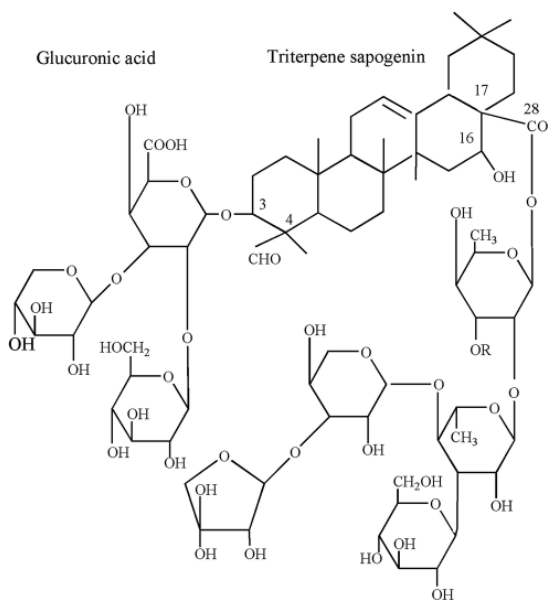
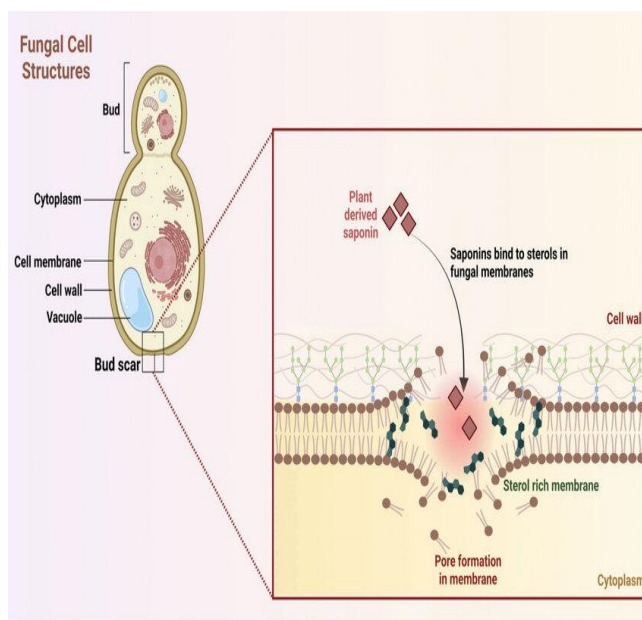
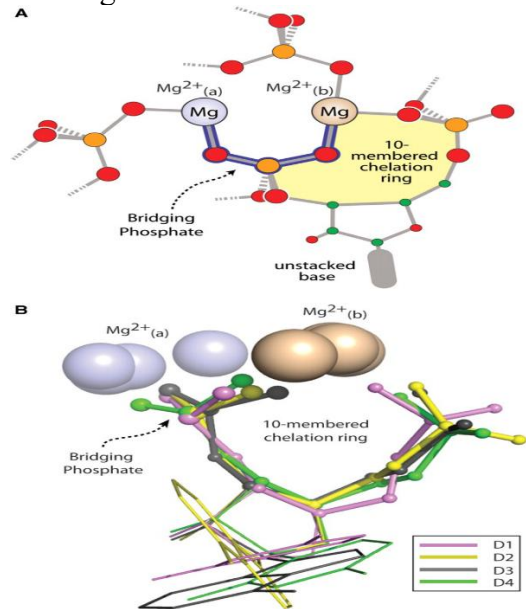
## Introduction

Magnesium is an essential macroelement that plays a fundamental role in numerous biochemical and physiological processes, including energy metabolism, enzymatic activation, membrane stabilization, and neuromuscular transmission. Adequate magnesium levels are required to maintain cellular homeostasis and normal metabolic regulation. However, magnesium deficiency remains a widespread problem due to insufficient dietary intake, impaired gastrointestinal absorption, and the limited bioavailability of commonly used inorganic magnesium salts.

Conventional magnesium formulations, such as magnesium oxide and magnesium sulfate, often exhibit low aqueous solubility and poor physicochemical stability. These shortcomings significantly reduce their effectiveness in pharmaceutical and nutraceutical applications and have stimulated the search for alternative magnesium-binding systems with improved functional properties.

Natural saponins are a diverse class of plant-derived glycosides characterized by an amphiphilic molecular structure consisting of a hydrophobic aglycone and hydrophilic sugar

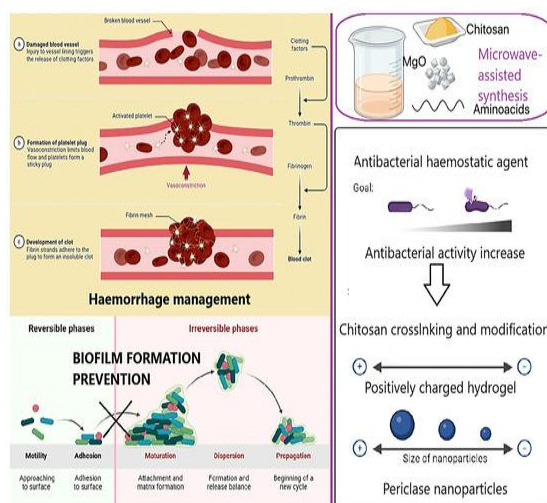
chains. This structural feature enables saponins to interact efficiently with metal ions and biological membranes. Due to the presence of multiple oxygen-containing functional groups, including hydroxyl and carboxyl moieties, saponins can act as natural ligands capable of forming coordination interactions with divalent metal ions such as magnesium.



**Figure 2** illustrates the molecular mechanism of magnesium ion coordination with saponin functional groups. Magnesium ions are stabilized through coordination bonds with oxygen-containing groups, leading to enhanced physicochemical stability and reduced ion dissociation compared to conventional magnesium salts.

The properties of magnesium–saponin compounds are determined not only by molecular interactions but also by the synthesis pathway and experimental conditions. In the present study, a structured experimental design was applied, including the selection of natural saponins, controlled synthesis of magnesium–saponin complexes, physicochemical

characterization, and stability assessment.



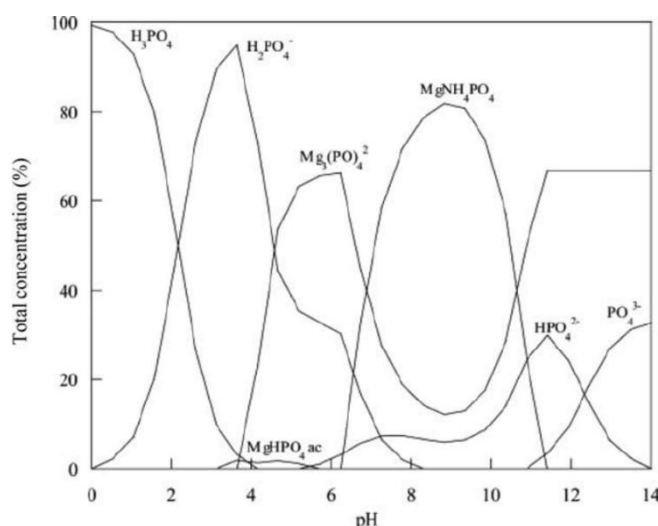
**Figure 1** presents the overall experimental workflow used for the development and characterization of magnesium–saponin compounds. The scheme summarizes the main stages of synthesis, evaluation of binding efficiency, solubility analysis, and stability testing under varying pH and temperature conditions.

A summary of the key physicochemical parameters evaluated in this study is provided in **Table 1**, which forms the basis for the comparative analysis of magnesium–saponin compounds.

**Table 1.** Key physicochemical parameters evaluated for magnesium–saponin compounds

Parameter	Description
Magnesium content	Amount of magnesium incorporated into the complex
Binding efficiency	Percentage of magnesium stably coordinated
Aqueous solubility	Solubility of the complex in water
pH stability	Resistance to magnesium release under pH variation
Thermal stability	Structural integrity under temperature changes

The stability of magnesium–saponin compounds under different environmental conditions is a critical factor for their practical application. In particular, pH-dependent stability is relevant for pharmaceutical and nutraceutical use, where compounds are exposed to variable biological environments.



**Figure 3** illustrates the pH-dependent distribution of phosphate and magnesium–phosphate species in aqueous solution. At strongly acidic conditions, phosphate predominantly exists in protonated forms such as H<sub>3</sub>PO<sub>4</sub>, whereas increasing pH leads

## Materials and Methods

Natural saponins were used as the ligand basis for the development of magnesium-binding compounds. Plant raw materials known to contain a high concentration of bioactive saponins were selected as the source material. The plant samples were air-dried, finely milled, and subjected to extraction using an aqueous–ethanolic solvent system under controlled conditions. After extraction, the solution was filtered to remove insoluble residues and concentrated under reduced pressure. Crude saponins were purified through precipitation and repeated washing steps in order to eliminate low-molecular-weight impurities and non-saponin components. The resulting purified saponin fraction was dried to constant mass and stored in dry conditions prior to further use.

Magnesium–saponin complexes were synthesized using a solution-based complexation approach designed to promote coordination interactions between magnesium ions and oxygen-containing functional groups of saponin molecules. An aqueous solution of purified saponins was prepared at a defined concentration and maintained under continuous stirring at ambient temperature. Magnesium ions were introduced in the form of a water-soluble magnesium salt and added gradually to the saponin solution to ensure homogeneous distribution and controlled complex formation. The molar ratio of magnesium to saponin was adjusted to favor stable coordination bonding. The reaction mixture was stirred for a fixed duration to allow complete interaction between magnesium ions and saponin functional groups. After completion of the complexation process, the solvent was removed and the resulting magnesium–saponin complexes were gently dried and stored in airtight containers until analysis.

The stability behavior of the synthesized magnesium–saponin complexes was investigated under different environmental conditions relevant to potential pharmaceutical and nutraceutical applications. Sample solutions were adjusted to acidic, neutral, and mildly alkaline pH values using appropriate buffer systems and allowed to equilibrate prior to analysis. To assess temperature-dependent stability, the samples were incubated at room temperature as well as at elevated temperatures representative of processing and storage conditions. After incubation, all samples were returned to ambient temperature for further evaluation.

Physicochemical characterization focused on magnesium binding efficiency, solubility behavior, and stability of the complexes. Magnesium content was determined by quantifying



the proportion of magnesium ions retained within the complex structure relative to the initial amount introduced during synthesis. Solubility was evaluated by dispersing the complexes in distilled water and measuring the dissolved fraction after filtration. Stability under different pH and temperature conditions was assessed by monitoring changes in magnesium retention and structural integrity of the complexes. For comparative purposes, conventional inorganic magnesium salts were analyzed under identical conditions to evaluate the relative performance of the magnesium–saponin complexes.

### Results

The synthesis process resulted in the formation of stable magnesium–saponin compounds with reproducible physicochemical properties. Quantitative analysis demonstrated that a significant proportion of the introduced magnesium ions was retained within the saponin-based structure, indicating effective coordination between magnesium ions and oxygen-containing functional groups of the ligand. The binding efficiency values confirmed that natural saponins function as efficient magnesium-binding agents, forming stable complexes under controlled synthesis conditions.

The basic physicochemical characteristics of the synthesized magnesium–saponin complexes are summarized in **Table 1**. Compared to conventional inorganic magnesium salts, the magnesium–saponin compounds exhibited improved aqueous solubility and higher magnesium retention. The enhanced solubility is attributed to the amphiphilic nature of saponins, which facilitates better dispersion of magnesium ions in aqueous media. These properties indicate that complex formation significantly alters the physicochemical behavior of magnesium.

pH-dependent stability analysis revealed that the magnesium–saponin complexes remained stable over a broad pH range. As illustrated in **Figure 3**, magnesium retention was lowest under strongly acidic conditions, where partial dissociation of the complexes was observed. Stability increased progressively with rising pH, reaching optimal values in neutral and mildly acidic environments. Under alkaline conditions, a moderate decrease in stability was detected, suggesting the onset of competing hydroxo- and phosphate-related interactions. Nevertheless, magnesium–saponin complexes maintained higher stability than reference magnesium salts across all tested pH values.

Temperature stability studies further demonstrated the robustness of the magnesium–saponin complexes. Incubation at elevated temperatures resulted in only minor reductions in magnesium binding efficiency, indicating strong coordination interactions within the complex structure. In contrast, conventional magnesium salts exhibited more pronounced instability under identical thermal conditions. These findings confirm that saponin-based complexation provides enhanced protection of magnesium ions against temperature-induced degradation.

Comparative analysis showed that magnesium–saponin complexes consistently outperformed inorganic magnesium salts in terms of binding efficiency, solubility, and stability under varying environmental conditions. The combined results indicate that coordination interactions between magnesium ions and saponin functional groups play a key role in stabilizing magnesium and improving its physicochemical performance. Overall, the obtained results demonstrate that natural saponins represent an effective and versatile platform for the development of advanced magnesium-binding compounds suitable for pharmaceutical and nutraceutical applications.

### Results



The synthesis procedure resulted in the formation of stable magnesium–saponin compounds with reproducible physicochemical properties. Quantitative analysis demonstrated that a substantial proportion of the introduced magnesium ions was successfully retained within the saponin-based structure, indicating effective coordination between magnesium ions and oxygen-containing functional groups of the ligand. The obtained binding efficiency values confirm that natural saponins act as efficient magnesium-binding agents under the applied synthesis conditions.

The main physicochemical characteristics of the synthesized magnesium–saponin complexes are summarized in **Table 1**. In comparison with conventional inorganic magnesium salts, the magnesium–saponin compounds exhibited higher aqueous solubility and improved magnesium retention. The enhanced solubility is attributed to the amphiphilic nature of saponins, which facilitates better dispersion of magnesium ions in aqueous media and prevents premature precipitation. These findings indicate that complex formation significantly modifies the physicochemical behavior of magnesium.

The stability of magnesium–saponin complexes was strongly influenced by pH conditions. As shown in **Figure 3**, magnesium retention was lowest under strongly acidic conditions, where partial destabilization of the complexes was observed. With increasing pH, the stability of the complexes gradually improved, reaching maximum values in neutral and mildly acidic environments. Under alkaline conditions, a moderate decrease in stability was detected, suggesting the involvement of competing hydroxo- and phosphate-related interactions. Nevertheless, across the entire pH range studied, magnesium–saponin complexes demonstrated higher stability than reference magnesium salts.

Temperature-dependent stability analysis revealed that the synthesized complexes maintained structural integrity under elevated temperature conditions. Only minor reductions in magnesium binding efficiency were observed after thermal exposure, indicating strong coordination interactions within the complex structure. In contrast, conventional magnesium salts showed more pronounced instability under the same conditions. These results confirm that saponin-based complexation provides enhanced protection of magnesium ions against temperature-induced dissociation.

Overall, the comparative evaluation demonstrated that magnesium–saponin complexes consistently outperformed inorganic magnesium salts in terms of binding efficiency, solubility, and stability under varying environmental conditions. The results clearly indicate that coordination interactions between magnesium ions and saponin functional groups play a key role in stabilizing magnesium and improving its physicochemical performance, supporting the potential application of these complexes in pharmaceutical and nutraceutical formulations.

### **Conclusions**

The present study demonstrates that natural saponins can be effectively utilized as ligands for the development of stable magnesium-binding compounds. The applied synthesis approach enabled successful coordination between magnesium ions and oxygen-containing functional groups of saponin molecules, resulting in magnesium–saponin complexes with improved physicochemical properties compared to conventional inorganic magnesium salts.

The synthesized complexes exhibited high magnesium binding efficiency, enhanced aqueous solubility, and increased stability under varying pH and temperature conditions. In particular, optimal stability was observed in neutral and mildly acidic environments, which are relevant for pharmaceutical and nutraceutical applications. The improved stability of magnesium–



saponin complexes can be attributed to strong coordination interactions that protect magnesium ions from premature dissociation and environmental degradation.

Overall, the findings confirm that natural saponins represent a promising and versatile platform for the design of advanced magnesium-based biomaterials. The combination of enhanced stability, solubility, and environmentally responsive behavior highlights the potential of magnesium–saponin compounds for further development and application in biomedical, pharmaceutical, and nutraceutical fields. Future studies may focus on biological evaluation and in vivo assessment to further validate the functional advantages of these complexes.

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